FINAL REPORT

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

Extensions and Applications of the Simulated Yoked Study Concept

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ABSTRACT

In a simulated yoked study, estimates of roadway travel times are archived from web-based Advanced Traveler Information Systems (ATIS) and used to recreate hypothetical, retrospective paired driving trials between travelers with and without ATIS. Previous research using this technique on a three-month archive of data from the Washington, DC metropolitan area demonstrated that travelers who receive notification of current congestion prior to departure can realize substantial time management benefits from improved on-time reliability and trip predictability. In this report, this key finding relating to on-time reliability is further supported and extended in two larger, parallel twelve-month case studies in the Washington DC as well as the Minneapolis/St. Paul (Twin Cities) metropolitan area. Further, we show that annual improvements in travel reliability from a pre-trip notification service modifying both time of departure and route choice can be valued at over $1,300 for selected trips in the Washington area and over $400 in the Twin Cities area. Modification of trip timing is shown to be the most frequent and most significant pre-trip decision. In the Washington case study, changes in trip timing suggested by an ATIS service are ten times more frequent than pre-trip route choice decision; even during peak congestion periods – in the Twin Cities they are six times more frequent. Extending the pre-trip service to include an en route guidance component appears to be highly valuable only in a minority of Washington area trips exhibiting longer trip durations (>30 minutes), high travel time variability, and viable alternative routes with diversion points occurring late in the trip.

KEYWORDS: Intelligent Transportation Systems, Federal Highway Administration, benefits, modeling, simulation, HOWLATE, Advanced Traveler Information Systems, travel time, on-time reliability, variability, simulated yoked trials, Washington DC, Minneapolis/St. Paul MN, Twin Cities.

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EXECUTIVE SUMMARY

This report further explores the hypothesis that the delivery of real-time roadway congestion reports from Advanced Traveler Information Systems (ATIS) provides benefit to users in urban areas over the long run primarily from improved on-time reliability and reduced stress, and only marginally from reduced in-vehicle travel time. Research at Mitretek Systems previously identified on-time reliability impacts for subscribers to a prospective notification-based pre-trip ATIS service in the Washington metropolitan area through a new analytical technique using archives of roadway travel time data (Wunderlich *et al.*, 2001). In this sequel to that report, Mitretek Systems, at the request of the Intelligent Transportation Systems (ITS) Joint Program Office (JPO) of the U.S. Department of Transportation (USDOT), investigates several hypotheses relating to the applicability of these earlier findings to metropolitan areas nationwide and the monetary value of on-time reliability improvements for long-term pre-trip ATIS users.

Background

Initiatives to evaluate the impact of traveler information services providing real-time congestion reports (hereafter, simply referred to ATIS in this report) in the 1990s provided what appeared to be contradictory results with respect to the time savings of ATIS users: large *perceived* time savings reported by ATIS users in survey-based research, but marginal to no *observed* in-vehicle travel time savings when measured empirically in field operational tests.

ATIS user perception has been measured in several independent studies undertaken in Boston, Seattle, Washington, and other metropolitan areas (Englisher et al., 1995; Jensen et al., 2000; Schintler, 1999; Lappin, 2000). Between 85-95% of respondents in each of these surveys reported high confidence that their use of ATIS helped them to save time.

Quantifying this perceived impact proved difficult using traditional evaluation techniques. For example, a number of field studies based on the concept of paired yoked trials were conducted wherein two subjects were directed simultaneously to drive from one point to another and report experienced, in-vehicle travel time. The experimental subject was allowed to consult ATIS services when determining route choice, while the control subject did not consult ATIS. Tests in San Francisco (JHK and Assoc., 1993), Orlando (Inman et al, 1995), and Chicago (Schofer et al,

1997) found either reductions of less than 4% in travel time for ATIS users or no statistically significant difference in travel time between users and non-users.

In order to reconcile the apparent contradiction between *perceived* and *observed* ATIS benefits, Mitretek Systems developed the Heuristic On-line Web-Linked Arrival Time Estimation (HOWLATE) method, utilizing the concept of a *simulated yoked trial*. This technique efficiently reconstructs millions of hypothetical, retrospective paired driving trials using archives of roadway travel times. The HOWLATE methodology was tested in a three-month study in the Washington area (Wunderlich *et al.*, 2001). That study found that the apparent contradiction between perceived time savings and observed in-vehicle travel time reductions were not, in fact, contradictory. ATIS users do realize time savings, but they accrue from improvements to on-time reliability, not from reductions of in-vehicle travel time. ATIS users save time by budgeting less time for travel and still arriving on-time at an acceptable rate; by arriving far too early less frequently and by fewer minutes when they are early; and by arriving late less frequently and by fewer minutes when they are late.

Approach

As in the field experiments conducted in the 1990s, HOWLATE mimics the conduct of a paired driving trial between a simulated ATIS user and a comparable, simulated non-user. Unlike the field trials where subjects effectively departed trip origins simultaneously, the HOWLATE pairing is based on trip origin, trip destination and target time arrival at the destination. Using an extensive archive of roadway travel times obtained from SmarTraveler, a traveler information provider (www.smartraveler.com), the decision of when to start a trip and which route to take is made differently for the ATIS user and the non-user. The ATIS user waits for notification to start a trip from an ATIS service, which scans roadway congestion conditions every five minutes and relays the expected travel time on the fastest route under current conditions. The non-user, conversely, does not adjust trip timing or route based on current conditions, but rather relies on past experience to establish a habitual time of departure and habitual route. The yoked study simulator in HOWLATE, referencing the travel times on a particular work day in the study period, plays out what would have happened in millions of such synthetic paired trials.

Simulated travelers are designated as arriving *late* (1 second or more after the target arrival time), *early* (10 minutes or more earlier than the target arrival time), or *just-in-time* (not late and up to 10 minutes early) in each trial. Travelers who are not late are considered *on-time*, regardless of whether they are just-in-time or early. HOWLATE collects statistics on each trial and presents a picture of whether, on average, the simulated ATIS user experiences fewer late arrivals and less wasted time by arriving too early than the simulated counterpart who does not use ATIS. A dollar-valued benefit of reductions in travel disutility (based on the work of Small *et al.*, 1999) is calculated from the reductions in the frequency and magnitude of early or late arrivals as well as in-vehicle travel time.

In this study, two large-scale case studies are conducted to test the hypotheses of the project. First, a comprehensive, twelve-month HOWLATE study based on data from the Washington metropolitan area was conducted using a study period from June 2000 to May 2001. A parallel study over the same period was conducted using data from the Minneapolis/St. Paul (hereafter, Twin Cities) metropolitan area. The yoked study simulator in HOWLATE was enhanced to accommodate both familiar and unfamiliar traveler models, as well as the modeling of en route guidance.

Hypotheses and Key Findings

Hypothesis: The gains in on-time reliability and reductions in early and late schedule delay for pre-trip ATIS users found in the Washington area during a three-month period (August-October 1999) will also be observed when a longer study period (June 2000-May 2001) is considered. Further, the benefits of on-time reliability improvements will dominate the value of reductions of in-vehicle travel time for pre-trip ATIS.

Findings: Pre-trip ATIS users realize significant on-time reliability benefits in the Washington DC network over the twelve-month period studied (Table ES-1). Looking across the entire day, travelers waste less time by arriving more than 10 minutes at their destinations, and are late far less frequently. In-vehicle travel time is reduced by roughly six seconds per trip, and represents only 1.2% of the travel disutility reduction observed for ATIS users – the other 98.8% is a product of fewer late arrivals and less wasted time from early arrivals. Note that the time of day plays a key role in the kind of benefit seen in the Washington study, although the use of ATIS is beneficial throughout the 6:30 AM – 6:30 PM time period studied. In the AM and PM peak travel periods, the reduction in wasted time from arriving too early is the primary benefit, while in the off-peak periods the reduction in frequency and magnitude of late and early arrivals are comparable.

Percent Change, Savvy ATIS User vs. Familiar Non-User						
	ALL DAY		PEAK		OFF PEAK	
Frequency of Early Arrivals	56%	ι	60%	ι	47%	ι
Frequency of Late Arrivals	52%	ι	2%	ι	79%	ι
On Time Reliability	2.4%	η	0.2%	η	4.1%	η
In-Vehicle Trip Time	0.3%	ι	0.01%	ι	0.5%	ι
Disutility of Travel	15%	ι	18%	ι	12%	ι

Table ES-1. ATIS Impact for Familiar Travelers, Washington (June 2000-May 2001)

Hypothesis: Our general hypothesis of high-value reliability improvements and relatively low-value in-vehicle travel time reduction benefits will hold in other major ATIS markets nationwide, not just in Washington. This hypothesis is tested in a parallel 12-month case study (June 2000-May 2001) in the Twin Cities metropolitan area.

Findings: The results from the Twin Cities case study follow the same basic pattern of overall benefit for ATIS users seen in the Washington area, although there are significant differences by time of day (Table ES-2). Overall, trips see a 4% reduction in travel disutility, largely because of reduction in late arrivals and less wasted time by arriving too early. Benefit is not seen across the day, however. In the mid-day off-peak period (9 AM – 4 PM), ATIS users experience a 9% *increase* in travel disutility. This is because during the middle of the day, the Twin Cities network experiences very little variability in roadway travel times. When variability is low, the inherent error in ATIS observations causes ATIS users to misjudge trip timings and routing decisions more frequently than a familiar non-user who expects a trip close to the average and experiences that nearly every day. The ATIS user sees increased disutility because of the 47% increase in early arrivals. Even though late arrivals are reduced, as well as in-vehicle trip time, the time wasted by arriving too early outweighs the benefit of reduced disutility from these other impacts.

Percent Change, Savvy ATIS User vs. Familiar Non-User						
	ALL DAY		PEAK		OFF PEAK	
Frequency of Early Arrivals	37%	ι	62%	ι	47%	η
Frequency of Late Arrivals	88%	ι	83%	ι	94%	ι
On Time Reliability	3.9%	η	5.2%	η	2.8%	η
In-Vehicle Trip Time	1.0%	ι	1.5%	ι	0.5%	ι
Disutility of Travel	4%	ι	14%	ι	9%	η

Table ES-2. ATIS Impact for Familiar Travelers, Twin Cities (June 2000-May 2001)

Hypothesis: The absolute and relative benefits of pre-trip ATIS will be higher in the Washington case study than in the Twin Cities case study because the Washington network is more congested. This assessment is made *a priori* based on Texas Transportation Institute (TTI) Congestion Index ranking. The Washington metropolitan area is third nationwide in the most recent ranking, while the Twin Cities is 15th.

Findings: From Tables ES-1 and ES-2 it is clear that the percent reduction in disutility is higher in the Washington network (15%) than in the Twin Cities (4%). Table ES-3 shows that absolute reductions are larger as well. The average value of reduced disutility in Washington is valued at $0.41 per trip, compared to $0.06 in the Twin Cities. These differences are primarily related to unpredictability of travel time day-to-day in both peak and off-peak periods in Washington, particularly in the PM peak period where high travel time variability is seen in conjunction with much higher link travel times. Worse congestion is seen in the Washington area across all link and trip-related metrics. For example, the average disutility per trip is valued at $2.70 in Washington compared with $1.50 in the Twin Cities. By using the $3.36/hour disutility of in-vehicle travel time from Small *et al.* and average trip duration, we can identify the proportion of the average disutility associated with in-vehicle travel, and conversely, reliability. Table ES-3 shows that $0.93 per trip can be attributed to variability of travel in Washington, compared with $0.47 per trip in the Twin Cities.

Congestion Measures and ATIS Impacts, Washington DC vs. Twin Cities		
	WASHINGTON	TWIN CITIES
TTI Congestion Measures		
TTI Congestion Index	1.44	1.31
TTI Congestion Index Rank	3rd	14th
HOWLATE Congestion Measures		
Average Disutility/Trip	$2.70	$1.50
Variability Disutility/Trip	$0.93	$0.47
Maximum Disutility/Trip	$13.29	$5.09
Average Trip Duration	31.3 min	18.4 min
Average Trip Speed	40 mph	46 mph
HOWLATE ATIS Impacts		
Pct. Reduction, Disutility/Trip	15%	4%
Reduction in Disutility/Trip	$0.41	$0.06

Table ES-3. Comparison of Washington and Twin Cities Congestion Measures

Hypothesis: There will be some trips in both Washington DC and the Twin Cities where the value of reductions in disutility will exceed the benchmark \$3-5/month (\$60/year) rate reported as the typical charge for a traffic alert system (Ulnick and Haupricht, 2001).

Findings: As shown in Figure ES-1, 40% of trips in the Washington network accrue an average annual benefit in excess of \$60, compared with 20% of trips in the Twin Cities network (220 trips/year). Figure ES-1 also illustrates that ATIS impact is highly concentrated. That is, there are a limited number of similar trips in both cities for which ATIS can be highly beneficial. The profile of these "high-benefit" trips in Washington are primarily PM peak trips traversing the network from north to south, while the profile of the highest-benefit trips in the Twin Cities are PM peak trips ending in the southwestern quadrant of the metropolitan area. Similar to the concentration of benefit among a limited number of similar trips, there is an even smaller subset of trips for which ATIS is regularly unhelpful. We have not completed our analysis of these but we conjecture that they are shorter trips with low variability.

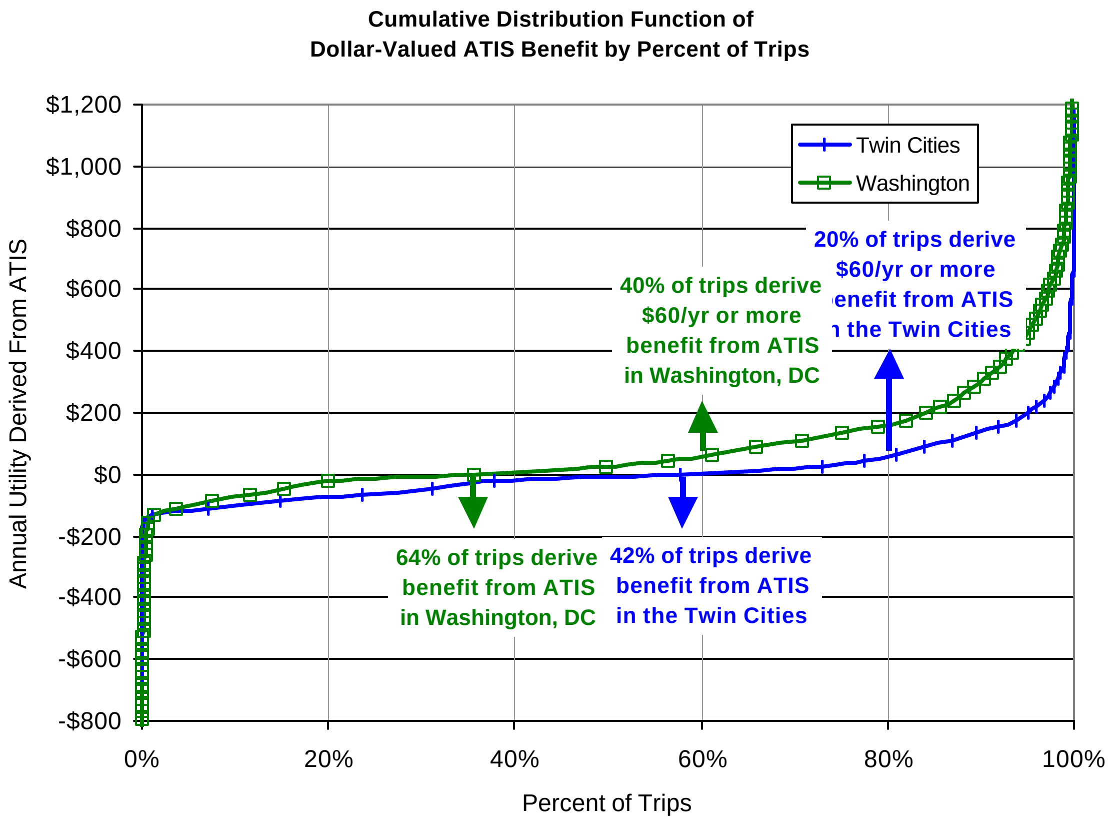

Figure ES-1. Distribution of ATIS Benefit in Washington DC and Twin Cities Analyses

Hypothesis: Pre-trip ATIS will prove valuable to both users who are familiar with their trips and congestion, as well as to users unfamiliar with particular trips and congestion patterns.

Findings: ATIS use by travelers unfamiliar with time-of-day congestion on the network significantly improves on-time reliability measures. In fact, these improvements are more highly valued on a per-trip basis than in yoked trials pairing travelers familiar with the network ($1.20 in Washington, $0.50 in the Twin Cities) as shown in Tables ES-4 and ES-5. Unfamiliar drivers are modeled differently from familiar drivers – instead of relying on past experience, they assume flatly that any trip in the AM or PM peak periods (Washington DC: 7:00-9:30 AM, 4:15-6:30 PM, Twin Cities: 7:00-9:00 AM, 4:00-6:30 PM) will have congestion equal to the free-flow travel time multiplied by the TTI congestion index factor, and free-flow travel time during off-peak periods. This strategy turned out to be too aggressive (many late arrivals) in the peak periods in both Washington and the Twin Cities. In the off-peak periods, the strategy for unfamiliar travelers was too aggressive in Washington but too conservative (many early arrivals) in the Twin Cities.

Percent Change, Naive ATIS User vs. Unfamiliar Non-User						
	ALL DAY		PEAK		OFF PEAK	
Frequency of Early Arrivals	4-fold	η	12-fold%	η	3-fold	η
Frequency of Late Arrivals	92%	ι	90%	ι	96%	ι
On Time Reliability	49.6%	η	105.4%	η	26.3%	η
In-Vehicle Trip Time	1.3%	ι	2.0%	ι	0.8%	ι
Disutility of Travel	34%	ι	45%	ι	22%	ι

Table ES-4. ATIS Impact for Unfamiliar Travelers, Washington DC (June 2000-July 2000)

Percent Change, Naïve ATIS User vs. Unfamiliar Non-User						
	ALL DAY		PEAK		OFF PEAK	
Frequency of Early Arrivals	38%	η	84%	η	52%	ι
Frequency of Late Arrivals	97%	ι	96%	ι	158%	η
On Time Reliability	16.2%	η	39.5%	η	0%	η
In-Vehicle Trip Time	2.2%	ι	3.56%	ι	1%	ι
Disutility of Travel	25%	ι	36%	ι	9%	ι

Table ES-5. ATIS Impact for Unfamiliar Travelers, Twin Cities, (June 2000-July 2000)

Hypothesis: The addition of an en route guidance supplement to the pre-trip ATIS service will provide additional on-time reliability benefits, as well as reduced in-vehicle travel time.

Findings: Supplementing pre-trip ATIS with an en route guidance service provides improved on-time reliability and reduced in-vehicle travel time – but only in relatively rare circumstances: long trips with unexpected congestion and viable diversion opportunities late in the trip. Even when these benefits occur, their value does not exceed $0.50/occurence.

Implications

The results of this study have several significant implications for both public- and private- sector providers of ATIS services. Both types of ATIS providers are motivated to provide the highest possible value of service to their constituencies, although their motivations are different. The results of this study have implications regarding the kind of ATIS services most helpful to users, and shed light on what kinds of trip-makers are likely to benefit the most from these services.

Pre-trip ATIS benefit is highly concentrated, both geographically and by time of day. In the Washington DC network, 78% of the benefit of pre-trip ATIS provision accrues to 25% of possible trips in the network. In the Twin Cities, the target clientele of users likely to significantly benefit is even more concentrated, (82% of benefit accrues to 19% of possible trips). In the Twin Cities, the vast majority of high-value trips occur in a fairly narrow time window within the PM peak. Although we have not fully completed our analysis to characterize the highest value trips in either city, the implication is clear for ATIS service providers – in terms of benefit to the user, *the best target market for services differs in each city and marketing efforts, along with surveillance and reporting resources are likely more effectively deployed to reach and support these trips*. Keep in mind that our unit of observation here is trips, not population – a larger share of the traveling population makes trips in the PM peak than during off-peak periods.

Although pre-trip ATIS is shown to be beneficial in both metropolitan areas, the absolute value of pre-trip ATIS provision is higher in Washington DC than in the Twin Cities. This is simply because variability of travel times is more pronounced and seen through a larger portion of the day than in the Twin Cities. It is clear that variability of travel times are the key attribute that separates trips that benefit from pre-trip ATIS from those that do not. *Congestion metrics like the TTI Index* *can provide a rough guide as to the likely magnitude of regional pre-trip ATIS benefits because high demand-to-capacity ratios are strongly correlated with high variability, but the key for pre-trip ATIS benefit appears related less to the magnitude of peak period congestion than the magnitude of day-to-day variability seen at any time of day.*

Our findings with respect to the concentration of benefit among a relatively small set of trips within the region also has implications for targeting different types of travelers with a requirement to arrive on-time. *The provision of trip planning guidance to unfamiliar travelers has high benefit in peak periods, even if peak period variability is not particularly pronounced*. The benefit for unfamiliar travelers in the Twin Cities averages $0.50 per trip across the day and $1.40 per trip in the PM peak ($1.20 and $2.40, respectively in Washington DC). Reaching travelers who are planning trips in the peak period for which they have little experience with congestion patterns appears to be a high-value activity. Further, the notion of the unfamiliar traveler is broader than the "tourist in the rental car" and includes regional residents that do not regularly make a particular trip (e.g., a requirement to be at the airport at 8:30 AM). Note that the value to unfamiliar travelers in the Twin Cities is, on average, over six times higher on a per-trip basis than ATIS provision to familiar travelers.

Reaching the high-value target clientele may mean providing different kinds of ATIS services than are typically provided. Today, the most frequently deployed ATIS service reporting real-time congestion are websites with color-coded maps showing current conditions and, frequently, travel times. However, the unfamiliar traveler seeking to plan when to leave to be on-time at the airport next Tuesday is not well-served by such a display of the data. Even if the traveler happens to be checking out the website at roughly the same time of day, there is no way of knowing whether this particular day is a much worse or much better prediction of conditions likely encountered in the next week.

Likewise, the oft-repeated paradigm of the ATIS user jumping in the car, getting the best route and screeching out of the parking lot may in not in fact be the most effective way to incorporate ATIS effectively into one's regular travel pattern. On-time reliability benefits are most strongly influenced by the trip departure time choice; shifting time of departure by five or ten minutes is 6-20 times more frequently suggested than route diversion by the notification-based ATIS service examined in our study. Clearly, checking in with a website every five minutes to construct a trip time estimate would be too onerous for the ATIS user and the "jump in the car" scenario implies a fixed trip start time. Instead, the key to on-time reliability benefits appears to be supporting the trip timing decision, as in the provision of a notification-based service that constantly scans the data based on the user's habitual trip schedule. The service would then notify the user only when appropriate trip timing and route choice differ from the user's default route and timing. In both Washington and the Twin Cities, we estimate that such notification would occur roughly three out of every five workdays. Further, although our study of en route guidance is only preliminary at this point, it appears that the value of route diversion generally diminishes after trip-start except in relatively rare combinations of long duration trips with key diversion points and roadway segments with high variability close to the destination.

Conclusions and Future Work

Not all current ATIS users are motivated by the desire to be on-time in urban networks. A survey of Seattle ATIS web-site users (Lappin, 2000) characterized roughly one-third of current users as commuters who needed to be on-time and used the web-site to help them be on time. The on-time reliability benefits reported in this document are clearly applicable for this one-third of the current ATIS using market. Other users are characterized by an intense dislike of congestion and slow travel. Still others utilized the service primarily because it was new and technically interesting, rather than to simply improve their own mobility. Other metrics (e.g., reduction in travel under 20 mph) may better represent the utilities of these travelers; and different kinds of services based on the roadway congestion and configuration may have higher value than the pre-trip notification service tested in this study.

Clearly our study indicates that for travelers who need to be on time and who face considerable variability in their trip travel times, a notification-based pre-trip ATIS can be a useful and high-value service. Although not currently available in either Washington or the Twin Cities, this type of service can be provided through the manipulation of the roadway travel time data similar to that already being collected and disseminated in both Washington and the Twin Cities. The term "similar" is used as a qualifier here because there has been only preliminary work done so far by Mitretek and others to identify the accuracy of reported travel time data by times of day, situations and individual facilities. Our initial assessment is that the accuracy levels (roughly plus/minus 20%) used in this report based on limited observations on two facilities in the Washington network may be optimistic based on some additional measurements recently completed, however a comprehensive assessment is yet to be undertaken. A key extension of this work will be to examine the benefits of ATIS under various levels of link travel time reporting accuracy. This extension includes an evaluation of qualitative congestion alerts like those made during periodic traffic reports on commercial radio.

Other extensions include the assessment of additional metropolitan networks beyond the two already studied, a comparative analysis of benefit from a notification-based service and user-initiated service that includes assessment of access time, as well as continuing work evaluating of the benefits of en route guidance. The paradigm for en route benefit may well be found in intercity or inter-regional travel, rather than repetitive urban commuter travel.

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1.0 Introduction

Evaluations of Advanced Traveler Information Systems (ATIS), particularly those reporting on real-time roadway congestion conditions, have traditionally focused on the reduction of in-vehicle travel time as the key metric for defining ATIS user benefit. More recently, however, ATIS evaluation has broadened from a concentration on in-vehicle travel to a more comprehensive view of the predictability of urban travel. This wider view has revealed substantial ATIS user benefits associated with improved on-time reliability, rather than purely in-vehicle travel time reductions. The shift in focus parallels findings from research on commuting stress (Koslowsky *et al.*, 1995) in which the unpredictability of urban commutes was more likely to be identified by respondents as a source of stress than long driving times. In 1999, at the request of the Intelligent Transportation Systems (ITS) Joint Program Office of the United States Department of Transportation (USDOT), researchers at Mitretek Systems developed a new technique for the evaluation of on-time reliability impacts of ATIS services based on the analysis of archived roadway travel time data, the Heuristic On-line Web-linked Arrival Time Estimation (HOWLATE) methodology. The methodology and a three-month case study in the Washington DC area are described in the Volume I prequel to this document (Wunderlich *et al.*, 2001) and in other papers (Shah *et al.*, 2001).

The key finding from the initial HOWLATE methodology test in Washington was that although ATIS users did in fact experience reduced in-vehicle travel time when paired with comparable travelers who did not use ATIS, more substantial gains were found in reliability-related metrics: travel budget, on-time reliability, and just-in-time reliability. This report documents an exploration of this result from the smaller-scale three-month Washington case study in two larger twelve-month case studies in both the Washington network and in the Minneapolis/St. Paul (Twin Cities) metropolitan area. Recent research in the area of valuing the disutility of on-time reliability (Small *et al.*, 1999) is also incorporated throughout this report, providing a highly-useful method of monitizing reductions in in-vehicle travel time as well as improved travel reliability. Finally, the report covers some preliminary analysis of the likely benefits of supplementing a pre-trip ATIS service with en route guidance.

This introductory section is intended to provide the reader with the necessary background regarding the HOWLATE methodology to read and understand this full report as a stand-alone document without the prerequisite of having read Volume I (Wunderlich *et al.*, 2001). First, a brief summary of the background and motivation on the history of ATIS evaluations and the role of HOWLATE are presented in Section 1.1. An overview of the HOWLATE methodology is presented in Section 1.2. Section 1.3 outlines the motivations and hypotheses of the new HOWLATE research covered as a part of this document. Readers familiar with Wunderlich *et al.*, 2001 may wish to skip directly to Section 1.3.

1.1 Background

Initiatives to evaluate the impact of traveler information services providing real-time congestion reports (hereafter, simply referred to ATIS in this report) in the 1990s provided what appeared to be contradictory results with respect to the time savings of ATIS users: large *perceived* time savings reported by ATIS users in survey research, but marginal to no *observed* in-vehicle travel time savings when measured empirically in field operational tests.

ATIS user perception has been measured in several independent studies undertaken in Boston, Seattle, Washington , and other metropolitan areas (Englisher *et al.*, 1995; Jensen *et al.*, 2000; Schintler *et al.*, 1999; Lappin, 2000). Between 85% and 95% of respondents in each of these surveys reported high confidence that their use of ATIS helped them to save time.

Finding and quantifying these perceived time savings proved more difficult, despite a range of field experiments and traffic simulation studies. The field studies featured paired driving trials ("yoked driver studies") wherein two subjects were directed simultaneously to drive from one point to another and report experienced in-vehicle travel time. The experimental subject was allowed to consult ATIS services when determining route choice, while the control subject did not consult ATIS. Several yoked driver trials involving in-vehicle devices were conducted throughout the last decade. Results from the Pathfinder test in San Francisco (JHK and Assoc., 1993), the TravTek test in Orlando (Inman *et al.*, 1995), and the ADVANCE operational test in Chicago (Schofer *et al.*, 1997) found either reductions of less than 4% in travel time for ATIS users or no statistically significant difference in travel time between users and non-users.

Corridor studies using traffic simulation were also undertaken, partly in response to the lack of field evidence of travel time savings. Examples include studies in Orlando (Van Aerde and Rakha, 1996), Detroit (Hadj-Alouane *et al.*, 1996; Underwood *et al.*, 1998), and central New Jersey (Glassco *et al.*, 1996; Glassco *et al.*, 1997). The results of these studies are fairly consistent: in-vehicle travel time savings on the order of 10% when incidents occur, but no travel time savings under normal (non-incident) conditions. Later work identifying the frequency and intensity of incident, weather and variable travel demand conditions (Bunch *et al.*, 1999; Wunderlich *et al.*, 1999; Carter, 2000) showed that significant travel time savings accrue to ATIS users under conditions of intense, unexpected congestion but total savings on an annualized basis for ATIS users is often statistically insignificant.

These seemingly contradictory results presented a difficult position for a public-sector decision makers planning new or continued investment in ATIS. However, we argue that the results are not contradictory. As survey research suggests, ATIS users do realize time savings, but not necessarily in terms of the most frequently utilized measure, in-vehicle travel time. ATIS users can significantly reduce time wasted by arriving too early at their destination as well as the frequency and magnitude of late arrivals. Time saving and stress reductions associated with more predictable travel are much larger and more highly valued than purely reductions of in-vehicle travel time.

In order to quantify these reliability-related benefits of incorporating ATIS into a regular commuting behavior, the HOWLATE method utilizes the concept of a *simulated yoked trial*. This technique entails the efficient reconstruction of millions of hypothetical, retrospective paired driving trials using archives of roadway travel times. The archives provide not only estimates of what roadway segment travel times were during the period studied but what was known about congestion conditions by ATIS providers at any point in time.

1.2 Overview of the HOWLATE Methodology

The HOWLATE methodology (Figure 1-1) 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.

A key input required for simulated yoked studies is statistical distributions of error between the ATIS link travel time reports and observed travel times. 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 Washington regional network. 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 limits. The test car drivers in Hardy *et al.*, 2000, 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 are constructed from each day in the travel time archive and passed to the yoked study simulator.

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 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* (Figure 1-1) 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.

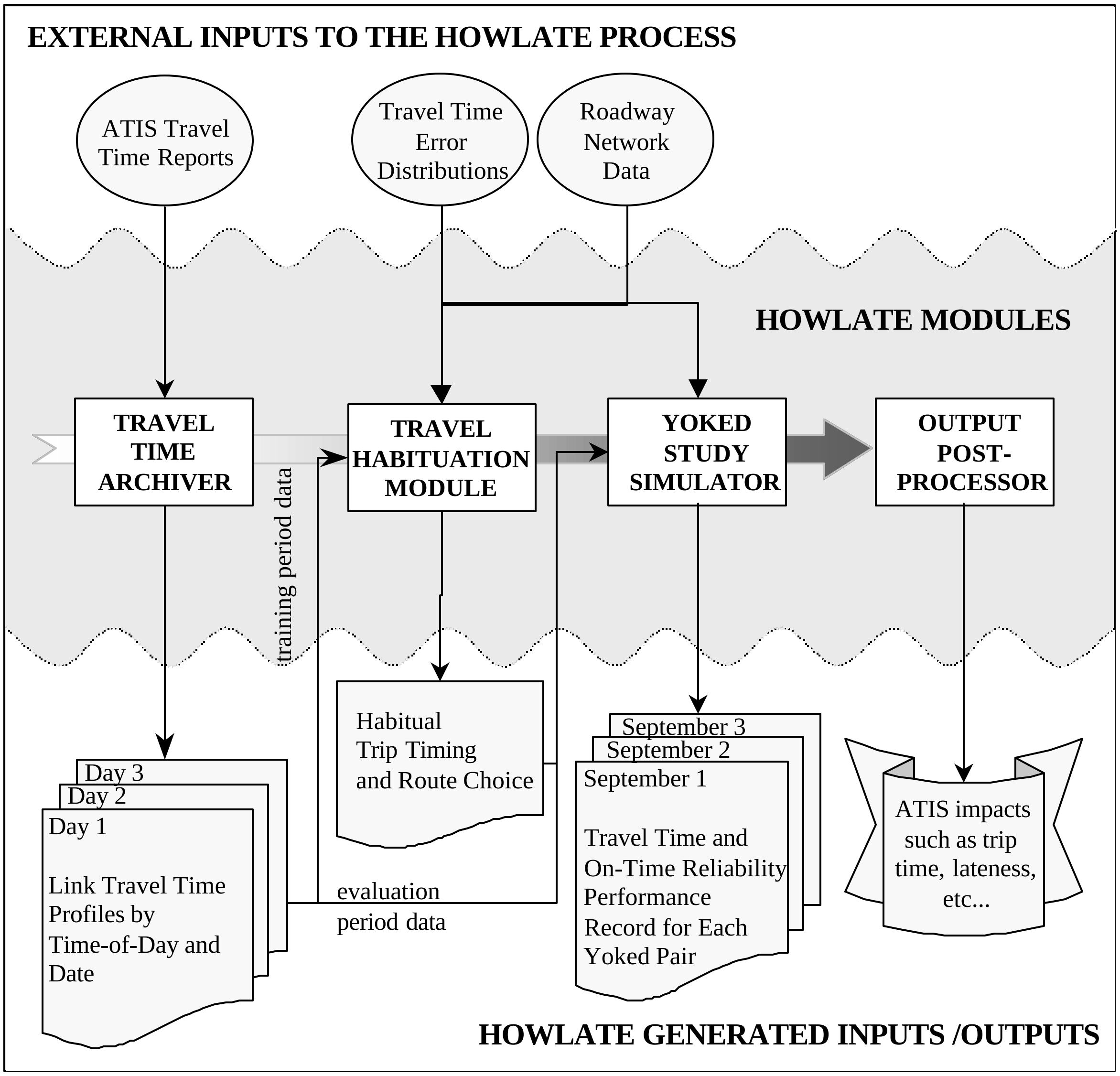

Figure 1-1. Overview of HOWLATE Method

We estimate travel time variability for each habitual path by computing the variability of its travel time over the days in the training period. 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 determines the time of habitual trip start. 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 traveler with a 95% on-time reliability requirement has a larger time buffer for variability than traveler with an 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 desired flexibility of the ATIS user to adjust trip starts in real time. ATIS user preference to remain on the habitual route is modeled using a travel time threshold. The ATIS service does not contact the user about diversion 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 service identifies a suggested trip start time by checking the travel time on the current fastest path. The first check is initiated at a set time (e.g., 30 minutes) prior to the habitual start time. The service postpones notifying the user about 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 service alerts the user of the projected trip start time and the fastest path (subject to the habitual route preference threshold). No notification is made if there is no change from the habitual trip start time and habitual path. HOWLATE assumes that the ATIS user adopts the suggested trip start time and traverses the network on the suggested path. Note that the service may also contact the traveler to suggest trip start timing *later* than the habitual start time if congestion conditions are lighter than normal during that particular day. An en route guidance supplement to the basic pre-trip service can also be modeled.

In-vehicle travel time 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.* by 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. (Figure 1-1) 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 have happened on a particular day in the evaluation period.

1.3 Study Hypotheses

The primary hypothesis of this report is that the findings of the three-month Washington case study described in Wunderlich *et al*., 2001 hold true more generally. That is, the observed gains in on-time reliability, reduced early and late schedule delay, in combination with small reductions in in-vehicle travel time, will also be observed when longer test periods are considered. Further, these observations should hold true in other metropolitan areas like the Twin Cities.

Other hypotheses include:

- When the on-time reliability impacts of pre-trip ATIS are converted into monitized reductions in traveler disutility (using the relationship in Small *et al.*, 1999), there will be some trips in both Washington and the Twin Cities where these reductions in disutility will exceed the reported $3-5$/month ($60/year) figure typically posited as a target subscription rate for such a service (Ulnick and Haupricht, 2001).
- The absolute and relative benefits of pre-trip ATIS will be higher in the Washington network than in the Twin Cities case study because the Washington network is inherently more congested.
- Pre-trip ATIS will prove valuable to both users who are familiar with their trips and congestion patterns, as well as to users unfamiliar with particular trips and congestion patterns.
- The addition of an en route guidance supplement to the pre-trip ATIS service will provide additional on-time reliability benefits, as well as reduced in-vehicle travel time.

To test these hypotheses, certain aspects of the HOWLATE methodology had to be altered. For example, the ability to model and evaluate an en route guidance service had to be designed and implemented. Section 2 presents revisions and extensions made to the HOWLATE process from the algorithm implemented in Wunderlich *et al.*, 2001. In addition, Section 2 provides an overview of the travel behaviors tested in HOWLATE, parameters held in common throughout all of the tests, and the measures of effectiveness used to determine benefit. Special attention is paid to the process by which various measures are processed in the computation of dollar-valued disutility based on the work of Small *et al.*, 1999.

Section 3 presents a Washington case study conducted for the twelve-month evaluation period of June 2000-June 2001. Section 4 presents the parallel Twin Cities case study conducted over the same twelve-month period. Section 5 explores the potential impact and value of supplementing the pre-trip ATIS service modeled in Sections 3 and 4 with an en route guidance service for some selected routes in the Washington area.

Section 6 reviews implications of the evaluations in Sections 3, 4 and 5, including a comparative analysis of ATIS benefit in Washington and Minneapolis. Section 6 also presents some conclusions and discusses the direction of future applications of the HOWLATE methodology.

2.0 Extensions and Revisions to the HOWLATE Methodology

In order to test the hypotheses posed in Section 1.3, the HOWLATE methodology required several enhancements as well as the ability to calculate new measures of effectiveness. This section provides detail on those enhancements as well as key parameter settings held in common in each of the experiments presented in Sections 3, 4, and 5. A complete, revised HOWLATE algorithmic statement is provided in Appendix A.

Section 2.1 discusses enhancements made to the yoked trial simulator to accommodate a wider range of ATIS user behaviors and non-user behaviors. Section 2.2 covers key sets of parameters held constant in all experiments. Section 2.3 presents some revisions to the measures of effectiveness used for the determination of ATIS benefits, as well as a discussion of how these measures are then converted into dollar-weighted disutility figures using the technique of Small *et al.*, 1999. Section 2.4 discusses the nature of the prospective pre-trip and en route guidance services tested as a part of this study *vis a vis* currently available ATIS services.

2.1 Modeling of ATIS User and Non-User Travel Behaviors

As described in Section 1, the HOWLATE methodology evaluates the on-time performance of travelers making repeated trips at the same time of day over the evaluation period. Each simulated yoked trial conducted pairs of an ATIS user (experimental subject) and a traveler who does not utilize traveler information. In Wunderlich, *et al.*, 2001 this pairing was limited to ATIS non-users who rely on habitual routes and times of departure established over at least a month of travel in the training period. In reality, many trips made in a network may in fact be made by travelers who are unfamiliar with the network and congestion conditions by time of day – or by travelers who may be familiar with one part of the network but are facing a trip to an unfamiliar part of the network. In this report, we expand the ATIS non-user universe to include both familiar and unfamiliar behavioral models (detailed in Sections 2.1.1 and 2.1.2, respectively).

Likewise, ATIS users were all defined similarly, each making decisions on what route to take and when to leave based solely on the current conditions reported by the ATIS service. We dub the approach taken in Wunderlich *et al.*, 2001, as the implementation of a naïve ATIS user, one who takes at face value that conditions reported by the ATIS service will persist throughout the trip. It became clear that a regular user of an ATIS service would likely begin to bias estimates of travel time when making trip departure decisions that reflect the reality of using the service on a daily basis. For example, a commuter with a long trip (e.g., averaging about an hour) leaving at 7:00 AM would soon realize that the relatively light congestion conditions at the trip start did not persist over the whole trip. Since the ATIS modeled in this study does not predict future travel times, the user instead would discount or alter the current travel time report to reflect the natural increase in travel time as the AM peak period begins to build up. In this report, we break out ATIS user behavior along the same lines as the non-user, into savvy and naïve behaviors that reflect the depth of understanding and experience a user might have not only with the network itself, but an experienced accuracy of the ATIS travel time estimates themselves. Sections 2.1.3 describes how these ATIS user behaviors have been implemented in the HOWLATE methodology. Section 2.1.4 covers the modeling of an en route supplement to the pre-trip ATIS behaviors modeled in Section 2.1.3.

2.1.1 Familiar Non-User Behavior (F95, F80)

Familiar non-user behavior is implemented for this study identically as in Wunderlich *et al.*, 2001. In training, habitual route choice and time of departure are determined by finding the fastest path from origin to destination using average link travel times over the training period. Two forms of familiar non-users are modeled – one adopting a more conservative approach to buffering in additional time to account for travel variability (F95), the other a less conservative approach (F80).

The F95 traveler (familiar with 95% on time requirement) sets the habitual time of trip start as the target time of arrival minus the expected trip time on the fastest route, plus a buffer period large enough to insure a 95% on-time reliability outcome in the training period. These travelers are more conservative with respect to arriving late and budget the largest amount of time for travel of the two familiar ATIS non-user types. This behavior is appropriate for travelers for whom it is imperative to arrive on time (late no more than roughly once per month). The F95 traveler here is equivalent to the conservative non-user modeled in Wunderlich *et al.*, 2001.

The F80 traveler (familiar with 80% on time requirement) sets the habitual time of trip start as the target time of arrival minus the expected trip time on the fastest route, plus a buffer period large enough to insure an 80% on-time reliability outcome in the training period. These travelers accept fairly frequent late arrivals, and are the more aggressive of the two familiar non-user types modeled with respect to lateness. The buffer size here is smaller than for F95 travelers. The tradeoff made by the F80 travelers is a smaller total amount of time budgeted for travel at the expense of more frequent late arrivals. The F80 traveler in this report is equivalent to the aggressive non-user modeled in Wunderlich *et al.*, 2001.

2.1.2 Unfamiliar Non-User Behavior (UNF)

The unfamiliar travel behavior type is an addition to the HOWLATE methodology since Wunderlich *et al.*, 2001. Instead of using experience in a month-long or longer training period, trip timing and route selection are determined to mimic the traveler who has a good map but no first-hand knowledge of congestion conditions throughout the day.

Route choice is made based on link times associated with the fastest route under uncongested (free-flow) conditions. Time of departure is determined by subtracting the uncongested travel time from the target time of arrival, as well as a time-of-day dependent buffer. The size of the buffer depends on whether the target time of arrival falls into the nominal peak periods of 7:00-9:00 AM or 4:00-6:30 PM. No buffer is added for non-peak target times of arrival, while a buffer proportional to travel time is added for peak target times of arrival.

The size of the buffer is determined by considering the Texas Transportation Institute (TTI) congestion index (Schrank and Lomax., 2000) for a particular city (1.42 in Washington DC and 1.31 for the Twin Cities). In DC, a buffer time equal to 42% of the travel time is added for peak travel; similarly in the Twin Cities, a buffer time of 31% is added for peak travel.

2.1.3 Naïve and Savvy ATIS User Behavior (ANV, ASV)

As discussed above, the ATIS travel behavior model in Wunderlich *et al.*, 2001 inherently modeled a naïve approach to regular ATIS use. This model is retained as naïve ATIS user (designated ANV), and used without alteration in these studies.

In addition, a savvier model of ATIS user behavior is also incorporated (ASV). The savvy user discounts or inflates the estimates of travel time provided by the ATIS service based on the observed accuracy of those reports in the training period. For example, if reports during the early morning periods frequently underestimated the experienced travel time of the commuter during the training period, that user would likely begin to adopt the position of "when they say it's going to be 45 minutes, I know that it's really going to be 60 minutes." For each origin-destination and time of arrival, a discounting/inflating factor, dubbed omega, is computed based on experience in the training period.

The lower section of Figure 2-1 illustrates a typical pattern for the omega factor for a long trip like the one in Washington from Laurel, Maryland to Dale City, Virginia. In the early morning hours, omega is as high as 1.13, indicating that the projections for 7:30 AM target arrival times were typically 13% too low (when leaving at approximately 6:30 AM). During the mid-day offpeak, however, the ATIS travel times were 5 to 10% too high, and the savvy ATIS user discounts travel time estimates in the evaluation period by that amount. This is related to a SmarTraveler policy not to post travel times implying faster than speed limit travel (see Section 2.2).

The impact of the use of the savvy omega factor can be seen in the upper half of Figure 2-1. Consider the 7:15 AM target arrival time in Dale City. Our ANV traveler arrives five minutes late, while the ASV is five minutes earlier than the target time of arrival. The reason is that when time of trip start was determined in HOWLATE, the ASV user inflated the ATIS estimate of travel time by approximately 13% (the appropriate omega factor from the lower half of Figure 2-1). This resulted in a departure time five minutes earlier than the ANV traveler. That five minutes was critical, as it turned out, because the worsening traffic eventually separated the two by almost ten minutes when arriving in Dale City.

The trip decisions and outcomes for June 3, 2000 are shown in Figure 2-1. Note that the ASV user does not always outperform the ANV user in every trial, because not every day in the evaluation period conforms precisely to the experience of the ASV user in the training period. For example, for the 4:15 PM target arrival time in Dale City, the ASV user marginally inflates the ATIS estimate of travel time (5%), leaves five minutes earlier than the ANV commuter, and ends up getting to Dale City 12 minutes early, earlier than the desired 10 minute arrival window. Scanning the entire day, the ASV users are early in six trials and late in three. The ANV users are early in five trials and late in five trials.

Yoked trial pairings throughout this document follow the convention of matching unfamiliar non-users with naïve ATIS users (UNF vs. ANV), and familiar non-users with savvy ATIS users (F95 or F80 vs. ASV). In Wunderlich, *et al.*, 2001, the yoked trials were conducted between familiar non-users and naïve ATIS users (F95 or F80 vs. ANV).

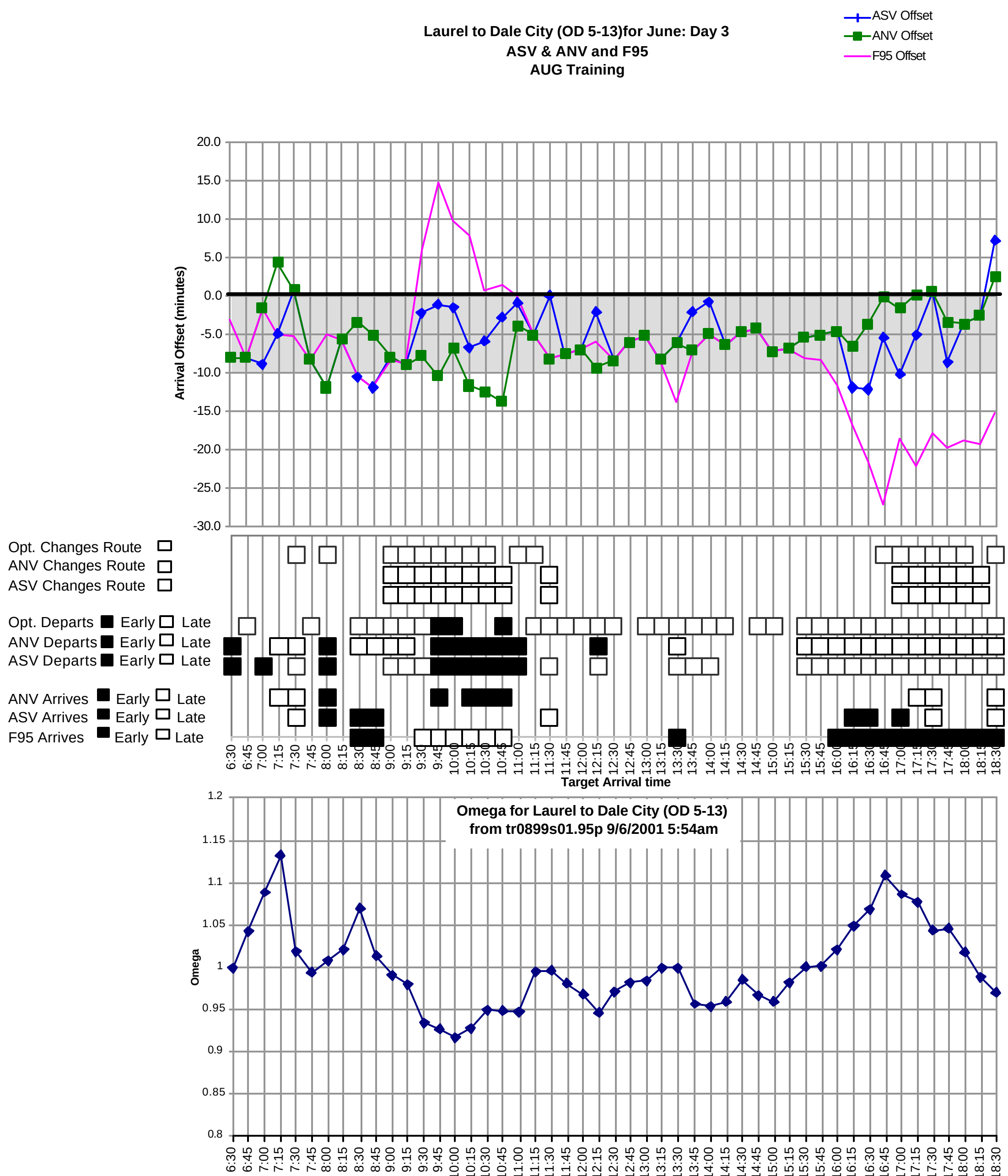

Figure 2-1. Comparison of Savvy and Naïve ATIS User Behavior

2.1.4 Savvy ATIS User with En Route Guidance (ASR)

The pre-trip ATIS user chooses the fastest path and the optimal trip start time, based on the conditions prior to the start of the trip. The commuter who uses en route ATIS corresponds to a savvy ATIS user (ASV) who has access to and utilizes traveler information service throughout a trip.

Trip start time and pre-trip route choice are determined exactly as for the ASV traveler.

Once the trip start time and the initial route are determined, the fastest path is determined each time the user enters a new link on the path (based on current ATIS link travel time estimates). If the travel time on the new path is lower than the travel time on the current path by more than the diversion indifference threshold (here, three minutes), the en route ATIS user will divert to the new path.

If the travel time differential does not exceed the diversion indifference threshold, the user will remain on the current path. Note that a pre-trip ATIS user does not change route once the initial path is fixed. Hence, if the pre-trip ATIS user faces congestion en route, they will remain on the pre-determined path, while the en route ATIS user will switch to the alternate route if the travel time on the new path is less than the travel time on the current path by more than the indifference threshold. A revised HOWLATE algorithmic statement is shown in Appendix A.

2.2 Key Parameters

A number of key parameters are held constant in all the experiments performed: ATIS error bands, diversion threshold, and ATIS notification window.

2.2.1 ATIS Error Bands

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

Table 2-1. Link Travel Time Error Distribution

The link travel time error bands used to generate the Monte Carlo realizations of actual travel times in HOWLATE remain unchanged from Wunderlich *et al.*, 2001 (Table 2-1). These error bands were determined by conducting a number of travel time runs on I-66 and Route 50 in the Washington metropolitan area. More recent studies of the accuracy of these travel time estimates indicate that these error bands are somewhat optimistic compared with more comprehensive assessments in both Washington and in the Twin Cities. Some discussion of this impact is included in Section 2.4.

2.2.2 *Diversion Indifference Threshold*

As in Wunderlich *et al.*, 2001, an indifference threshold for route switching is set to three minutes, based on the work of Srinivasan and Mahmassani *et al.*, 1999.

2.2.3 ATIS Notification Window

The window in which the ATIS service looks to notify the ATIS user of a change in trip departure time or route is centered around the habitual time of trip start (for yoked trials with familiar non-users) or the projected time of trip start (for unfamiliar non-users). For this study, we assume that the service begins scanning 30 minutes before the trip start time to see if early departure time notification is warranted – and up to 30 minutes after the trip start time for late departure time notification.

2.3 Measures of Effectiveness

As in Volume I (Wunderlich *et al.*, 2001), we define various core measures of effectiveness:

On-time reliability is defined as the proportion of simulated yoked trials wherein a traveler arrives at the destination node at or prior to the target arrival time.

Just-in-time reliability is defined as the proportion of simulated yoked trials wherein a traveler arrives at the destination node both on-time and no more than 10 minutes early.

Schedule delay is defined as the difference between the actual arrival at the destination and the target time of arrival. If schedule delay is negative, it is called *early schedule delay*. If it is positive it is termed *late schedule delay*.

Travel expenditure is defined as the time between trip start and the target arrival time, as well as any late schedule delay. Travel expenditure is the same measure defined in Wunderlich *et al.*, 2001 as travel budget. We reserve the term *travel budget* in this study to refer only to the amount of time between trip start and target arrival time. In addition, *in-vehicle travel time* and *trip distance* measures are collected for each simulated yoked trial.

Dollar-valued disutility provides a measure of disutility associated with a trip by assigning a cost to the duration of travel time and how early or late one reaches one's destination based on the work of

Small *et al.*, 1999. The disutility of in-vehicle travel time is set at \$3.38/hour based on their research. The cost of early arrival is a quadratic function of the magnitude of early arrival. The cost of a late arrival is a linear function of the magnitude of late arrival plus a one-step penalty for arriving late. Note that the cost of late or early arrival is not sensitive to the duration of the trip, however. That is, being five minutes late has equal disutility, or cost, regardless of the fact that the trip may be five or 50 minutes long.

The disutility function is defined functionally as:

$$c = \acute{a}T + \hat{a}_{SDE}(SDE) + 2\ \hat{a}_{SDE2}(SDE)^2 + \tilde{a}(SDL) + \grave{e}D_L$$

T:	Travel Time
SDE:	Schedule delay early
SDL:	Schedule delay late
D_L:	Late arrival index $= \begin{cases} 1 & \text{if} \quad SDL > 0 \\ 0 & \text{otherwise} \end{cases}$

The estimates of the parameters are:

a:	\$0.0564/min. (linear cost of in-vehicle travel time)
$\hat{a}_{SDE}$:	\$-0.023/min (linear component of quadratic early cost)
$\hat{a}_{SDE2}$:	\$0.005/min (quadratic component of quadratic early cost)
g:	\$0.310/min (linear cost of late arrival)
q:	\$2.87 (one step penalty for arriving late)

Figure 2-2 illustrates the shape of the dollar-valued disutility function for both 30 and 60 minute duration trips.

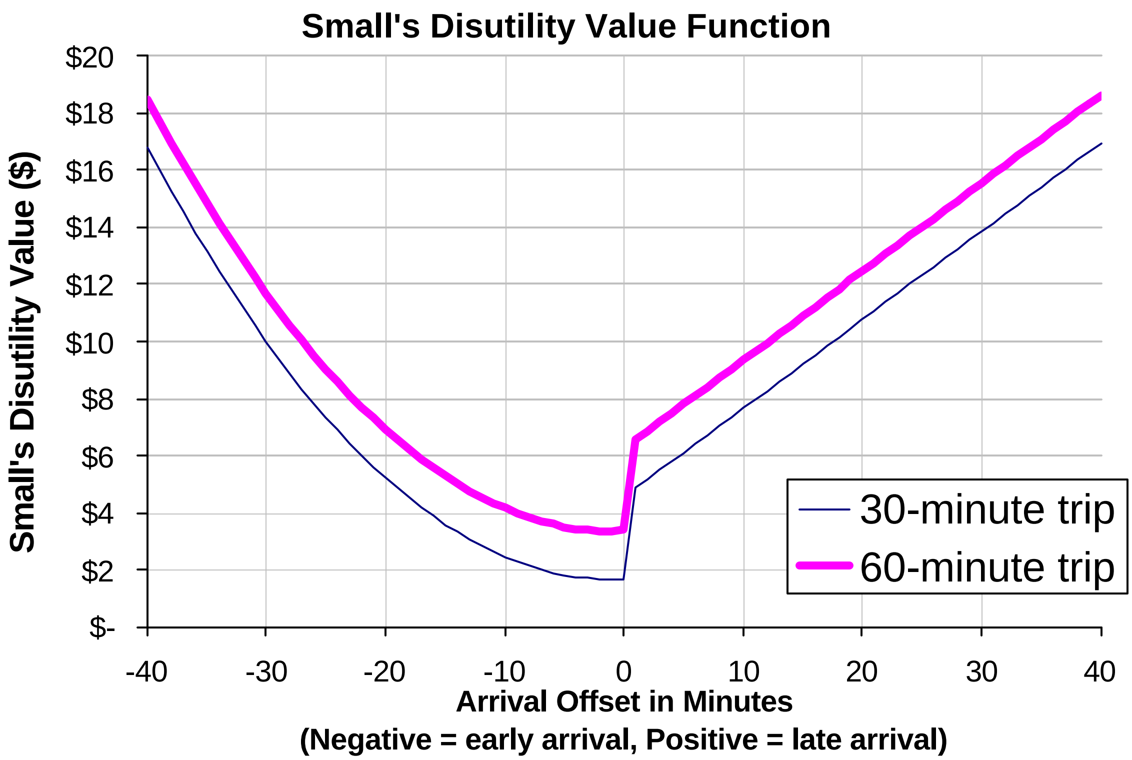

Figure 2-2 Dollar-Valued Disutility Function

2.4 Notification ATIS Services and Current ATIS Services

It is important to note again that the ATIS benefit assessment conducted here is not an evaluation of the current SmarTraveler system. What is modeled in HOWLATE is a prospective notification-based service based on the same basic data collected and disseminated by SmarTraveler. Users of SmarTraveler access the service through the Internet and must construct their own estimates of travel time on multi-link routes. Seen this way, the notification service we prospectively model here manipulates the travel time data to suggest changes in trip timing and route choice in manner that is possible but time-consuming for the current SmarTraveler user. Further, the accuracy of the data is based on comparisons of SmarTraveler reported travel time and experienced travel time in instrumented probe vehicles on only two facilities in the Washington area. Findings from other more comprehensive studies of ATIS accuracy indicate that the error bands used herein may be somewhat optimistic. The overall result is that the benefit estimates made in this report are likely to be somewhat higher than would be realized by a user of the SmarTraveler system in either of the two metropolitan areas studied.

3.0 Washington DC 12-Month Case Study

The Washington metropolitan region spans from Baltimore, Maryland through northern Virginia. This is a region of significant population growth, population density, and traffic congestion. The Washington roadway network used for this case study encompasses five counties, three incorporated cities, and the District of Columbia. Table 3-1 lists these entities along with their population, density, and growth rates. TTI ranks the combined Washington/Baltimore metropolitan area as the third most congested region in the United States.

	Year 2000 Census Data				% Population
Jurisdictions	Popula-tion	Area (sq. mi)	Median Income	Persons per Sq. Mile	Change from 1990 to 2000
Montgomery County, MD	873,341	496	$62,130	1761	+15%
Prince George's County, MD	801,515	485	$47,882	1653	+10%
Arlington County, VA	189,453	26	$57,244	7287	+11%
Fairfax County, VA	969,749	395	$71,057	2455	+18%
Prince William County, VA	280,813	266	$44,845	1056	+30%
Alexandria city, VA	128,283	15	$51,052	8552	+15%
Fairfax city, VA	21,498	6	$61,099	3583	+10%
Falls Church city, VA	10,377	2	$64,420	5189	+8%
District of Columbia, DC	572,059	61	$34,980	9378	-6%
Regional Summary	3,847,088	1752	$55,503	2196	12%

Table 3-1. US Census 2000 Population and Income Data

The rate of regional population growth is projected to increase, while the opportunities for building or expanding existing roadway infrastructure are becoming fewer and more costly, given the density of regional housing and employment. Advanced Traveler Information Systems (ATIS) hold significant promise in efficiently utilizing existing roadway infrastructure by promoting more informed travel decisions by commuters. In this section we evaluate the impacts of a next-generation pre-trip ATIS on various commuter types using the HOWLATE method.

We evaluate the trip outcomes of various commuter types using the HOWLATE method and detailed archives of roadway trip times from March 2000 through May 2001. We define commuter type by two primary characteristics: their level of tolerance for late arrivals, and their familiarity with patterns of congestion on their route.

Trip experience and outcome differences among commuter types are in large part a reflection of the geographic, congestion and variability characteristics of the network. Specifically, trip outcomes are a result and reflection of how the roadway travel has changed or varies day to day from the period when a commuter establishes travel habits. In this chapter we first focus on the primary roadway travel time data (Section 3.1). In Section 3.2 we explain the set of experiments conducted, and we describe the outcomes of these experiments in terms of changes in commuter departure decisions and trip outcomes through the use of ATIS. In Section 3.3 we evaluate relationships between roadway trends and trip outcomes. Section 3.4 outlines the major findings from this Washington DC evaluation.

3.1 Analysis of Link Travel Time Data

Because underlying changes in roadway travel times and variability drive HOWLATE trip results, we explore in this section trends in the archived data. Here we first describe the source and geographic coverage of data used in our study (§3.1.1). We also describe the extent of coverage of the archived data (§3.1.2). We then highlight aggregate changes in the average and standard deviation of travel time from the period used to train commuter behavior to the period used to evaluate trip outcomes (§3.1.3).

In order to make meaningful inferences about commuter outcomes during differing levels of congestion, we parse the data into peak and off-peak time periods (§3.1.4). In this subsection, we discuss the process used define the peak periods, and we explore trends in peak duration.

In §3.1.5, we evaluate aggregate month-to-month trends in the primary data by peak and off-peak periods; while in §3.1.6, we explore individual roadway trends. The final sub-section, §3.1.7, summarizes the findings of the various analyses conducted using primary roadway travel time data.

3.1.1 Geographic Coverage

The link travel time data used for the Washington DC HOWLATE analysis is based on Mitretek's archiving of Internet postings made by SmarTraveler (www.SmarTraveler.com). The SmarTraveler Internet postings are publicly available, and list by facility real-time travel time information as well as information on accidents, special programs, and construction. Information is posted as early as 5:30 AM to as late as 8:30 PM, excluding weekends and some holidays. The geographic coverage by SmarTraveler of the Washington region ranges from Laurel and Germantown in Maryland, through the District of Columbia to Centreville and Dale City in Virginia. Figure 3-1 presents the Internet representation of the region and the network conversion of the Internet data map for the HOWLATE Washington DC analysis.

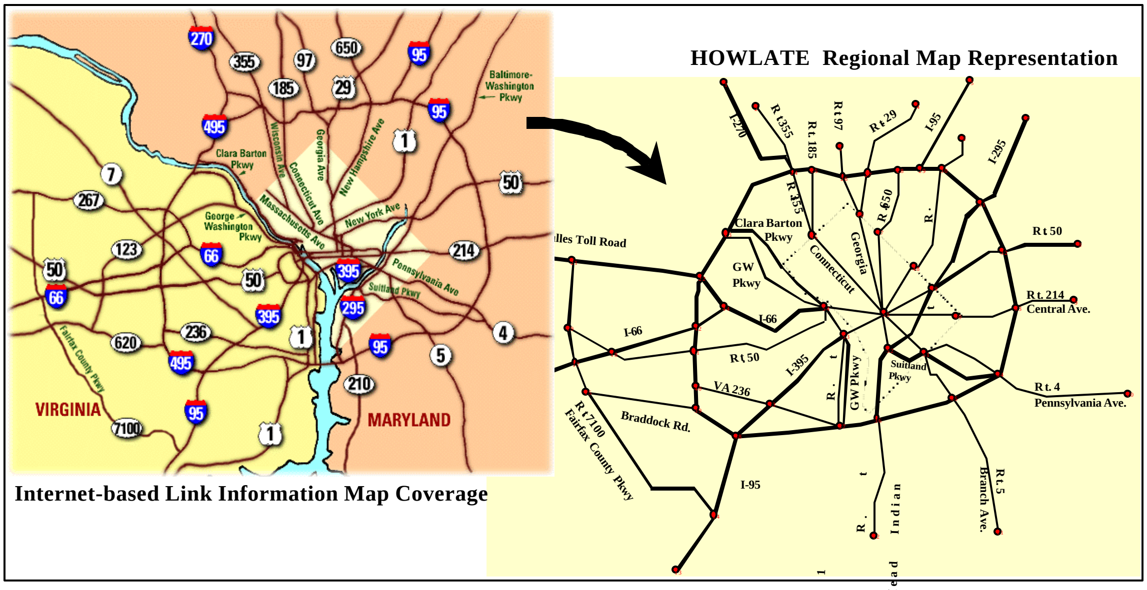

Figure 3-1 Map of Washington DC Network

SmarTraveler travel time data is consistently reported for this region on 33 facilities, spanning a total of 711.8 miles, counting directionality. The average length of these 33 facilities is 10.8 miles with maximum and minimum facility lengths of 25.0 and 2.6 miles respectively. Of the 33 facilities, 18 are freeways and 15 are major arterials. The 18 freeway facilities constitute 472.4 of the 711.8 miles for which SmarTraveler posts travel times. The 15 arterial facilities constitute the remainder (239.4 miles).

Table 3-2 lists the 33 facilities, their length, their facility type, and the number of HOWLATE network links comprising each facility. The 33 facilities are divided into 75 links, or 150 links accounting for direction, for use in the HOWLATE Washington network. The facilities are divided into links to realistically represent route choice options available within the region.

SmarTraveler does not post quantitative information on the arterial facilities within the District of Columbia. These facilities, however, are important in representing realistic route choice options. Thus, static links, independent of the SmarTraveler data are also incorporated in the Washington HOWLATE network. A more detailed description of the process used to construct the Washington

HOWLATE network is presented in (REFERENCES). The average link length for the Washington HOWLATE network is 4.6 miles. The longest link is 13.5 miles while the shortest link is 1.0 mile.

Facility Number	Facility (SmarTraveler) Description	Length (miles)	Number of Links	Facility Type
1	I-95/I-495 in MD btwn. Woodrow Wilson Bridge & College Park	25.0	7	Freeway
2	I-495 in MD between US 1 & the American Legion Bridge	17.4	7	Freeway
3	I-495 in VA between the American Legion Bridge & US 50	8.3	3	Freeway
4	I-95/I-495 in VA between US 50 & the Woodrow Wilson Bridge	13.2	4	Freeway
5	I-295 in MD between Laurel & East Capitol St. NE	10.9	2	Freeway
6	Suitland Pkwy. in MD between MD 4 & the Douglass Bridge	10.7	2	Freeway
7	G. W. Pkwy. in VA within I-495 (N. of DC and S. of DC)	16.5	3	Freeway
8	Clara Barton Pkwy. between I-495 & the Roosevelt Bridge	8.6	1	Freeway
9	MD 5/Branch Ave. in MD between US 301 & the DC Line	12.8	2	Arterial
10	MD 4 in MD between US 301 & the DC Line	12.6	2	Arterial
11	US 50 in MD between Bowie & Kenilworth Ave.	11.1	2	Freeway
12	US 1 in MD between MD 212 & the DC Line	8.0	2	Arterial
13	I-95 in MD between Laurel & I-495	6.1	1	Freeway
14	US 29 in MD between Cherry Hill Rd. & the DC Line	6.9	2	Arterial
15	MD 97 between Wheaton & the DC Line	4.8	2	Arterial
16	MD 355 between Gude Drive & the DC Line	12.0	2	Arterial
17	I-270 between Gaithersburg & I-495	9.1	1	Freeway
18	MD 214 between MD 202 & the DC Line	4.7	2	Arterial
19	MD 650 between I-495 & the DC Line	4.1	1	Arterial
20	MD 185 between I-495 & the DC Line	2.6	1	Arterial
21	VA 267 between Dulles Airport & I-66	14.4	3	Freeway
22	US 50 in VA between the VA 7100 & I-495	9.7	2	Arterial
23	US 50 in VA between I-495 & the Arlington Memorial Bridge	9.3	1	Arterial
24	I-66 between Centreville & I-495	12.5	3	Freeway
25	I-66 between I-495 & the Roosevelt Bridge	9.9	2	Freeway
26	I-95 between Dale City & I-495	14.0	2	Freeway
27	I-395 between I-495 & the Potomac River	9.5	2	Freeway
28	US 1 in VA between Kings Highway & the 14th St. Bridge	5.6	1	Arterial
29	VA 236 between I-495 & the King St. Metro	9.3	2	Arterial
30	VA 620 between the VA 7100 & I-495	8.9	1	Arterial
31	I-295 between I-495 & East Capitol St.	10.3	2	Freeway
32	MD 210 between Berry Road & the DC Line	8.4	1	Arterial
33	VA 7100 between Springfield Metro Station & VA 267	23.8	4	Freeway

Table 3-2 Facilities Comprising the Washington Network

3.1.2 Travel Time Archive

Mitretek archives through an automated process the travel time postings for the 33 facilities listed in Table 3-2 at five-minute intervals from 6:30 AM to 6:30 PM, Monday through Friday. SmarTraveler does not report travel times consistently on weekends or holidays, so these days could not be used. The travel time for each facility is then apportioned to its corresponding links based on the assumption of constant speed on the facility.

The analyses conducted in this study are based on data from March 2000 through May 2001. Table 3-3 lists the dates within each calendar month for which data was sufficient for use in the HOWLATE analysis. In this study, the months of March 2000 through May 2000 (termed training period) form the basis for determining the habitual or 'normal' commuting patters, whereas the months of June 2000 through May 2001 (termed evaluation period) form the basis for determining the trip outcomes of the normal commuting patterns.

Calendar Month	Complete Days	Potential Days	Percent Coverage	**Washington DC Dates of Coverage** Gray dates are potential days (weekends and holidays excluded). " - " indicates missing data. The numbers are dates with complete data.																								
				M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Mar-00	3	23	13%			-	-	3	-	-	-	9	-	-	-	-	-	-	-	21	-	-	-	-	-	-	-	-
Apr-00	12	20	60%	-	-	-	-	-	-	-	-	13	14	17	18	19	20	21	24	25	26	27	28					
May-00	18	22	82%	1	2	3	4	5	8	9	10	11	12	-	-	-	18	19	22	23	24	-	26		30	31		
Jun-00	12	22	55%				1	2	-	-	-	-	-	-	13	14	-	-	-	20	21	22	23	26	27	28	29	-
Jul-00	17	20	85%	3		5	6	7		11	12	13	14	17	18	19	20	21	24	25	26	27	-	-				
Aug-00	19	23	83%		1	2	3	4	7	8	9	10	11	14	-	-	17	18	21	-	23	24	25	28	29	30	-	
Sep-00	12	21	57%					-	4	-	-	-	8	11	12	-	14	-	18	19	20	21	-	25	-	-	28	29
Oct-00	16	21	76%	2	-	4	-	-		-	11	-	13	16	17	18	19	20	23	24	25	26	27	30	31			
Nov-00*	2	20	10%			-	-	-	-	-	-	-		-	-	-	-	-	-	-	-		-	-	-	29	30	
Dec-00	16	20	80%					1		5	6	7	8	-	12	13	-	15	18	19	20	21	22		-	27	28	29
Jan-01	15	21	71%		-	3	4	5	8	9	10	11	12		-	-	-	19	22	23	24	-	26	29	30	-		
Feb-01	15	20	75%				1	2	-	6	7	-	-	-	13	14	15	16	19	20	21	-	23	26	27	28		
Mar-01	16	22	73%				1	2	5	6	7	8	9	-	-	-	15	-	-	-	21	22	23	26	27	28	29	30
Apr-01	19	21	90%	2	3	4	5	6	9	10	11	-	13	-	17	18	19	20	23	24	25	26	27	30				
May-01	19	23	83%		1	2	3	4	7	-	-	-	11	14	15	16	17	18	21	22	23	24	-	28	29	30	31	
Total	211	319	66%																									

* Note: Due to the limited number of Nov-00 days, 11/29 and 11/30 are grouped with Dec-00 for monthly analyses.

Table 3-3 Calendar of Coverage

Shaded areas in Table 3-3 indicate potential dates for coverage within the month, while numerical entries in the shaded boxes indicate that sufficient data is collected for a particular day. The number in the shaded area indicates the day of the month for the data.

A number of days had to be excluded from consideration due to gaps in the data archive. Days not used account for occasions when, for some duration of time greater than 20 minutes, data on a facility was not archived. The absence in archiving is attributed to any combination of the following: the SmarTraveler site was down, Internet connectivity for the Mitretek site was down, or SmarTraveler modified significantly the format and/or content of the web pages causing problems with the automated download process. Of 319 potential dates for archiving data, 211 (66%) have sufficiently complete entries for use in this study.

An automated process for data collection, which has been in place since December 1999, underwent a major revision during the month of November 2000 to increase data capturing reliability. Prior to the revision, 63% of the days were archived. After the revision, 79% of the days were archived. The 211 days' coverage by day-of-week from Monday through Friday is 37, 41, 45, 43, and 45 days respectively.

3.1.3 Training Vs. Evaluation: Aggregate Changes

Here we explore differences in travel time and travel time variability aggregated across the 33 facilities. For each basic data point in the data archive (the time required to traverse a facility) we identify the facility name, facility direction, the calendar date, and the time-of-day. In this section we provide travel time statistics aggregated across facility, direction, date, and time-of-day for the training and evaluation periods.

Average travel times for the training and evaluation periods are 18.62 and 18.86 minutes, respectively. The average standard deviations for the training and evaluation periods are 3.06 minutes and 3.34 minutes, respectively. Travel time increases by 1.3% while variation in time increases by 9.2% from the training to the evaluation period. The increase in average and standard deviation of travel time for arterial facilities (2.0% and 19.0% respectively) is more than twice that of freeway facilities (0.8% and 4.6% respectively). Differences in average and variation in travel time between the training and evaluation period for the region are statistically significant at a 0.01 level. Given the average facility length of 10.6 miles, a network speed reduction from 34.2 miles per hour (mph) to 33.7 mph occurs from training to evaluation.

The key findings from this aggregate evaluation are:

1. *Link travel times and travel time variability increase from the training to evaluation period,*
2. *Variability increases are significantly greater than average travel time increases.*
3. *Increases in both travel time and variation in time are much higher for arterial facilities compared to freeway facilities.*

3.1.4 Time of Day Trends: Defining the Peak and Off-Peak Periods

As expected, travel time and variability in travel time are significantly higher during the morning and evening rush periods. Figures 3-2(a) and (b) chart the average and standard deviation in average facility travel time, respectively, at five-minute time intervals for the training and evaluation periods. These charts illustrate that from the training period to the evaluation period (1) the travel times have increased most in the morning followed by the evening, (2) variability in travel time increases throughout the day, and (3) the evening peak exhibits the largest travel time and variability in travel time. Also to note from these charts is the fact that the evening peak extends beyond the 6:30 PM cutoff of our data.

The hour from 5:30 PM and 6:30 PM has the greatest average network travel time and travel time standard deviation at 21.0 minutes and 3.3 minutes, respectively. The greatest increases in travel time from the training to evaluation period occur in the morning hours, between 6:30 AM and 9:30 AM. For the morning hours, average facility travel time increases by 3.1% and the standard deviation in facility travel time increases by 24.3%. The greatest increases in travel time standard deviation occur between 10:30 AM and 2:30 PM. The average increase in standard deviation of facility travel times during this period is 48%.

We conducted cluster analyses to establish time borders for AM peak, PM peak, and off peak categories. Cluster analysis as a technique separates data points into groups. Objects in a group tend to be similar to each other, and objects in different groups tend to be dissimilar. The objects used as the basis for conducting the cluster analysis by month are the facility-averaged travel time for each five-minute interval. Here, our cluster analysis requires data to be placed into two groups. The first group defines the AM and PM peak, while the second group defines the off peak.

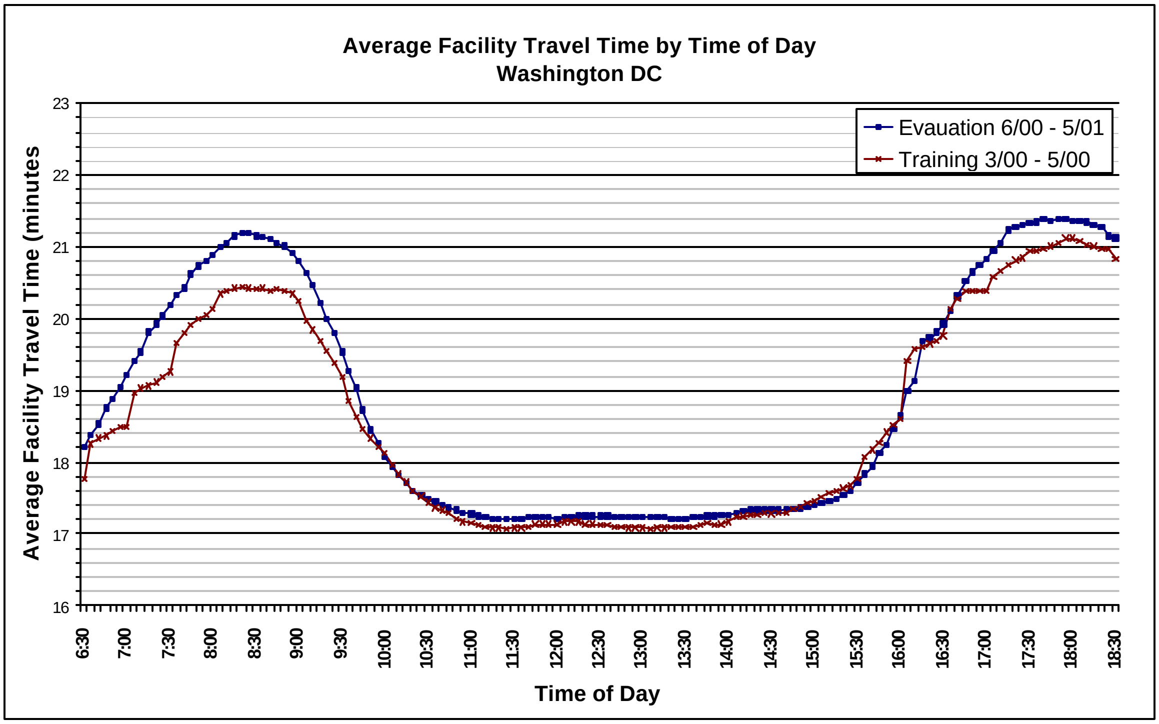

Figure 3-2(a) Washington DC Average Travel Time By Five-Minute Increments

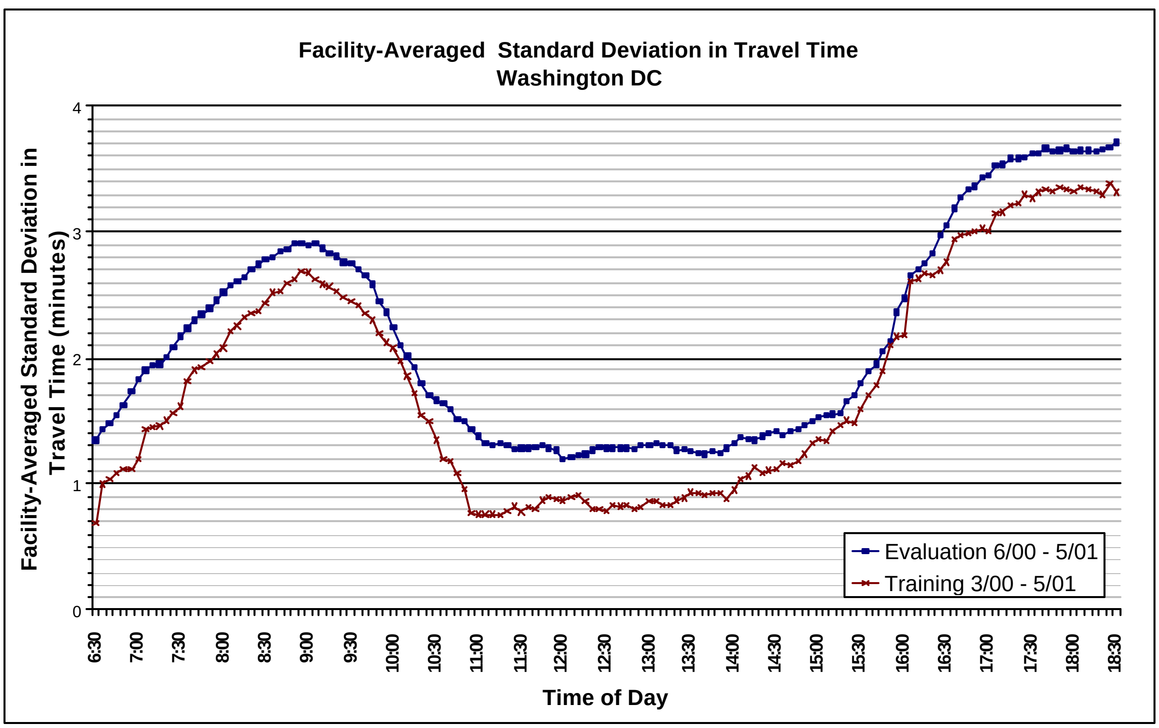

Figure 3-2(b) Standard Deviation of Travel Time By Five-Minute Increments

Figures 3-3(a) and (b) graph the AM and PM peak clusters respectively. AM peak start shows a strong linear trend towards earlier start times, while the AM peak end and the PM peak start are relatively flat in terms of extending the peak. The slope of the linear trend for the AM peak is statistically significant at a 0.01 level and its R-square value, a measure of linear fit, is 0.785. Based on the linear slope, the AM peak period starts approximately 30 minutes earlier over the course of one year. Statistics on the AM peak end or PM peak borders are not statistically significant.

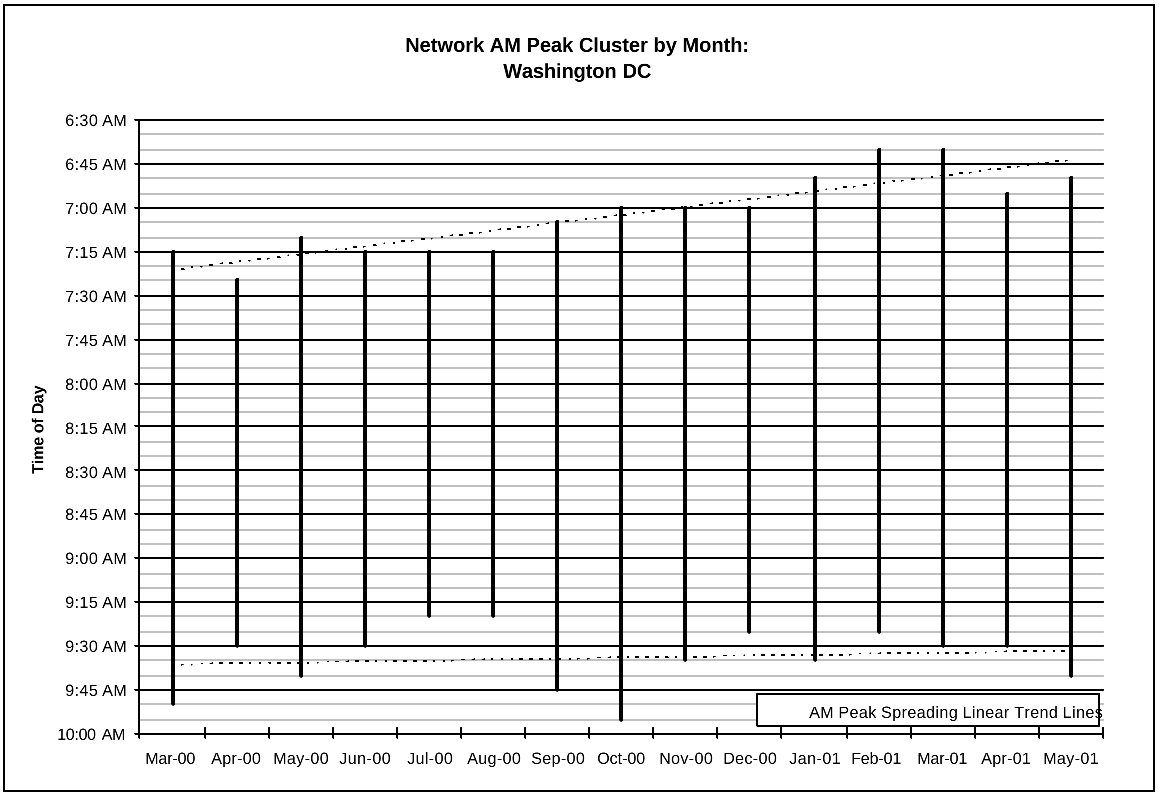

Figure 3-3(a) AM Peak Period Cluster Analysis

Based on the cluster analysis of data by month, the AM peak is defined as 7:00 am to 9:30 am, the PM peak is defined as 4:15 pm to 6:30 pm, and off-peak is defined as 6:30 am to 7:00am and 9:30 am to 4:15 pm. Table 3-4 lists the average and standard deviation of travel time for the peak and off peak periods for both the training and evaluation periods. To note, the largest travel time on any facility, 90 minutes, occurs on I-95 South in Virginia traveling from I-495 to Dale City. The basis of this record, occurring on February 22, 2000 was a 128-vehicle crash around 11:00 am when a sudden slick snowfall set upon the area. The event was featured on the front page of most

Washington area newspapers occurred was reported as a record pileup for the region. Due to large gaps in data on that day, however, it was excluded as a date assessed in these analyses.

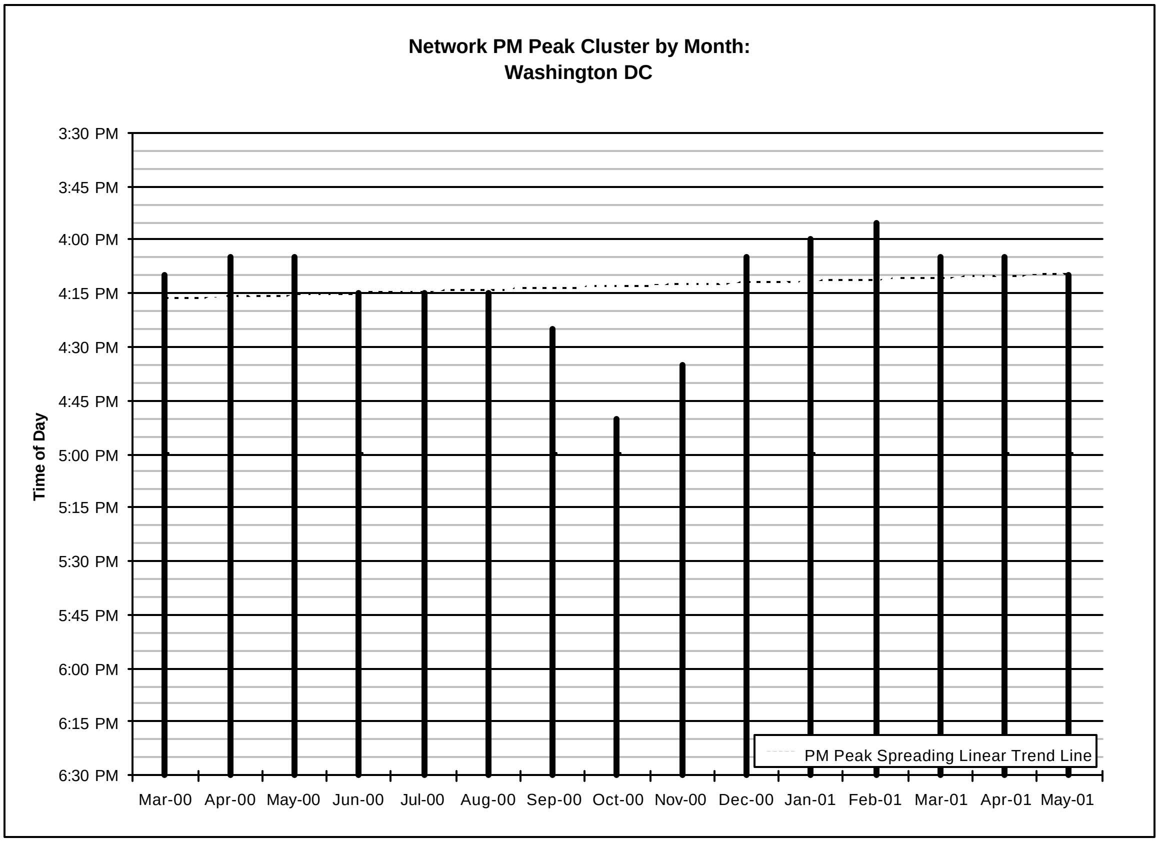

Figure 3-3(b) PM Peak Period Cluster Analysis

Time of Day Category	Training Average (minutes)	Training StDev (minutes)	Evaluation Average (minutes)	Evaluation StDev (minutes)
AM Peak	19.8	1.7	20.5	2.1
Off Peak	17.5	0.7	17.6	0.9
PM Peak	20.6	2.7	20.9	2.9
All Day	18.6	0.9	18.9	1.1

Table 3-4 Change in Facility Travel Times and Travel Time Variability

The key findings from the time of day evaluation are:

1. *The greatest increases in travel time and standard deviation from the training to evaluation period occur in the AM peak period, although the PM peak has higher average travel time and travel variability compared to the AM peak.*

2. *The greatest increases in travel variability from the training to evaluation period between the hours of 10:30 AM – 2:30 PM; however, averaging the remaining hours in the off-peak, the off-peak variability increase is at par with the PM peak.*
3. *Overall, the data reveals a spreading of peak period congestion 25 minutes earlier in the morning, starting at 6:55 AM rather than 7:20 AM .*

3.1.5 Month to Month Trends

We conducted an analysis to assess whether travel time and variability in travel time increase linearly by month. Figures 3-4(a) and (b) display by month and by peak, the average facility travel time and standard deviation in facility travel time, respectively.

The linear trend lines in Figure 3-4(a) shows a small positive slope for the AM peak. The R2-value, a measure of linear goodness of fit, is relatively low (0.38) suggesting a poor linear fit to the data. However, the difference between the slope of the AM trend line and zero is statistically significant at the 95% level suggesting that there is an increase in travel time by month, although the increase may not be linear. Based on the trend line slope, the AM peak travel time increases at a rate of 0.70 minutes per year. PM peak and off-peak average travel time trend lines' slope and R2-value are not statistically significant.

The linear trend lines in Figure 3-4(b) show positive, statistically significant slopes for both the AM and PM peak in terms of travel time standard deviation. As with trends in average travel time, the R2-value are relatively low suggesting a poor linear fit. Yet, the level of significance of the slope indicates that a positive relationship does exist between progression in calendar month and increase in standard deviations in travel time. Based on the AM and PM peak linear slopes, travel time standard deviation increase 0.29 minutes/year and 0.71 minutes/year. Of note, in the aggregate metrics, the AM peak shows a greater increase in variability compared to the PM peak from training to evaluation; however, here the PM peak shows a greater rate of increase. This can be reconciled by the fact that in the AM peak the increases in standard deviation occur earlier in the evaluation months compared to the PM peak.

Key findings from the monthly linear analyses:

1. *Increases in AM travel time and variability do occur at rates of 0.70 minutes/year and 0.29minutes/year, respectively. These increases do not occur gradually from month to month, given the relatively low R2-values.*
2. *The rate of increase in PM peak travel time standard deviation is 0.71minutes/year.*

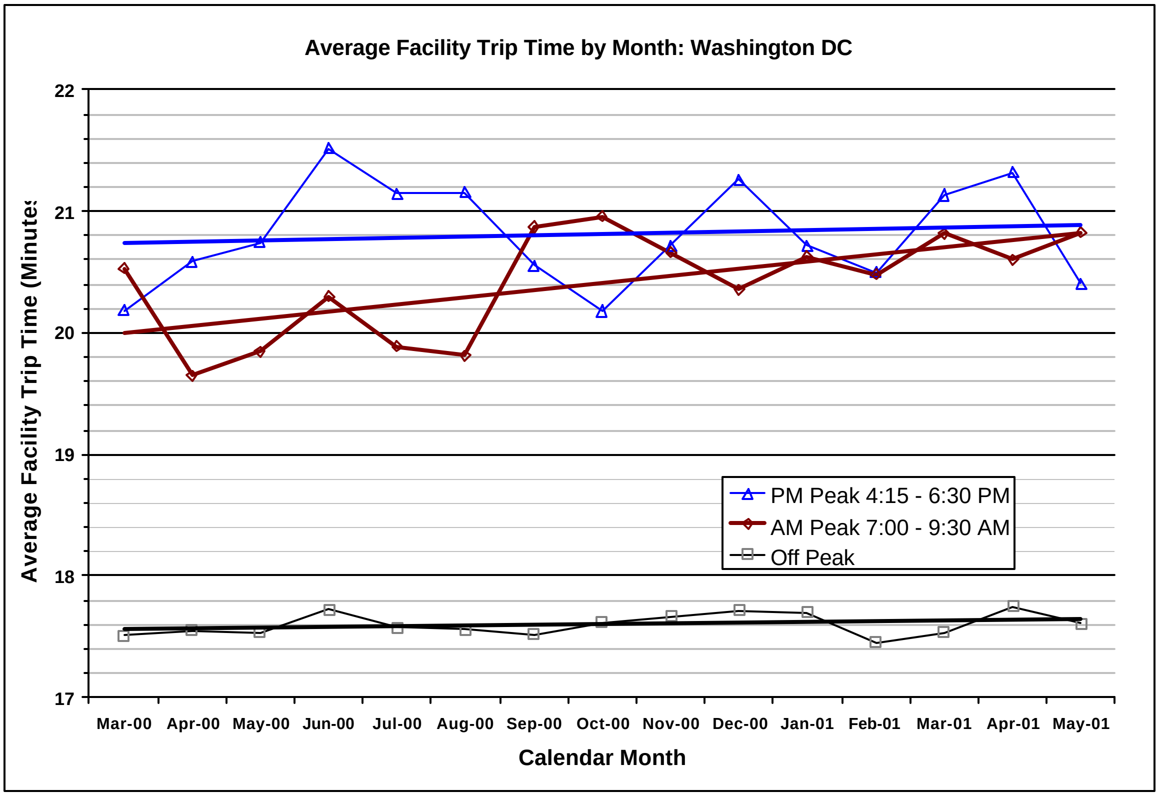

Figure 3-4(a) Average Facility Travel Time in Peak and Off-Peak Periods

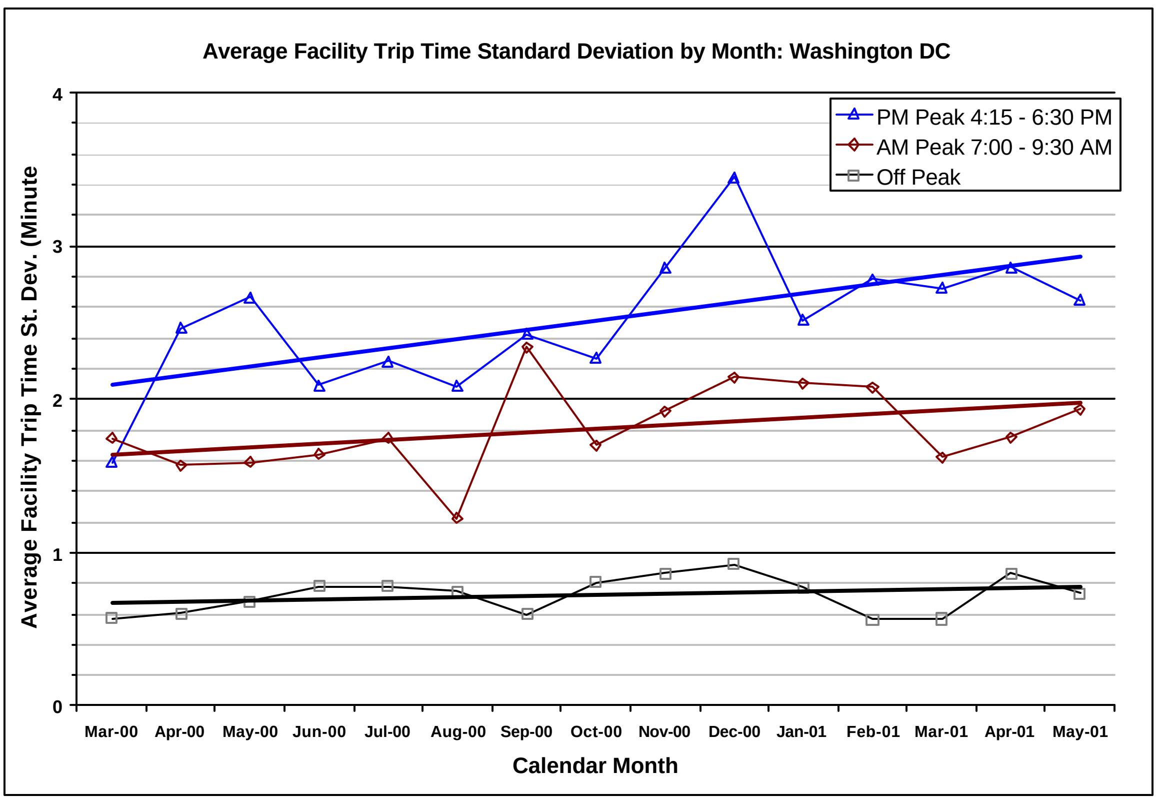

Figure 3-4(b) Standard Deviation of Facility Travel Times in Peak and Off-Peak Periods

3.1.6 Individual Facility Trends

In this section, we identify the facilities with greatest or least change from training to evaluation period as well as the level of congestion on facilities. Table 3-5 lists for each directional facility the average, standard deviation, and free flow travel time for the training and evaluation periods. The values are based on data archives from 6:30 AM to 6:30 PM for all dates of data used in training and evaluation. The free flow travel time is based on the time required to travel the facility at its speed limit.

From the training to evaluation period, the largest increase in freeway travel time (1.0 minute) and travel time standard deviation (1.3 minutes) occur on the George Washington Parkway. From training to evaluation, these values constitute a 3.1% and 33.6% increase in travel time and standard deviation, respectively. From training to evaluation, the largest percent increase in freeway travel time, 4.8%, occurs on I-295 south between East Capitol Street and I-495 in Greenbelt, MD. The largest percent freeway increase in travel time standard deviation is 96%, and occurs on I-95 north between Laurel, MD and I-495. From training to evaluation, the largest arterial increases in travel time and standard deviation are 1.0 and 1.7 minutes, respectively, and occur on MD 355 north between Gude Drive and the DC line.

A measure of the weekday level of congestion from March 2000 to May 2001 is calculated for each directional facility by dividing it's average trip time by its free flow trip time. We name this measure the *congestion index* because it is similar to the Texas Transportation Institute's travel time index that measures peak period travel to free flow travel. Our congestion index differs in a significant way from the TTI index in that it does not weigh facilities by the amount of travel on that facility and it is based on data that already incorporates incident and recurrent delay, whereas the TTI index accounts for these two delay types individually.

For the entire network, the congestion index is 1.59. For freeway facilities this index is 1.44 while for arterial facilities the index is 1.77. The arterial facility congestion index is expected to be higher given the level of signalization and cross traffic along the routes.

Facility No.	Facility Description	Direction	Free Flow	Facility Travel Time (minutes) From Training to Evaluation Avg.	%diff	St.Dev	%diff	Congestion Index
1	I-95/I-495 in MD btwn. Woodrow Wilson Bridge & College Park	N	23.1	31.1	-0.3%	5.0	-9.3%	1.34
		S		36.4	-2.6%	9.0	-4.0%	1.54
2	I-495 in MD btwn. US 1 & the American Legion Bridge	E	16.1	25.2	2.6%	7.5	-0.7%	1.60
		W		27.4	-3.7%	7.6	-10.1%	1.65
3	I-495 in VA btwn. the American Legion Bridge & US 50	N	7.7	11.0	-1.0%	2.6	0.2%	1.42
		S		11.4	-2.8%	3.1	-3.9%	1.46
4	I-95/I-495 in VA btwn. US 50 & the Woodrow Wilson Bridge	E	12.2	20.3	-0.7%	5.8	-0.5%	1.66
		W		19.1	1.7%	3.6	15.4%	1.59
5	I-295 in MD btwn. Laurel & East Capitol St. NE	N	11.9	17.3	0.9%	3.3	11.1%	1.47
		S		17.5	1.0%	3.1	0.0%	1.49
6	Suitland Pkwy. in MD btwn. MD 4 & the Douglass Bridge	N	14.3	16.3	1.3%	2.5	17.0%	1.15
		S		17.1	-1.5%	4.4	-30.2%	1.18
7	G. W. Pkwy. in VA within I-495 (N. of DC and S. of DC)	N	18.0	32.0	2.8%	4.4	21.4%	1.82
		S		31.7	3.1%	3.8	33.6%	1.81
8	Clara Barton Pkwy. btwn. I-495 & the Roosevelt Bridge	N	11.5	15.2	-1.9%	2.5	-12.4%	1.30
		S		15.8	2.5%	2.6	3.7%	1.41
9	MD 5/Branch Ave. in MD btwn. US 301 & the DC Line	N	17.1	20.3	1.5%	2.5	11.5%	1.20
		S		20.2	-0.6%	2.5	-2.4%	1.18
10	MD 4 in MD btwn. US 301 & the DC Line	E	16.5	23.0	2.6%	1.9	50.3%	1.42
		W		22.8	1.3%	1.8	23.6%	1.40
11	US 50 in MD btwn. Bowie & Kenilworth Ave.	E	11.6	14.1	0.3%	2.8	6.7%	1.21
		W		14.4	3.4%	2.7	22.6%	1.27
12	US 1 in MD btwn. MD 212 & the DC Line	N	12.0	25.0	1.6%	2.0	30.8%	2.11
		S		24.8	4.2%	2.3	28.2%	2.14
13	I-95 in MD btwn. Laurel & I-495	N	5.6	6.3	4.1%	0.8	95.8%	1.15
		S		6.7	4.6%	2.2	20.1%	1.23
14	US 29 in MD btwn. Cherry Hill Rd. & the DC Line	N	9.6	14.5	2.9%	1.4	46.0%	1.54
		S		15.7	0.5%	3.7	-9.1%	1.64
15	MD 97 btwn. Wheaton & the DC Line	N	6.8	13.6	0.9%	1.2	36.0%	2.03
		S		13.4	3.3%	1.2	92.1%	2.04
16	MD 355 btwn. Gude Drive & the DC Line	N	16.0	36.1	3.9%	2.2	78.5%	2.33
		S		37.0	2.6%	3.0	35.4%	2.36
17	I-270 btwn. Gaithersburg & I-495	N	8.4	13.8	2.6%	2.7	22.4%	1.68
		S		15.1	-2.5%	4.2	-5.6%	1.76
18	MD 214 btwn. MD 202 & the DC Line	E	6.3	10.2	4.4%	1.1	65.1%	1.70
		W		10.4	3.1%	1.3	7.4%	1.71
19	MD 650 btwn. I-495 & the DC Line	N	6.2	8.4	6.2%	1.2	84.2%	1.44
		S		8.4	2.0%	0.9	38.0%	1.38
20	MD 185 btwn. I-495 & the DC Line	N	3.9	10.7	0.5%	1.5	10.9%	2.75
		S		10.9	1.7%	1.5	13.0%	2.83
21	VA 267 btwn. Dulles Airport & I-66	E	14.4	17.0	3.4%	3.0	20.6%	1.21
		W		16.3	1.4%	2.0	10.2%	1.14
22	US 50 in VA btwn. the VA 7100 & I-495	E	12.9	19.0	4.0%	2.3	29.7%	1.52
		W		20.0	-1.9%	3.4	-31.8%	1.52
23	US 50 in VA btwn. I-495 & the Arlington Memorial Bridge	E	12.4	19.5	2.7%	2.4	31.9%	1.61
		W		19.6	0.6%	3.0	14.6%	1.59
24	I-66 btwn. Centreville & I-495	E	11.5	17.3	0.9%	4.2	18.2%	1.51
		W		16.4	-2.6%	3.9	-12.5%	1.39
25	I-66 btwn. I-495 & the Roosevelt Bridge	E	9.1	14.4	0.1%	3.4	-7.1%	1.57
		W		13.8	-0.2%	3.0	3.5%	1.51
26	I-95 btwn. Dale City & I-495	N	12.9	18.4	1.1%	4.7	5.4%	1.43
		S		18.5	0.6%	5.1	6.9%	1.44
27	I-395 btwn. I-495 & the Potomac River	N	8.8	13.1	0.1%	4.4	5.3%	1.49
		S		11.6	0.5%	3.3	2.1%	1.33
28	US 1 in VA btwn. Kings Highway & the 14th St. Bridge	N	8.4	16.9	2.7%	3.6	-3.7%	2.06
		S		17.2	-3.0%	4.4	-24.8%	1.99
29	VA 236 btwn. I-495 & the King St. Metro	E	14.0	20.1	5.4%	2.0	35.1%	1.51
		W		20.4	0.0%	1.9	-12.6%	1.46
30	VA 620 btwn. the VA 7100 & I-495	E	13.4	20.8	5.3%	2.1	63.9%	1.63
		W		21.7	-0.8%	2.9	-8.0%	1.61
31	I-295 btwn. I-495 & East Capitol St.	N	11.0	17.2	3.8%	3.0	18.5%	1.62
		S		17.0	4.8%	2.8	23.8%	1.61
32	MD 210 btwn. Berry Road & the DC Line	N	11.2	20.0	1.8%	2.0	31.8%	1.82
		S		19.5	0.8%	1.2	40.3%	1.75
33	VA 7100 btwn. Springfield Metro Station & VA 267	N	26.0	31.9	1.0%	4.6	-0.3%	1.24
		S		31.1	2.3%	3.5	19.4%	1.22

Table 3-5 Change in Facility Travel Time and Variability

The most congested freeway facility by far is the George Washington Parkway with congestion index values of 1.82 northbound and 1.81 southbound. The most congested arterial facility is by far MD 185 with congestion index values of 2.75 northbound and 2.83 southbound. The least congested facilities are the Suitland Parkway with congestion index values of 1.15 northbound and 1.18 southbound.

The key finding from the individual facility evaluation is that the Washington region is not experiencing uniform increases in travel time or variability. Rather, some facilities show increases in travel time and variability while other facilities show decreases in travel time and variability.

3.1.7 Summary of Link Analysis

1. *Link travel times and travel time variability increase from the training to evaluation period.*
2. *The greatest increases in travel time as well as travel time variability from the training to evaluation period occur in the AM peak, from 7:00 – 9:30 AM. The PM peak and off-peak average about the same variability in both training and evaluation periods.*
3. *The percent increases in travel time standard deviation, a measure of variability, are significantly greater than the percent increases in average travel time.*
4. *Overall, the data reveals a spreading of peak period congestion 25 minutes earlier in the morning, starting at 6:55 AM rather than 7:20 AM. AM peak period end and PM peak spreading was not statistically significant.*
5. *Although increases in travel time and variability occur from the training to evaluation period, these increases do not occur gradually from month to month.*
6. *Although network travel time taken as an aggregate are increasing, the Washington network is not experiencing uniform increases in travel time at the link level. Some facilities show increases in travel time and variability while other facilities show decreases in both travel time and variability.*

3.2 Simulated Yoked Study Analyses

The objective of all simulated yoked trial participants in the HOWLATE study is to arrive at their unique destination at their scheduled arrival time. We conducted three sets of experiments to evaluate the potential travel impacts of regular ATIS use in the Washington region. These experiments, described in Section 3.2.1, differ in the level of tolerance a commuter has for late arrivals, the level of knowledge a commuter has of variability in travel time, and the level of understanding the commuter's ATIS-using counterpart has of the inaccuracies of the ATIS service.

Sections 3.2.2 through 3.2.4 summarize for the three experiments how the commuter and his ATIS-using counterpart differ in travel departure decision and in trip outcomes for the set of trips modeled within each experiment. Section 3.2.5 highlights findings across the three experiments and proffers inferences on the relationship between ATIS benefit and commuter awareness of his trip's variability. Evaluations presented in these four sections are aggregate summaries across a number of calendar days.

In Section 3.2.6 we identify the trips that benefit most from ATIS as well as those trips with highest commute disutility. We explore in this section whether the 'worst' trips can garner the most benefit from ATIS use.

3.2.1 Overview of Experimental Design

We conducted three simulated yoked trial experiments to evaluate the potential travel impacts of regular ATIS use in the Washington region. Each of these experiments is described in the following three paragraphs. The subsequent two paragraphs provide calculations on the number of unique trials conducted.

The first experiment evaluates the travel outcomes of familiar commuters (F95) that do not deviate from their normal departure time and routes, and their counterparts, savvy ATIS users (ASV). A detailed description of the F95 and ASV commuter types is presented in Section 2. The experiment is evaluated from June 2000 through May 2001. The familiar commuter departs at a time on a specific route such that his on-time arrival rate is 95% based on the 33 training days from March 2000 through May 2000. ASV may modify pre-trip departure as much as 30 minutes earlier or later than the familiar commuter. He may also modify pre-trip route if the route change yields a trip savings of 3 minutes or greater. ASV has knowledge of the recurrent inaccuracies of the ATIS services, as were present during the training days from March 2000 through May 2000, and adjusts the ATIS information accordingly in making pre-trip decisions. Findings of this experiment are presented in Section 3.2.2.

The second experiment is similar to the first with the difference that the familiar commuter departs at a time on a specific route such that his on-time arrival rate is 80%, rather than 95%. This experiment evaluates the travel outcomes over a shorter two-month period, from June 2000 through July 2000. The familiar commuters and their savvy ATIS user counterparts in this experiment are referred to as the F80 and ASV commuters, respectively. Findings of this experiment are presented in Section 3.2.3.

The third experiment models the commuting behavior of those unfamiliar with the region, such as a tourist, or those making trips on routes unfamiliar to them. This unfamiliar commuter, labeled UNF, assumes free flow travel conditions during off-peak periods. He elevates the free flow travel by a flat percent as an estimate for peak-period travel times. The factor selected for elevating travel times is 1.42, the Texas Transportation Institute travel rate index for the Washington region for 1999. The ATIS using counterpart, labeled ANV (Naïve ATIS user) modifies pre-trip departure or route, but does not have knowledge of the recurrent inaccuracies of the ATIS service. Findings of this experiment are presented in Section 2.3.

A unique trip in each of these experiments is defined by trip date, origin, destination, and scheduled arrival time. The set of scheduled arrival times evaluated in simulation range from 6:30 AM to 6:30 PM at 15-minute intervals –totaling 49 different trips from an origin to a destination in one day. Given, a total of 55 nodes in the Washington network, the set of unique origin-destination pairs evaluated in simulation total 2970 (55 origins x 54 destinations). All results presented do not account for the proportion of regional travel made for each of these unique trips, but rather, treat each trip with equal weight.

To confirm that differences in trip outcomes are statistically significant, multiple realizations of each unique trip are conducted, reflecting uncertainty in the accuracy of SmarTraveler link travel time estimates (Section 2.2). Thus, the simulation of each unique trip is conducted a number of times with different streams of starting random numbers. These results are based on runs using five different random seeds.

3.2.2 Familiar Non-User (F95) vs. Savvy ATIS User (ASV) Experiment

As stated previously, a unique trip is defined by trip date, origin, destination, and scheduled arrival time. For this experiment, 178 days from June 2000 through May 2001 are evaluated; thus, the total number of unique trips in this experiment is 25,904,340 (178 days x 55 origins x 54 destination x 49 arrival times). Here, we first establish the differences in trip decisions between the F95 and ASV commuters across the 25.9 million trips. We then explore the trip outcomes of all trips in the

Washington region aggregated by time of day categories. Statistics presented in this section are based five potential outcomes of the 25.9 million unique trips, representing the conduct of over 129 million simulated yoked trials.

Aggregate Differences in Trip Decisions: Over the 178 days simulated between June 2000 and May 2001, in 4.6% of all trips, the ASV commuters modified their routes from their F95 counterparts. In 58.7% of all trips, the ASV commuters modified their departure times from their F95 counterparts. The ASV commuters modified both departure time and route in 3.3% of all trips.

Table 3-6 summarizes differences in trip decisions between the F95 commuters and their ASV counterparts. ASV commuters shift departure times from the habitual trip start time approximately 13 times more frequent than route shifts over the analysis year. The ratio of departure time to route shifts is 14:1 for the AM peak, 17:1 for the off-peak, and only 8:1 for the PM peak –indicating that for this region, throughout the day, commuters using ATIS are more likely to improve their trip by changing departure time than pre-trip route. Of note, the percent of trips making pre-trip route shifts is more than twice as high in the PM peak as compared to the AM peak.

The number of ASV commuters that change their departure time compared to their F95 counterparts and the direction of their change, be it earlier or later, varies significantly by time of day. The percentage of ASV trips that depart earlier compared to their F95 counterparts for the AM peak is 27% and drops to 15% for the PM peak. The percentage of ASV trips that depart later compared to their F95 counterparts for the AM peak is also 27%, but increases to 54% for the PM peak.

When ASV commuters leave early, they leave on average 5.5 minutes earlier than their F95 counterparts; while, when late, they leave on average 7.5 minutes later. Averaged across the analysis year, the ASV commuter departs 0.6 minutes later than the F95 commuter. During the PM peak, however, the ASV commuters depart 3.9 minutes later compared to their F95 counterparts.

TRIP DECISIONS OF ASV COMPARED TO F95 : JUNE 2000 - MAY 2001				
TRAVEL CHOICE CATEGORY	All Day	AM Peak	Off-Peak	PM Peak
Both Route and Departure Time Change	3.3%	2.4%	2.3%	7.2%
Only Route Change	1.3%	1.3%	1.1%	1.7%
Only Departure Time Change	55.4%	50.8%	54.7%	62.3%
No Change	40.0%	45.5%	41.9%	28.8%
Of Trips With Departure Time Change				
% Departing Early	49%	50%	61%	22%
% Departing Late	51%	50%	39%	78%
Avg. Minutes Early Departure (when departing early)	5.5	5.2	5.5	5.4
Avg. Minutes Late Departure (when departing late)	7.5	6.3	6.7	8.7
Of Trips With Route Change				
% Taking Shorter Route	34%	24%	37%	36%
% Taking Longer Route	66%	76%	63%	64%
Avg. Miles Route is Shorter (when taking shorter route)	4.3	4.0	5.4	3.6
Avg. Miles Route is Longer (when taking longer route)	4.6	4.7	4.9	4.4

Table 3-6. ASV Pre-Trip Departure Changes from F95: June 2000 – May 2001

On average, F95 trips are 21.2 miles long. ASV commuters' alternate routes, compared to the F95 routes, were longer in 66% of trips, and by an average of 4.6 miles. The remaining 34% of trips where the ASV commuters chose an alternate route, the chosen routes were shorter on average by 4.3 miles. This suggests that the F95 chosen shortest time-based routes are not necessarily the shortest distance-based route.

To summarize, the key differences in trip departure times and routes of the ASV commuters compared to their F95 counterparts are:

1. *For 71% of PM peak trips and for 55% of AM peak trips, ATIS recommends a change in the F95 commuter's normal travel plan.*
2. *To achieve just-in-time arrivals, the ATIS service recommends changes in trip departure time 13 times more frequently than changes in route.*
3. *F95 commuters trained in March-May 2000 may have allocated more time than necessary in the PM peak, given that in half of all PM trips, the ATIS service recommends a later departure.*

<u>Aggregate Differences in Trip Outcomes</u>: Based on the 178 days of evaluation, F95 commuters are early 28%, just-in-time 67%, and late 4% of all trips simulated. Their ASV counterparts are early 12%, just-in-time 85%, and late 2% of all trips. ASV commuters experience a 56% and 52% reduction in early and late arrivals, respectively compared to their F95 counterparts.

When F95 commuters do arrive early or late, they are on average 14.8 minutes early and 3.4 minutes late. Comparatively, the ASV commuters' averages when early and late are 11.5 and 3.2 minutes, respectively. These values constitute 22% and 7% reductions in the magnitude of early and late schedule delay, respectively.

Table 3-7 presents the annual aggregate outcome metrics for the entire day as well as by time of day categories. Trip outcomes of the F95 commuters vary significantly by time of day. ASV benefits in terms of trip outcomes, trip disutility and travel expenditure are greatest in the PM peak period. This is because F95 commuters in the PM peak period arrive on early nearly half of the time and by 16 minutes on average. ASV commuters in the PM peak arrive early for only 13% of the trips and only by 12 minutes on average. For the PM peak, however, 1% more of the ASV commuters arrive late compared to their F95 counterparts. The increase in frequency of late arrivals can be viewed as the price paid by ASV commuters for the significant reductions in the magnitude and frequency of early arrivals.

TRIP OUTCOMES OF ASV COMPARED TO F95: JUNE 2000 - MAY 2001								
	ALL DAY		AM PEAK		OFF PEAK		PM PEAK	
Aggregate Trip Metrics	F95	ASV	F95	ASV	F95	ASV	F95	ASV
% of Trips Early	28%	12%	25%	13%	22%	12%	49%	13%
% of Trips Just in Time	67%	85%	71%	84%	73%	87%	48%	83%
% of Trips Late	4%	2%	4%	3%	5%	1%	3%	4%
When Early, Avg. Min. Early	14.8	11.5	14.0	11.4	13.8	11.4	16.4	11.7
When Late, Avg. Min. Late	3.4	3.2	3.0	2.8	3.6	3.2	3.2	3.4
Small's Disutility Value	$ 2.68	$ 2.27	$ 2.66	$ 2.42	$ 2.39	$ 2.12	$ 3.48	$ 2.53
Travel Expenditure	39.1	38.4	41.0	40.6	36.1	36.4	45.4	41.4
Trip Time	31.3	31.2	33.6	33.5	29.2	29.1	34.5	34.5

Table 3-7. F95 and ASV Trip Outcomes: June 2000 – May 2001

Small's value, our dollar-valued disutility measure incorporating trip duration and the magnitudes of early and late arrivals, is as much as 27% lower for ASV commuters compared to F95 commuters (PM peak period). Overall, ASV commuters have a 15% lower Small's disutility value over the entire year than their F95 counterparts. This corresponds to an absolute reduction in disutility valued at $0.41 per trip.

The travel expenditure of ASV commuters is 1.8% lower than F95 commuters. The reduction in expenditure is largely concentrated in the PM peak where the average reduction is 8.7%. During the off-peak periods, travel expenditure actually increases by 0.8%. This is because ASV commuters depart earlier more often in this period compared to other times of day to accommodate for increased trip variability and to avoid arriving late.

Trip time differences between the F95 and ASV commuters are statistically significant, but small in magnitude. Across all trips, ASV commuters have a 0.3% lower trip time compared to F95 commuters, a reduction of roughly six seconds. Using Small's $3.38/hour value for in-vehicle travel time, this reduction in travel time is valued at just over $.005, one half of one cent per trip. Thus, in-vehicle travel time reduction accounts for only 1.2% of the total dollar-valued benefit accrued to the ATIS users. The remaining 98.8% of the benefit relates to travel reliability. Table

PERCENT CHANGE FROM F95 TO ASV: JUNE 2000 - MAY 2001				
AGGREGATE TRIP METRICS	ALL DAY	AM PEAK	OFF PEAK	PM PEAK
Frequency of Early Arrivals	56% ι	47% ι	47% ι	73% ι
Frequency of Late Arrivals	52% ι	29% ι	79% ι	25% η
On Time Reliability	2.4% η	1.2% η	4.1% η	0.9% ι
In-Vehicle Trip Time	0.3% ι	0.1% ι	0.5% ι	0.0% η
Travel Expenditure	1.8% ι	0.9% ι	0.8% η	8.7% ι
Small's Value	15% ι	9% ι	12% ι	27% ι

3-8 presents the percent change ASV commuters achieve in various trip metrics.

Table 3-8. Percent Change from F95 to ASV: June 2000 – May 2001

Key findings from this aggregate evaluation are:

1. *ATIS benefits the ASV commuters most in the PM peak by reducing the frequency and magnitude of early arrivals. ATIS also benefits the ASV commuters in the AM peak and off-peaks by reducing the frequency and magnitude of both early and late arrivals.*
2. *ATIS benefits in terms of in-vehicle trip time reductions are statistically significant, but practically small –representing only 1.2% of the dollar-valued ATIS benefit. The other 98.8% of ATIS benefit accrues from improvements in travel reliability.*
3. *By using ATIS, the ASV commuters reduce their travel disutility, or cost of travel, by 15% over the 178 days of evaluation, and most noticeably by 27% ($0.96 per trip) during the PM peak period followed by 12% in the off-peak ($0.28 per trip).*

3.2.3 Familiar Non-User (F80) vs. Savvy ATIS User (ASV) Experiment

For this experiment, 29 days from June 2000 through May 2001 are evaluated; thus, the total number of unique trips in this experiment is 4,220,370 (29 days x 55 origins x 54 destination x 49 arrival times). Here, we first establish the differences in trip decisions between the F80 and ASV commuters across the 4.2 million trips. We then explore the trip outcomes of all trips in the Washington DC region aggregated by time of day categories. Statistics presented in this section are based on 10 potential outcomes (random seeds) of each of the 4.2 million unique trips.

<u>Aggregate Differences in Trip Departure Decisions</u>: Over the 29 days simulated between June 2000 and July 2000, in 4.7% of all trips, the ASV commuters modified their routes from their F80 counterparts. In 61.2% of all trips, the ASV commuters modified their departure times from their F80 counterparts. The ASV commuters modified both departure times and routes in 2.9% of all trips.

Table 3-9 summarized the aggregate trip decision differences between the F80 commuters and their ASV counterparts. ASV departure time shifts are approximately 13 times more frequent than route shifts over the analysis year. The ratio of departure time to route shifts is 16:1 for the AM peak, 17:1 for the off-peak, and only 7:1 for the PM peak –indicating that for this region, throughout the day, commuters using ATIS are more likely to improve their trip by changing departure time than pre-trip route. Of note, the percent of ASV trips making pre-trip route shifts is nearly three times as high in the PM peak as compared to the AM peak.

TRIP DECISIONS OF ASV COMPARED TO F80: JUNE 2000 - JULY 2000				
TRAVEL CHOICE CATEGORY	All Day	AM Peak	Off-Peak	PM Peak
Both Route and Departure Time Change	2.9%	1.7%	2.5%	5.4%
Only Route Change	1.8%	1.7%	1.2%	3.6%
Only Departure Time Change	58.3%	51.4%	62.1%	55.2%
No Change	37.0%	45.2%	34.2%	35.8%
Of Trips With Departure Time Change				
% Departing Early	81%	80%	90%	55%
% Departing Late	19%	20%	10%	45%
Avg. Minutes Early Departure (when departing early)	5.8	5.3	5.9	5.6
Avg. Minutes Late Departure (when departing late)	6.0	5.4	5.7	6.2
Of Trips With Route Change				
% Taking Shorter Route	37%	23%	42%	38%
% Taking Longer Route	63%	77%	58%	62%
Avg. Miles Route is Shorter (when taking shorter route)	4.2	3.3	5.7	3.3
Avg. Miles Route is Longer (when taking longer route)	4.5	4.7	4.8	4.0

Table 3-9. ASV Pre-Trip Departure Changes from F80: June 2000 – July 2000

The number of ASV commuters that change their departure time compared to their F80 counterparts and the direction of their change, be it earlier or later, varies significantly by time of day. The percent of ASV trips that depart earlier compared to their F80 counterparts for the AM peak is 42% and drops to 33% for the PM peak. The percentage of ASV trips that depart later compared to their F80 counterparts for the AM peak is only 11%, but increases to 27% for the PM peak.

When ASV commuters leave early, they leave on average 5.8 minutes earlier; while, when leaving late, they leave on average 6.0 minutes later than their F80 counterparts. Averaged across all trips throughout the day, the ASV commuter departs approximately 2.2 minutes earlier than the F80 commuter.

ASV commuters' alternate routes, compared to the F80 routes, were longer in 63% of trips, and by an average of 4.5 miles. The remaining 37% of trips where the ASV commuters chose an alternate route, the chosen routes were shorter on average by 4.2 miles.

The aggregate differences in trip departure times and routes of the ASV commuters compared to their F80 counterparts indicate that:

1. *For approximately half of the trips during the AM peak, and six of ten trips during the PM peak, ATIS recommends a change in the F80 commuter's normal travel plan.*
2. *To achieve just-in-time arrivals, the ATIS service recommends changes in trip departure time 13 times more frequently than changes in route based on the F80 commuters' starting point of trip decisions.*
3. *The ASV counterparts shift to an earlier departure in 42% of all AM trips and 58% of all off-peak trips.*

<u>Aggregate Differences in Trip Outcomes</u>: Based on the 29 days, F80 commuters are early 11%, just-in-time 79%, and late 10% of all trips simulated. Their ASV counterparts are early 12%, just-in-time 86%, and late 2% of all trips. This is an 80% decrease in late arrivals at the expense of a 7% increase in early arrivals. To note, the F80 commuter aims for an 80% on-time arrival rate and achieves a 90% on time arrival rate over the months of June and July 2000. Table 3-10 presents the annual aggregate outcome metrics by time of day categories.

TRIP OUTCOMES OF ASV COMPARED TO F80: JUNE 2000 - JULY 2000								
	ALL DAY		AM PEAK		OFF PEAK		PM PEAK	
Aggregate Trip Metrics	F80	ASV	F80	ASV	F80	ASV	F80	ASV
% of Trips Early	11%	12%	10%	12%	7%	12%	24%	13%
% of Trips Just in Time	79%	86%	82%	85%	81%	87%	66%	83%
% of Trips Late	10%	2%	7%	3%	11%	1%	10%	4%
When Early, Avg. Min. Early	13.1	11.4	12.6	11.4	12.5	11.4	13.8	11.6
When Late, Avg. Min. Late	3.7	3.1	3.2	2.5	4.0	3.8	3.1	3.0
Small's Disutility Value	$ 2.50	$ 2.27	$ 2.46	$ 2.38	$ 2.37	$ 2.14	$ 2.90	$ 2.52
Travel Expenditure	36.7	38.6	38.6	40.1	34.2	36.9	41.7	41.7
Trip Time	31.6	31.4	33.3	33.2	29.6	29.5	35.0	34.8

Table 3-10. F80 and ASV Trip Outcomes: June 2000 – July 2000

When F80 commuters do arrive early or late, they are on average 13.1 minutes early and 3.7 minutes late, respectively. Comparatively, the ASV commuters' averages when late and early are 11.4 and 3.1 minutes, respectively. These values constitute 13% and 16% reductions in the magnitude of early and late schedule delay, respectively. Benefits in terms of the magnitude of late and early reductions are much greater for the peak periods. In the AM peak, ASV commuters, when late, reduce lateness by 21% compared to their F80 counterparts.

Small's disutility value is as much as 13% lower for ASV commuters compared to F80 commuters (PM peak period). Overall, ASVcommuters have a 9% lower Small's disutility value over the two-month period, which corresponds to an absolute reduction in disutility valued at $0.22.

The travel expenditure of ASV commuters is actually 5.1% higher than the F80 commuter. The increase in expenditure is largely concentrated in the morning and off-peak where late arrivals are reduced by 60% and 90%, respectively.

Trip time differences between the F80 and their ASV counterparts are statistically significant, but small in magnitude. Across all trips, ASV commuters have a 0.4% lower trip time compared to their F80 counterparts. Table 3-11 presents the percent change ASV commuters achieve in various trip metrics.

Key findings from this aggregate evaluation are:

1. *ATIS benefits the ASV commuters most in the PM peak by reducing the frequency and magnitude of both early and late arrivals.*
2. *ATIS benefits in terms of in-vehicle trip time reductions are statistically significant, but practically insignificant, consistent with the F95 experiment.*
3. *By using ATIS, the ASV commuters reduce their travel disutility by 9% ($0.20 per trip) over the 28 days of evaluation, and most noticeably by 13% ($0.38 per trip) during the PM peak period.*
4. *The ASV commuters, in shifting to earlier departure times actually increase their aggregate travel expenditure compared to the travel expenditure of their F80 counterparts.*

PERCENT CHANGE FROM F80 TO ASV: JUNE 2000 - JULY 2000				
AGGREGATE TRIP METRICS	ALL DAY	AM PEAK	OFF PEAK	PM PEAK
Frequency of Early Arrivals	7% h	16% h	65% h	46% ι
Frequency of Late Arrivals	80% ι	60% ι	91% ι	59% ι
On Time Reliability	9% η	5% η	12% η	6% η
In-Vehicle Trip Time	0.4% ι	0.4% ι	0.4% ι	0.5% ι
Travel Expenditure	5.1% h	3.9% h	7.9% h	0.1% ι
Small's Value	8.9% ι	3.0% ι	9.4% ι	13.1% ι

Table 3-11. Percent Change from F80 to ASV: June 2000 – July 2000

3.2.4 Unfamiliar Non-User (UNF) vs. Naïve ATIS User (ANV) Experiment

For this experiment, 29 days from June 2000 through May 2001 are evaluated for the UNF and ANV commuters; thus, the total number of unique trips in this experiment is 4,220,370 (29 days x 55 origins x 54 destination x 49 arrival times). As with previous sections, we first establish the differences in trip decisions between the UNF and ANV commuters across the 4.2 million trips. We then explore the outcomes of all trips in the Washington region aggregated by time of day categories. Statistics presented in this section are based on 10 random seed, or conversely 10 potential outcomes of the 4.2 million unique trips.

<u>Aggregate Differences in Trip Departure Decisions</u>: Over the 29 days simulated between June 2000 and July 2000, in 8.2% of all trips, the ANV commuters modified their routes from their UNF counterparts. In 77.4% of all trips, the ANV commuters modified their departure times from their UNF counterparts. The ANV commuters modified both departure times and routes were modified in 6.2% of all trips.

Table 3-12 summarized the aggregate trip decision differences between the UNF and ANV commuters. ANV departure time shifts are nine times more frequent than route shifts over the analysis year. This varies by as much as 12 times for the AM peak and as little as eight times for the PM peak. The frequency of departure time changes ranges from 70% during the off-peak to 88% during the PM peak. The direction of the departure time change is predominantly the same (90% - 98% by time of day) toward earlier departures throughout the day.

TRIP DECISIONS OF ANV COMPARED TO UNF: JUNE 2000 - JULY 2000				
TRAVEL CHOICE CATEGORY	All Day	AM Peak	Off-Peak	PM Peak
Both Route and Departure Time Change	6.2%	6.2%	5.1%	9.1%
Only Route Change	2.0%	1.0%	2.6%	1.4%
Only Departure Time Change	71.2%	79.3%	65.2%	79.0%
No Change	20.7%	13.5%	27.1%	10.5%
Of Trips With Departure Time Change				
% Departing Early	93%	93%	90%	98%
% Departing Late	7%	7%	10%	2%
Avg. Minutes Early Departure (when departing early)	8.6	9.1	7.7	9.9
Avg. Minutes Late Departure (when departing late)	5.3	5.4	5.3	5.4
Of Trips With Route Change				
% Taking Shorter Route	46%	32%	50%	47%
% Taking Longer Route	54%	68%	50%	53%
Avg. Miles Route is Shorter (when taking shorter route)	9.0	4.4	10.3	9.3
Avg. Miles Route is Longer (when taking longer route)	4.2	4.6	4.2	3.8

Table 3-12. ANV Pre-Trip Departure Changes from UNF: June 2000 – July 2000

When ANV commuters leave early, they leave on average 8.6 minutes earlier; while, when leaving late, they leave on average 5.3 minutes later than their UNF counterparts. Averaged across all trips throughout the day, the ANV commuter departs approximately 5.9 minutes earlier than the UNF commuter. During the PM peak, the ANV commuters depart 8.5 minutes earlier than their UNF counterparts for a 35.8-minute trip.

ANV commuters' alternate routes, compared to the UNF routes, were longer in 54% of trips, and by an average of 4.2 miles. The remaining 46% of trips where the ANV commuters chose an alternate route, the chosen routes were shorter on average by 9.0 miles.

The aggregate differences in trip departure times and routes of the ANV commuters compared to their UNF counterparts indicate that:

1. *For approximately nine of ten days during the peak periods, ATIS recommends a change in the ANV commuter's normal travel plan.*

2. *The UNF commuters have allocated too little trip time through out the day, and particularly in the PM peak wherein ANV counterparts shift to earlier departures in 86% of PM peak trips.*
3. *To achieve just-in-time arrivals, the ATIS service recommends changes in trip departure time nine times more frequently than changes in route to the ANV commuter using UNF as the starting point of trip decisions.*

Aggregate Differences in Trip Outcomes: Table 3-13 presents the annual aggregate outcome metrics by time of day categories for the UNF and ANV commuters. Based on the 29 days, UNF commuters are early 4%, just-in-time 61%, and late 35% of all trips simulated. Their ANV counterparts are early 16%, just-in-time 82%, and late 3% of all trips. Although 12% more of the ANV commuters are earlier, 32% more of the ANV commuters avoid being late.

TRIP OUTCOMES OF ANV COMPARED TO UNF: June-July 2000								
	ALL DAY		AM PEAK		OFF PEAK		PM PEAK	
Aggregate Trip Metrics	UNF	ANV	UNF	ANV	UNF	ANV	UNF	ANV
% of Trips Early	4%	16%	1%	13%	6%	17%	1%	14%
% of Trips Just In Time	61%	82%	50%	80%	72%	82%	41%	81%
% of Trips Late	35%	3%	48%	6%	21%	1%	58%	4%
When Early, Avg. Min. Early	11.9	11.8	11.4	11.7	11.9	11.8	12.0	11.8
When Late, Avg. Min. Late	5.8	3.5	5.9	3.6	4.7	3.9	6.9	3.1
Small's Disutility Value	$ 3.58	$ 2.35	$ 4.26	$ 2.54	$ 2.81	$ 2.20	$ 4.99	$ 2.57
Travel Expenditure	35.0	39.0	35.9	40.3	33.9	37.4	37.3	41.9
Trip Time	32.0	31.6	34.0	33.5	29.9	29.6	35.8	35.0

Table 3-13. UNF and ANV Trip Outcomes: June 2000 – July 2000

When UNF commuters do arrive early or late, they are on average 11.9 minutes early and 5.8 minutes late. Comparatively, the ANV commuters' averages when late and early are 11.8 and 3.5 minutes respectively. These values constitute a 1% and 39% decrease in the magnitude of early and late schedule delay, respectively.

ANV benefits are, as expected, greater in the peak periods compared to the off-peak periods. Small's disutility value is as much as 48.6% lower for ANV commuters on average compared to UNF commuters (PM peak period). Overall, ANV commuters have a 34% lower disutility over the two-month period, corresponding to a per-trip ATIS value of $1.23.

The travel expenditure of ANV commuters is actually 11.2% higher than the UNF commuter. The increase in expenditure is of course a product of reducing the frequency of late arrivals by departing earlier.

Trip time differences between the UNF and ANV commuters are statistically significant, but small in magnitude. Across all trips, ANV commuters have a 1.3% lower trip time compared to UNF commuters. During the PM peak, ANV commuters reduce their trip time by 2.5% compared to their UNF counterparts. Table 3-14 presents the percent change ANV commuters achieve in various trip metrics.

Key findings from this aggregate evaluation are:

1. *ATIS benefits the ANV commuters most in the PM peak by reducing the frequency and magnitude of late arrivals.*
2. *ATIS benefits in terms of in-vehicle trip time reductions are statistically significant, but are practically small. The greatest average savings in trip time, 2.5%, occur in the PM peak.*
3. *By using ATIS, the ANV commuters reduce their travel disutility by 34% ($1.23 per trip) over the 29 days of evaluation, and most noticeably by 49% ($2.43 per trip) during the PM peak period.*
4. *The ANV commuters in shifting to earlier departure times actually increase their aggregate travel expenditure by 4.0 minutes compared to the travel expenditure of their UNF counterparts.*

PERCENT CHANGE FROM UNF TO ANV: JUNE 2000 - JULY 2000				
AGGREGATE TRIP METRICS	ALL DAY	AM PEAK	OFF PEAK	PM PEAK
Frequency of Early Arrivals	284% η	832% η	176% η	1192% η
Frequency of Late Arrivals	92% ι	87% ι	96% ι	92% ι
On Time Reliability	49.6% η	81.3% η	26.3% η	129.5% η
In-Vehicle Trip Time	1.3% ι	1.5% ι	0.8% ι	2.5% ι
Travel Expenditure	11.2% η	12.0% η	10.5% η	12.3% η
Small's Value	34% ι	40% ι	22% ι	49% ι

Table 3-14. Percent Change from UNF to ANV: June 2000 – July 2000

3.2.5 Comparative Analysis of Results Across Experiments

The outcome of a trip in terms of arrival time is a direct product of the minutes one budgets for the trip. Furthermore, appropriate budgeting of trip time is based directly on one's level of knowledge of the network variability and risk tolerance for late arrival. For a commuter, the outcome of ATIS use is influenced by the time window within which one consults ATIS and the level of understanding on the potential shortcomings of the information service.

Here, we first highlight the differences in trip decisions between the three ATIS commuter counterparts. We then explore how the counterpart ATIS users change trip outcomes. Comparisons are based on the 29 days from June to July 2000.

Trip Decisions: Table 3-15 highlights differences in trip decisions among the three ATIS user types. The travel departure behaviors of the three ATIS counterpart groups form a continuum from the F95 to the F80 to the UNF in terms of the total percent of ATIS counterparts making departure time changes as well as the proportions departing earlier and later. Of note, the ANV counterparts tend to shift route much more often than both ASV counterparts. Figure 3-5 presents the percent of ATIS counterparts that depart either earlier or later associated with the three commuter types throughout the day, and by AM and PM peak periods. The height of each bar represents the total percent of trips wherein the ATIS user changed time of departure from their counterpart not using ATIS. The upper portion of each bar represents the proportion of trips when the departure shift was to an earlier time compared to the ATIS non-user, while the lower portion of each bar represents the proportion of trips when the departure shift was to a later time compared to the ATIS non-user.

The percent of trips for which ATIS users change time of departure from their UNF counterparts (over 77.4%) is much higher as compared to the F95 and F80 commuters (58.1% and 61.2% respectively). This is expected given that commuters having lesser knowledge of system variability have greater potential to capitalize on the information provided by ATIS services.

Also, as one budgets less time for a trip and consults ATIS, one is more likely to identify instances an trip start earlier that the habitual time is required. Thus, ATIS counterparts for the F80 commuters have a larger percentage departing earlier compared to the ATIS counterparts of the F95 commuters. Conversely, as one budgets more for a trip and consults ATIS, one is more likely to adopt trip starts later than the habitual time. Thus, ATIS counterparts for the F95 commuters have a larger percentage departing later compared to the ATIS counterparts of the F80 commuters.

ALL DAY TRIP DECISIONS OF ATIS COUNTERPARTS: JUNE 2000 - JULY 2000			
TRAVEL CHOICE CATEGORY	F95 v. ASV	F80 v. ASV	UNF v. ANV
Both Route and Departure Time Change	3.4%	2.9%	6.2%
Only Route Change	1.3%	1.8%	2.0%
Only Departure Time Change	54.7%	58.3%	71.2%
No Change	40.5%	37.0%	20.7%
Of Trips With Departure Time Change			
% Departing Early	51%	81%	93%
% Departing Late	49%	19%	7%
Avg. Minutes Early Departure (when departing early)	5.6	5.8	8.6
Avg. Minutes Late Departure (when departing late)	7.3	6.0	5.3
Of Trips With Route Change			
% Taking Shorter Route	37%	37%	46%
% Taking Longer Route	63%	63%	54%
Avg. Miles Route is Shorter (when taking shorter route)	4.2	4.2	9.0
Avg. Miles Route is Longer (when taking longer route)	4.5	4.5	4.2

Table 3-15 Pre-Trip Departure Changes of Three ATIS User Types

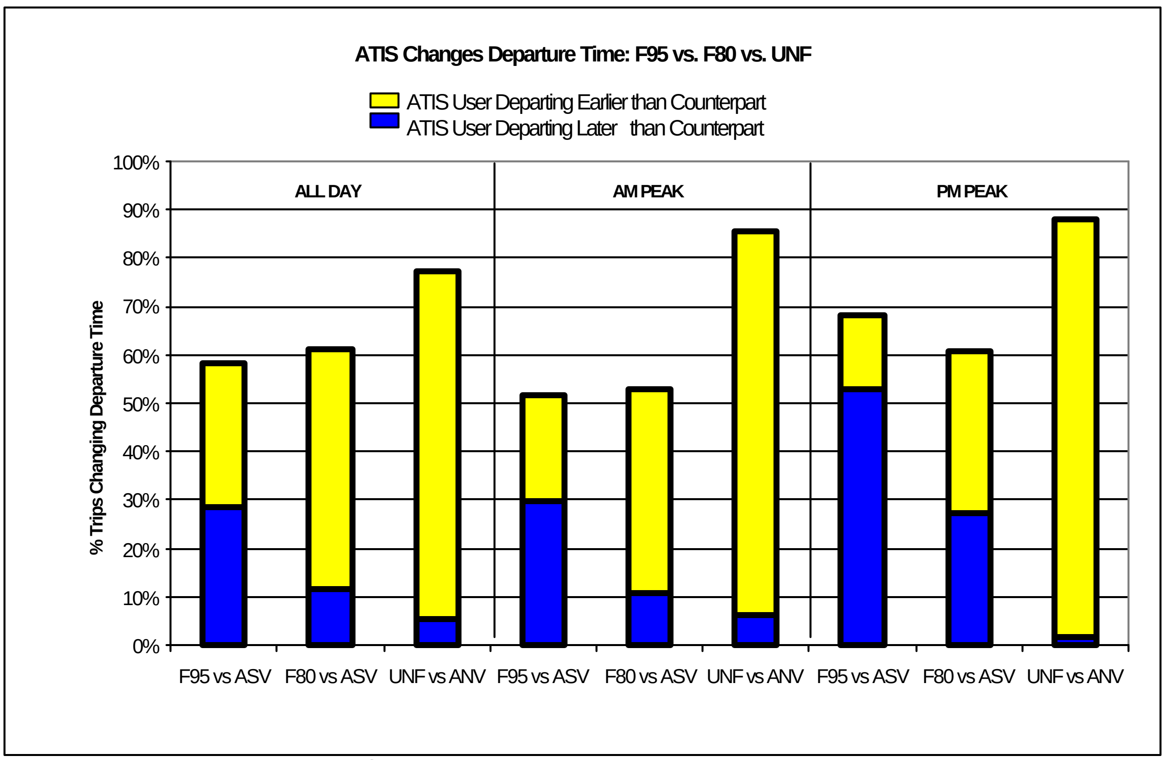

Figure 3-5. Percentage of ATIS User Changing Departure Time--by Commuter Type

Trip Outcomes: Table 3-16 summarizes the trip outcomes of the three experiments. Figure 3-6 more clearly illustrates the percent of ATIS non-user trips with early/late arrival outcomes, and how ATIS use impacts these outcomes. The three sets of columns on the left graph the percent of commuters arriving early while the three sets of columns on the right graphs the percent of commuters arriving late. The background columns represent the percent of ATIS non-users that arrive early or late; while, the darker columns in the foreground represent the percent of ATIS users that arrive early or late.

The ability of ATIS to reduce early and late arrivals definitely depends on how conservative the commuter is in allocating travel time. For example, the F80 and UNF ATIS-user counterparts are able to achieve tremendous reductions in the frequency of late arrivals at the expense of some increase in the frequency of early arrivals. The F95 counterparts using ATIS, have little in terms of late arrival to reduce, but achieve significant reductions in frequency of early arrivals.

F95 commuters tend to have a slightly higher disutility compared to the F80 commuters, while the UNF commuter has a much higher disutility (Table 3-16). This is likely because the F95 commuter is too conservative, resulting in too frequent and large early arrivals whereas the UNF commuter does not account for variability within peak periods. Figure 3-7 illustrates the extent to which ATIS users reduce their average disutility throughout the day and for the AM and PM peak periods. The height of each column represents the ATIS non-user's average disutility while the shaded portion of the column represents the counterpart ATIS user's average disutility. The percentage value above each column represents the percent reduction in disutlity achieved through ATIS use.

There appears to be a base disutility level which ATIS commuters are able to reach. This base level is slightly lower for the ASV commuters compared to the ANV commuters, given ASV commuters' familiarity with the shortcomings of the traveler information. To note, this base level achieved by ATIS commuters would vary based on the level of accuracy of the ATIS service.

Also of note, the level of disutility associated with early and late arrivals is constant among the three non-user types. In reality, however, one would expect a commuter with greater tolerance for late arrivals to have a lower disutility associated with late arrival compared to a commuter with a low tolerance for late arrivals. Similarly, in terms of early arrivals, the F80 commuter may likely have a greater disutility associated with arriving earlier than the F95 commuter. Literature on disutility associated with arrival offsets provides no information on how to operationalize these factors, but perhaps a sensitivity experiment should be conducted along these lines in the future.

TRIP OUTCOMES OF THE THREE COMMUTER TYPES: June-July 2000 ALL DAY						
	F95 vs. ASV		F80 vs. ASV		UNF vs. ANV	
Aggregate Trip Metrics	F95	ASV	F80	ASV	UNF	ANV
% of Trips Early	27%	12%	11%	12%	4%	16%
% of Trips Just In Time	68%	86%	79%	86%	61%	82%
% of Trips Late	5%	2%	10%	2%	35%	3%
When Early, Avg. Min. Early	14.6	11.5	13.1	11.4	11.9	11.8
When Late, Avg. Min. Late	3.8	3.1	3.7	3.1	5.8	3.5
Small's Disutility Value	$ 2.66	$ 2.28	$ 2.50	$ 2.27	$ 3.58	$ 2.35
Travel Expenditure	39.1	38.6	36.7	38.6	35.0	39.0
Trip Time	31.5	31.4	31.6	31.4	32.0	31.6

Table 3-16 Trip Outcomes of Three Commuter Pairs

Key findings from the trip evaluation and comparisons among different commuter types include:

1. *ATIS more frequently benefits both familiar and unfamiliar ATIS users by suggesting alternative departure times, rather than by suggesting alternative routes.*
2. *The level of benefit is very much dependent on the variability of the system as well as on how much time one allocates for their trip.*
3. *Unfamiliar (ANV) ATIS users have the largest absolute and percentage reduction in disutility, although familiar ATIS users also benefit.*
4. *ATIS increases travel expenditure for the ATIS counterparts of the F80 and UNV commuters, but not for the F95 counterparts.*
5. *A naïve user of ATIS performs nearly as well as a savvy user of ATIS as measured by Small's disutility and frequency of late and early arrivals*

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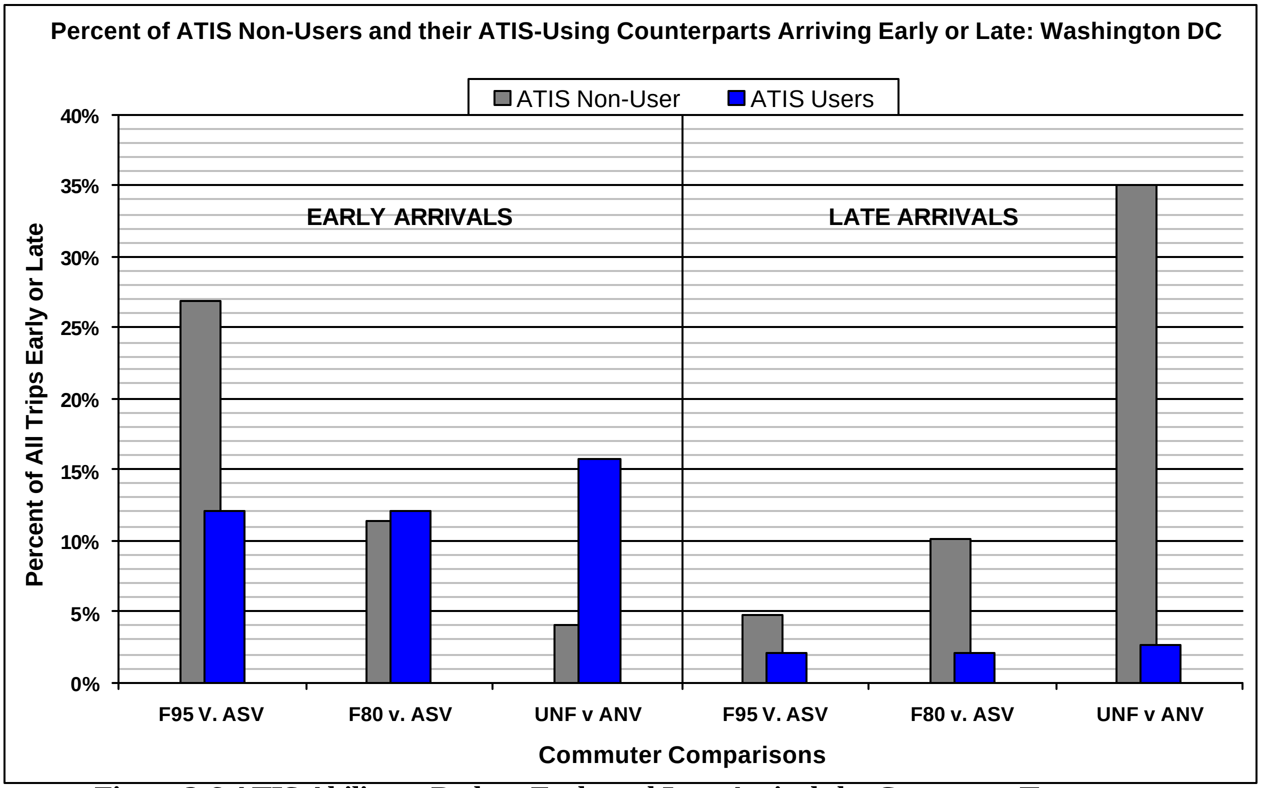

Figure 3-6 ATIS Ability to Reduce Early and Late Arrivals by Commuter Type

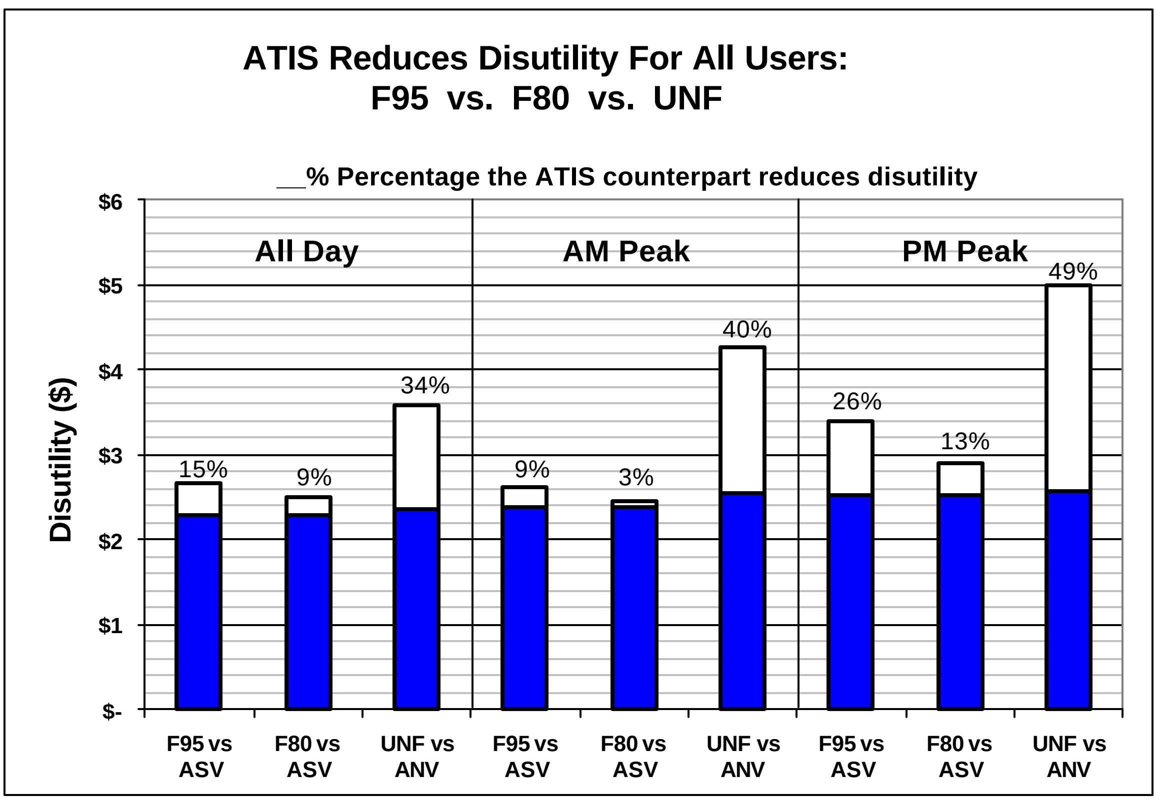

Figure 3-7. Ability of ATIS to Reduce Trip Disutility by Commuter Type

3.2.6 Trips Benefiting Most from ATIS

In this section we identify the worst trips in the network based on the F95 trip outcomes from June 2000 through May 2001 for the AM peak and for the PM peak. Specifically, we identify the ten trips with the highest value of disutility for each peak period. We then identify the trips most benefited by ATIS for each peak period. That is, we identify the ten trips that have the greatest reduction in disutility from F95 commuters to their ASV counterparts. By identifying these two sets of 'worst' and 'best' trips, we highlight overlaps between these sets. As the disutility value is expressed in terms of dollars, we can estimate annual savings in dollars associated with ATIS use as a reduction in trip disutility.

<u>AM Peak Worst and Best Trips</u>: Three sets of trips are by far the 'worst' trips in the region during the AM peak period. These trips are shown in Figure 3-8. The worst AM trips, those with greatest disutility, are from north-west to south-east in the network, and trips from the eastern edge to the western edge of the network. As expected, the worst trips are some of the longest trips in the network. Assuming the AM commute trip is made 220 workdays per year, the average annual disutility of the ten worst AM trips is $1,201. Table 3-17(a) lists the F95 and ASV commuters' average disutility over the evaluation year for the ten worst trips in the AM peak. Counterpart ASV commuters using ATIS to make pre-trip modifications have an annual average cost of $958. Thus, the value of ATIS in terms of reducing trip disutility for the ten worst trips in the AM peak is approximately $243.

Table 3-17(b) lists the F95 and ASV commuters' average disutility over the evaluation year for the ten trips most benefited by ATIS. There is clearly an overlap between these two sets of trips as three of the worst trips are also among the set of 10 trips most benefited by ATIS. The greatest percent reduction in annual disutility from ATIS is approximately 32%. Figure 3-9 illustrates the ten trips most benefited by ATIS during the AM peak. The ten trips most benefited by ATIS benefit an average of $356 per year in terms of reduced trip disutility.

In the AM peak over the 178 evaluation days, 68% of all origin-destination trips benefit in the AM peak from ATIS. The service yields benefit equal to $0.41 per trip for the 68% who incur a benefit. Approximately 32% of trips, however, incur a net annual disbenefit equal to $0.19 per trip. Thus, the net impact of ATIS can be viewed as yielding benefit equal to $0.22 per trip ($48/year).

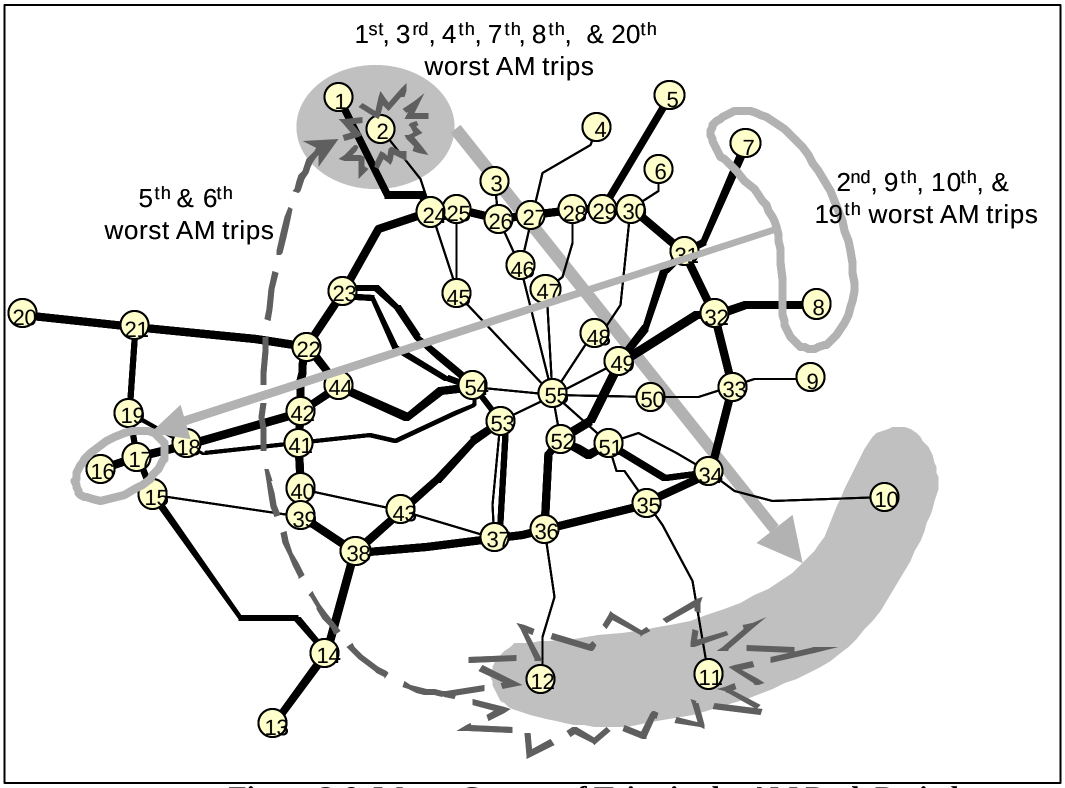

Figure 3-8. Worst Groups of Trips in the AM Peak Period

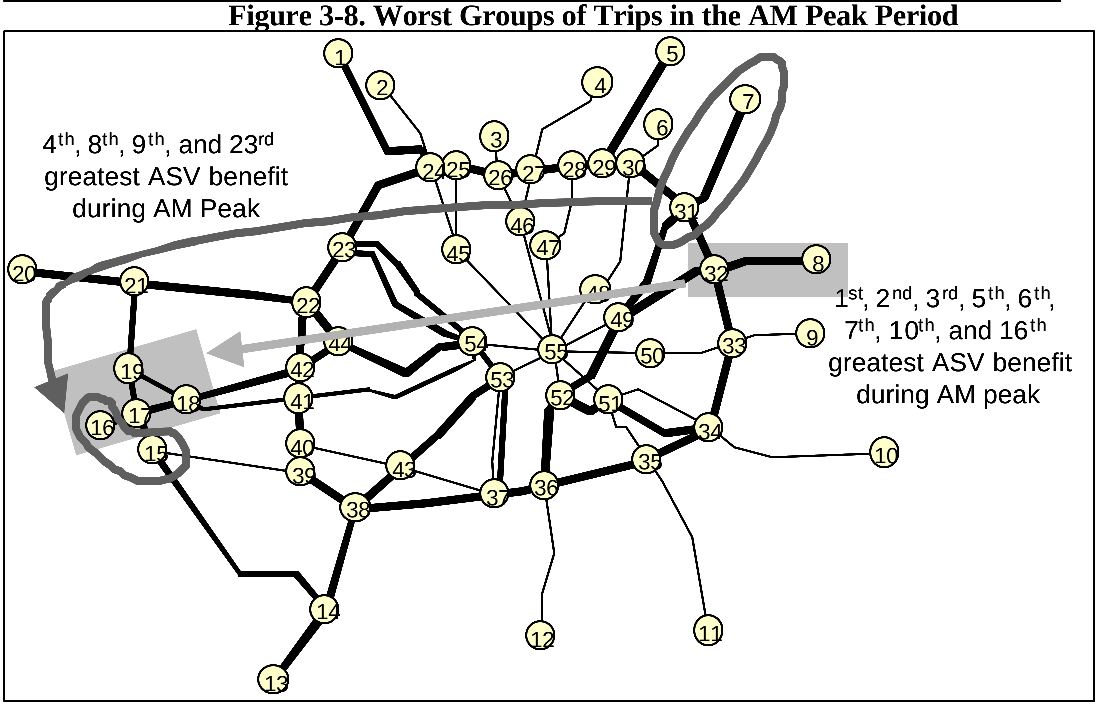

Figure 3-9. Groups of Trips in the AM Peak Most Benefited by ATIS

AM PEAK: WORST 10 TRIPS						
		Desti-	Length	Small's Disutility Value		
Rank	Origin	nation	(miles)	F95	ASV	Diff.
1	2	11	44.5	$ 5.70	$ 4.63	$ 1.08
2	8	16	49.6	$ 5.70	$ 3.87	$ 1.83
3	2	12	45.4	$ 5.57	$ 5.04	$ 0.53
4	1	11	46.2	$ 5.51	$ 4.10	$ 1.41
5	11	2	44.5	$ 5.47	$ 4.52	$ 0.96
6	12	2	45.1	$ 5.45	$ 5.09	$ 0.36
7	1	12	47.1	$ 5.44	$ 4.49	$ 0.95
8	7	16	45.2	$ 5.26	$ 3.74	$ 1.52
9	8	17	46.0	$ 5.26	$ 3.61	$ 1.65
10	2	10	39.5	$ 5.26	$ 4.49	$ 0.77
Average of Top 10:			45.3	$ 5.46	$ 4.36	$ 1.11

AM PEAK: 10 TRIPS MOST BENEFITED BY ATIS						
		Desti-	Length	Small's Disutility Value		
Rank	Origin	nation	(miles)	F95	ASV	Diff.
1	8	16	49.6	$ 5.70	$ 3.87	$ 1.83
2	32	16	43.4	$ 5.11	$ 3.42	$ 1.69
3	32	17	39.8	$ 4.78	$ 3.12	$ 1.66
4	31	16	39.9	$ 4.84	$ 3.18	$ 1.65
5	8	17	46.0	$ 5.26	$ 3.61	$ 1.65
6	32	19	39.1	$ 4.72	$ 3.13	$ 1.59
7	8	19	45.3	$ 5.19	$ 3.66	$ 1.53
8	7	15	43.9	$ 5.11	$ 3.57	$ 1.53
9	7	16	45.2	$ 5.26	$ 3.74	$ 1.52
10	8	18	43.1	$ 4.96	$ 3.45	$ 1.52
Average of Top 10:			43.5	$ 5.09	$ 3.47	$ 1.62

Table 3-17(a) and (b). 10 Worst and 10 Best AM Trips Over June 2000 – May 2001

PM Peak Worst and Best Trips: The set of 10 worst trips in the PM peak are different from the AM peak by geography and by magnitude of disutility. The 10 worst trips in the PM originate from the Maryland suburbs along the northwest side of the network and all end in Dale City, Virginia, node 13. Figure 3-10 shows these trips as well as the set of 10 trips most benefited though ATIS use. Tables 3-18 (a) and (b) list these two set of ten trips. Eight of ten trips are the same in both tables. The two worst trips not in the 'most benefit' top ten table are ranked 11 and 13 in terms of ATIS benefit. Moreover, the two 'best' trips not in the 'worst' top ten table are ranked 14th and 16th worst.

These trips, although not the longest trips in the network, are trips with multi-point route options along their trip. To note, route switching was most frequent in the PM peak. The most benefit achieved during the PM peak by a specific origin-destination trip through ATIS use is a 59% reduction in trip disutility. The ten worst PM peak trips incur an annual cost of $2,487 associated with the disutility of travel. The ATIS-using counterparts incur an annual cost of $1,097. Thus, for the ten worst PM trips, the benefit of ATIS can be valued at $1,390 annually. The value of ATIS in terms of reducing trip disutility for the ten trips most benefited through ATIS is $1,404.

In the PM peak over the 178 evaluation days, 84% of all origin-destination trips benefit from ATIS. The service yields benefit equal to $1.12 per trip for the 84% who incur a benefit. Approximately 16% of trips, however, incur a net annual *increase* in disutility equal to $0.14 per trip. Thus, the net impact of ATIS can be viewed as yielding benefit equal to $0.98 per trip ($216/year).

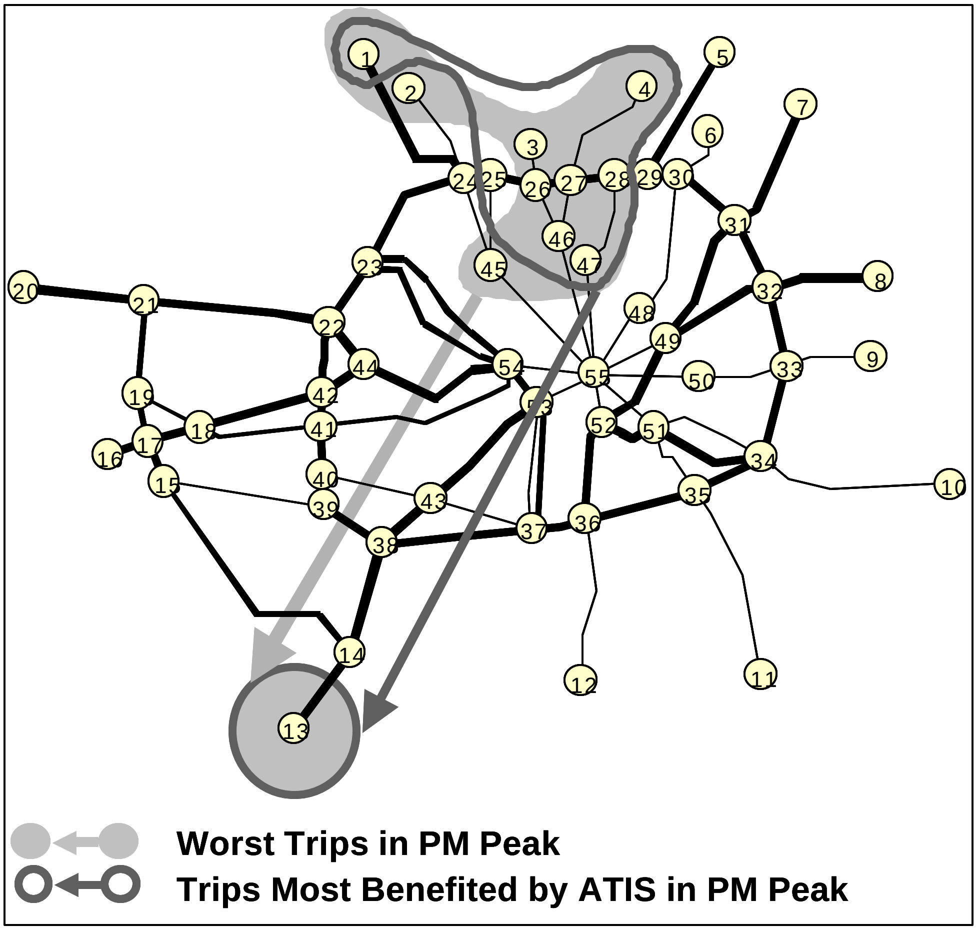

Figure 3-10 Worst Trips and Trips Most Benefited By ATIS for the PM Peak

PM PEAK: WORST 10 TRIPS						
		Desti-	Length	Small's Disutility Value		
Rank	Origin	nation	(miles)	F95	ASV	Diff.
1	47	13	33.9	$ 13.29	$ 5.41	$ 7.88
2	28	13	43.5	$ 12.26	$ 4.78	$ 7.49
3	1	13	45.3	$ 11.65	$ 5.03	$ 6.62
4	4	13	45.8	$ 11.52	$ 5.21	$ 6.31
5	46	13	42.3	$ 11.12	$ 4.91	$ 6.21
6	27	13	41.3	$ 11.05	$ 4.58	$ 6.47
7	3	13	42.4	$ 11.04	$ 4.91	$ 6.13
8	2	13	43.6	$ 10.73	$ 5.62	$ 5.11
9	45	13	40.5	$ 10.20	$ 4.99	$ 5.21
10	26	13	39.9	$ 10.16	$ 4.42	$ 5.74
Average of Top 10:			41.9	$ 11.30	$ 4.99	$ 6.32

PM PEAK: 10 TRIPS MOST BENEFITED BY ATIS						
		Desti-	Length	Small's Disutility Value		
Rank	Origin	nation	(miles)	F95	ASV	Diff.
1	47	13	33.9	$ 13.29	$ 5.41	$ 7.88
2	28	13	43.5	$ 12.26	$ 4.78	$ 7.49
3	1	13	45.3	$ 11.65	$ 5.03	$ 6.62
4	27	13	41.3	$ 11.05	$ 4.58	$ 6.47
5	4	13	45.8	$ 11.52	$ 5.21	$ 6.31
6	46	13	42.3	$ 11.12	$ 4.91	$ 6.21
7	3	13	42.4	$ 11.04	$ 4.91	$ 6.13
8	26	13	39.9	$ 10.16	$ 4.42	$ 5.74
9	25	13	37.7	$ 9.68	$ 4.18	$ 5.50
10	32	16	43.4	$ 9.61	$ 4.17	$ 5.44
Average of Top 10:			41.6	$ 11.14	$ 4.76	$ 6.38

Table 3-18(a) and (b). 10 Worst and 10 Best PM Trips over June 2000 – May 2001

3.2.7 Day-To-Day Trends and Travel Budget

The day-to-day variability of aggregate metrics of trip time, percent of trips late, travel expenditure, and Small's disutility are first contrasted in this section for F95 commuter and their ASV counterparts. Comparisons are based on the standard deviation of the daily aggregate metric across the 178 evaluation days.

Thus far we have established the travel departure decisions of the commuter based on the months of March –May 2000. In this analysis we instead maintain constant the tolerance level for late arrivals and establish according travel departure decisions month by month. In effect, we train the commuter for each month of data and evaluate how travel budgets vary from month to month. This evaluation provides insight into whether commuters would to increase their travel budget to maintain their standards for on time arrivals.

Day to Day Variability in Trip Metrics for F95 and ASV: In virtually all accounts, the ASV counterparts' aggregate metric has lower variability compared to the F95 commuter. The exception is average daily travel budget. This is expected, though given that the ASV commuters vary their departure time relatively frequently.

Figure 3-11 presents the probability distribution functions of the ASV and F95 commuters' AM disutility value travel expenditure to highlight the relationships between average metrics and their standard deviations. Clearly, ASV commuters reduce their disutility and to a lesser extent travel expenditure at the cost of higher variability in travel expenditure. To note, the variability in travel expenditure of F95 commuters is driven by arrival offsets while the variability in travel expenditure of ASV commuters is driven by departure offsets.

Figure 3-12 charts the AM on-time reliability for each day in the evaluation period for both the ASV and F95 commuters. This figure illustrates to what extent ATIS can reduce variability. The F95 commuters' show a statistically significant trend line in degradation of on-time reliability, at a rate of 2.7% per year. The ASV commuter, however, show no statistically significant degradation in on-time reliability.

Figure 3-13 charts the percent of total benefit garnered through ASV (in terms of disutility reduction) as a function of the percent of 'best' performing ATIS days. For the AM peak, the 18 worst days (10% of days), in terms of F95 on-time-reliability, account for 30% of the benefit in terms of reduced disutility. This chart also demonstrates that for the AM peak, in approximately 4% of days, no benefit in terms of reduced disutility is achieved. For the PM peak and off-peak, all days garner some net benefit from ATIS.

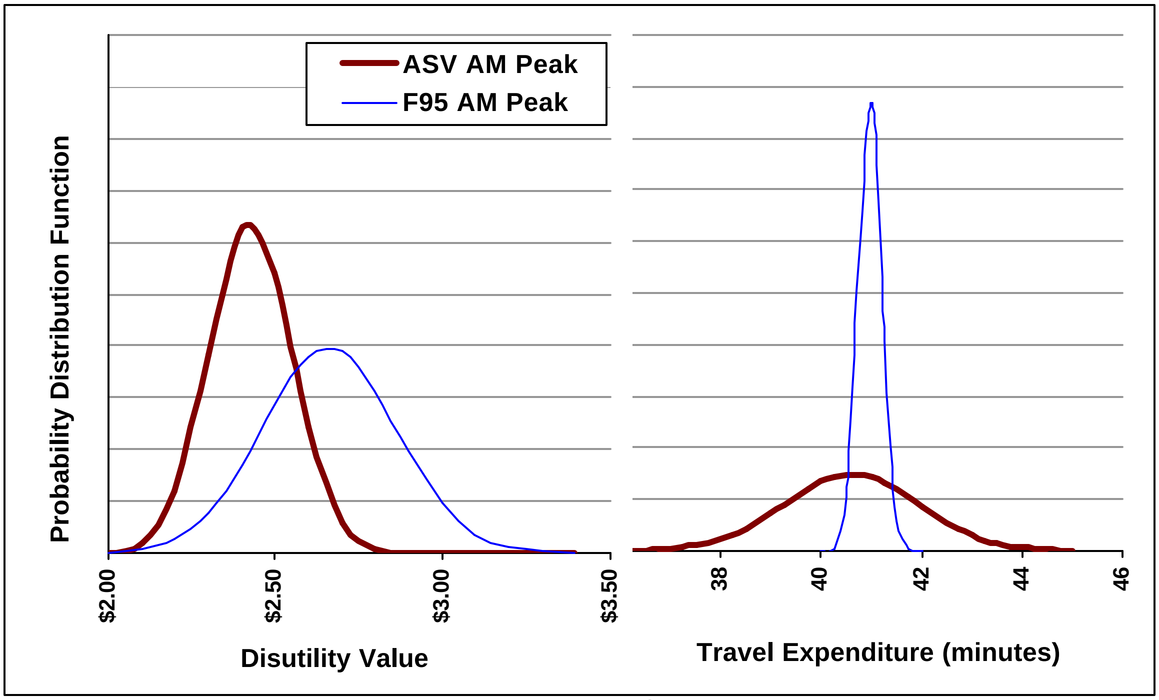

Figure 3-11. Probability Distribution Functions of AM Disutility and Travel Expenditure

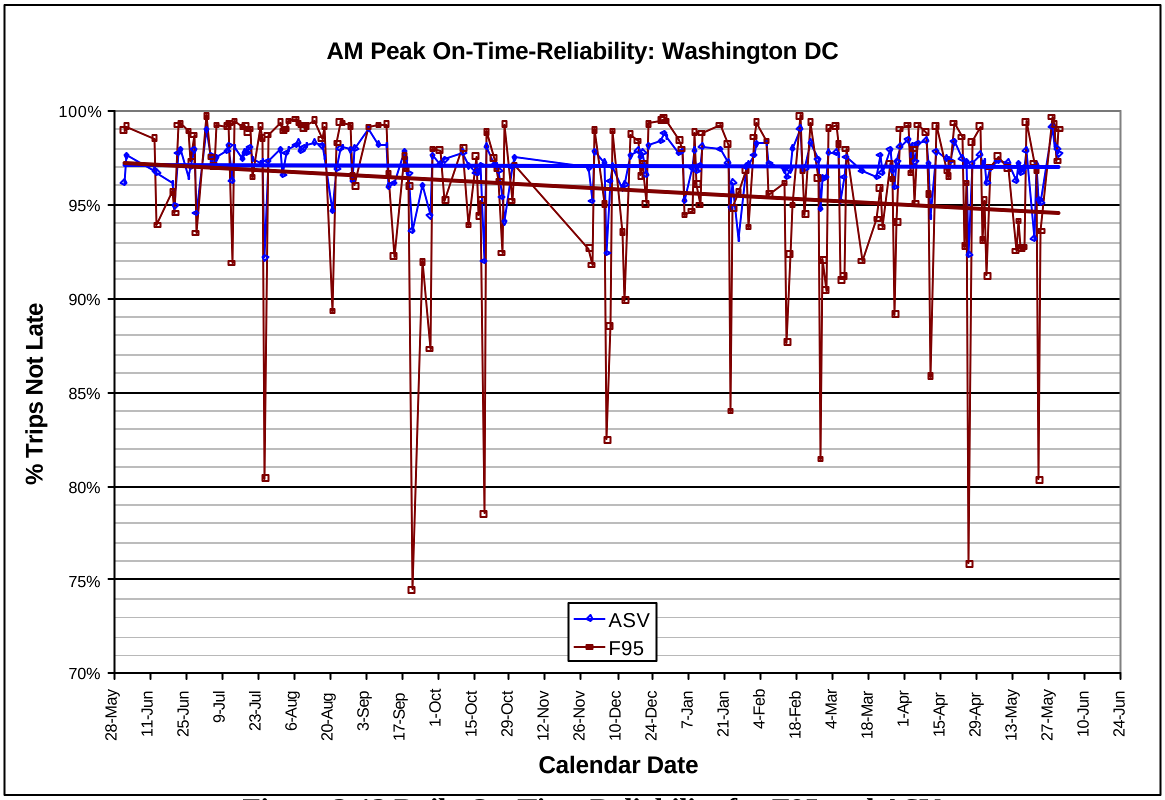

Figure 3-12 Daily On-Time Reliability for F95 and ASV

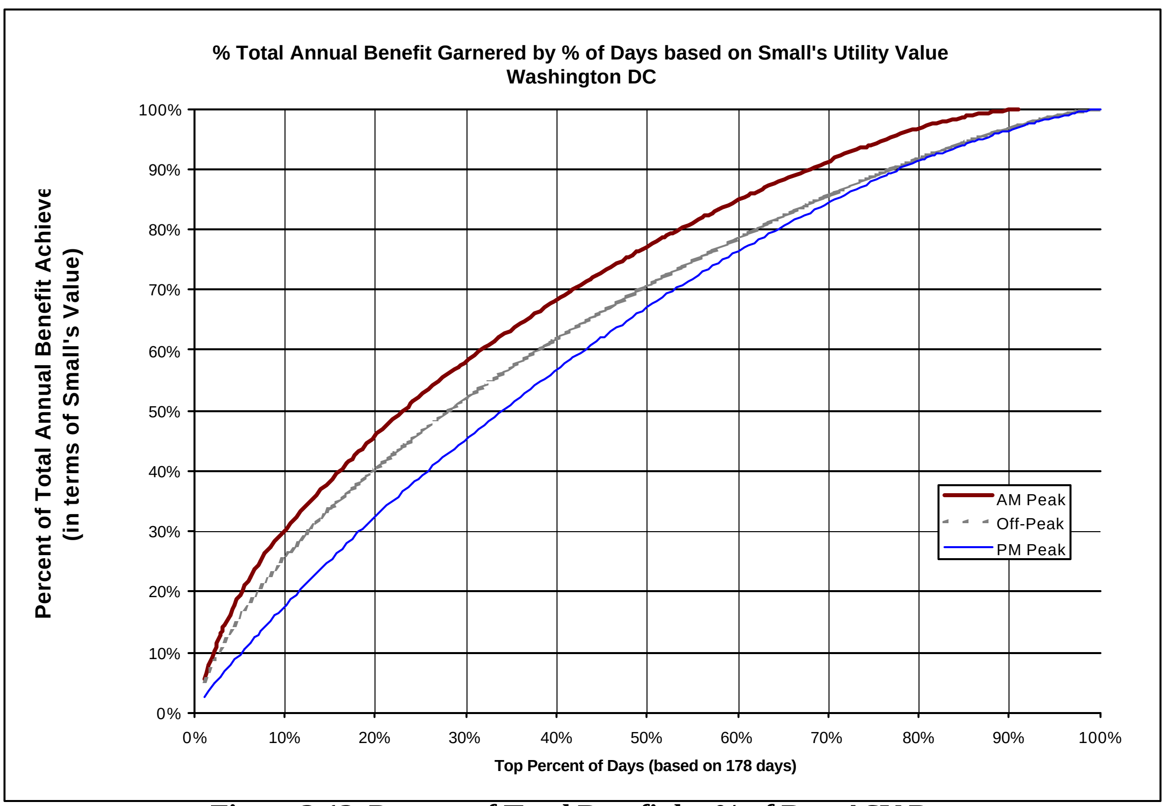

Figure 3-13. Percent of Total Benefit by % of Best ASV Days

<u>Travel Budget Trends Month to Month</u>: Travel budget is the amount of time the habitual commuter allots for a trip, defined as the difference between the target arrival time and the actual departure time. In all previous trials the budget of the habitual commuter was fixed based on the months of March through May 2000. In this section we fix the level of on-time arrival to 95% and determine what the required budget should be to achieve this rate of on-time arrival.

Figure 3-14 shows the travel budget required to maintain the 95% on-time arrival rate for the AM peak, PM peak, and off-peak periods. This data reveals a linear trend in the AM toward increasing travel budget at a rate of 1.7 minutes per year. The R2-value, a measure of linear goodness of fit, is relatively low (0.30) suggesting a poor linear fit to the data. However, the difference between the slope of the AM trend line and zero is statistically significant at the 95% level suggesting that there is a relationship on increases in travel times by month, although the increase may not be linear. No statistically significant trends in travel budget for the PM peak or off-peak periods were present.

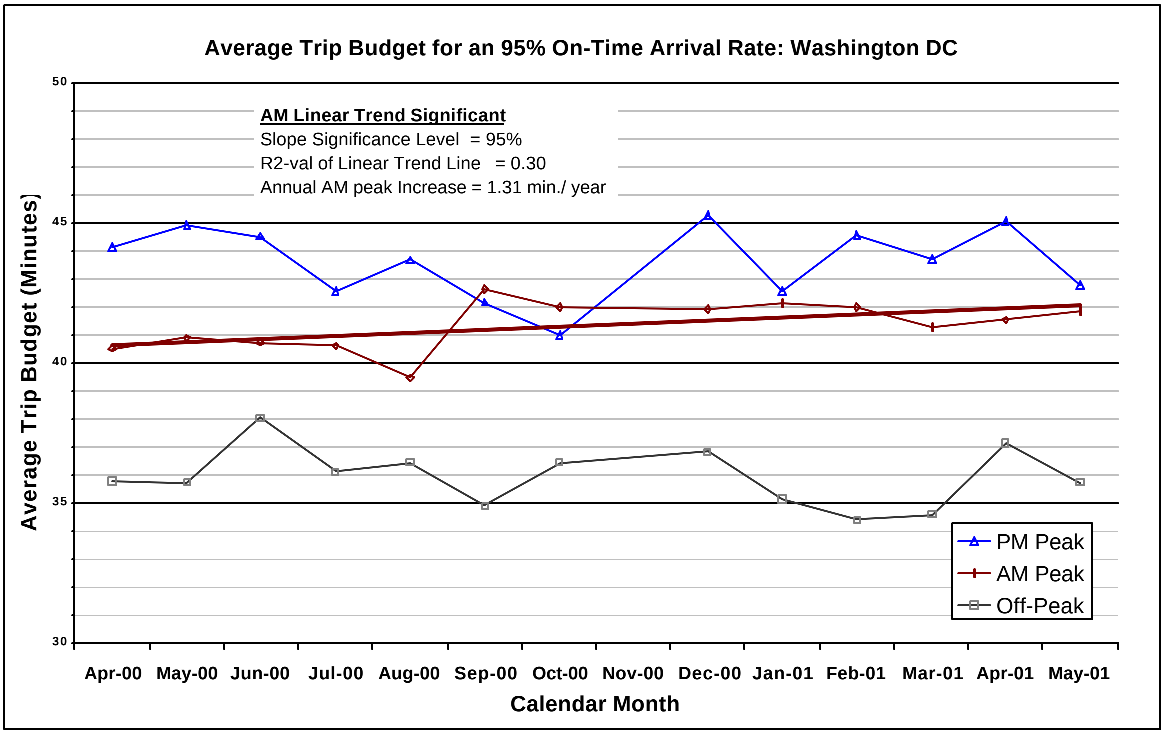

Figure 3-14. Travel Budget by Peak/Off-Peak to Maintain 95% On-Time Reliability

3.3 Case Study Summary

In Section 3 we explored trends in link travel time metrics and trip metrics for the Washington DC region over a 15-month period from March 2000 though May 2001. We focused on how commuters using ATIS perform in contrast to those fixed to a specific trip departure time and route.

We established that link travel times show clear trends for increasing travel time and variability during the AM peak (7:00 AM – 9:30 AM) from the first three months to the remaining 12 months. Travel time and variability during the PM peak (4:15 PM – 6:30 PM) also increase but to a lesser extent. During the hours of 10:30 AM – 2:30 PM in the off-peak there is substantial increase in travel time variability; however, given that the off-peak encompasses the hours from 6:30 AM - 7:00 AM and 9:30 AM – 4:15 PM, the overall increase in travel time variability for the off-peak is at par with the PM peak.

In terms of the magnitude of facility travel time, the PM peak is slightly worse than the AM peak. In terms of travel time variability, the PM peak is much worse than the AM peak. The off-peak trails far behind in terms of the magnitude of travel time and variability.

ATIS benefits commuters by suggesting departure time changes overwhelmingly compared to pre-trip route changes. The ratio of time to route changes is 13:1 for the annual analysis of the F95 and ASV commuters. More importantly, in 58% of all trips ATIS recommends a change in trip departure, be it route or departure time or both.

Based on the annual analysis of the F95 and ASV commuters, ATIS reduces the disutility associated with travel by 27% during the PM peak, mainly by eliminating the frequency and magnitude of early arrivals. Off-peak, ATIS reduces the disutility associated with travel by 12%, mainly by eliminating the frequency of late arrivals during the hours of 10:30 AM -2:30 PM and reducing the frequency of early arrivals throughout the off-peak. ATIS reduces the disutility associated with travel equally in magnitude for the AM peak as in the off-peak, but as a percent, the reduction is only 9%. This is because in the AM, travel times are higher, providing fewer opportunities for ATIS to cut early arrivals. Moreover, because of relatively higher congestion, the opportunity to cut late arrivals is not as great as in the less-congested off-peak periods. Across the board, increases in travel time variability drives ATIS benefits much more than increases in travel time.

Two additional experiments, one with a commuter with a lower on-time arrival threshold of 80%, and one with commuter with lesser knowledge of peak/off-peak variability were also conducted for a two-month period in June through July 2000. These experiments, compared to the F95-ASV experiment, highlighted the fact that ATIS benefits vary based on how much a commuter budgets for travel. The naïve user of ATIS performs nearly as well as a savvy ATIS user as measured by the aggregate trip disutility and frequency of late and early arrivals.

For the Washington region, the net benefit garnered through ATIS use is positive for all 178 days of evaluation of the F95 and ASV commuters. Moreover, the ten worst trips in the AM and PM peak, those with a dollar-valued disutility of travel at approximately \$5.60 and \$11.41 per trip respectively, benefit on the order of \$1.10 and \$6.50 per trip. Assuming 220 such trips per year, the annual savings for the ten worst AM and PM trips are \$242 and \$1430. On average across all trips studied in all time periods, the reduction in dollar-valued disutility is \$0.41, yielding an annual value of \$90.20.

4.0 Twin Cities 12-Month Case Study

In this chapter, a parallel case study of the Minneapolis/St. Paul metropolitan area (hereafter referred to as the Twin Cities) will be presented. The chapter is structured as follows: Section 4.1 presents analysis of link travel times is based on data archived from an Internet-based Advanced Traveler Information System (ATIS). The data source is described along with a study of trends over the study period. In Section 4.2, the HOWLATE simulated yoked study is presented. The experimental design is described followed by the results of three experiments and a comparison between them. Results are broken down by day and by origin-destination pair. Section 4.3 makes a connection between the link analysis and the HOWLATE trip analysis results. Finally, key points are summarized in Section 4.4.

The Twin Cities metropolitan area was selected for study for two main reasons: First, an ATIS service is operational in the Twin Cities and its real-time travel time data was available. Second, the Twin Cities is a smaller metropolitan area, has less congestion and is in a different part of the country from Washington DC. Therefore, by performing parallel studies of the two cities, a better understanding of ATIS benefits and the factors that contribute to ATIS benefits may be ascertained. According to 2000 U.S. Census data, the Twin Cities is the 13th most populated metropolitan area in the nation with 3.0 million residents, a 16.9% increase from 1990. According to the latest Urban Mobility Study published by the Texas Transportation Institute, the Twin Cities was the 15th most congested metropolitan area in the United States 1999 (Schrank and Lomax, 2000).

4.1. Analysis of Link Travel Time Data

As in the Washington case study, we first analyze the primary data input to the yoked trial simulator – the roadway travel time data archived from the ATIS service provider. Trends and attributes seen in the primary data will have significant impact on the type, nature and magnitude of benefits accrued to ATIS users.

4.1.1. Geographic Coverage

The HOWLATE method is based on travel time data, which is posted on the Internet by SmarTraveler, downloaded every five minutes by Mitretek, and archived in a database. These data represent what an ATIS user would utilize to aid his trip decisions. While we know ATIS data is subject to a certain amount of error relative to what a driver would actually experience, we can use this archived travel time data to identify trends in network travel time and travel time variability.

SmarTraveler (http://www.smartraveler.com) is an Internet-based ATIS providing real-time travel time estimates on major freeways and arterials in 21 U.S. cities. SmarTraveler was selected for travel time archiving by Mitretek because its relatively long-standing service in Washington and the Twin Cities. It is important to note again that this study is meant to be an assessment of a prospective notification-based ATIS based on data similar to SmarTraveler, not an evaluation of SmarTraveler specifically. It is expected that in the future, various traveler information services based on travel time estimation will become more widely available as consumer demand for this type of service increases.

In the Twin Cities, SmarTraveler defines 31 unique roadway sections, which for purposes of this report will be termed facilities. For each of the 31 facilities, SmarTraveler reports travel times in both directions for a total of 62 directional facilities. The coverage area encompasses 510 directional miles, 418 of which are freeways and 92 of which are major arterials. Longer roads such as I-35W, which traverse the entire length of the metropolitan area, are broken up into multiple shorter lengths for travel time reporting. The average facility length is 8.2 miles. The shortest is Highway 280 between Roseville and St. Paul, which is 3.3 miles long. The longest is I-494 between Minnetonka and Bloomington, which is 15.3 miles long. Figure 4-1 shows for the Twin Cities SmarTraveler web page how the 31 facilities are delineated. Table 4.1 gives a description of each facility.

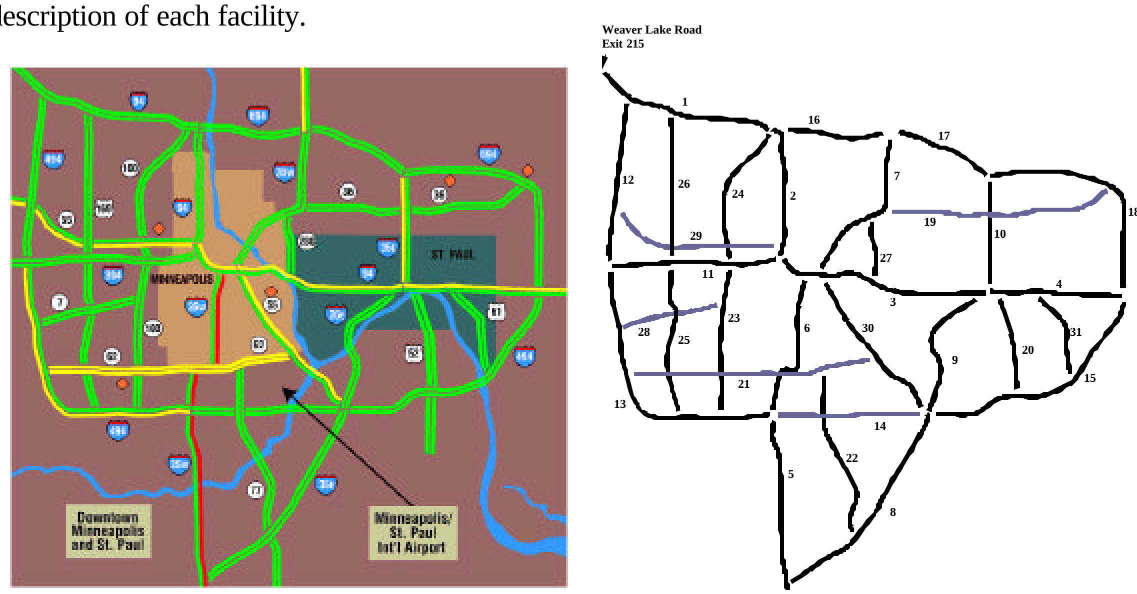

Figure 4-1. Internet-based ATIS Network Coverage and Corresponding Facility Delineations

Facility Number	Facility (SmarTraveler) Description	Length (miles)	Number Of Links	Facility Type
1	I-94 between Maple Grove and Brooklyn Center	9.0	3	Freeway
2	I-94 between Brooklyn Center and Minneapolis	5.8	1	Freeway
3	I-94 between Minneapolis and St. Paul	10.0	3	Freeway
4	I-94 between St. Paul and Woodbury	6.7	2	Freeway
5	I-35W between Bloomington and Burnsville	8.6	1	Freeway
6	I-35W between Minneapolis and Bloomington	7.3	2	Freeway
7	I-35W between Arden Hills and Minneapolis	9.2	3	Freeway
8	I-35E between Eagan and Burnsville	10.9	2	Freeway
9	I-35E between St. Paul and Eagan	8.2	1	Freeway
10	I-35E between Little Canada and St. Paul	5.6	2	Freeway
11	I-394 between Minnetonka and Minneapolis	8.7	3	Freeway
12	I-494 between Maple Grove and Minnetonka	8.4	2	Freeway
13	I-494 between Minnetonka and Bloomington	13.9	5	Freeway
14	I-494 between Bloomington and Eagan	7.5	2	Freeway
15	I-494 between Eagan and Woodbury	12.7	3	Freeway
16	I-694 between Brooklyn Center and Arden Hills	4.9	2	Freeway
17	I-694 between Arden Hills and Little Canada	5.4	1	Freeway
18	I-694 between Little Canada and Woodbury	11.0	2	Freeway
19	Hwy. 36 between Roseville and Oakdale	11.7	2	Freeway
20	Hwy. 52/Lafayette Freeway between St. Paul and Inver Grove Heights	5.7	1	Freeway
21	Hwy. 62/Crosstown between Minnetonka and Fort Snelling	12.0	6	Freeway
22	Hwy. 77/Cedar Ave. between Minneapolis and Eagan	8.5	2	Freeway
23	Hwy. 100 between Golden Valley and Bloomington	7.7	3	Freeway
24	Hwy. 100 between Brooklyn Center and Golden Valley	8.0	2	Arterial
25	Hwy. 169 between Golden Valley and Bloomington	7.9	3	Freeway
26	Hwy. 169 between Brooklyn Park and Golden Valley	7.6	2	Arterial
27	Hwy. 280 between Roseville and St. Paul	3.3	1	Freeway
28	Hwy. 7 between Minnetonka and St. Louis Park	5.3	2	Arterial
29	Hwy. 55 between Plymouth and Minneapolis	9.1	3	Arterial
30	Hwy. 55 between Minneapolis and Mendota Heights	9.3	2	Arterial
31	Hwy. 61 between St. Paul and Newport	5.1	1	Arterial

Table 4-1. SmarTraveler Facility Descriptions

Figure 4-2 shows the Twin Cities HOWLATE link-node representation. The HOWLATE network is based on the SmarTraveler facility network. However, in order to increase connectivity and more realistically represent route choice options available, links must be broken up and additional nodes introduced. For example, Facility 26, Highway 169 between Brooklyn Park and Golden Valley, is divided into two links in the HOWLATE network by adding an additional node where it intersects with Highway 55 between Plymouth and Minneapolis (Facility 29). This allows a traveler to exit from one facility to the other at this point.

In some cases link end points were consolidated into a single node where two nodes would otherwise be very close together. For example, I-94 is comprised of Facilities 1 and 2, connecting where I-94 intersects with Highway 100 (Facility 24). I-694 intersects I-94 slightly further east.

Because the intersections are so close together they are approximated with a single node. The same was done at node 21 near downtown Minneapolis. Here, Facilities 6, 7, and 30 intersect with Facility 3, meet, though not at precisely the same location. However, their intersection was approximated with a single node.

A related situation is the intersection of Facilities 6 and 21, I-35W between Minneapolis and Bloomington and Highway 62/Crosstown between Minnetonka and Fort Snelling. Here, the two facilities overlap over a short east-west stretch. In the HOWLATE network, two nodes were introduced here, one where the two routes merge and one where they diverge. A decision then had to be made regarding which facility to use for the travel time between these two points. Facility 21 was chosen because it was deemed less variable in travel time across its length as Facility 6 goes into downtown Minneapolis, a likely more congested area.

In the sections to follow, travel times on SmarTraveler facilities (not HOWLATE links) will be used to identify peak period durations and to detect trends in travel time and day-to-day travel time variability.

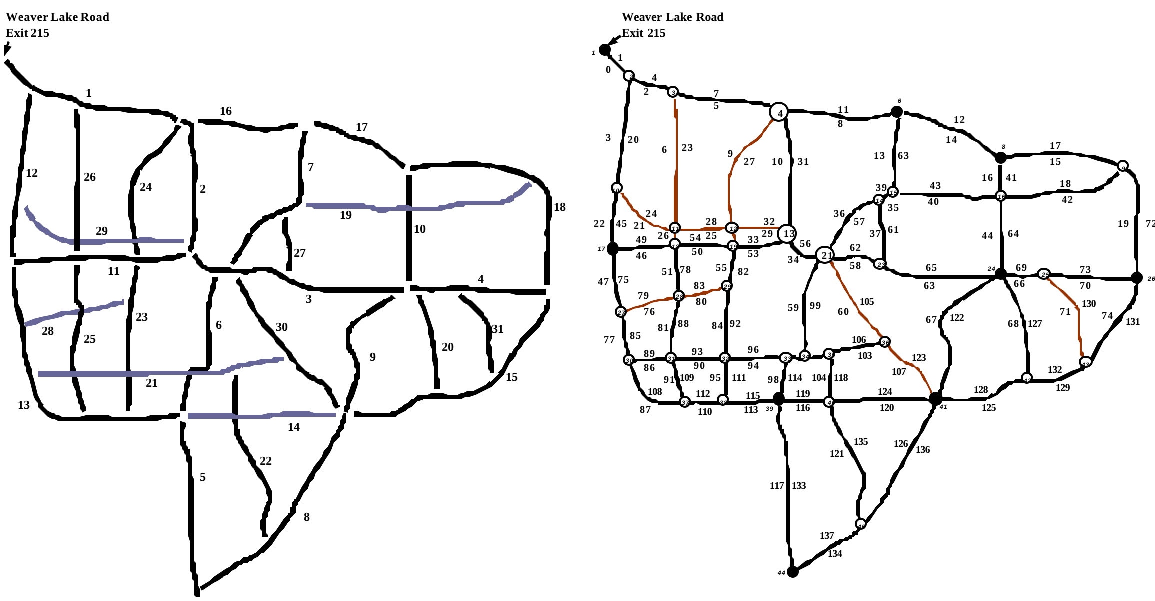

Figure 4-2. SmarTraveler Facilities and HOWLATE Link-Node Network Representation

4.1.2. Travel Time Archive

Travel times for each of the 62 directional facilities were downloaded and archived every five minutes from 6:30 a.m. to 6:30 p.m. each weekday, excluding holidays. Data was collected from March 2000 to May 2001. This study period is divided into two distinct parts: The 39 days during March, April and May 2000 form the training period. The 176 days from June 2000 through May 2001 form the evaluation period.

A number of days had to be excluded from the study due to gaps in the data archive. Data collection could be interrupted by problems with the automated download process, disruptions in the Internet connection, or temporary down time on the part of SmarTraveler. Whenever four consecutive data points (a span of 20 minutes) were missed for even one of the facilities, the entire day was unusable. Shorter gaps were filled by linear interpolation. Table 4.2 shows the days for which usable data was collected in each month of the study period as a percentage of the total number of potential days. Each row represents a day and each column the day of the week. Gray dates represent weekdays that are not holidays, days for which data is typically archived barring any of the problems mentioned. Those with a “ – ” are days for which data gaps made the day unusable. All dates shown were used in the study. In total, the study includes 67% of all possible days.

Calendar Month	Complete Days	Potential Days	Percent Coverage	Dates of Coverage Gray dates are potential days (weekends and holidays excluded). " - " indicates missing data. The numbers are dates with complete data.																								
				M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Mar-00	7	23	30%			-	-	3	-	-	-	9	-	-	-	-	-	17	20	21	-	23	24	-	-	-	-	-
Apr-00	13	20	65%	3	4	-	6	-	-	-	-	13	14	-	-	19	20	21	24	25	26	27	28					
May-00	19	22	86%	1	2	3	-	5	8	9	10	11	12	-	16	17	18	19	22	23	24	25	-		30	31		
Jun-00	11	22	50%				1	2	-	6	-	-	-	-	13	-	-	-	-	20	21	22	23	26	27	28	-	-
Jul-00	17	20	85%	3		5	-	7		11	12	13	14	17	18	19	20	21	24	25	26	27	28	-				
Aug-00	22	23	96%		1	2	3	4	7	8	9	10	11	14	15	16	17	18	21	22	23	24	25	28	29	30	-	
Sep-00	20	21	95%					-	4	5	6	7	8	11	12	13	14	15	18	19	20	21	22	25	26	27	28	29
Oct-00	19	21	90%	2	3	4	5	-		-	11	12	13	16	17	18	19	20	23	24	25	26	27	30	31			
Nov-00*	4	20	20%			1	2	3	-	-	-	-		-	-	-	-	-	-	-	-		-	-	28	-	-	
Dec-00	6	20	30%					1		5	6	7	8	11	-	-	-	-	-	-	-	-	-		-	-	-	-
Jan-01	15	21	71%		2	3	4	5	8	9	10	11	12		16	17	-	-	22	23	-	-	-	29	30	-		
Feb-01	11	20	55%				-	-	5	6	-	-	-	12	13	14	15	16	-	20	21	-	23	-	27	-		
Mar-01	14	22	64%				-	-	-	6	7	8	9	-	-	-	15	-	-	20	21	22	23	26	27	28	29	30
Apr-01	18	21	86%	2	3	4	5	6	9		11	-	13	-	17	18	19	20	23	24	25	26	27	30				
May-01	19	23	83%		1	2	3	4	7	8	-	-	11	14	15	16	17	18	21	-	23	24	25	-	29	30	31	
Total	215	319	67%																									

* Note: Due to the limited number of November days, 11/1, 11/2 and 11/3 were grouped with October and 11/28 was grouped with December for monthly analyses.

Table 4-2. Dates of Coverage in the Travel Time

4.1.3. Training vs. Evaluation Periods: Aggregate Changes

Figures 4-3(a-b) show, by five-minute interval, the travel time and travel time variability difference between the training and evaluation periods. These are indicative of trends that will be discussed in Section 4.1.5, namely that the travel time and day-to-day travel time variability increase in the PM

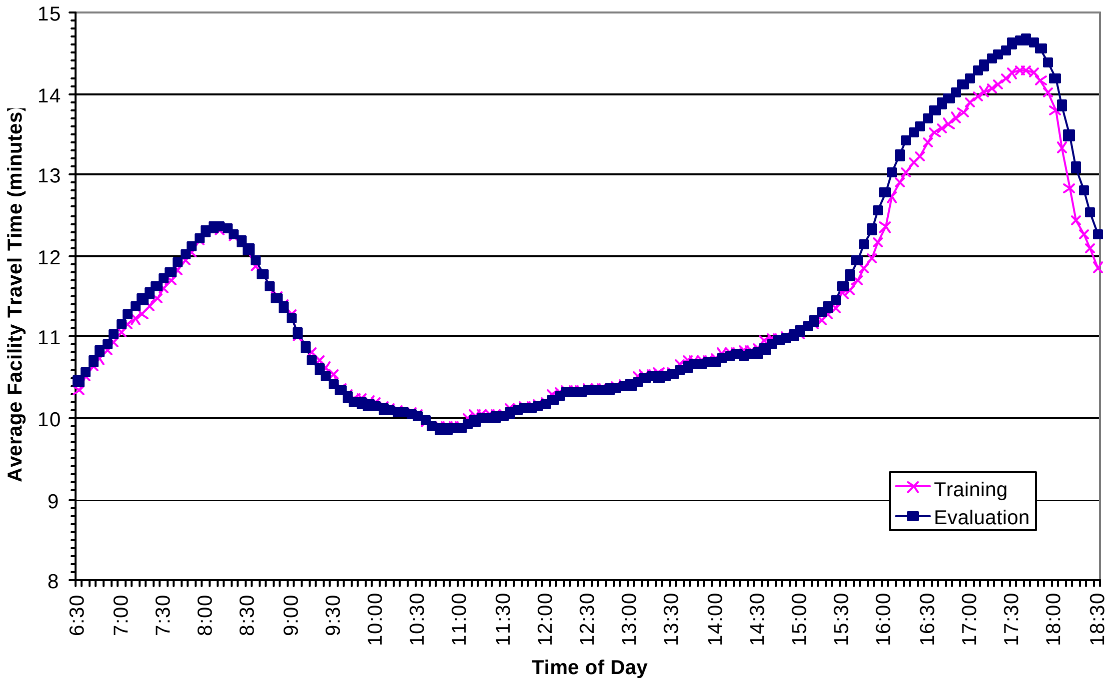

Figure 4-3 (a) Network Averaged Travel Time by 5-Minute Increments

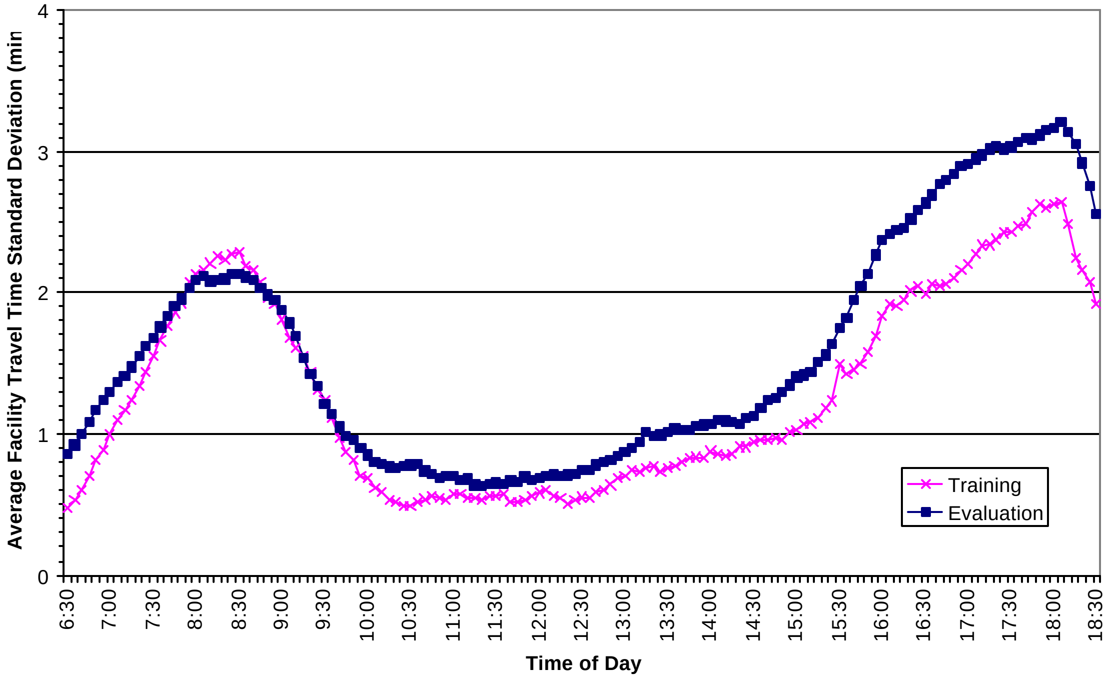

Figure 4-3 (b) Network Average Standard Deviation of Travel Time by 5-Minute Increments

peak. During the off peak and AM peak, travel time and day-to-day travel time variability are largely constant. In the off-peak, average travel times remain the same, but travel time variability increases. This is predominately due to two days, October 11 and 12, when morning and off peak travel times were unusually high (probably as a result of a major accident or other episodic event). This highlights how a few exceptional days can have significant impact on overall performance.

The difference between the training and evaluation period is also presented by time of day category in Table 4.3. Based on this data, one would expect to see deteriorated performance for ATIS non-users in the PM peak since they habituate to shorter travel times than what they experience on average during evaluation. As a result, ATIS will likely prove to be more beneficial for PM peak trips compared with trips during the rest of the day. As for the off peak, the adverse conditions of October 11 and 12 will certainly affect trip outcomes on those days but it is not certain how large an impact they will have when averaging trips outcomes over the entire year.

	Training Period (03/2000 - 05/2000)		Evaluation Period (06/2000 - 05/2001)	
Time of Day Category	**Average**	**StDev**	**Average**	**StDev**
AM Peak	11.78	1.57	11.85	1.56
Off Peak	10.32	0.53	10.29	0.61
PM Peak	13.46	1.86	13.85	2.43

Table 4-3 Peak/Off Peak Travel Time from Training Period to Evaluation Period

4.1.4. Time of Day Trends: Defining the Peak and Off-Peak Periods

Determining the durations of the AM and PM peak periods is important to this analysis for three reasons. First, it provides a measure of the overall congestion level in the Twin Cities metropolitan area and any trends in peak duration are indicative of congestion trends over time. Second, knowing when these peaks occur will allow us to aggregate the results of subsequent analyses by AM peak, PM peak or off-peak. Finally, the peak start and end times are an important input to the HOWLATE process, which will be discussed later.

Peak period start and end times were identified by a clustering analysis of the archived facility travel times. Clustering seeks to extract multiple subpopulations from a single population (time of day blocks, in this case) to minimize the intra-cluster variance and maximize the inter-cluster variance of the subpopulations. First, a two-cluster analysis was performed by month to distinguish peak periods from off peak periods by average travel time. Since the AM peak does not have the same high travel times as the PM peak, for a number of months the AM peak was not distinguished from the off peak. Stated another way, the AM peak associated more closely with the off peak than the PM peak in those months. Therefore, it made sense to define three clusters and repeat the analysis since the AM peak, off peak and PM peak are all different from each other. The three-cluster analysis separated the AM peak from the off peak and defined the ramping of travel times at the start and end of the PM peak. Based on these clustering analyses, the AM peak was defined by the three-cluster analysis and the PM peak was defined by the two-cluster analysis. The AM peak from the three-cluster analysis is shown in Figure 4-4 (a) and the PM peak from the two-cluster analysis is shown in Figure 4-4 (b).

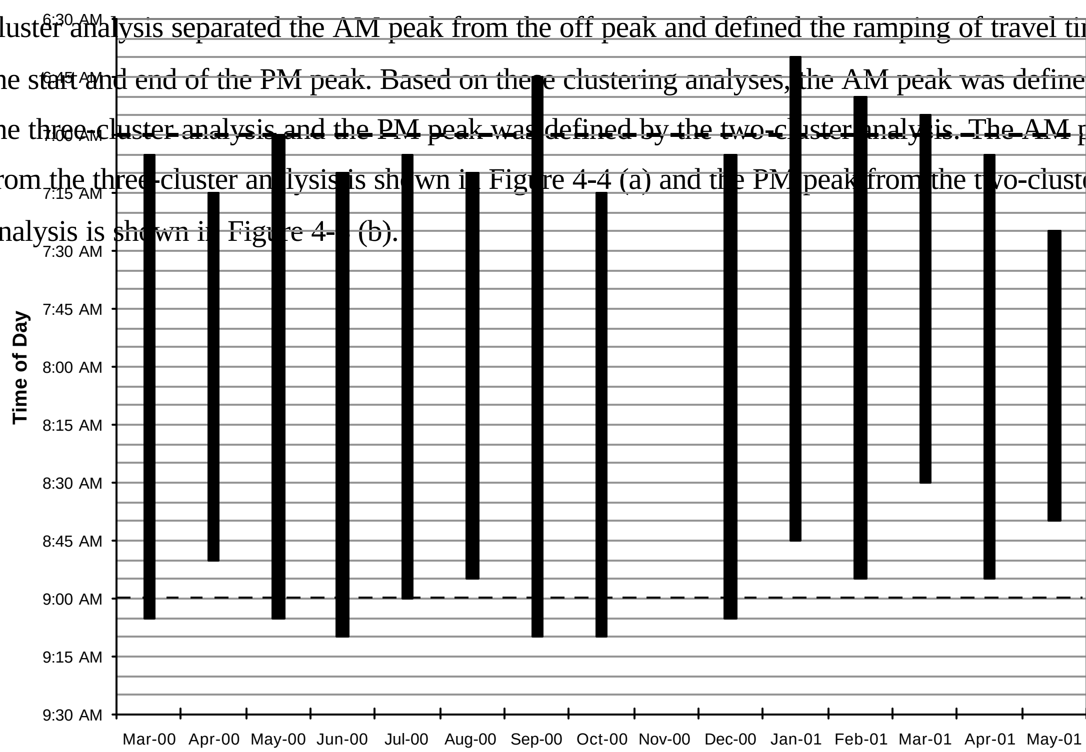

Figure 4-4 (a) Network AM Peak Travel Time Clusters by Month

Based on visual inspection of these figures, the AM peak was taken as 7:00 to 9:00 AM, and the PM peak was taken as 4:00 to 6:30 PM. Because the travel time archive only extends to 6:30 p.m., it was not necessary for the HOWLATE analysis to know whether and how far the PM peak extends beyond this time though it would be interesting for comparison with Washington and other cities. There is no significant trend of increasing or decreasing duration of either peak.

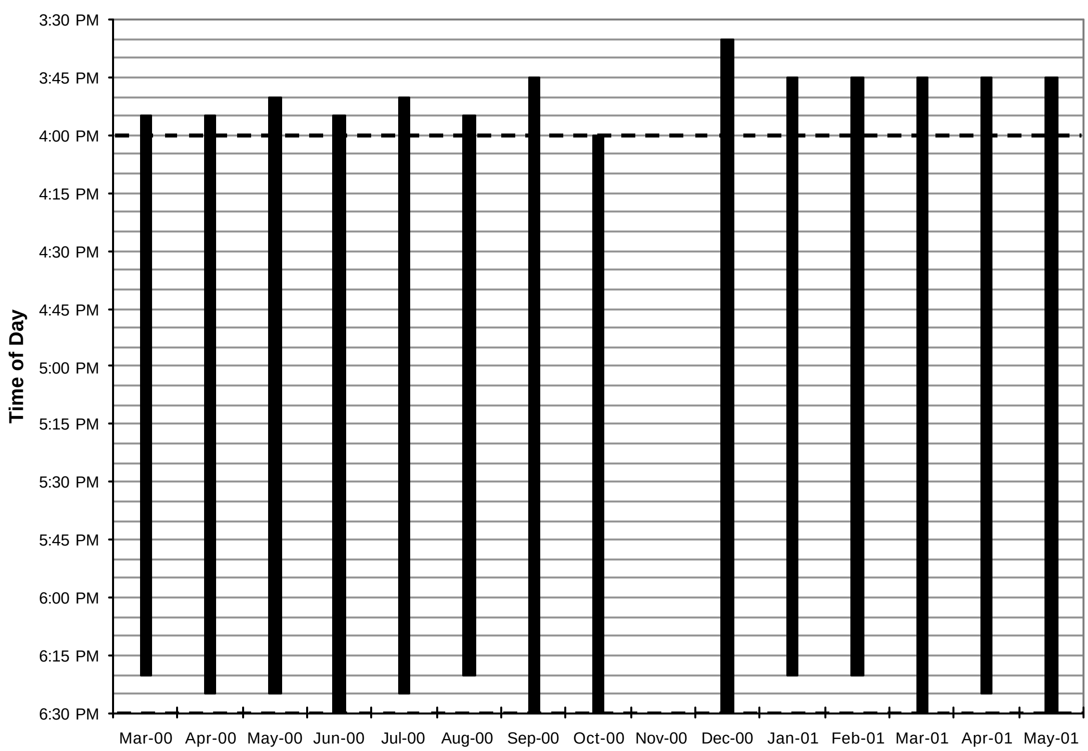

Figure 4-4 (a) Network PM Peak Travel Time Clusters by Month

4.1.5. Month-to-Month Trends

Figures 4-5 (a-b) display by month and peak, the average facility travel time and facility travel time standard deviation, respectively. While a large peak to off peak travel time differential is an important measure of congestion and a likely indicator of the potential benefit of ATIS, travel time variability from day to day within the peaks is equally important, particularly when considering on time reliability.

Of the three distinct periods of the day, the PM peak has the highest average travel time and travel time standard deviation in every month. The AM peak period has lower travel times and less variability, and the off-peak predictably has the least of both. This is what one would expect, particularly based on the clustering results. The two-cluster analysis showed the PM peak to be clearly set apart from the AM and off peak in terms of average travel time, while the AM clustered with the PM in some months and the off peak in others. With three clusters, however, the AM peak clustered with the ramping of the PM peak, which is less severe than the PM peak itself.

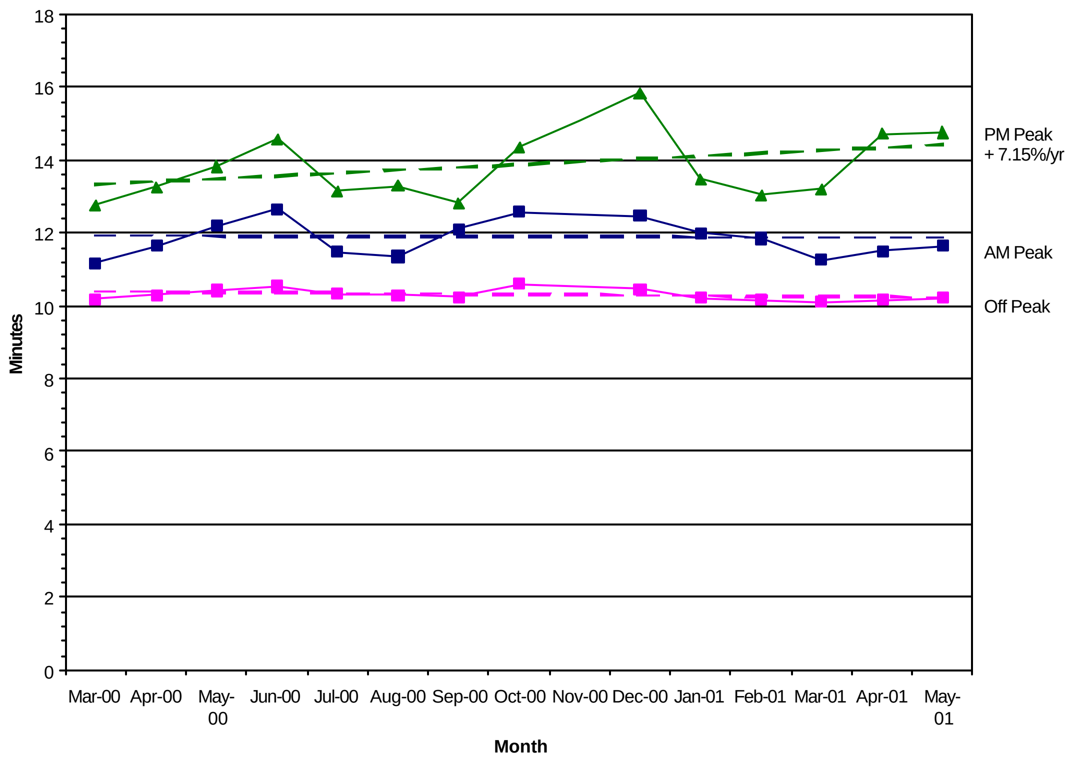

Figure 4-5 (a) Monthly Average Facility Travel Time by Period of the Day

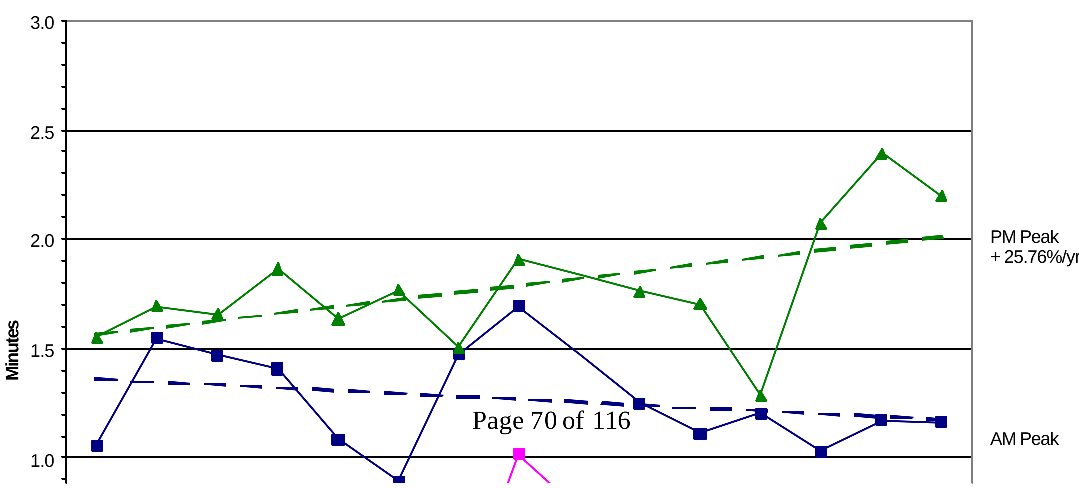

Figure 4-5 (b) Monthly Facility Travel Time Standard Deviation by Period of the Day

Over the 15-month study period, there is a trend of increasing average facility travel time in the PM peak of 7.2% per year, statistically significant at the 85% level. There is also a trend of increasing facility travel time standard deviation in the PM peak of 25.8% per year, statistically significant at the 95% level. During the AM peak and off peak, there is no statistically significant change in average travel time or travel time standard deviation. The increase in off peak day-to-day variability in October is due to the two especially bad days as described above. This raises an important point. It is likely that much of the benefit of ATIS comes in a few days where conditions are especially out of the ordinary. In addition, trends over time are likely driven more by an increase in the number of exceptional days than by a gradual change in recurring conditions. As a transportation network nears its functional capacity, the traffic impact of events such as accidents and poor weather are greater.

4.1.6. Individual Facility Trends

In Section 4.1.3 we considered aggregate changes in travel time and travel time variability between the training and evaluation periods. In this section, we will break down these changes by facility to show that while there is a gradual increase in average travel time across the network, not all facilities follow this trend. While most show a slight increase, some increase faster and some even decrease. As shown in Table 4.4, of the 62 directional facilities 55 (89%) show little change (less than 5%) from training to evaluation. One facility decreases significantly, Highway 100 southbound from Golden Valley to Bloomington (-15.6%). The largest increase is the northbound direction of the same facility (7.1%).

Following the trend shown in Figure 4-5 (b), the biggest changes occur in day-to-day travel time variability. Eleven facilities saw travel time standard deviation more than double from the training period to the evaluation period. The largest increase in variability occurs on Highway 61 southbound from downtown St. Paul to Newport (608%), mainly due to consistently higher travel times in the months of April and May.

The right hand column of Table 4.4 gives the congestion index. This is similar to the value computed by TTI referred to previously. The index is calculated by dividing the average travel time over the study period by the free flow travel time based on an assumption of the average speed of traffic. The link with the highest congestion index is I-94 southbound from Brooklyn Center to downtown Minneapolis (2.12). The facility with the lowest congestion index is I-35E northbound from Eagan to Burnsville (1.01), which sees very little deviation from free flow.

Facility No.	Facility Description	Direction	Free Flow	Facility Travel Time (minutes) From Training to Evaluation: Avg.	%diff	St.Dev	%diff	Congestion Index
1	I-94 between Maple Grove and Brooklyn Center	E	8.4	11.84	-0.1%	1.06	127.7%	1.41
		W		11.31	1.7%	0.98	42.5%	1.37
2	I-94 between Brooklyn Center and Minneapolis	N	5.4	11.31	1.7%	0.98	42.5%	2.12
		S		7.40	0.4%	0.26	5.2%	1.38
3	I-94 between Minneapolis and St. Paul	E	9.2	13.32	6.1%	0.92	30.7%	1.52
		W		13.29	6.2%	1.05	47.6%	1.52
4	I-94 between St. Paul and Woodbury	E	6.2	9.22	-1.2%	0.52	43.6%	1.49
		W		9.45	1.8%	0.59	17.6%	1.56
5	I-35W between Bloomington and Burnsville	N	8.0	9.86	5.1%	0.65	49.6%	1.29
		S		9.62	5.8%	0.23	251.4%	1.27
6	I-35W between Minneapolis and Bloomington	N	6.7	11.94	1.4%	0.98	13.8%	1.80
		S		13.03	1.4%	1.43	1.6%	1.97
7	I-35W between Arden Hills and Minneapolis	N	8.6	11.85	5.7%	0.41	87.6%	1.44
		S		11.86	1.4%	0.65	18.1%	1.40
8	I-35E between Eagan and Burnsville	N	10.1	10.13	0.9%	0.21	81.0%	1.01
		S		10.36	1.1%	0.11	231.1%	1.03
9	I-35E between St. Paul and Eagan	N	7.5	10.60	4.2%	0.72	2.5%	1.46
		S		10.38	3.7%	0.16	243.8%	1.42
10	I-35E between Little Canada and St. Paul	N	5.2	8.30	1.2%	0.52	11.3%	1.62
		S		7.98	3.0%	0.25	57.1%	1.58
11	I-394 between Minnetonka and Minneapolis	E	8.0	11.79	0.7%	0.96	10.5%	1.48
		W		10.75	1.9%	0.53	62.3%	1.36
12	I-494 between Maple Grove and Minnetonka	N	7.7	10.17	4.8%	0.34	125.2%	1.37
		S		10.09	0.7%	0.81	-27.8%	1.31
13	I-494 between Minnetonka and Bloomington	N	12.8	19.78	-0.9%	3.17	-23.9%	1.53
		S		19.33	4.8%	2.26	-4.0%	1.57
14	I-494 between Bloomington and Eagan	E	7.0	8.50	2.8%	0.18	202.5%	1.25
		W		10.37	-4.3%	1.31	-6.7%	1.44
15	I-494 between Eagan and Woodbury	E	11.7	15.20	-4.3%	1.09	15.1%	1.25
		W		14.09	-0.8%	0.79	15.4%	1.20
16	I-694 between Brooklyn Center and Arden Hills	E	4.6	6.34	1.8%	0.33	22.3%	1.41
		W		6.24	1.5%	0.25	55.7%	1.39
17	I-694 between Arden Hills and Little Canada	E	5.0	7.24	-3.9%	0.84	4.8%	1.41
		W		6.77	1.4%	0.42	81.4%	1.37
18	I-694 between Little Canada and Woodbury	E	10.2	12.59	-1.6%	0.31	43.4%	1.22
		W		12.75	0.4%	0.66	14.0%	1.26
19	Hwy. 36 between Roseville and Oakdale	E	12.6	14.07	2.3%	0.41	66.8%	1.14
		W		14.16	0.8%	0.62	18.8%	1.13
20	Hwy. 52/Lafayette Freeway between St. Paul and Inver Grove Heights	N	5.2	8.21	-3.2%	0.54	5.1%	1.53
		S		7.12	1.2%	0.28	66.9%	1.38
21	Hwy. 62/Crosstown between Minnetonka and Fort Snelling	E	11.1	20.20	0.4%	2.17	7.0%	1.83
		W		16.66	1.6%	1.16	10.7%	1.52
22	Hwy. 77/Cedar Ave. between Minneapolis and Eagan	N	7.9	10.59	1.4%	0.51	17.9%	1.36
		S		10.20	2.9%	0.11	405.0%	1.32
23	Hwy. 100 between Golden Valley and Bloomington	N	7.2	10.92	7.1%	0.91	75.8%	1.60
		S		12.94	-15.6%	3.42	-74.6%	1.57
24	Hwy. 100 between Brooklyn Center and Golden Valley	N	9.3	11.26	-3.2%	0.58	52.6%	1.18
		S		10.01	4.4%	0.41	62.2%	1.11
25	Hwy. 169 between Golden Valley and Bloomington	N	7.3	11.36	4.3%	1.07	22.4%	1.62
		S		10.79	-1.4%	0.91	-19.4%	1.47
26	Hwy. 169 between Brooklyn Park and Golden Valley	N	7.0	9.42	4.3%	0.43	54.8%	1.39
		S		10.05	-2.7%	1.11	-20.8%	1.40
27	Hwy. 280 between Roseville and St. Paul	N	4.0	5.31	-1.9%	0.13	21.8%	1.31
		S		5.42	-0.6%	0.24	-8.9%	1.35
28	Hwy. 7 between Minnetonka and St. Louis Park	E	6.4	8.78	0.4%	0.35	-18.1%	1.37
		W		8.81	2.3%	0.13	297.1%	1.39
29	Hwy. 55 between Plymouth and Minneapolis	E	10.9	16.11	1.8%	0.46	-29.7%	1.49
		W		17.06	0.1%	0.10	503.2%	1.56
30	Hwy. 55 between Minneapolis and Mendota Heights	N	11.1	21.32	-3.8%	4.07	-70.6%	1.86
		S		23.47	-4.0%	3.10	-65.7%	2.05
31	Hwy. 61 between St. Paul and Newport	N	6.1	8.38	0.7%	0.02	430.9%	1.39
		S		8.59	1.8%	0.05	608.5%	1.43

Table 4-4 Facility Based Travel Time and Standard Deviation

4.1.7. Summary of Link Analysis

The key results from the analysis of facility travel times are:

1. *The AM peak period is less severe than the PM peak both in terms of travel time and day-to-day travel time variability.*
2. *Average travel time in the PM peak is increasing, but travel time variability is increasing more. Over the study period, the PM peak average travel time increases at a rate of 7.2% per year while the travel time standard deviation increases at a rate of 25.8% per year. At other times of the day, conditions remain largely constant.*
3. *While there is general trend of increasing travel times across the network, some directional facilities increase by more and some actually decrease. The greatest increase and decrease from the training period to the evaluation period are 13.1% and -15.6%, respectively.*
4. *While average conditions worsen over the study period, more significant is the number of especially bad days. These days drive the increase in variability higher than the increase in average travel time over the study period.*

4.2. Simulated Yoked Study Analysis

Facility travel times such as those reported by SmarTraveler can give a general sense of congestion and congestion trends in a region. However, trip-related data such as trip travel time and on time reliability are valuable because they relate more closely to driver experience and the benefits of using ATIS are realized on a trip-by-trip basis. Because real life trip data is difficult to obtain in sufficient numbers to accurately gage system performance, the ability for the HOWLATE method to use simulated trips is extremely valuable. The HOWLATE simulated yoked study allows us to obtain the results of a sufficient number of simulated trips to:

- Assess the potential benefit of ATIS in the Twin Cities, and
- Correlate average trip performance across millions of trips across the entire network with network-wide average link data.

4.2.1. Overview of Experimental Design

Each HOWLATE simulated yoked trial is comprised of two travelers: one who uses ATIS and one who does not. The ATIS non-user acts as the control for the experiment, the baseline against which the ATIS user must be compared to isolate the benefit of employing ATIS. For this study, five different travelers are defined. F95, F80 and UNF commuters do not use ATIS and ASV and ANV commuters do. F95 and F80 commuters are familiar with their respective trips and who determine their route and departure time based on average conditions over the training period. They set their trips based on the 95th and 80th percentile trip time during the training period, respectively. The UNF traveler is not familiar with his trip, such as a business traveler from out of town or simply someone making a trip he does not normally make. He therefore does not have the benefit experience upon which he may base his trip decisions. The two ATIS users are also distinguished by their familiarity or unfamiliarity with the area. ASV commuter, the savvy ATIS user, knows whether the ATIS service tends to over or under report travel times for his trip based on his experience. ANV commuter, the naïve ATIS user, simply takes the ATIS information at face value because he does not have the experience to guide him otherwise. Details of the behavioral characteristics of these travelers are described in detail in Section 2.

Three different sets of yoked trials will be performed in this study pairing ATIS users and ATIS non-users as shown in Table 4.5. These are the same yoked trial combinations as were run in the Washington case study.

	NSV	ASV
F95		×
F80		×
UNF	×	

Table 4-5. Yoked Trial Pairings

The HOWLATE network described in Section 4.1 has 41 nodes and 138 links. There are therefore 41×40 = 1,640 origin-destination pairs. Since each trip is also defined in terms of its target arrival time, of which there are 49 in each day (every 15 minutes from 6:30 a.m. to 6:30 p.m.), the total number of yoked trials per day for each of pair of travelers is 1640×49 = 80,360. For each yoked trial ten repetitions are performed, each with a unique random number seed yielding a total of over 800,000 simulated trials per day of evaluation.

The training period, during which the habitual travelers route and departure time are determined as described in Section 2, takes place during March, April and May 2000, in which there are 39 days in the travel time archive. For the trial pairing F95 and ASV commuters, the evaluation period was June 2000 to May 2001, a total of 176 days. For F80 vs. ASV and UNF vs. ANV paired trials, the evaluation period was June 2000 to July 2000, a total of 28 days. Overall, roughly 186 million simulated trials were conducted and analyzed as part of the Twin Cities case study.

4.2.2. Familiar Non-User (F95) vs. Savvy ATIS User (ASV) Experiment

Tables 4.6 (a-c) present the deviations from the habitual route and departure time by the ASV commuter, the trip outcomes for F95 and ASV commuters, and the performance summary showing the relative improvement from using ATIS.

The trip decisions of ASV commuters compared to F95 commuters are broken down in Table 4.6 (a) by period of the day. Most notably, ASV commuters make far more departure time changes than route changes in response to the pre-trip information they employ. Over the entire day they modify departure time 57% of the time and change route 3.1% of the time, a ratio of more than 18:1. In the PM peak, however, ASV commuters are more likely to make a route change than at other times of the day. The ratio of departure time changes to route changes falls to less than 6:1.

The aggregate outcomes to these departure time and route decisions over the year are presented in Tables 4.6 (b-c). On average, ASV commuters are early less often than F95 commuters (6% compared to 10%), late less often (<1% compared to 4%) and as a result, just in time more often (93% compared to 86%). These numbers are somewhat lessened in that they include off peak trips where ATIS does not provide significant benefit (in the off peak ATIS use actually causes higher disutility); one would not expect it to be widely used for such trips. In addition, ASV commuters are able to reduce trip time from 18.3 minutes to 18.1 minutes on average over all trips in the yearlong study period. However, ASV commuters do realize greater travel expenditure than F95 commuters. Travel expenditure is defined as the time budget for travel (the difference between the target arrival time and the departure time) plus any late time.

Based on the on time reliability metrics in Table 4-6 (b), ASV commuters do a better job of arriving in the just-in-time window than F95 commuters. Instead of risking late arrivals, they tend to leave earlier as revealed by their trip decisions in Table 4-6 (a). Therefore, they will often arrive in the just-in-time window in trials where F95 commuters may be slightly late. Because lateness is penalized more severely than earliness in the disutility calculation, ASV commuters have smaller disutility than F95 commuters (1.5 vs. 1.4, a reduction of 7%).

TRIP DECISIONS OF ASV COMPARED TO F95: JUNE 2000 - MAY 2001				
Travel Choice Category	ALL DAY	AM PEAK	OFF PEAK	PM PEAK
Both Route and Departure Time Change	2.1%	2.3%	1.3%	6.9%
Only Route Change	1.0%	1.4%	0.7%	3.5%
Only Departure Time Change	55.1%	49.7%	57.7%	52.0%
No Change	41.7%	46.6%	40.3%	37.6%
Of Trips With Departure Time Change				
% Departing Early	76.7%	67.3%	90.8%	49.5%
% Departing Late	23.3%	32.7%	9.2%	50.5%
Avg. Minutes Early Departure (when departing early)	5.1	5.1	5.1	5.4
Avg. Minutes Late Departure (when departing late)	6.2	6.1	5.7	6.3
Of Trips With Route Change				
% Taking Shorter Route	32.0%	23.9%	29.0%	36.2%
% Taking Longer Route	68.0%	76.1%	71.0%	63.8%
Avg. Miles Route is Shorter (when taking shorter route)	1.4	1.1	1.2	1.5
Avg. Miles Route is Longer (when taking longer route)	2.1	1.8	2.2	2.6

Table 4-6 (a) ASV Pre-Trip Departure Changes from F95: June 2000 – May 2001

TRIP OUTCOMES OF ASV COMPARED TO F95: JUNE 2000 - MAY 2001								
Aggregate Trip Metrics	ALL DAY		AM PEAK		OFF PEAK		PM PEAK	
	F95	ASV	F95	ASV	F95	ASV	F95	ASV
% of Trips Early	10.1%	6.4%	13.9%	5.9%	4.1%	6.1%	22.9%	7.5%
% of Trips Just in Time	85.7%	93.1%	82.9%	93.5%	92.9%	93.7%	68.8%	91.3%
% of Trips Late	4.2%	0.5%	3.1%	0.6%	2.9%	0.2%	8.3%	1.2%
When Early, Avg. Min. Early	4.8	7.0	5.1	7.0	4.6	7.2	5.4	6.7
When Late, Avg. Min Late	2.7	2.4	2.3	2.3	2.3	2.4	3.2	2.3
Small's Disutility Value	$ 1.49	$ 1.44	$ 1.54	$ 1.45	$ 1.24	$ 1.35	$ 2.12	$ 1.66
Travel Expenditure	23.8	25.4	24.7	25.6	21.4	23.9	29.3	29.0
Trip Time	18.3	18.1	18.6	18.4	16.7	16.6	22.5	22.0

Table 4-6 (b) F95 and ASV Trip Outcomes: June 2000 – May 2001

% CHANGE FROM F95 TO ASV: JUNE 2000 - MAY 2001				
Aggregate Trip Metrics	ALL DAY	AM PEAK	OFF PEAK	PM PEAK
Frequency of Early Arrivals	37.1%	57.6%	47.4%	67.3%
Frequency of Late Arrivals	88.3%	80.9%	94.3%	85.0%
On Time Reliability	3.9%	2.6%	2.8%	7.7%
In-Vehicle Trip Time	1.0%	1.0%	0.5%	2.1%
Travel Expenditure	6.7%	3.5%	11.8%	1.1%
Small's Value	3.7%	6.0%	8.8%	21.5%

Table 4-6 (c) Percent Change from F95 to ASV: June 2000 – May 2001

The question is: Does ATIS provide benefit? Based on on time reliability, disutility and travel time, the answer is yes. However, ASV commuters do realize a higher travel expenditure. Because Small's value is the most comprehensive benefit measure available, one could argue that because ATIS improves disutility, it provides a conclusive benefit regardless of the increase in travel expenditure. It is important to note, however, that in the PM peak ATIS benefits by all measures including travel expenditure. This is related to the higher proportion of trips where ASV commuters depart later than F95 commuters compared with the remainder of the day. Over the entire day, ASV commuters depart late 23.3% of the time when changing departure time compared with 50.5% in the PM peak. In addition, ASV commuters are able to improve his lot by changing route more often in the PM peak compared with the rest of the day. They make a route change 10.4% of the time in the PM peak compared with 3.1% over the whole day.

It is important to note that this is not a direct comparison of specific trips, but rather an average benefit over all trips. In reality, some trips benefit greatly from ATIS, some benefit only slightly and some do not benefit at all. This will be discussed in more depth in section 4.6.7.

4.2.3. Familiar Non-User (F80) vs. Savvy ATIS User (ASV) Experiment

Tables 4-7 (a-c) show results for F80 commuters vs. ASV commuters analogous to those presented in the previous section. By definition, F80 commuters depart later than F95 commuters since departure time is based on the 80th percentile trip travel time in the training period as opposed to the 95th percentile. Therefore, it is not surprising that ASV commuters would depart earlier than F80 commuters more often than when paired against F95 commuters. Of the 68.1% of trips where ASV commuters make a departure time change, 94% are earlier departures.

As a result of F80 commuters' more aggressive approach, the ability of ATIS to minimize late arrivals is more significant. As well, ATIS also decreases early arrivals. While F80 commuters arrives early less often and late more often, these nearly cancel each other out so that his disutility is nearly the same as that of F95. So, by that measure ATIS provides the same amount of benefit to both habitual travelers. F80 commuters have longer trip times on average than F95 commuters, so the ASV commuters show larger improvement in this metric over F80 commuters than F95 commuters.

The biggest difference from the F95 vs. ASV pairing, however, is in travel expenditure. Over the entire day, the average increase in travel expenditure for ASV commuters over F80 commuters is

TRIP DECISIONS OF ASV COMPARED TO F80: JUNE - JULY 2000				
Travel Choice Category	ALL DAY	AM PEAK	OFF PEAK	PM PEAK
Both Route and Departure Time Change	2.4%	2.5%	2.2%	3.7%
Only Route Change	1.3%	1.7%	0.6%	3.0%
Only Departure Time Change	65.7%	58.6%	74.3%	52.6%
No Change	30.6%	37.3%	22.8%	40.7%
Of Trips With Departure Time Change				
% Departing Early	94.0%	91.4%	98.7%	77.6%
% Departing Late	6.0%	8.6%	1.3%	22.4%
Avg. Minutes Early Departure (when departing early)	5.3	5.2	5.3	5.4
Avg. Minutes Late Departure (when departing late)	5.3	5.3	5.3	5.3
Of Trips With Route Change				
% Taking Shorter Route	33.2%	20.3%	37.5%	35.3%
% Taking Longer Route	66.8%	79.7%	62.5%	64.7%
Avg. Miles Route is Shorter (when taking shorter route)	1.4	1.0	1.2	1.6
Avg. Miles Route is Longer (when taking longer route)	2.0	2.0	2.1	1.9

Table 4-7 (a) ASV Pre-Trip Departure Changes from F80: June 2000 – July 2000

TRIP OUTCOMES OF ASV COMPARED TO F80: JUNE - JULY 2000								
Aggregate Trip Metrics	ALL DAY		AM PEAK		OFF PEAK		PM PEAK	
	F80	ASV	F80	ASV	F80	ASV	F80	ASV
% of Trips Early	3.6%	6.5%	4.1%	6.0%	0.7%	6.4%	10.7%	7.2%
% of Trips Just in Time	89.4%	93.2%	88.5%	93.4%	93.1%	93.5%	80.2%	92.1%
% of Trips Late	7.1%	0.4%	7.4%	0.6%	6.2%	0.1%	9.2%	0.7%
When Early, Avg. Min. Early	4.1	7.0	4.3	6.9	3.7	7.1	4.9	6.8
When Late, Avg. Min Late	2.5	2.0	2.5	2.0	2.3	2.0	2.8	1.9
Small's Disutility Value	$ 1.44	$ 1.43	$ 1.51	$ 1.45	$ 1.27	$ 1.36	$ 1.86	$ 1.61
Travel Expenditure	22.4	25.4	23.2	25.7	20.4	24.1	26.9	28.4
Trip Time	18.3	18.1	18.8	18.6	16.9	16.8	21.6	21.4

Table 4-7 (b) F80 and ASV Trip Outcomes: June 2000 – July 2000

% CHANGE FROM F80 TO ASV: JUNE - JULY 2000				
Aggregate Trip Metrics	ALL DAY	AM PEAK	OFF PEAK	PM PEAK
Frequency of Early Arrivals	81%	45%	784%	33%
Frequency of Late Arrivals	95%	91%	98%	93%
On Time Reliability	8%	9%	7%	11%
In-Vehicle Trip Time	0.9%	1.4%	0.6%	1.3%
Travel Expenditure	13.3%	10.8%	18.1%	5.4%
Small's Value	1%	4%	7%	13%

Table 4-7 (c) Percent Change from F80 to ASV: June 2000 – July 2000

13.6%. This is nearly double that seen in the F95 vs. ASV trials. In addition, ATIS does not decrease expenditure in the PM peak compared with F80 as it does in the trials with F95 commuters. In terms of travel expenditure, it is better for F80 commuters to rely on experience than to use ATIS. This is a function of the way ASV commuters use ATIS. Since their goal is to arrive within ten minutes of his target arrival time, they will leave earlier to avoid being even one minute late. In such a situation, a particular ASV commuter would allot five more minutes for the trip. Now assuming the trip times of both counterparts were roughly equal, the F80 commuter would arrive one minute late; the ASV commuter four minutes early. The ASV commuter travel expenditure would be the travel time plus nine minutes—but only travel time plus one minute for the F80 counterpart. The ASV commuter, however, is just in time and since Small's disutility curve penalizes lateness more strictly than earliness, his disutility would be less as well.

4.2.4. Unfamiliar Non-User (UNF) vs. Naïve ATIS User (ANV) Experiment

The yoked trials comparing UNF and ANV commuters are fundamentally different from the previous two in that these two travelers must make crude assumptions regarding their predicted travel times since neither has experience making his intended trip. UNF commuters budget 31% more time than the free flow travel time, a value corresponding to the TTI travel rate index for the Twin Cities metropolitan area. The results of these yoked trials are shown in Tables 4-8 (a-c). As one would expect, this simple assumption is no substitute for experience. UNF commuters are late 14% of the time and early 14% of the time, significantly worse outcomes than their familiar counterparts.

ANV commuters, because they do not have any experience to draw on, can only assume the ATIS travel times suggested are accurate. As it turns out, ANV commuters do not fare much worse than their savvy counterparts, ASV. Therefore, since UNF commuters fare worse than the familiar habitual commuters F95 and F80, ATIS potentially benefits an unfamiliar traveler more than a familiar traveler. In addition, the ATIS user (ANV in this case) realizes greater travel expenditure than the ATIS non-user (UNF). In the case where an unfamiliar traveler, a business traveler for instance, needs to arrive on time, it is reasonable to assume the trip is important enough that he would tolerate a greater travel expenditure to do so.

ANV commuters deviate from the UNF route and departure time 79 percent of the time compared with 58.3 percent and 69.4 percent for ASV vs. F95 and ASV vs. F80, respectively. As with

TRIP DECISIONS OF ANV COMPARED TO UNF: JUNE - JULY 2000				
Travel Choice Category	ALL DAY	AM PEAK	OFF PEAK	PM PEAK
Both Route and Departure Time Change	6.6%	7.8%	4.0%	14.4%
Only Route Change	1.2%	1.6%	1.4%	0.6%
Only Departure Time Change	71.0%	72.0%	70.5%	79.9%
No Change	21.2%	18.6%	24.0%	5.1%
Of Trips With Departure Time Change				
% Departing Early	98.5%	98.3%	97.9%	99.7%
% Departing Late	1.5%	1.7%	2.1%	0.3%
Avg. Minutes Early Departure (when departing early)	6.6	6.5	5.6	8.7
Avg. Minutes Late Departure (when departing late)	5.0	5.0	5.0	5.0
Of Trips With Route Change				
% Taking Shorter Route	14.2%	17.5%	11.5%	15.0%
% Taking Longer Route	85.8%	82.5%	88.5%	85.0%
Avg. Miles Route is Shorter (when taking shorter route)	0.8	0.8	0.7	0.9
Avg. Miles Route is Longer (when taking longer route)	1.9	1.9	2.1	1.7

Table 4-8 (a) ANV Pre-Trip Departure Changes from UNF: June 2000 – July 2000

TRIP OUTCOMES OF ANV COMPARED TO UNF: JUNE - JULY 2000								
Aggregate Trip Metrics	ALL DAY		AM PEAK		OFF PEAK		PM PEAK	
	UNF	ANV	UNF	ANV	UNF	ANV	UNF	ANV
% of Trips Early	13.6%	8.5%	11.6%	7.3%	17.8%	8.5%	4.0%	9.3%
% of Trips Just in Time	72.9%	91.1%	72.7%	91.8%	82.5%	91.4%	59.3%	89.7%
% of Trips Late	13.5%	0.5%	15.7%	0.8%	-0.3%	0.1%	36.7%	0.9%
When Early, Avg. Min. Early	5.2	7.1	4.9	7.0	5.5	7.2	4.1	6.9
When Late, Avg. Min Late	4.5	2.1	4.2	2.1	3.0	1.8	5.1	2.2
Small's Disutility Value	$ 1.96	$ 1.47	$ 2.04	$ 1.49	$ 1.52	$ 1.39	$ 3.06	$ 1.66
Travel Expenditure	24.1	25.7	23.3	26.0	23.5	24.4	25.6	28.9
Trip Time	18.7	18.3	19.4	18.8	17.0	16.9	22.7	21.7

Table 4-8 (b) UNF and ANV Trip Outcomes: June 2000 – July 2000

% CHANGE FROM UNF TO ANV: JUNE - JULY 2000				
Aggregate Trip Metrics	ALL DAY	AM PEAK	OFF PEAK	PM PEAK
Frequency of Early Arrivals	38%	37%	52%	130%
Frequency of Late Arrivals	97%	95%	158%	97%
On Time Reliability	16%	20%	0%	59%
In-Vehicle Trip Time	2.2%	2.8%	0.9%	4.3%
Travel Expenditure	6.5%	11.5%	3.8%	12.9%
Small's Value	25%	27%	9%	46%

Table 4-8 (c) Percent Change from UNF to ANV: June 2000 – July 2000

the two previous yoked pairs, the vast majority of choices made by the ATIS user are departure time changes as opposed to route changes (10:1 for all day, 6:1 for PM trips). Since ANV commuters change departure time on 78 percent of all trips, 99 percent of which involve leaving earlier, and he is almost never late (less than 1% of the time) suggest that ANV commuters make conservative departure time choices, likely resulting from conservative travel time estimation by the ATIS service. When ANV commuters make a route change, they take a longer route 86 percent of the time. This suggests that what UNF commuters consider the best route is probably the shortest route for the majority of trips.

4.2.5. Comparative Analysis of Results Across Experiments

To summarize the three, yoked pairs, the results of all three pairings are presented side-by-side in Figures 4-6 and 4-7. The values for F95 vs. ASV are different from the full year analysis results presented in section 4.2.2 because for purposes of comparison between yoked trial pairs, these only consider the two-month period of June and July 2000, common among all three yoked trial pairs. Familiar subjects perform similarly and the resulting benefits of ASV over F95 and F80 are comparable. Although F80 arrives late more often than F95 (7.7% to 4.2%), he is early less often (3.2% to 10.1%). These cancel out and his disutility is nearly the same. For both F95 and F80, therefore, ASV improves his disutility by using ATIS by approximately 2% for all trips.

Between unfamiliar subjects, however, ATIS has the potential to make a far greater difference. Even though ANV tends to be early more often (8.5% of the time), suggesting conservative ATIS travel time reporting, UNF performs significantly worse, arriving late 13.5% of the time. The net improvement in disutility for ANV over UNF is 25%, an absolute decrease of 0.49 points, compared with 2% and 0.03 for familiar pairs.

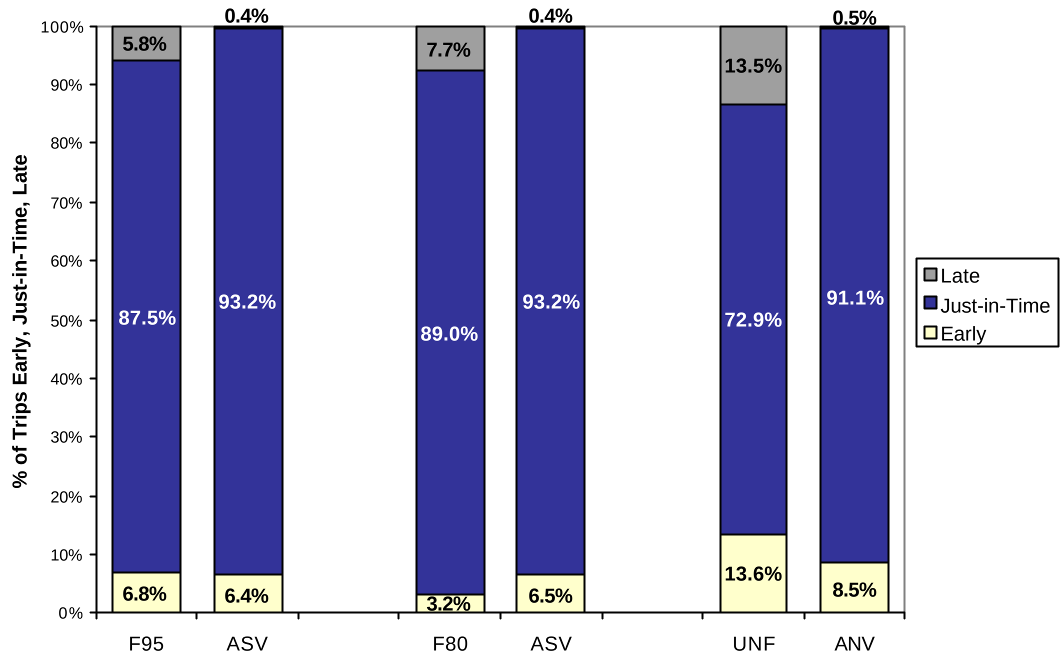

Figure 4-6 Average On Time Reliability by Yoked Trial Pairing (June 2000 – July 2000)

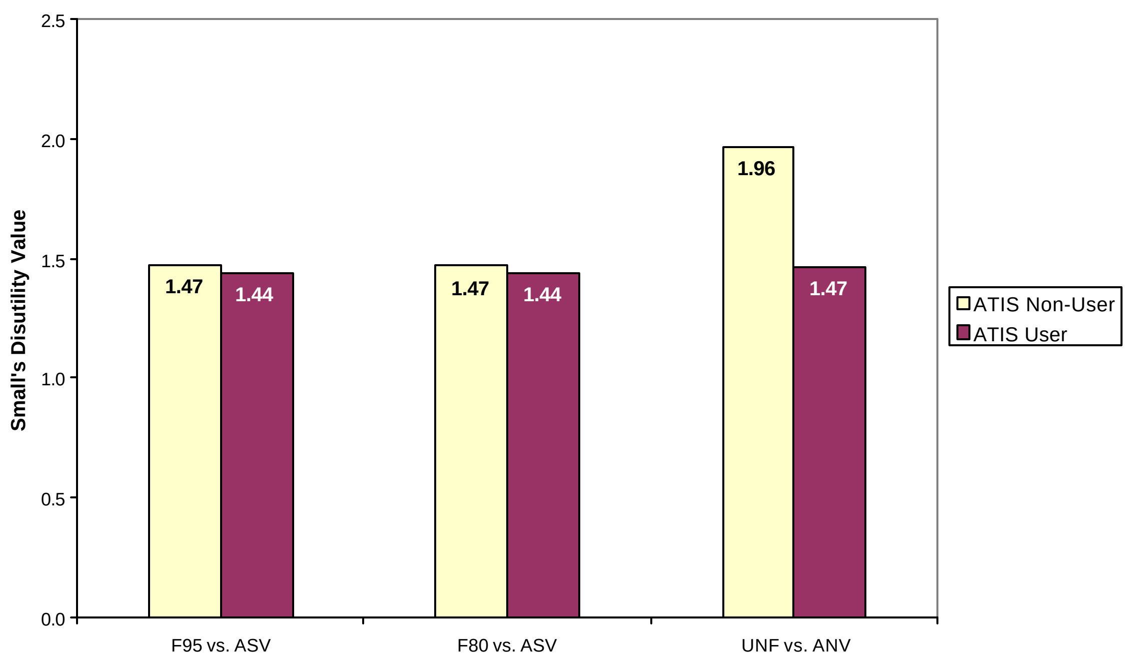

Figure 4-7 Average Small's Disutility by Yoked Trial Pairing (June 2000 – July 2000)

A lower on time reliability requirement (95% for F95 and 80% for F80) for habitual commuters translates into more late arrivals and fewer early arrivals. However, the results of these experiments suggest at least within the range of 80%-95%, the on time reliability requirement does not have an impact on utility. Therefore, ATIS improves the utility of all familiar commuters the same. However, the potential benefits are greater for unfamiliar travelers such as out of town visitors or those simply making a trip they do not make regularly, such as a trip to the airport. Incidentally, out of town visitors are also least likely to know of the ATIS services available.

4.2.6. Trends in Regional Performance

The yearlong evaluation period for the yoked pair of F95 vs. ASV not only provide for more robust results, they allow us to examine trends in on time reliability over time. In the following sections, trip results will be broken down by day to show how ATIS benefit fluctuates from day to day. Subsequently, trends in travel budget will be presented to show how changing conditions over the year affect the amount of time a habitual traveler would need to allot to achieve his target on time reliability.

Daily Performance: Subdividing trip results by day reveals the magnitude of day-to-day trip time variability. Figure 4-8 depicts daily average on time reliability for all trips by F95 and ASV. Not only is ASV on time more often than F95, he does not exhibit the same wide fluctuations in day-to-day performance. On a particularly unusual day in October for instance, F95 is only on time in 75% of trips. ASV on the other hand, does not deviate from his typical 99% on time reliability. Figure 4-9 depicts average daily disutility for PM trips, which shows the same result. Clearly, ATIS has the potential to provide the most benefit during outlier conditions. The two worst days for F95 as measured by disutility are October 11 and 12 (average F95 disutility is $2.40, while average ASV disutility is $1.50), the two days noted previously for their higher than usual travel times in the morning and midday. These are also the days that are benefited the most by ATIS. In fact, based on the differential in utility between ASV and F95, 89% of all ATIS benefit is realized in 20% of days.

While we previously showed consistent ATIS benefits averaging trip results by month, the full impacts of ATIS are only realized when considering day-to-day variability. Because F95's departure time and route are fixed, all variability in his trip time is reflected in his on time reliability. ASV, on the other hand, not only accommodates trip time variability by adjusting his departure time, he is able to reduce his trip time variability by switching routes when advantageous.

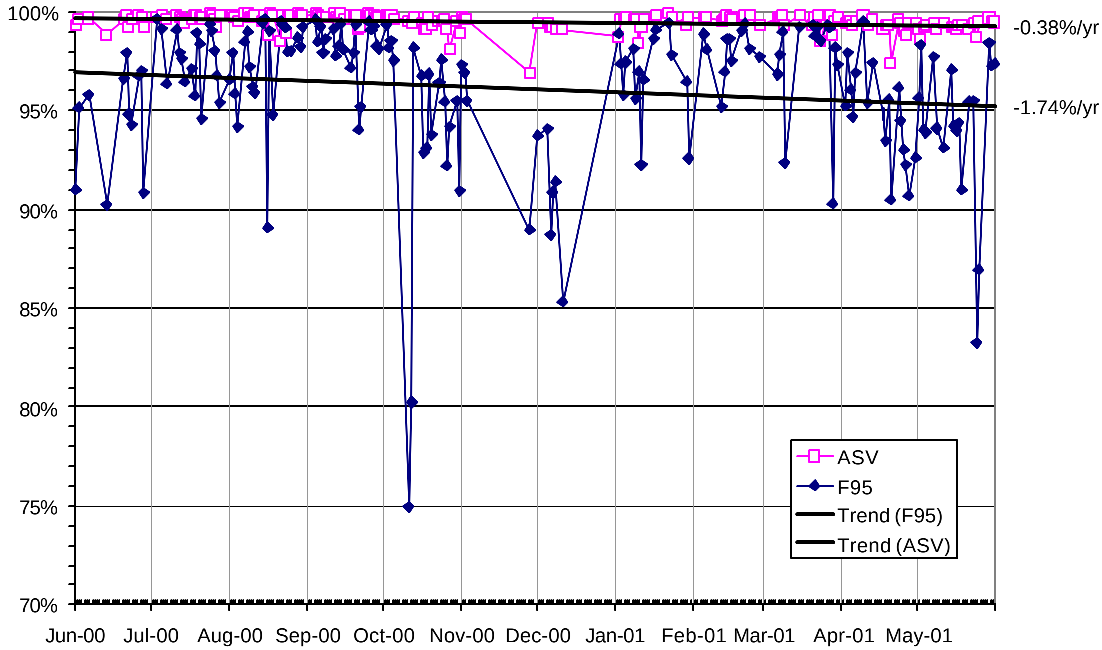

Figure 4-8 On Time Reliability by Day for All Trips, F95 vs. ASV

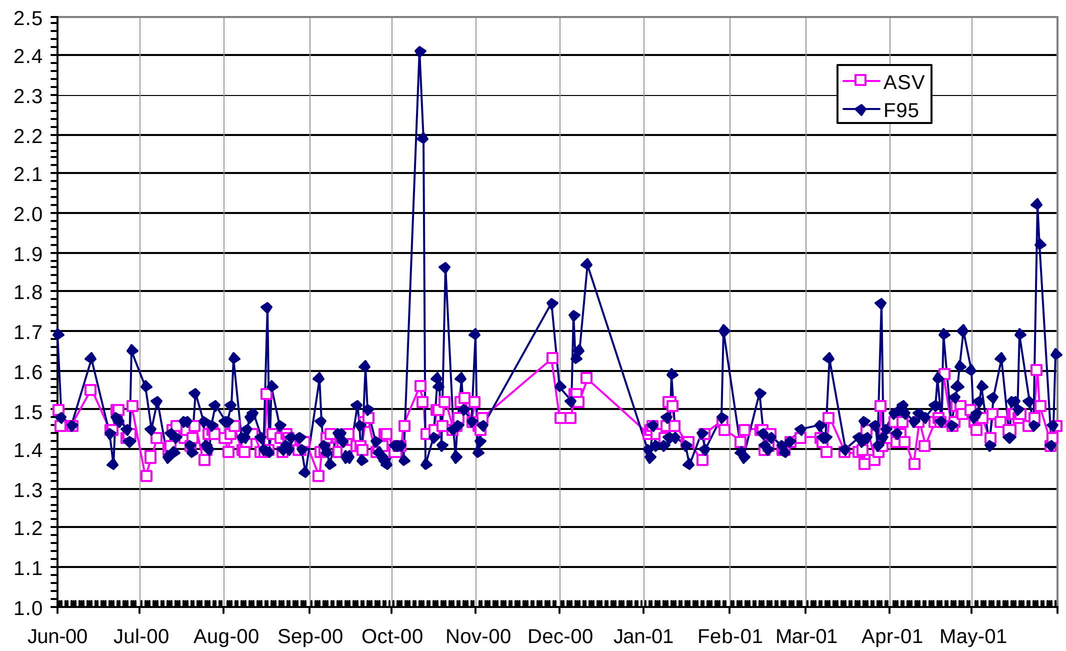

Figure 4-9 Trip Disutility Value by Day for All Trips, F95 vs. ASV

It is not known to what extent incidents compared with normal random fluctuations contribute to the day-to-day variability in on time performance. No data was collected on the frequency and severity of incidents (Incorporating incident data is planned as a future extension of this work). From the perspective of the traveler, however, this is largely irrelevant assuming the effects of incidents are accurately reflected in the ATIS travel time data.

Travel Budget: Travel budget is the amount of time the habitual commuter allots for a trip, defined as the difference between the target arrival time and the actual departure time. In the HOWLATE simulated yoked trials to which the previous results correspond, travel budget is set in the training period and fixed for the duration of the evaluation period. The yoked trial results then show how system variability affects on time performance. A related way to measure the effects of system variability on travel would be to assume habitual commuters are continuously habituating to the latest conditions.

Figure 4-10 shows the travel budget resulting from rehabituation in each month. Instead of fixing budget and measuring the effect of on time reliability, this fixes on time reliability (at 95% for F95) and measures the effect on the budget required to maintain the target on time reliability. This data reveals no significant trend over the year of increasing budget as a result of changing network travel times over the year. This will be revisited in Section 4.3.

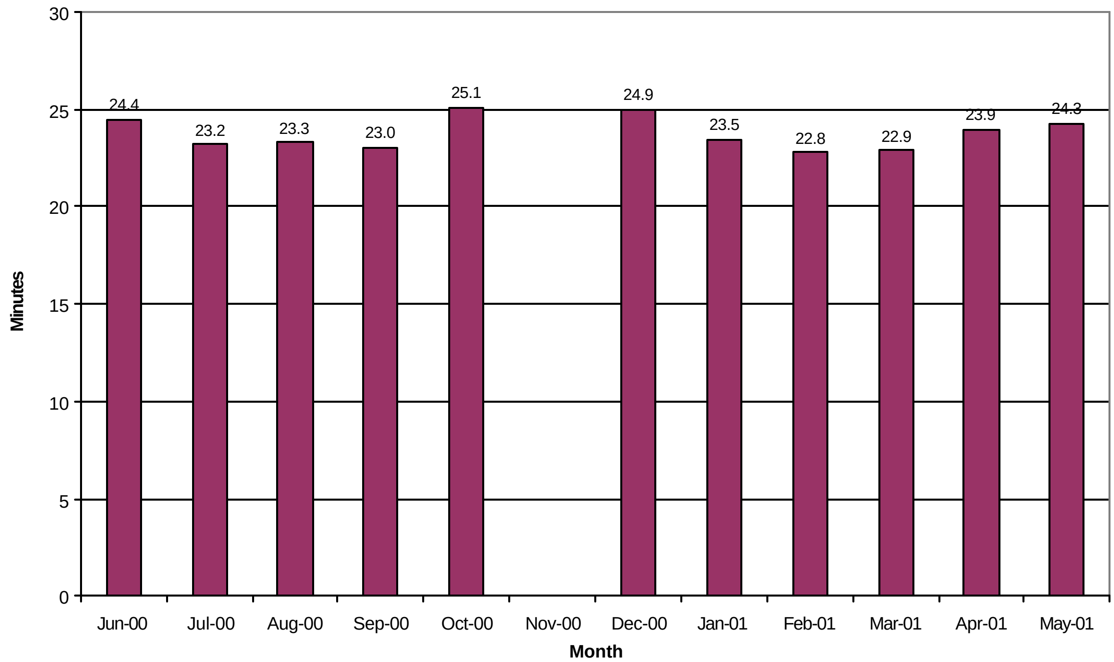

Figure 4-10 Monthly Average Travel Budget to Achieve 95% On Time Reliability

4.2.7. Trips Benefiting Most from ATIS

The results presented thus far focus on the aggregate benefits of ATIS when all trips are considered. However, since not all trips benefit equally, it is instructive to examine in detail the characteristics of specific trips. The next section will address the worst trips in the region for a habitual commuter, F95. The subsequent section will discuss the those trips that benefit the most from ATIS.

<u>Worst trips for Habitual Commuters</u>: The ten worst trips for habitual commuters in the Twin Cities metropolitan area in terms of disutility are listed in Table 4-9 by origin-destination pair averaged over all arrivals in the (a) AM peak and (b) PM peak. Since the utility function increases linearly with trip time, it is not surprising that the worst trips are the longest trips. Figures 4-11 (a-b) show how these trips are distributed geographically across the region. Since utility is a dollar value, we can estimate the monetary cost of each trip. The higher the cost of a trip, the more potential there is for the traveler to find a service that will improve his trip (reduce his travel time and improve his on time reliability) cost effective. In the next section, we will present the monetary value of ATIS by its ability to improve trip-related utility. The worst morning and afternoon trips for F95 cost $4.38 and $5.09, respectively. Assuming 220 commuting days in a year that comes to $960 and

$1120, respectively. While ATIS cannot eliminate this cost, there is significant potential for real-time travel time information to be cost effective for these trips. A mere 5% improvement in utility would mean a $48 and $56 value for these trips, respectively.

Rank	O	D	Disutility ($) F95	ASV	Trip Len(mi)
1	9	39	$4.38	$2.42	32.0
2	26	37	4.37	2.44	24.8
3	9	38	4.15	2.55	27.6
4	26	38	4.10	2.23	25.0
5	3	44	3.93	2.48	30.9
6	26	39	3.86	2.13	28.9
7	43	30	3.72	2.23	32.1
8	1	44	3.60	3.05	33.7
9	1	41	3.59	2.97	30.1
10	3	45	3.59	2.49	22.8
Mean			1.51	1.43	14.0
Std Deviation			0.77	0.50	7.0

(a)

Rank	O	D	Disutility ($) F95	ASV	Trip Len(mi)
1	44	10	$5.09	$2.64	25.8
2	30	26	5.03	3.14	29.5
3	1	26	4.99	2.96	30.7
4	1	43	4.84	3.19	34.8
5	2	26	4.74	2.80	29.6
6	42	1	4.71	3.29	30.5
7	45	10	4.65	2.65	26.5
8	44	1	4.65	3.48	33.0
9	45	1	4.57	3.33	31.7
10	27	43	4.54	2.78	25.8
Mean			2.04	1.65	14.0
Std Deviation			0.99	0.60	7.0

(b)

Table 4-9. Ten Worst Trips (a) AM Peak (b) PM Peak

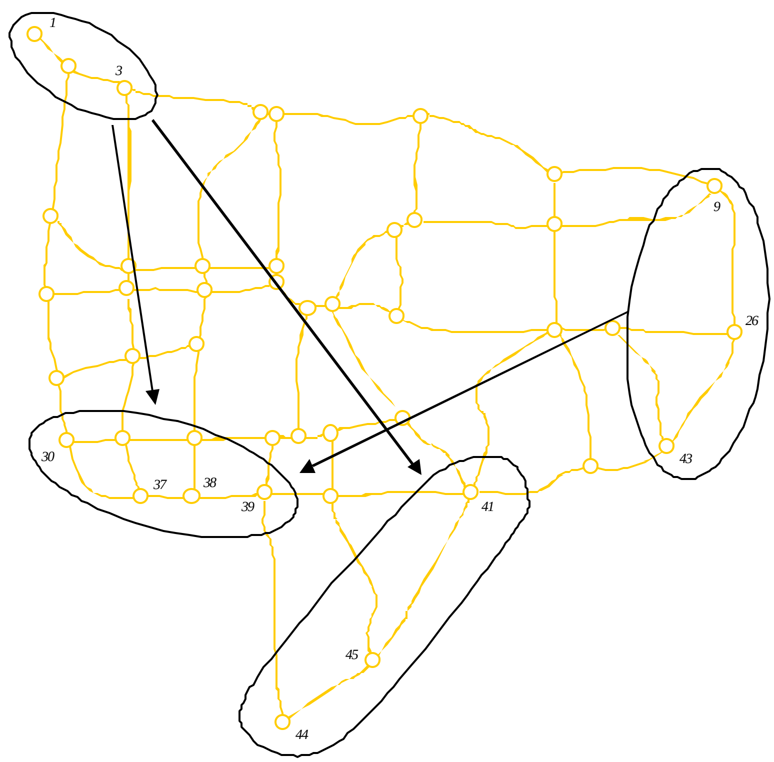

Figure 4-11 (a) Ten Worst AM Trips for Habitual Commuters

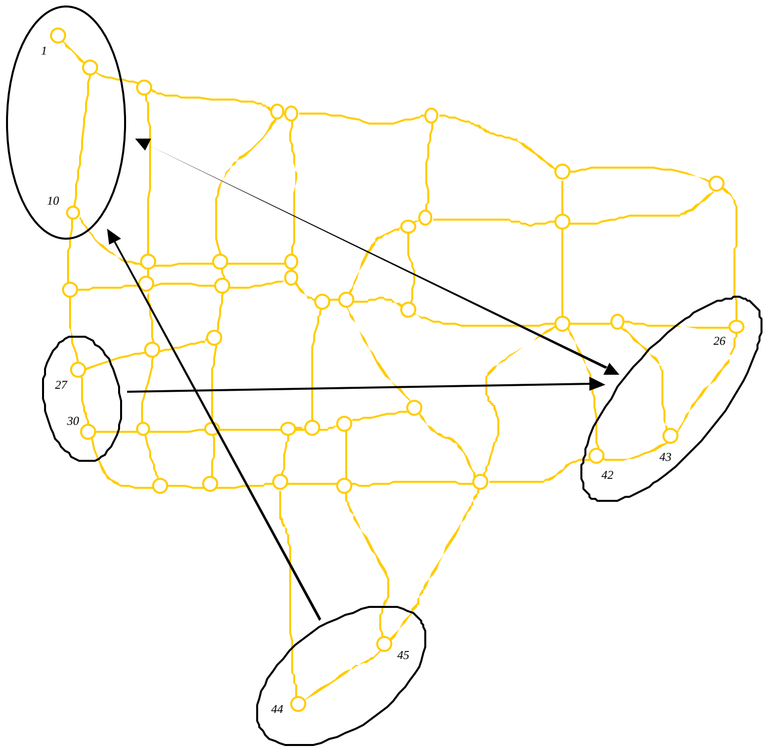

Figure 4-11 (b) Ten Worst PM Trips for the Habitual Commuter

Trips Benefiting Most from ATIS: Table 4-10 lists the ten trips benefiting the most by ATIS based on the difference in disutility realized by ASV over F95. A dollar value, this can be viewed as what one might be willing to pay for real-time travel time information. For trip (9,39) in the AM peak, Oakdale to Bloomington for instance, ATIS might be worth \$1.95 per trip, or \$430 per year if the trip is taken 220 times in a year. For trip (44,10) in the PM peak, Burnsville to Plymouth, ATIS might be worth \$2.45 per trip, or \$540 per year. These represent utility improvements of 44% and

			Disutility (\$)			Trip
Rank	O	D	F95	ASV	Savings	Len(mi)
1	9	39	\$4.38	\$2.42	\$1.95	24.8
2	26	37	4.37	2.44	1.93	25.0
3	26	38	4.10	2.23	1.86	22.8
4	3	32	3.44	1.69	1.76	15.9
5	26	39	3.86	2.13	1.73	20.2
6	3	37	3.44	1.73	1.71	15.5
7	9	38	4.15	2.55	1.60	27.6
8	3	39	3.55	1.99	1.56	20.3
9	43	30	3.72	2.23	1.50	23.5
10	3	44	3.93	2.48	1.45	28.9
Percentage of Trips Benefiting						49%

(a)

			Disutility (\$)			Trip
Rank	O	D	F95	ASV	Savings	Len(mi)
1	44	10	\$5.09	\$2.64	\$2.45	25.8
2	39	10	4.37	2.00	2.38	17.2
3	38	10	4.11	1.75	2.36	14.2
4	41	17	4.41	2.29	2.12	21.7
5	37	1	4.39	2.35	2.04	18.7
6	1	26	4.99	2.96	2.03	30.7
7	37	10	3.59	1.56	2.03	11.9
8	45	10	4.65	2.65	2.00	26.5
9	2	26	4.74	2.80	1.93	29.6
10	30	26	5.03	3.14	1.89	29.5
Percentage of Trips Benefiting						80%

(b)

Table 4-10 Ten Trips Where ATIS Benefits the Most (a) AM Peak (b) PM Peak

48%, respectively. The average benefit over all trips is $.08 in the morning and $.39 in the afternoon. If the average traveler saw an improvement of $.47 per day, that would represent an annual value of ATIS of just over $100.

According to Small's utility function, trip disutility increases linearly with trip time. Because of this and because longer trips tend to have more day to day travel time variability, one would expect ATIS benefit to increase with trip length. While it is often true that longer trips benefit more, a number of morning and afternoon trips with the greatest improvement are nearer the average trip (14.0 miles) than the longest (33.7 miles). Figures 4-12 (a-b) show how these trips are distributed across the region. In Figure 4-12 (b), it can be seen that the shortest of PM trips among those that realize the most benefit tend to follow the north-south corridor paralleling Highway 100, Highway 169 and I-494. In this corridor, there are multiple alternate routes and many opportunities for route switching based on which is best on a given day. Therefore, it appears that the availability of multiple alternate routes is an equally important predictor of potential ATIS benefit.

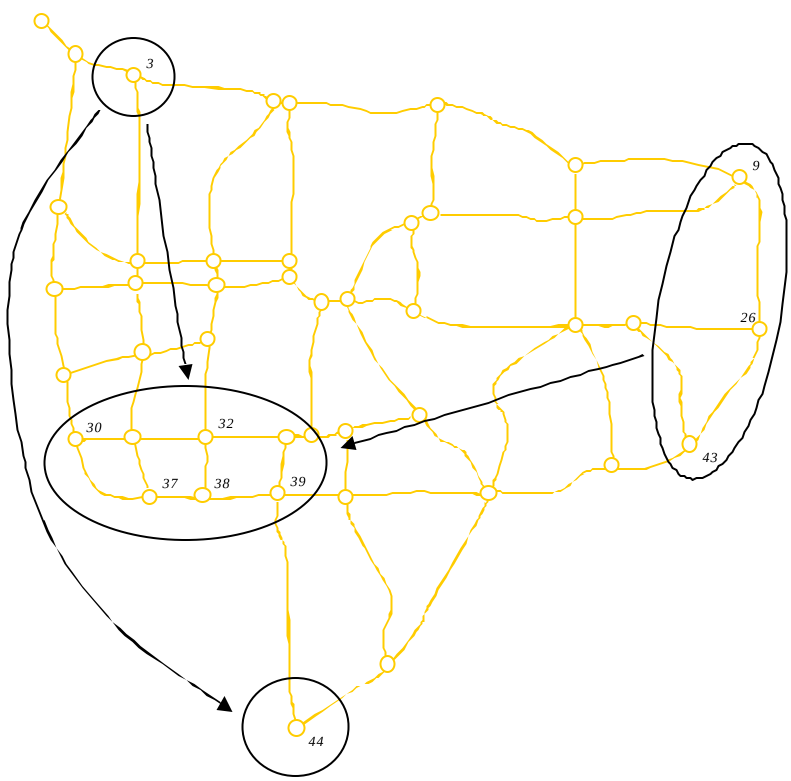

Figure 4-12 (a) Ten AM Trips Benefiting the Most by ATIS

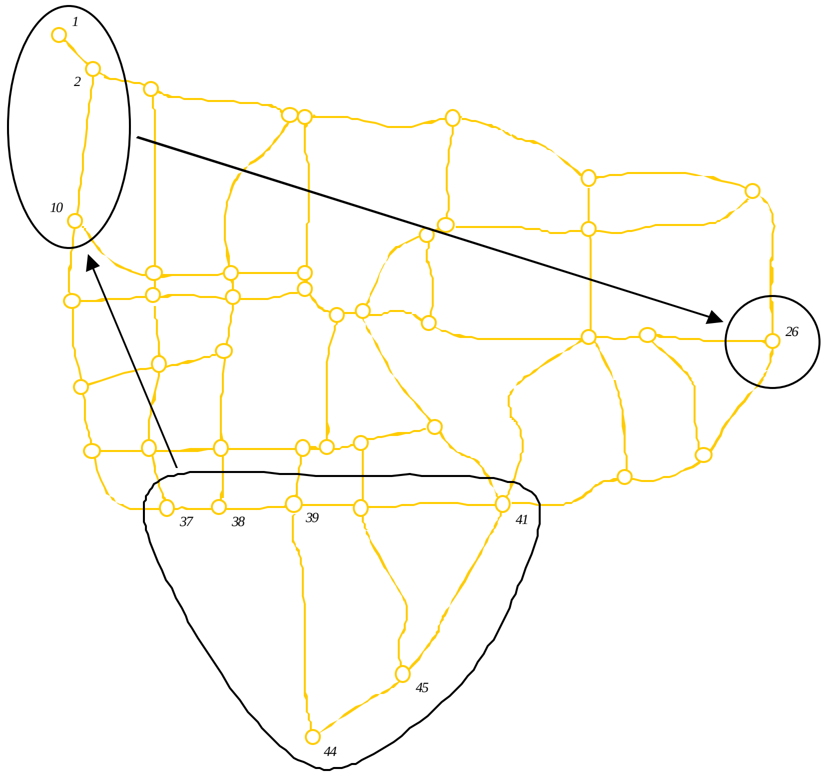

Figure 4-12 (b) Ten PM Trips Benefiting the Most by ATIS

Over all origin-destination pairs, ATIS improves utility for 49% of AM trips. It is surprising that ATIS benefits less than half of all morning trips. It is worth noting that the average morning trip is helped. The trip hurt the most by ATIS would have its utility decreased by 0.60 whereas the morning trip helped the most would have a utility increase of 1.95. The potential gains are therefore greater than the potential losses and overall, the gain is positive in the AM peak.

In the PM peak, ATIS is a clear benefit, improving utility in 80% of trips. Overall, the average improvement is 0.38. Since the PM peak has more travel time variability and given the results for all trips shown in previous sections, it is not surprising that a higher percentage of PM trips would show benefit and that the potential improvement would be higher than during the AM.

5.0 Evaluation of A Supplementary En Route Guidance Service

The principal objective of the study was to evaluate the benefits of an additional en route guidance service delivered to supplement the ATIS delivered pre-trip modeled in Sections 3 and 4. Hence, in this study an en route ATIS user also uses pre-trip traveler information. The methodology developed was applied to the Washington DC metropolitan area network.

The hypotheses of the study were as follows:

- En route ATIS provides some incremental benefit to the user over pre-trip ATIS of similar quality, i.e., for any trip in the network.
- The longer the trip length, the higher the incremental benefits of adding en route traveler information. ATIS users will benefit more from en route traveler information than from pre-trip information for longer trips because the reports received at the start of the trip will likely be somewhat inaccurate by the time the trip ends.
- In addition to sensitivity to trip length, the benefit of en route traveler information will be dependent on the amount of day-to-day travel time variability in the transportation network. The greater the day-to-day travel time variability, the greater should be the benefit of en route ATIS as measured by performance metrics such as on-time reliability, travel time, and time budgeted for travel.
- The benefits of en route ATIS will be higher than that of pre-trip ATIS for trips with multiple alternative routes, with multiple interconnections, i.e., the benefits will be higher for a denser network.

5.1 Experimental Design

This project used the existing archived travel time data for the Washington metropolitan network for the period starting on March 1, 2000 and ending on May 31, 2001. The archived data comprised of travel time for each of the 168 links in the Washington network at five-minute intervals from 6:30 AM to 6:30 PM, for each day. Thus, the travel time was archived for each link for 49 target arrival times. The Washington HOWLATE network is presented in Figure 5-1.

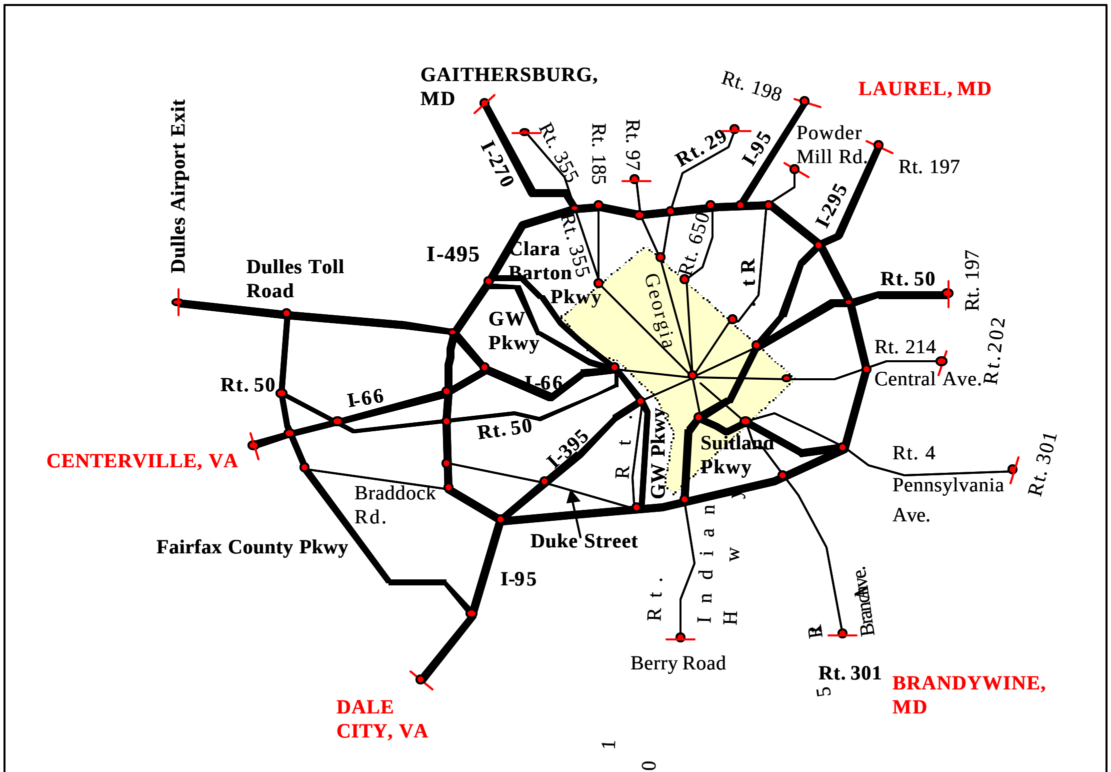

Figure 5-1. Washington, D.C. HOWLATE Network

HOWLATE simulated yoked trials were conducted for the Washington case study for the savvy (or the familiar) conservative non-ATIS user and two types of the savvy ATIS user, one who uses pre-trip traveler information, and the other who uses both pre-trip as well as en route traveler information. The HOWLATE simulation includes training and evaluation of data. During training, the non-ATIS users establish their habitual routes and determine the trip start time that enables them to arrive at their destination at their preferred arrival time. The ATIS users habituate themselves over their routes, and determine the error in the predicted pre-trip/en route traveler information and the actual travel time that they experience.

The training period for this study was from March 1, 2000 to May 31, 2000, and comprised of 33 days. The evaluation period was from June 1, 2000 to May 31, 2001. Simulated yoked trials between the non-ATIS and the ATIS users were conducted using five Monte Carlo realizations for each day in the evaluation period, for each of the 49 target arrival times. Although the Monte Carlo realizations were conducted for each of the 2970 (55 x 54) origin-destination pairs that exist in the Washington HOWLATE network, only two trips were examined in detail for this study: (i)

Brandywine-to-Centerville trip, and (ii) Laurel-to-Dale City trip. The trip from Brandywine, in Southern Maryland to Centerville in Virginia is about 65 km long (41 miles), and has well-connected multiple alternate routes, as can be seen from Figure 5-1. Based on our fourth hypothesis, it is expected that the trip should benefit from a supplemental en route ATIS service, as it has multiple routes, with multiple interconnections. An en route ATIS user is afforded the capability of making en route decisions all along the trip. The trip from Laurel in Maryland to Dale City in Virginia is one of the longest trips (52 miles) in the Washington HOWLATE network. It is expected that the Laurel-to-Dale City trip being a long trip would be subjected to greater travel time variability, and hence, an en route ATIS user would benefit more in comparison to a pre-trip ATIS user.

Traveler behaviors modeled in this experiment include:

Savvy Conservative Non-ATIS Traveler (F95): This type of traveler is familiar with his or her route, and is conservative since s/he expects to arrive on-time 95% of the time. Thus this type of non-ATIS commuter chooses a trip start time that allows him or her to arrive on time at his or her destination 95 percent of the time, and consequently will often arrive early, but is rarely late. This traveler is identical to the ones tested in Sections 3 and 4.

Savvy Pre-Trip ATIS Traveler (ASV): This type of traveler is also familiar with his or her route. Prior to starting the trip, the commuter uses the current traveler information, and adjusts the reported travel time based on his or her experience of the accuracy of the ATIS, which is learned during the training period. Once the route and trip start time are fixed, using the reported travel time and the prediction error, this traveler does not alter the route, even if s/he faces congestion on the chosen route. This traveler is identical to the ASV traveler modeled in Sections 3 and 4.

Savvy En Route ATIS Traveler (ASR): This commuter is a new addition to the HOWLATE methodology. This type of traveler is similar to the pre-trip ATIS traveler, but also uses en route traveler information. Each time the user enters a new link s/he determines the fastest or the optimal path to his or her destination based on the available en route traveler information. It should be noted that this type of commuter uses the prediction error in ATIS (i.e., the “savvy factor”), when determining the trip start time and the initial route before the start of the trip.

5.2 Results

The Brandywine-to-Centerville trip has a normal travel time of about 54 minutes. On December 20, 2000, the trip experiences a high travel time variability with the optimal travel time ranging from 41 minutes during the off peak period to 69 minutes during the PM peak period. Hence according to our hypotheses, the trip should prove beneficial to an en route ATIS user, as it not only has multiple routes, with multiple interconnections, but also has high travel time variability, even within the peak and off peak periods. Figure 5-2 shows the travel decisions made by each of the three commuters on the Brandywine-to-Centerville trip on December 20, 2000, and the resulting travel times. The upper half shows the variation of trip or travel time on the y-axis with the desired arrival time on the x-axis, while the lower half illustrates the travel decisions of each of the three behaviors studied. For instance, for the trip with the desired arrival time of 10:30 AM, the lower half of the chart shows ASR to have made an en route change, while ASV does not deviate from the habitual route. Both ASR and ASV depart earlier than their habitual departure times, and both arrive at the destination (Centerville) on time. The upper half of the chart shows that ASR was able to reduce his trip time from 54 minutes to 52 minutes by deviating from his habitual route en route.

To illustrate the impact of traveler information on both trip decision-making and outcome, we will discuss in detail the experiences of travelers with and without the en route supplement, targeting a 2:00 PM arrival time in Centerville. For the desired arrival time of 2:00 PM, the en route ATIS user and the pre-trip ATIS user are not aware of any delays when they start the trip. The traveler information service reports a travel time of about 60 minutes on the habitual route shown in Figure 5-3. However, from past experience the two ATIS users know that the traveler information service typically overestimates the travel time for the trip with the desired arrival time of 2:00 PM. Therefore, they apply a prediction error (or the “savvy factor”) of 93% (learned during the training period) to the ATIS reported travel time, and estimate a travel time of 55 minutes. They decide to take the habitual route of I-495W and I-66W and leave at their normal time (1:05 PM) in order to reach the destination on time. On nearing the exit for Duke Street on I-495W (23.5 minutes into the trip), the en route ATIS user learns from the traveler information service that continuing on the habitual route will take him another 40 minutes to reach the destination while changing to a new route will only take 33 minutes. The en route ATIS user decides to make a route change, since continuing on his habitual route will now result in a late arrival of more than 8.5 minutes, while the new route will only delay him by 1.5 minutes.

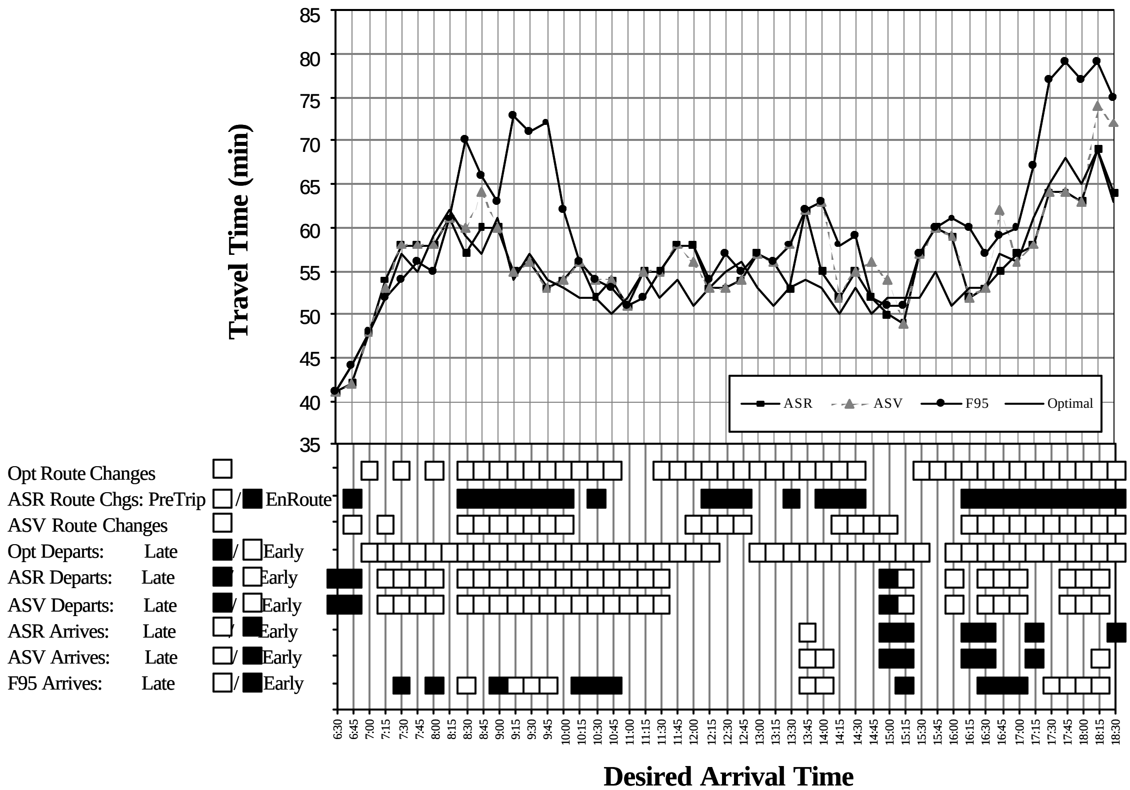

Figure 5-2. Travel Time and Trip Outcome Summary: December 20, 2000 – Brandywine, MD to Centerville, VA

By taking the new route, the en route ATIS commuter reaches his destination on time, 5 minutes before the desired arrival time, while the pre-trip ATIS user who is unable to alter his route in response to the changing traffic conditions experiences a higher trip time and is delayed by 3 minutes, as can be seen from Figure 5-4. Figure 5-4 shows the arrival offset with respect to the target arrival time. A positive value indicates a late arrival while a negative value represents an early arrival at the destination; the shaded area represents a just-in-time arrival. Although the traveler information services did not underestimate the travel time for this trip, the two ATIS users disregarded the predicted travel time due to past experience. However, the en route ATIS user was able to rectify his pre-trip decision by making use of traveler information reports en route, while the pre-trip ATIS user was forced to stay on the route that he chose prior to starting the trip. If the pre-trip ATIS user had access to en route traveler information services he would have been able to reduce his travel time by 12.7%. Note that the pre-trip ATIS user makes no changes from the non-ATIS user, and has the same outcome.

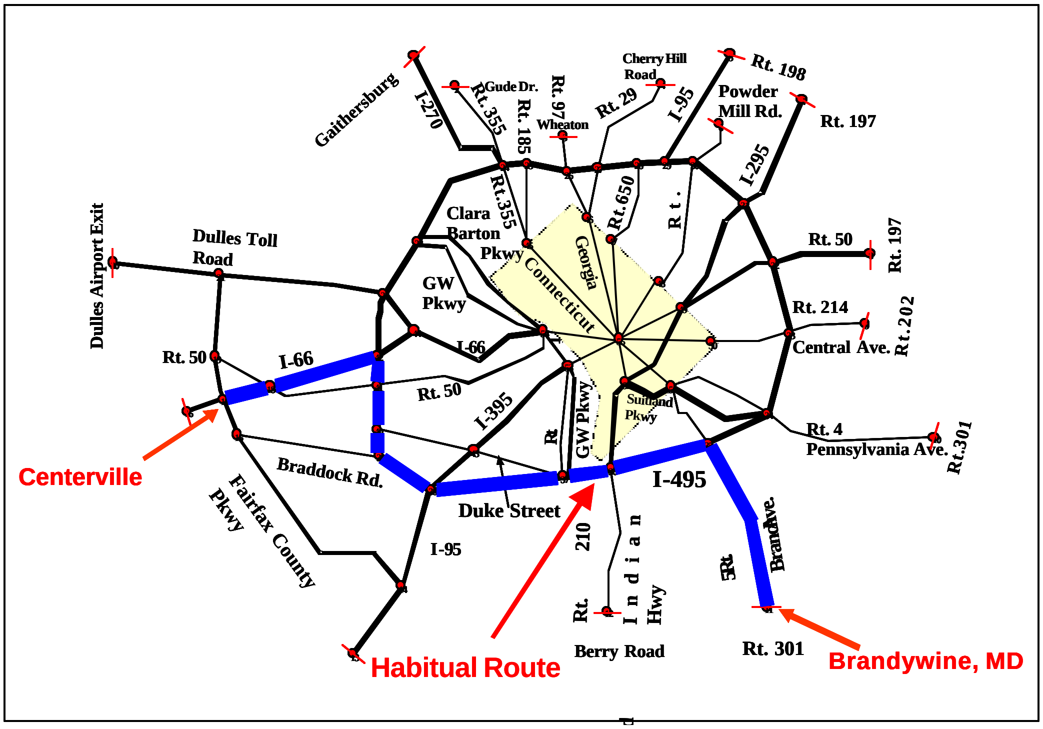

Figure 5-3. Habitual Route for the Brandywine-to-Centerville Trip: Target Arrival Time of 2:00 PM

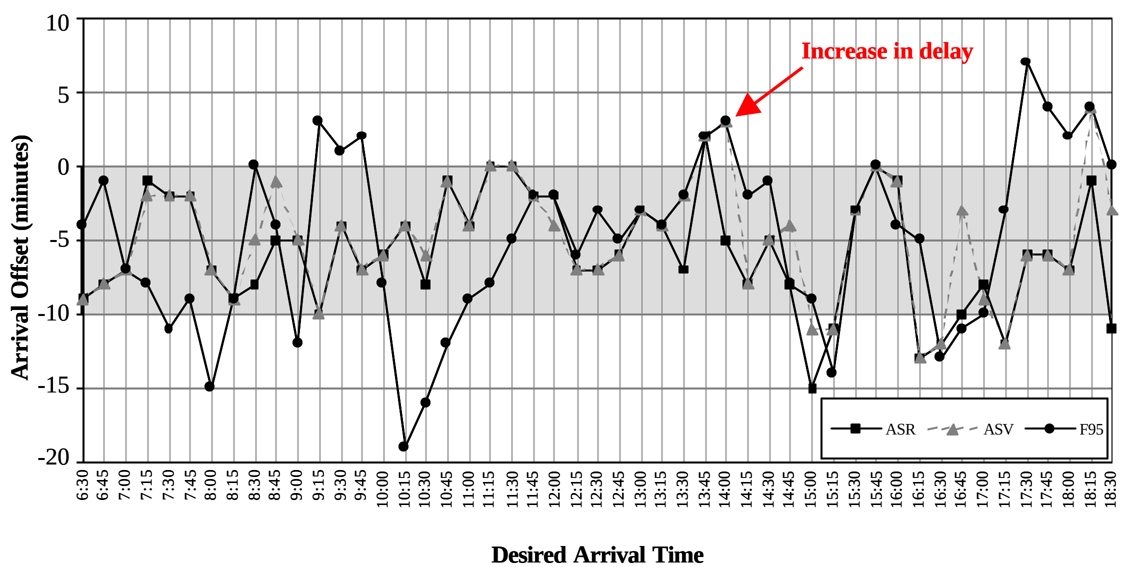

Figure 5-4. Variation of Arrival Offset with Desired Arrival Time: December 20, 2000 – Brandywine, MD to Centerville, VA

An en route path switch occurs whenever an en route ATIS user is able to improve his current perceived remaining travel time by more than the indifference threshold. Figure 5-2 shows that the en route ATIS user deviates from the pre-trip ATIS user's route on trips with desired arrival times of 8:30 AM, 8:45 AM, 10:30 AM, 1:30 PM, 2:00 PM, 4:45 PM, 5:00 PM, 6:15 PM, and 6:30 PM, and was found to reduce his trip time on all these occasions, except for the trip targeting a 5:00 PM arrival time. Hence, the en route ATIS user made use of en route guidance 18% of the time, and was able to save on his trip time 89% of the time in comparison to the pre-trip ATIS user. For the trip with desired arrival time of 5:00 PM, both ATIS users deviate from their habitual routes, but on nearing the exit for Duke Street, the en route ATIS user on getting reports of higher travel time on the new route chosen pre-trip, decides to make an en route path switch. Although from the ATIS reports the en route ATIS user expects a reduction of 3 minutes in travel time, the final outcome of the en route path change is that the commuter is not able to achieve his expected reduction in trip time. He experiences a slight increase of 1 minute (Figure 5-2) in travel time from 54 to 55 minutes, but is able to reach his destination just in time (Figure 5-4).

Table 5-1 compares the deviations made on December 20, 2000 on the Brandywine-to-Centerville trip by the en route ATIS user (ASR) and the pre-trip ATIS user (ASV) from their habitual behavior (F95), with respect to route and departure time changes. The results indicate that ASV deviated from the habitual behavior on 79.6% of the trips, while ASR deviated on 80.5% of the trips. It should be noted that since both ASV and ASR have the same departure time, they have identical percentages for trips with departure time changes. They leave early on 11% of the trips, and late on 89% of the trips. Table 5-2 lists the trip decisions made by the en route ATIS user (ASR) and the pre-trip ATIS user (ASV), and the outcome of the route decisions made by ASR in comparison to that made by ASV. On 45% (22 trips) of the trips both ASV and ASR deviate from their habitual route. Of these 22 trips, whenever ASR and ASV take different routes, ASR experiences a lower travel time 83% of the time since he has access to en route guidance, and therefore can improve his travel time. However, both ATIS users end up taking the same route 73% of the time.

Travel Choice Category	ASV vs. F95	ASR vs. F95
Trips with Both Route and Departure Time Changes	32.7%	30.6%
Trips with Only Route Changes	22.4%	22.4%
Trips with Only Departure Time Changes	24.5%	26.5%
Trips with Route Changes: % Resulting in Shorter Routes (with respect to distance) % Resulting in Longer Routes (with respect to distance)	7.41% 92.59%	7.69% 92.31%
Avg. Miles Route is Shorter (when taking shorter route)	0.4	0.4
Avg. Miles Route is Longer (when taking longer route)	1.39	1.48
Trips with Departure Time Changes: % With Early Departure % With Late Departure	11% 89%	11% 89%
Avg. Minutes Early Departure (when departing early)	5	5
Avg. Minutes Late Departure (when departing late)	6.6	6.6

Table 5-1. ASV and ASR Trip Decisions with respect to F95 on December 20, 2000: Brandywine, MD to Centerville, VA, 6:30 AM – 6:30 PM Target Arrivals

Travel Choice Category	Trip Decision	Trip Outcome for ASR in Comparison to ASV	
		Decrease in Trip Time	Increase in Trip Time
Percentage of Trips when Both ASV and ASR made a Route Change from Habitual Route % Resulting in identical routes % Resulting in different routes	45% (22 of 49 trips) 73% (16 of 22 trips) 27% (6 of 22 trips)	83% - 83%	17% - 17%
Percentage of Trips when Only ASV made a Route Change from Habitual Route, and ASR did not	8% (4 of 49 trips)	50%	50%
Percentage of Trips when Only ASR made a Route Change from Habitual Route, and ASV did not	6% (3 of 49 trips)	100%	0%
Percentage of trips when ASR deviated from ASV's route (en route switch; with and without pre-trip switch)	18% (9 of 49 trips)	89%	11%
Percentage of trips when ASR and ASV behave identically (with and without route changes)	73% (36 of 49 trips)	-	-

Table 5-2. ASR vs. ASV Trip Decisions and Outcomes on December 20, 2000 Brandywine, MD to Centerville, VA, 6:30 AM – 6:30 PM Target Arrivals

Table 5-3 shows the overall performance of en route ATIS, pre-trip ATIS and non-ATIS users over 5 realizations for December 20, 2000 for the Brandywine-to-Centerville trip for peak and off-peak periods. For this trip, en route ATIS proves to be more beneficial than pre-trip ATIS with regard to on-time reliability, and in-vehicle travel time. The en route ATIS user sees a significant improvement in on-time travel reliability, but has higher early schedule delays, and consequently lower just-in-time reliability. This is because in the HOWLATE methodology, en route ATIS users leave their origin at the same time as pre-trip ATIS users. Once en route ATIS users start their trip, they make route change decisions based only on trip time. If the predicted travel time on a new path is less than the predicted remaining travel time on the current path by more than the indifference threshold of 3 minutes, the en route ATIS users will choose the new route even if this may result in an early arrival at the destination. Figures 5-2 and 5-4 further substantiate this behavior.

Commuter	In-Vehicle Travel Time (min)	Travel Expenditure (min)	Small's Average Disutility Cost ($)	On Time Reliability	Just-In-Time Reliability	Late Schedule Delay (min)		Early Schedule Delay (min)	
						Average Delay	Max. Delay	Average Delay	Max. Delay
F95	59.6	65.5	4.5	82.9%	62.0%	4.1	20.9	13.2	20.3
ASV	56.6	62.1	3.7	92.6%	83.7%	2.7	5.3	11.7	14.1
ASR	55.8	62.0	3.7	94.3%	80.0%	2.7	5.3	12.2	16.9

Table 5-3. Performance Summary for December 20, 2000
Brandywine, MD to Centerville, VA, 6:30 AM – 6:30 PM Target Arrivals

Table 5-3 shows the travel expenditure to be nearly the same for the en route and pre-trip ATIS users. This is because the archived data has over estimated the travel time for this trip on this day. Hence, both types of ATIS users have budgeted more time than is necessary. Any difference in the travel expenditure is caused due to the late schedule delay. However, since both ATIS users have nominal late schedule delays, the difference in travel expenditure is minimal.

The two types of ATIS users have identical Small's disutility cost. Small's disutility cost is dependent on the travel time, early schedule delays, and late schedule delays. The overall late schedule delays for both users are the same (Table 5-3). The cost for every minute of travel time is $0.0564. Small's disutility cost equation, which is quadratic in early schedule delay, penalizes early schedule delays of more than 2.3 minutes. Hence, although the en route ATIS user experiences a reduction in travel time in comparison to the pre-trip ATIS user, the benefits are nullified due to higher early schedule delays.

It is evident from Table 5-3 that both ATIS users outperform the non-ATIS user in terms of all seven measures of effectiveness described in 5.2.2. This finding is in agreement with our hypotheses that en route ATIS users will show a benefit in comparison to non-ATIS users. Table 5-4 compares the performance of pre-trip ATIS, with and without the supplemental en route guidance. Overall for this trip, the supplemental en route guidance proves to be beneficial in terms of reducing in-vehicle travel time and increasing on-time reliability.

Commuter	In-Vehicle Travel Time	Travel Expenditure	Small's Average Disutility Cost	On Time Reliability	Just-In-Time Reliability
ASV	5.0% ↓	5.2% ↓	17.8% ↓	9.7% ↑	21.7% ↑
ASR	6.4% ↓	5.3% ↓	17.8% ↓	11.4% ↑	18.0% ↑

Table 5-4. Change in Performance from F95 to ASV and ASR for December 20, 2000: Brandywine, MD to Centerville, VA, 6:30 AM – 6:30 PM Target Arrivals

Tables 5-5 and 5-6 show the overall performance summary for the Brandywine-to-Centerville trip during the entire month of December 2000, comprising of 16 days. It is based on the aggregation of results for 16 days over 5 realizations. The results indicate that on average ASR commuters experience lower travel time, travel expenditure, and late schedule delays than ASV or F95 commuters. ASR commuters also have higher travel reliability than ASV or F95 commuters. Commuters who made use of only pre-trip traveler information service could have reduced their late schedule delay by 7%, while non-ATIS users could have reduced it by 36.5% had they made use of traveler information service with the pre-trip and en route components.

Commuter	In-Vehicle Travel Time (min)	Travel Expenditure (min)	Small's Average Disutility Cost ($)	On Time Reliability	Just-In-Time Reliability	Late Schedule Delay (min)		Early Schedule Delay (min)	
						Average Delay	Max. Delay	Average Delay	Max. Delay
F95	56.2	65.2	4.5	89.7%	44.3%	4.1	23.2	13.1	30.8
ASV	54.0	60.2	3.6	94.6%	83.6%	2.8	21.0	11.5	16.1
ASR	53.7	60.1	3.6	95.6%	83.0%	2.6	16.0	11.6	18.1

Table 5-5. Performance Summary for December 2000: Brandywine, MD to Centerville, VA, 6:30 AM – 6:30 PM Target Arrivals

Commuter	In-Vehicle Travel Time	Travel Expenditure	Small's Average Disutility Cost	On Time Reliability	Just-In-Time Reliability
ASV	3.9% ↓	7.7% ↓	20.0% ↓	4.9% ↑	39.3% ↑
ASR	4.4% ↓	7.8% ↓	20.0% ↓	5.9% ↑	38.7% ↑

Table 5-6. Performance Summary for December 2000: Brandywine, MD to Centerville, VA, 6:30 AM – 6:30 PM Target Arrivals

The Brandywine-to-Centerville trip, which has more than 11 well-connected alternate routes, afforded an en route ATIS user with multiple route choices. However, the Laurel-to-Dale City trip (Figure 5-1), one of the longest trips in the Washington network did not prove to be as beneficial to an en route ATIS user.

Figure 5-5 shows the variation of travel time on the y-axis with the desired arrival time on the x-axis for the Laurel-to-Dale City trip on January 19, 2001. For the desired arrival time of 5:30 PM, the pre-trip ATIS user decides to deviate from the habitual route, since the predicted travel time from the traveler information service is reported to be about 1 hour and 18 minutes on the habitual route, while the new route has a reported travel time of 1 hr and 14 minutes. The new route differs from the habitual route only at the exit for Duke Street on I-495W. On the new route, a commuter would take the exit for Duke Street and then the exit for I-95S, while a habitual commuter would continue on I-495W until taking the exit for I-95S. The en route ATIS user also takes the new route but does not record this as a pre-trip route change since in the HOWLATE methodology, only if the first link on a path is different from that on the habitual route, it is recorded as a pre-trip route change for an en route ATIS user. It should be remarked that an en route ATIS user reconsiders his route choice decision after traversing each link. The en route ATIS user is afforded the first en route decision within 5 minutes of the trip start time. However, the reported travel times on other viable alternate routes are more than the remaining travel time of 1 hr and 9 minutes (1 hr 22 minutes on the outer loop of I-495; 1 hr 21 minutes on the inner loop of I-495). Hence, the en route ATIS user continues on the current path. On reaching the exit for Duke Street, the en route ATIS user learns from the traveler information service that continuing on the habitual route would only increase his travel time by less than 1 minute due to an increase in travel time on the route chosen by the pre-trip ATIS user. Since the increase is less than his indifference threshold, the en route ATIS user does not make any route changes. The en route ATIS user reduces his early schedule delay by 3 minutes to arrive just in time, while the pre-trip ATIS although saving on the trip time is faced with an early schedule delay of 10 minutes.

It was expected that the Laurel-to-Dale City trip being a long trip would be subjected to greater travel time variability, and hence, an en route ATIS user would benefit more in comparison to a pre-trip ATIS user. For this trip, the en route ATIS user has multiple alternative routes, but only four are viable with respect to travel time. The en route ATIS user is further limited since he has to make his first en route decision, which eliminates either one or three of the four routes, within a few minutes of starting the trip, and hence often chooses the same route as chosen pre-trip. Figure 5-5 shows that only for 2 out of the 40 trips did the commuter who had access to en route guidance decide not to take the route that he had chosen prior to the start of the trip. On all other occasions, he continued on the route chosen pre-trip. Consequently the performa[illegible] nearly the same as that of pre-trip ATIS. Tables 5-7 and 5-8, which summarize the trip results for January 19, 2001, are indicative of this behavior.

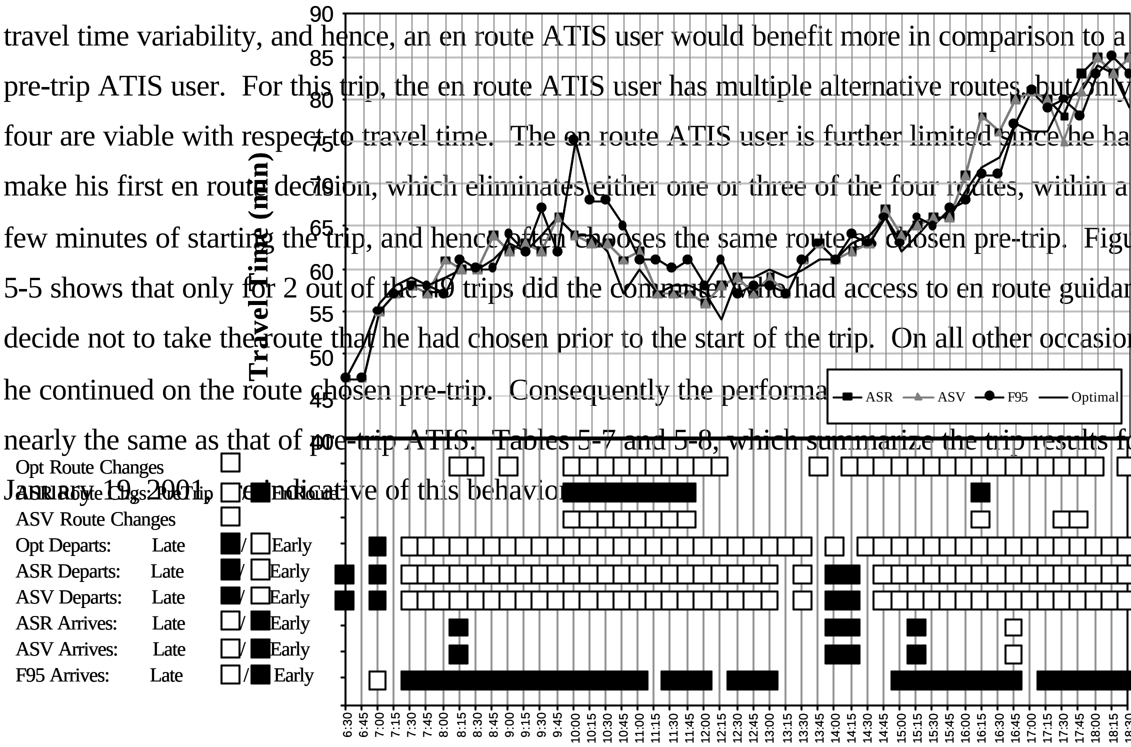

Figure 5-5. Commuter Travel Decisions and Performance: Laurel to Dale City, January 19, 2001

Commuter	In-Vehicle Travel Time (min)	Travel Expenditure (min)	Small's Average Disutility Cost ($)	On Time Reliability	Just-In-Time Reliability	Late Schedule Delay (min)		Early Schedule Delay (min)	
						Average Delay	Max. Delay	Average Delay	Max. Delay
F95	65.0	79.1	6.0	97.6%	25.3%	1.4	3.2	17.4	35.1
ASV	64.7	71.3	4.1	98.0%	84.1%	0.8	1.7	11.7	15.7
ASR	64.7	71.3	4.1	97.5%	83.7%	1.1	4.0	11.8	15.7

Table 5-7. Performance Summary for Laurel to Dale City, January 19, 2001

Commuter	In-Vehicle Travel Time	Travel Expenditure	Small's Average Disutility Cost	On Time Reliability	Just-In-Time Reliability
ASV	0.5% ↓	9.9% ↓	31.7% ↓	0.4% ↑	58.8% ↑
ASR	0.5% ↓	9.9% ↓	31.7% ↓	0.1% ↓	58.4% ↑

Table 5-8. Change in Performance (F95 vs. ASV and ASR), Laurel to Dale City

When the full set of trips from the Washington network was analyzed for the month of December 2000 (Table 5-9), it was found that the impact of en route ATIS was nearly identical to that of pre-trip ATIS. This indicates that the situations in which en route guidance proves beneficial are relatively rare – and are washed out of bottom line impacts when aggregations of trips are considered. One possible caveat with respect to this result is that in the HOWLATE network not all surface streets were modeled due to lack of data, only major roadways. Hence, the impact of en route guidance may be underestimated here because in reality there are more route choices than represented in this study. That said, similar gains from pre-trip route choice would also be expected from an increase in network complexity. The geometry of the Washington area roadway network, a circular beltway system with feeder routes, may also play a role in the benefit of route choice, both pre-trip and en route.

Commuter	In-Vehicle Travel Time (min)	Travel Expenditure (min)	Small's Average Disutility Cost ($)	On Time Reliability	Just-In-Time Reliability	Late Schedule Delay (min)		Early Schedule Delay (min)	
						Average Delay	Max. Delay	Average Delay	Max. Delay
F95	31.9	39.5	3.1	88.8%	59.9%	5.0	63.3	14.7	53.2
ASV	31.3	38.5	2.3	97.4%	84.6%	3.3	56.8	11.5	42.3
ASR	31.3	38.5	2.3	97.4%	84.4%	3.3	56.8	11.5	42.4

Table 5-9. Performance Summary for December 2000, All DC Trips

5.3 Conclusions

In this study the en route HOWLATE methodology was applied to the Washington metropolitan network, and the benefits of providing ATIS en route was compared to that provided pre-trip. The study shows that even in the most favorable cases, the pre-trip component provides 75% of the benefits of ATIS. For most trips, this pre-trip component is close to 100%. However, the study was limited in that not all arterials and surface streets could be modeled in the HOWLATE network, as archived data was not available. Hence, a traveler who made use of en route ATIS may have had more route choices than presented to him in this study. The key findings and future work are summarized below.

5.3.1 Key Findings

It was noticed that for most of the trips in the study area, the benefits of providing pre-trip ATIS with a supplemental en route guidance was nearly the same as that of providing pre-trip ATIS without the en route component, in terms of on-time travel reliability, in-vehicle travel time, and travel expenditure (Table 5.5). En route ATIS measurably outperformed pre-trip ATIS for trips that had multiple choices, with interconnected routes, as was seen for the Brandywine-to-Centerville trip (Tables 5.3 and 5.4). Benefits of en route ATIS are most significant on some specific time-of-day. Some of the main findings of this study are as follows:

- En route ATIS improved overall on-time reliability, reduced in-vehicle travel time, travel expenditure and late schedule delays in comparison to pre-trip ATIS, especially for trips that had multiple routes viable in terms of travel time (e.g. Brandywine-to-Centerville trip), but those improvements are small compared to the difference between pre-trip ATIS and F95;
- A commuter makes en route path changes to improve travel time. Hence, higher the travel time variability on any given trip, greater will be the benefits afforded by en route ATIS with regard to trip time reduction (Figure 5-2);
- Pre-trip ATIS users could have reduced their travel time by 12.7% if they had employed en route traveler information service, and eliminated late schedule delays (e.g. Figures 5-2, Brandywine-to-Centerville trip with a desired arrival time of 2:00 PM);
- A long trip does not necessarily translate into more benefits for an en route ATIS user, as was observed for the Laurel-to-Dale City trip, unless the commuter is given multiple feasible route choice decisions at different stages of the trip;

- Overall, en route ATIS performs as well as pre-trip ATIS; and
- En route ATIS users always perform better than non-ATIS users in terms of travel expenditure, just-in-time reliability, and early schedule delays.

5.3.2 Future Work

The study shows that en route ATIS provides some benefit in terms of on-time reliability and travel time on some of the trips that have multiple alternate routes. However, for most of the trips, en route ATIS did not outperform pre-trip ATIS. The study is not conclusive since the HOWLATE network did not model all the arterials, which limited the route choices for an en route ATIS user. We plan to continue our evaluation of en route ATIS for other cities, such as Minneapolis/St Paul, which although smaller than the Washington network, has archived data for a well-connected system of freeways and surface streets.

Another probable future work could be to evaluate the benefits of pre-trip ATIS with en route guidance for inter-city travel. It is expected that the en route component may be more beneficial for inter-city travel, while the benefits of the pre-trip component may be negligible.

6.0 Key Findings and Future Work

In this section, we revisit the hypotheses of the study first presented in Section 1.3 and provide a summary of key findings from across both the Washington and Twin Cities case studies in Section 6.1. Implications of these findings are presented in Section 6.2. Conclusions and future work are presented in Section 6.3.

6.1 Hypotheses and Key Findings

Hypothesis: The gains in on-time reliability and reductions in early and late schedule delay for pre-trip ATIS users found in the Washington area during a three-month period (August-October 1999) will also be observed when a longer study period (June 2000-May 2001) is considered. Further, the benefits of on-time reliability improvements will dominate the value of reductions of in-vehicle travel time for pre-trip ATIS.

Findings: Pre-trip ATIS users realize significant on-time reliability benefits in the Washington DC network over the twelve-month period studied (Table 6-1). Looking across the entire day, travelers waste less time by arriving more than 10 minutes at their destinations, and are late far less frequently. In-vehicle travel time is reduced by roughly six seconds per trip, and represents only 1.2% of the travel disutility reduction observed for ATIS users – the other 98.8% is a product of fewer late arrivals and less wasted time from early arrivals. Note that the time of day plays a key role in the kind of benefit seen in the Washington study, although the use of ATIS is beneficial throughout the 6:30 AM – 6:30 PM time period studied. In the AM and PM peak travel periods, the reduction in wasted time from arriving too early is the primary benefit, while in the off-peak periods the reduction in frequency and magnitude of late and early arrivals are comparable.

Percent Change, Savvy ATIS User vs. Familiar Non-User						
	ALL DAY		PEAK		OFF PEAK	
Frequency of Early Arrivals	56%	ι	60%	ι	47%	ι
Frequency of Late Arrivals	52%	ι	2%	ι	79%	ι
On Time Reliability	2.4%	η	0.2%	η	4.1%	η
In-Vehicle Trip Time	0.3%	ι	0.01%	ι	0.5%	ι
Disutility of Travel	15%	ι	18%	ι	12%	ι

Table 6-1. ATIS Impact for Familiar Travelers, Washington (June 2000-May 2001)

Hypothesis: Our general hypothesis of high-value reliability improvements and relatively low-value in-vehicle travel time reduction benefits will hold in other major ATIS markets nationwide, not just in Washington. This hypothesis is tested in a parallel 12-month case study (June 2000-May 2001) in the Twin Cities metropolitan area.

Findings: The results from the Twin Cities case study follow the same basic pattern of overall benefit for ATIS users seen in the Washington area, although there are significant differences by time of day (Table 6-2). Overall, trips see a 4% reduction in travel disutility, largely because of reduction in late arrivals and less wasted time by arriving too early. Benefit is not seen across the day, however. In the mid-day off-peak period (9 AM – 4 PM), ATIS users experience a 9% *increase* in travel disutility. This is because during the middle of the day, the Twin Cities network experiences very little variability in roadway travel times. When variability is low, the inherent error in ATIS observations causes ATIS users to misjudge trip timings and routing decisions more frequently than a familiar non-user who expects a trip close to the average and experiences that nearly every day. The ATIS user sees increased disutility because of the 47% increase in early arrivals. Even though late arrivals are reduced, as well as in-vehicle trip time, the time wasted by arriving too early outweighs the benefit of reduced disutility from these other impacts.

Percent Change, Savvy ATIS User vs. Familiar Non-User						
	ALL DAY		PEAK		OFF PEAK	
Frequency of Early Arrivals	37%	ι	62%	ι	47%	η
Frequency of Late Arrivals	88%	ι	83%	ι	94%	ι
On Time Reliability	3.9%	η	5.2%	η	2.8%	η
In-Vehicle Trip Time	1.0%	ι	1.5%	ι	0.5%	ι
Disutility of Travel	4%	ι	14%	ι	9%	η

Table 6-2. ATIS Impact for Familiar Travelers, Twin Cities (June 2000-May 2001)

Hypothesis: The absolute and relative benefits of pre-trip ATIS will be higher in the Washington case study than in the Twin Cities case study because the Washington network is more congested. This assessment is made *a priori* based on Texas Transportation Institute (TTI) Congestion Index ranking. The Washington metropolitan area is third nationwide in the most recent ranking, while the Twin Cities is 15th.

Findings: From Tables 6-1 and 6-2 it is clear that the percent reduction in disutility is higher in the Washington network (15%) than in the Twin Cities (4%). Table 6-3 shows that absolute reductions are larger as well. The average value of reduced disutility in Washington is valued at $0.41 per trip, compared to $0.06 in the Twin Cities. These differences are primarily related to unpredictability of travel time day-to-day in both peak and off-peak periods in Washington, particularly in the PM peak period where high travel time variability is seen in conjunction with much higher link travel times. Worse congestion is seen in the Washington area across all link and trip-related metrics. For example, the average disutility per trip is valued at $2.70 in Washington compared with $1.50 in the Twin Cities. By using the $3.36/hour disutility of in-vehicle travel time from Small *et al.* and average trip duration, we can identify the proportion of the average disutility associated with in-vehicle travel, and conversely, reliability. Table 6-3 shows that $0.93 per trip can be attributed to variability of travel in Washington, compared with $0.47 per trip in the Twin Cities.

Congestion Measures and ATIS Impacts, Washington DC vs. Twin Cities		
	WASHINGTON	TWIN CITIES
TTI Congestion Measures		
TTI Congestion Index	1.44	1.31
TTI Congestion Index Rank	3rd	14th
HOWLATE Congestion Measures		
Average Disutility/Trip	$2.70	$1.50
Variability Disutility/Trip	$0.93	$0.47
Maximum Disutility/Trip	$13.29	$5.09
Average Trip Duration	31.3 min	18.4 min
Average Trip Speed	40 mph	46 mph
HOWLATE ATIS Impacts		
Pct. Reduction, Disutility/Trip	15%	4%
Reduction in Disutility/Trip	$0.41	$0.06

Table 6-3. Comparison of Washington and Twin Cities Congestion Measures

Hypothesis: There will be some trips in both Washington DC and the Twin Cities where the value of reductions in disutility will exceed the benchmark $3-5/month ($60/year) rate reported as the typical charge for a traffic alert system (Ulnick and Haupricht, 2001).

Findings: As shown in Figure 6-1, 40% of trips in the Washington network accrue an average annual benefit in excess of $60, compared with 20% of trips in the Twin Cities network (220 trips/year). Figure 6-1 also illustrates that ATIS impact is highly concentrated. That is, there are a limited number of similar trips in both cities for which ATIS can be highly beneficial. The profile of these "high-benefit" trips in Washington are primarily PM peak trips traversing the network from north to south, while the profile of the highest-benefit trips in the Twin Cities are PM peak trips ending in the southwestern quadrant of the metropolitan area. Similar to the concentration of benefit among a limited number of similar trips, there is an even smaller subset of trips for which ATIS is regularly unhelpful. We have not completed our analysis of these but we conjecture that they are shorter trips with low variability.

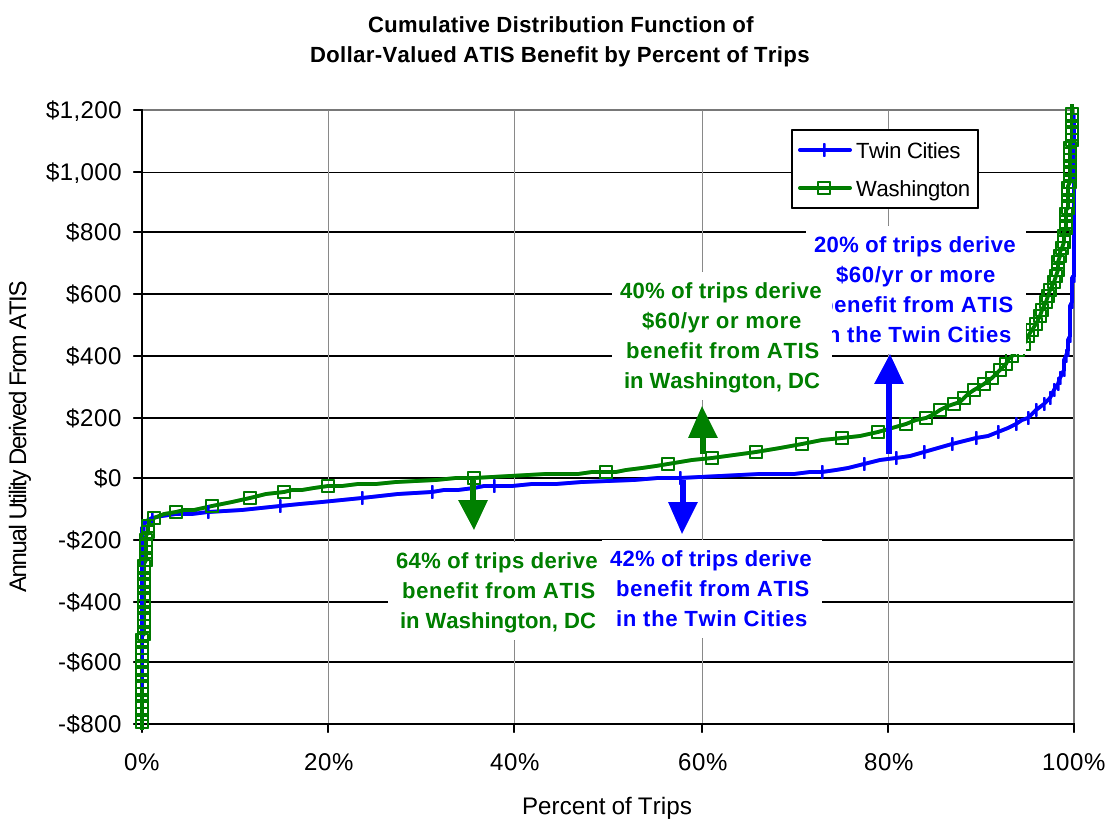

Figure 6-1. Distribution of ATIS Benefit in Washington DC and Twin Cities Analyses

Hypothesis: Pre-trip ATIS will prove valuable to both users who are familiar with their trips and congestion, as well as to users unfamiliar with particular trips and congestion patterns.

Findings: ATIS use by travelers unfamiliar with time-of-day congestion on the network significantly improves on-time reliability measures. In fact, these improvements are more highly valued on a per-trip basis than in yoked trials pairing travelers familiar with the network ($1.20 in Washington, $0.50 in the Twin Cities) as shown in Tables 6-4 and 6-5. Unfamiliar drivers are modeled differently from familiar drivers – instead of relying on past experience, they assume flatly that any trip in the AM or PM peak periods (Washington DC: 7:00-9:30 AM, 4:15-6:30 PM, Twin Cities: 7:00-9:00 AM, 4:00-6:30 PM) will have congestion equal to the free-flow travel time multiplied by the TTI congestion index factor, and free-flow travel time during off-peak periods. This strategy turned out to be too aggressive (many late arrivals) in the peak periods in both Washington and the Twin Cities. In the off-peak periods, the strategy for unfamiliar travelers was too aggressive in Washington but too conservative (many early arrivals) in the Twin Cities.

Percent Change, Naive ATIS User vs. Unfamiliar Non-User						
	ALL DAY		PEAK		OFF PEAK	
Frequency of Early Arrivals	4-fold	η	12-fold%	η	3-fold	η
Frequency of Late Arrivals	92%	ι	90%	ι	96%	ι
On Time Reliability	49.6%	η	105.4%	η	26.3%	η
In-Vehicle Trip Time	1.3%	ι	2.0%	ι	0.8%	ι
Disutility of Travel	34%	ι	45%	ι	22%	ι

Table 6-4. ATIS Impact for Unfamiliar Travelers, Washington DC (June 2000-July 2000)

Percent Change, Naïve ATIS User vs. Unfamiliar Non-User						
	ALL DAY		PEAK		OFF PEAK	
Frequency of Early Arrivals	38%	η	84%	η	52%	ι
Frequency of Late Arrivals	97%	ι	96%	ι	158%	η
On Time Reliability	16.2%	η	39.5%	η	0%	η
In-Vehicle Trip Time	2.2%	ι	3.56%	ι	1%	ι
Disutility of Travel	25%	ι	36%	ι	9%	ι

Table 6-5. ATIS Impact for Unfamiliar Travelers, Twin Cities, (June 2000-July 2000)

Hypothesis: The addition of an en route guidance supplement to the pre-trip ATIS service will provide additional on-time reliability benefits, as well as reduced in-vehicle travel time.

Findings: Supplementing pre-trip ATIS with an en route guidance service provides improved on-time reliability and reduced in-vehicle travel time – but only in relatively rare circumstances: long trips with unexpected congestion and viable diversion opportunities late in the trip. Even when these benefits occur, their value does not exceed $0.50/occurence.

6.2 Implications

The results of this study have several significant implications for both public- and private- sector providers of ATIS services. Both types of ATIS providers are motivated to provide the highest possible value of service to their constituencies, although their motivations are different. The results of this study have implications regarding the kind of ATIS services most helpful to users, and shed light on what kinds of trip-makers are likely to benefit the most from these services.

Pre-trip ATIS benefit is highly concentrated, both geographically and by time of day. In the Washington DC network, 78% of the benefit of pre-trip ATIS provision accrues to 25% of possible trips in the network. In the Twin Cities, the target clientele of users likely to significantly benefit is even more concentrated, (82% of benefit accrues to 19% of possible trips). In the Twin Cities, the vast majority of high-value trips occur in a fairly narrow time window within the PM peak. Although we have not fully completed our analysis to characterize the highest value trips in either city, the implication is clear for ATIS service providers – in terms of benefit to the user, *the best target market for services differs in each city and marketing efforts, along with surveillance and reporting resources are likely more effectively deployed to reach and support these trips*. Keep in mind that our unit of observation here is trips, not population – a larger share of the traveling population makes trips in the PM peak than during off-peak periods.

Although pre-trip ATIS is shown to be beneficial in both metropolitan areas, the absolute value of pre-trip ATIS provision is higher in Washington DC than in the Twin Cities. This is simply because variability of travel times is more pronounced and seen through a larger portion of the day than in the Twin Cities. It is clear that variability of travel times are the key attribute that separates trips that benefit from pre-trip ATIS from those that do not. *Congestion metrics like the TTI Index* *can provide a rough guide as to the likely magnitude of regional pre-trip ATIS benefits because high demand-to-capacity ratios are strongly correlated with high variability, but the key for pre-trip ATIS benefit appears related less to the magnitude of peak period congestion than the magnitude of day-to-day variability seen at any time of day.*

Our findings with respect to the concentration of benefit among a relatively small set of trips within the region also has implications for targeting different types of travelers with a requirement to arrive on-time. *The provision of trip planning guidance to unfamiliar travelers has high benefit in peak periods, even if peak period variability is not particularly pronounced*. The benefit for unfamiliar travelers in the Twin Cities averages $0.50 per trip across the day and $1.40 per trip in the PM peak ($1.20 and $2.40, respectively in Washington DC). Reaching travelers who are planning trips in the peak period for which they have little experience with congestion patterns appears to be a high-value activity. Further, the notion of the unfamiliar traveler is broader than the "tourist in the rental car" and includes regional residents that do not regularly make a particular trip (e.g., a requirement to be at the airport at 8:30 AM). Note that the value to unfamiliar travelers in the Twin Cities is, on average, over six times higher on a per-trip basis than ATIS provision to familiar travelers.

Reaching the high-value target clientele may mean providing different kinds of ATIS services than are typically provided. Today, the most frequently deployed ATIS service reporting real-time congestion are websites with color-coded maps showing current conditions and, frequently, travel times. However, the unfamiliar traveler seeking to plan when to leave to be on-time at the airport next Tuesday is not well-served by such a display of the data. Even if the traveler happens to be checking out the website at roughly the same time of day, there is no way of knowing whether this particular day is a much worse or much better prediction of conditions likely encountered in the next week.

Likewise, the oft-repeated paradigm of the ATIS user jumping in the car, getting the best route and screeching out of the parking lot may in not in fact be the most effective way to incorporate ATIS effectively into one's regular travel pattern. On-time reliability benefits are most strongly influenced by the trip departure time choice; shifting time of departure by five or ten minutes is 6-20 times more frequently suggested than route diversion by the notification-based ATIS service examined in our study. Clearly, checking in with a website every five minutes to construct a trip time estimate would be too onerous for the ATIS user and the "jump in the car" scenario implies a fixed trip start time. Instead, the key to on-time reliability benefits appears to be supporting the trip timing decision, as in the provision of a notification-based service that constantly scans the data based on the user's habitual trip schedule. The service would then notify the user only when appropriate trip timing and route choice differ from the user's default route and timing. In both Washington and the Twin Cities, we estimate that such notification would occur roughly three out of every five workdays. Further, although our study of en route guidance is only preliminary at this point, it appears that the value of route diversion generally diminishes after trip-start except in relatively rare combinations of long duration trips with key diversion points and roadway segments with high variability close to the destination.

6.3 Conclusions and Future Work

Not all current ATIS users are motivated by the desire to be on-time in urban networks. A survey of Seattle ATIS web-site users (Lappin, 2000) characterized roughly one-third of current users as commuters who needed to be on-time and used the web-site to help them be on time. The on-time reliability benefits reported in this document are clearly applicable for this one-third of the current ATIS using market. Other users are characterized by an intense dislike of congestion and slow travel. Still others utilized the service primarily because it was new and technically interesting, rather than to simply improve their own mobility. Other metrics (e.g., reduction in travel under 20 mph) may better represent the utilities of these travelers; and different kinds of services based on the roadway congestion and configuration may have higher value than the pre-trip notification service tested in this study.

Clearly our study indicates that for travelers who need to be on time and who face considerable variability in their trip travel times, a notification-based pre-trip ATIS can be a useful and high-value service. Although not currently available in either Washington or the Twin Cities, this type of service can be provided through the manipulation of the roadway travel time data similar to that already being collected and disseminated in both Washington and the Twin Cities. The term "similar" is used as a qualifier here because there has been only preliminary work done so far by Mitretek and others to identify the accuracy of reported travel time data by times of day, situations and individual facilities. Our initial assessment is that the accuracy levels (roughly plus/minus 20%) used in this report based on limited observations on two facilities in the Washington network may be optimistic based on some additional measurements recently completed, however a comprehensive assessment is yet to be undertaken. A key extension of this work will be to examine the benefits of ATIS under various levels of link travel time reporting accuracy. This extension includes an evaluation of qualitative congestion alerts like those made during periodic traffic reports on commercial radio.

Other extensions include the assessment of additional metropolitan networks beyond the two already studied, a comparative analysis of benefit from a notification-based service and user-initiated service that includes assessment of access time, as well as continuing work evaluating of the benefits of en route guidance. The paradigm for en route benefit may well be found in intercity or inter-regional travel, rather than repetitive urban commuter travel.

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Appendix A:
Heuristic On-line Web-Linked Arrival Time Estimator (HOWLATE)
Algorithmic Statement

Overview

Step 1. Expectation Under Training Period
Step 2. Optimal Paths and Travel Times in Evaluation Period
Step 3. Determine Performance of Non-Users in Evaluation Period
Step 4. Determine Performance of ATIS Users in Evaluation Period
OPTION 1: Pre-Trip Time Shift with Pre-Trip Route Choice
OPTION 2: Pre-Trip Time Shift with En Route Path Choice

Support Routines

A. Forward A-STAR Dynamic Program: D'
B. Reverse Time Dynamic Program: $\backprime\mathrm{D}$
C. Forward Path Traversal Under Estimated Travel Times: $\mathrm{T}'\left(\cdots,\hat{c}_\ell(t)\right)$
D. Forward Path Traversal Under Actual Travel Times: $\mathrm{T}'\left(\cdots,\widehat{c}_\ell(t)\right)$
E. Evaluating Arc Costs Between Lattice Points

Step 1. Expectation-Setting Under Training Period

Network Structure File:

For each link $\ell \in L$, the network of directed arcs:

$\ell:(a,b)$	link ℓ defined as unidirectional arc from node a to node b
f_ℓ	facility type (currently arterial or freeway)
x_ℓ	congestion threshold time (seconds)
d_ℓ	distance along link (miles)

Archived Daily Link Travel Time Files, Training Period

For each day $k = 1,2,3 \cdots N$ in the training period of N days, one file containing:
For each link $\ell \in L$, and 5-minute time slice day $k: t = 0,1,2 \cdots T$;

$\hat{c}_\ell^k(t)$	archived link travel time for link ℓ for arc traversal beginning at time t, day k

Monte Carlo Parameters from Control Parameter File:

m_f^k	offset for link travel time value by facility type and congestion
s_f^k	standard deviation of link travel time value by facility type and congestion

Experimental Control Parameters:

f	yoked trial toggle. Set = 1 if this is a yoked trial between ATIS users and habitual travelers who are FAMILIAR with congestion conditions; Set = 0 if this is a yoked trial between UNFAMILIAR subjects.
c	FAMILIAR parameter: subject on-time arrival requirement (scaredy/macho factor)
r	UNFAMILIAR parameter: estimated peak period travel time premium for DC, use TTI mobility index: 1.41.
$\mathbf{T}^p$	UNFAMILIAR parameter: set of time intervals designated as "peak" period for DC, use: 7:00-9:30 AM, 4:15-6:30 PM.

PROCEDURE:

1. Monte Carlo sampling to produce actual travel times in each day of the training period $\widehat{c}_\ell^k(t)$:

   a. compute congestion factor based on ℓ, t:

$$k = \begin{cases} 1 & \hat{c}_\ell^k(t) > x_\ell \\ 0 & \hat{c}_\ell^k(t) \le x_\ell \end{cases}$$

   b. compute estimates based on link characteristics, time of arc traversal, and adjustment factors:

$$\widehat{c}_\ell^k(t) = \mathrm{M}(\ell, t) = \mathrm{NORMAL}\left(\hat{c}_\ell^k(t) - m_f^k, s_f^k\right)$$

   c. enforce consistency in actual travel time profiles, enforcing FIFO for arc costs in time:

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

   d. if $f = 1$ then proceed to substep 2 to compute FAMILIAR training, else proceed to substep 5.

2. FAMILIAR TRAINING

Generate profile of average experienced conditions during training period $\hat{c}_\ell(t)$:

$$\hat{c}_\ell(t) = \frac{\sum_k \hat{c}_\ell^k(t)}{N}$$

3. For each destination node d and target arrival-at-destination time $\boldsymbol{t}$,
where $\boldsymbol{t}: 1, 2, 3 \cdots T_t$, a lattice of 15 minute target arrival times during the day,
perform DP recursively from d at time $\boldsymbol{t}$ using average arc costs to find:

$$\text{`D}\left(d, \boldsymbol{t}, \hat{c}_\ell(t)\right) \rightarrow \overline{\mathbf{P}}_{o,d,t}$$, the habitual path established for $o, d, \boldsymbol{t}$ and

$\overline{p}_{o,d,t}^1$, the expected travel time for this path (1st estimate)

4. For each day k in the training period; for each $o, d, \boldsymbol{t}$:
a. traverse $\overline{\mathbf{P}}_{o,d,t}$ forward at time $\boldsymbol{t} - \overline{p}_{o,d,t}^1$ using training day k arc costs:

$$\text{T}'\left(\overline{\mathbf{P}}_{o,d,t}, \boldsymbol{t} - \overline{p}_{o,d,t}^1{}_t, \hat{c}_\ell^k(t)\right) \rightarrow \quad \overline{p}_{o,d,t}^k$$, the travel time on the habituated path

b. from the vector series $\left\{\overline{p}_{o,d,t}^k : k = 1, 2, \cdots N\right\}$, compute $\overline{p}_{o,d,t}$, the average path travel time and $\boldsymbol{s}_{o,d,t}^{\overline{\mathbf{P}}}$, the standard deviation of the series of days of travel on the habitual path

c. compute the habituated time of trip start, $t_{o,d,t}^0 \, \forall \, o, d, \boldsymbol{t}$:

$t_{o,d,t}^0 = \boldsymbol{t} - \left(\overline{p}_{o,d,t} + Z_c \, \boldsymbol{s}_{o,d,t}^{\overline{\mathbf{P}}}\right)$, where Z_c is the Z-statistic for $\boldsymbol{c}$ %, normal dist.

Note: $t_{o,d,t}^0$ cannot take values between lattice points, so $t_{o,d,t}^0$ should be marked down to the previous five minute interval point, i.e., set $t_{o,d,t}^0 = t_{o,d,t}^0 - REM\left(\frac{t_{o,d,t}^0}{\Delta}\right)$, where REM() is the remainder after integer division.

d. compute the average travel distance on the habitual path $\overline{\boldsymbol{d}}_{o,d,t} = \sum_{\ell \in P_{o,d,t}} \boldsymbol{d}_\ell$.

e. identify the savvy ATIS user correction factor, $\boldsymbol{w}_{o,d,t}$.

traverse $\overline{\mathbf{P}}_{o,d,t}$ forward with ATIS-estimated arc costs fixed at time $t' = \boldsymbol{t} - \overline{p}_{o,d,t}^1$:

$$\text{T}'\left(\overline{\mathbf{P}}_{o,d,t}, t', \hat{c}_\ell^k(t')\right) \rightarrow \hat{p}_{o,d,t}^k$$, the pre-trip estimate of travel time on the habituated path.

Let $\boldsymbol{w}_{o,d,t} = \dfrac{\overline{p}_{o,d,t}}{\sum_k \hat{p}_{o,d,t}^k / k}$, the ratio of experienced to predicted travel times in the period.

f. skip forward to Step 2., Optimal Paths in Evaluation Period.

5. UNFAMILIAR TRAINING

Generate profile of roadway congestion estimated by unfamiliar travelers, $\tilde{c}_\ell\,(t)$:

$$\tilde{c}_\ell(t) = \begin{cases} \boldsymbol{r}\,\hat{c}_\ell(0) & t \in \mathbf{T}^p \\ \hat{c}_\ell(0) & t \notin \mathbf{T}^p \end{cases}$$

6. For each destination node d and target arrival-at-destination time $\boldsymbol{t}$,
where $\boldsymbol{t}:\ 1, 2, 3 \cdots T_t$, a lattice of 15 minute target arrival times during the day,
perform DP recursively from d at time $\boldsymbol{t}$ using average arc costs to find:

`$\mathrm{D}\left(d, \boldsymbol{t}, \tilde{c}_\ell(t)\right) \rightarrow \overline{\mathbf{P}}_{o,d,t}$, the habitual path established for $o, d, \boldsymbol{t}$ and

$\overline{p}_{o,d,t}$, the expected travel time for this path

7. Compute the habituated time of trip start, $t^0_{o,d,t}\ \forall\, o, d, \boldsymbol{t}$:

$t^0_{o,d,t} = \boldsymbol{t} - \overline{p}_{o,d,t}$,

Note: $t^0_{o,d,t}$ cannot take values between lattice points, so $t^0_{o,d,t}$ should be marked down to the previous five minute interval point, i.e., set $t^0_{o,d,t} = t^0_{o,d,t} - REM\left(\dfrac{t^0_{o,d,t}}{\Delta}\right)$, where REM() is the remainder after integer division.

8. Set $\boldsymbol{w}_{o,d,t} = 1\ \forall\, o, d, \boldsymbol{t}$.
Skip forward to Step 2, Optimal Paths and Travel Times.

Step 2. Optimal Paths and Travel Times in Evaluation Period

NEW INPUT FILES:

Archived Daily Link Travel Time Files, Evaluation Period

For each day $j = 1, 2, 3 \cdots M$ in the evaluation period of M days, one file containing:
For each link $\ell \in L$, and observed 5-minute time slice in day $j : t = 0, 1, 2 \cdots T$;

$\hat{c}_{\ell}^{j}(t)$ archived link travel time for link ℓ for arc traversal beginning at time t, day j

PROCEDURE:

1. Monte Carlo sampling to produce actual travel times in each day of the evaluation period $\widehat{c}_{\ell}^{j}(t)$:
   For each $\ell \in L, t \in T$:
   a. compute congestion factor based on ℓ, t as in Step 1.1.
   b. compute estimates based on link characteristics, time of arc traversal, and adjustment factors:
   $$\widehat{c}_{\ell}^{j}(t) = \mathrm{M}(\ell, t) = \mathrm{NORMAL}\left(\hat{c}_{\ell}^{j}(t) - m_{f}^{k}, s_{f}^{k}\right)$$
   c. enforce consistency in actual travel time profiles, enforcing FIFO for arc costs in time:
   if $\widehat{c}_{\ell}^{j}(t) - \widehat{c}_{\ell}^{j}(t+1) > 300$ then set $\widehat{c}_{\ell}^{j}(t+1) = \widehat{c}_{\ell}^{j}(t) - 300$.

2. Find fastest paths based on actual data from the evaluation period:

   For each destination node d, target arrival time of t, and day j:

   a. perform DP recursively for d, t, j under actual evaluation period conditions to establish:

   `$\mathrm{D}\left(d, t, \widehat{c}_{\ell}^{j}(t)\right) \rightarrow$ $\widehat{\mathbf{P}}_{o,d,t}^{j}$, the optimal path on day j for the o, d, t; and
   $\widehat{p}_{o,d,t}^{j}$, the travel time on $\widehat{\mathbf{P}}_{o,d,t}^{j}$.

   b. find path distance on the optimal route as $\widehat{d}_{o,d,t}^{j} = \sum_{\ell \in \widehat{\mathbf{P}}_{o,d,t}^{j}} d_{\ell}$.

Step 3. Determine Performance of Non-Users in Evaluation Period

NEW INPUT FILES:

None.

PROCEDURE:

1. recover habituated paths and trip start times from Step 1, $\overline{\mathbf{P}}_{o,d,t}$ and $t^{0}_{o,d,t} \forall o, d, t$

2. For each day j in the evaluation period, for each o, d, t :

   a. traverse $\overline{\mathbf{P}}_{o,d,t}$ forward from time $t^{0}_{o,d,t}$, using actual arc costs for day j:

   $\mathrm{T}'\left(\overline{\mathbf{P}}_{o,d,t}, t^{0}_{o,d,t}, \widehat{c}^{\,j}_{\ell}(t)\right) \rightarrow \quad \widehat{\overline{p}}^{\,j}_{o,d,t}$, actual experienced travel time on the habituated path

Step 4. Determine Performance of ATIS Users in Evaluation Period

OPTION 1: Pre-Trip ATIS, Concurrent Time-Shift and Route Choice

NEW INPUTS:

From Control File:

e^{+}	Maximum late departure, expressed in multiples of 300 seconds
e^{-}	Maximum early departure, expressed in multiples of 300 seconds
$\boldsymbol{e}$	Route diversion indifference threshold

PROCEDURE:

1. Recover archived and actual link travel time files for the evaluation period.

2. For each $o, d, \boldsymbol{t}$:
   a. set $t' = t^{0}_{o,d,t} - e^{-}$.
   b. perform forward DP from t' with arc costs fixed at $t = t'$;
   $\mathrm{D}'\left(o, d, t', \hat{c}^{j}_{\ell}(t')\right) \rightarrow \dot{\mathbf{P}}^{j}_{o,d,t}$, a candidate fastest path with predicted travel time $\dot{p}^{j}_{o,d,t}$
   c. check to see if trip start can be safely postponed five minutes longer
   CHECK#1: $t' + \boldsymbol{w}_{o,d,t}\ \dot{p}^{j}_{o,d,t} < \boldsymbol{t} - \Delta$ (predicted to be early?)
   CHECK#2: $t' < t^{0}_{o,d,t} + e^{+}$ (still have flexibility to postpone trip?)
   If CHECK#1 and CHECK#2 are true,
   then set $t' = t' + \Delta$ and GOTO step b;
   Otherwise we have determined the time of trip start, set $\tilde{t}^{j}_{o,d,t} = t'$.
   d. Check if candidate path is the habitual path;
   If $\dot{\mathbf{P}}^{j}_{o,d,t} = \overline{\mathbf{P}}_{o,d,t}$, set $\hat{\bar{p}}^{j}_{o,d,t} = \dot{p}^{j}_{o,d,t}$ and GOTO step h.
   e. forward traverse the habitual path, $\overline{\mathbf{P}}_{o,d,t}$, using arc costs fixed at $\tilde{t}^{j}_{o,d,t}$;
   $\mathrm{T}'\left(\overline{\mathbf{P}}_{o,d,t}, \tilde{t}^{j}_{o,d,t}, \hat{c}^{j}_{\ell}\left(\tilde{t}^{j}_{o,d,t}\right)\right) \rightarrow \hat{\bar{p}}^{j}_{o,d,t}$, the predicted travel time on the habitual path.
   f. perform check to see if the alternative route is attractive enough to warrant diversion
   CHECK#3: $\hat{\bar{p}}^{j}_{o,d,t} - \dot{p}^{j}_{o,d,t} > \boldsymbol{e}$
   If CHECK #3 is false, then GOTO step h.
   g. SWITCH to the alternative path:
   Traverse $\dot{\mathbf{P}}^{j}_{o,d,t}$ forward from time, using actual arc costs for day j , departing at $\tilde{t}^{j}_{o,d,t}$:
   $\mathrm{T}'\left(\dot{\mathbf{P}}^{j}_{o,d,t}, \tilde{t}^{j}_{o,d,t}, \hat{c}^{j}_{\ell}(t)\right) \rightarrow \tilde{p}^{j}_{o,d,t}$, experienced travel time for the ATIS user.
   Set pre-trip switch indicator $x^{j}_{o,d,t} = 1$, and trip distance $\tilde{\boldsymbol{d}}^{j}_{o,d,t} = \sum_{\ell \in \dot{\mathbf{P}}^{j}_{o,d,t}} \boldsymbol{d}_{\ell}$.
   Set $y^{j}_{o,d,t} = 0$. GOTO step i.

h. STICK with habituated path:

traverse $\overline{\mathbf{P}}_{o,d,t}$ forward from time, using actual arc costs for day j, departing at $\tilde{t}^{\,j}_{o,d,t}$:

$\mathrm{T}'\left(\overline{\mathbf{P}}_{o,d,t}, \tilde{t}^{\,j}_{o,d,t}, \hat{c}^{\,j}_{\ell}(t)\right) \rightarrow \tilde{p}^{\,j}_{o,d,t}$, experienced travel time for the ATIS user.

Set pre-trip switch indicator $x^{\,j}_{o,d,t} = 0$, trip distance $\tilde{d}^{\,j}_{o,d,t} = \sum_{\ell \in \overline{\mathbf{P}}^{j}_{o,d,t}} d_{\ell}$. Set $y^{\,j}_{o,d,t} = 0$.

h. Generate performance record (by day j):

o	trip origin
d	trip destination
t	target time of trip end at destination
$\hat{p}^{\,j}_{o,d,t}$	optimal travel time
$\hat{d}^{\,j}_{o,d,t}$	travel distance on optimal path
$t^{0}_{o,d,t}$	habitual time of trip start
$\widehat{\bar{p}}^{\,j}_{o,d,t}$	non-user experienced travel time (leaves at habitual trip start time)
$\bar{d}_{o,d,t}$	travel distance on habitual path
$\tilde{t}^{\,j}_{o,d,t}$	ATIS user time of trip start
$\hat{\bar{p}}_{o,d,t}$	predicted travel time on habitual path at trip start
$\dot{p}^{\,j}_{o,d,t}$	predicted fastest travel time for ATIS user at trip start
$\tilde{p}^{\,j}_{o,d,t}$	experienced travel time, ATIS user
$\tilde{d}^{\,j}_{o,d,t}$	experienced travel distance, ATIS user
$x^{\,j}_{o,d,t}$	number of pre-trip route changes by ATIS user
$y^{\,j}_{o,d,t}$	number of en route path changes by ATIS user
$w^{j}_{o,d,t}$	savvy ATIS user correction factor

OPTION 2 En Route ATIS

NEW INPUTS:

From Control File:

e^{+}	Maximum late departure, expressed in multiples of 300 seconds
e^{-}	Maximum early departure, expressed in multiples of 300 seconds
$\boldsymbol{e}$	Route diversion indifference threshold

PROCEDURE:

1. Recover archived and actual link travel time files for the evaluation period $\hat{c}_{\ell}^{j}(t), \widehat{c}_{\ell}^{j}(t) : \forall\ t,\ j.$.

2. For each $o, d, \boldsymbol{t}$: (Establish Time of Trip Start)
   a. set $t' = t_{o,d,t}^{0} - e^{-}$.
   b. perform forward DP from t' with arc costs fixed at $t = t'$;
   $\mathrm{D}'\left(o, d, t', \hat{c}_{\ell}^{j}(t')\right) \rightarrow\ \dot{\mathbf{P}}_{o,d,t}^{j}$, a candidate fastest path with predicted travel time $\dot{p}_{o,d,t}^{j}$

   c. check to see if trip start can be safely postponed five minutes longer
   CHECK#1: $t' + \boldsymbol{w}_{o,d,t}\,\dot{p}_{o,d,t}^{j} < \boldsymbol{t} - \Delta$ (predicted to be early?)
   CHECK#2: $t' < t_{o,d,t}^{0} + e^{+}$ (still have flexibility to postpone trip?)
   If CHECK#1 and CHECK#2 are true,
   then set $t' = t' + \Delta$ and GOTO step b;
   Otherwise we have determined the time of trip start, set $\tilde{t}_{o,d,t}^{j} = t'$.

3. Continue with the $o, d, \boldsymbol{t}$ by establishing en route behavior
   a. Initialize intermediate travel time $\boldsymbol{a} = \tilde{t}_{o,d,t}^{j}$, intermediate location $i = o$, and current path $\mathbf{P}_{i,d,t}(\boldsymbol{a}) = \overline{\mathbf{P}}_{o,d,t}$. Define $\mathrm{I}(\mathbf{P})$, a function which recovers the first link in a path, and $\mathrm{B}(\ell)$, a function that recovers the b-node of a link.
   Set the path taken by the traveler $\tilde{\mathbf{P}} = \varnothing$, and set $x_{o,d,t}^{j} = y_{o,d,t}^{j} = 0$.
   b. forward traverse the current path, $\mathbf{P}_{i,d,t}(\boldsymbol{a})$, using arc costs fixed at $t = \boldsymbol{a}$;
   $\mathrm{T}'\left(\mathbf{P}_{i,d,t}(\boldsymbol{a}), \boldsymbol{a}, \hat{c}_{\ell}^{j}(\boldsymbol{a})\right) \rightarrow\ p_{i,d,t}^{j}(\boldsymbol{a})$, the predicted remaining travel time on the current path.
   c. If $i = o$, set $\hat{\tilde{p}}_{i,d,t}^{j} = p_{i,d,t}^{j}(\boldsymbol{a})$.
   d. perform forward DP from i at $\boldsymbol{a}$ with arc costs fixed at $t = \boldsymbol{a}$;
   $\mathrm{D}'\left(i, d, \boldsymbol{a}, \hat{c}_{\ell}^{j}(\boldsymbol{a})\right) \rightarrow\ \hat{\mathbf{P}}_{i,d,t}^{j}(\boldsymbol{a})$, the fastest predicted intermediate path and $\hat{p}_{o,d,t}^{j}(\boldsymbol{a})$, the predicted remaining travel time on $\hat{\mathbf{P}}_{i,d,t}^{j}(\boldsymbol{a})$.
   If $\mathrm{I}\left(\hat{\mathbf{P}}_{i,d,t}^{j}(\boldsymbol{a})\right) = \mathrm{I}\left(\mathbf{P}_{i,d,t}(\boldsymbol{a})\right)$, GOTO Step g.

   e. Check to see that the alternative route saves more time than the indifference threshold
   If $p_{i,d,t}^{j}(\boldsymbol{a}) - \hat{p}_{i,d,t}^{j}(\boldsymbol{a}) < \boldsymbol{e}$, GOTO Step g.

f. Switch to the alternative path:

Let $\ell' = \mathrm{I}\left(\hat{\mathbf{P}}^{j}_{i,d,t}(a)\right)$ next link to be traversed from alternative path

If $i = o$, then set $x^{j}_{o,d,t} = x^{j}_{o,d,t} + 1$; increment route switch counter

Else set $y^{j}_{o,d,t} = y^{j}_{o,d,t} + 1$

Set $\mathbf{P}_{i,d,t}(a) = \hat{\mathbf{P}}^{j}_{i,d,t}(a)$, the alternative path is now the current path

GOTO step h.

g. Stick with the current path:

Let $\ell' = \mathrm{I}\left(\mathbf{P}_{i,d,t}(a)\right)$ next link to be traversed from current path

h. Set $\tilde{\mathbf{P}} = \tilde{\mathbf{P}} + \ell'$, update list of traversed links

Set $i = \mathrm{B}(\ell')$, update current position

Set $a = a + \hat{c}^{j}_{\ell'}(a)$, update current time

Set $\mathbf{P}_{i,d,t}(a) = \mathbf{P}_{i,d,t}(a)$ update path given we have advanced to a new node

If $i \neq d$ GOTO b.

i. Let $\tilde{p}^{j}_{o,d,t} = a - \tilde{t}^{j}_{o,d,t}$, the experienced travel time on $\tilde{\mathbf{P}}$, and $\tilde{d}^{j}_{o,d,t} = \sum_{\ell \in \tilde{\mathbf{P}}} d_{\ell}$.

k. Generate performance record (identical to OPTION 1)

A. Forward A-STAR Dynamic Program: D'

$\mathrm{D}'\left(o, d, t^0, c_\ell(t)\right)$: 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:

$\mathbf{O}$	the set of open nodes, set $\mathbf{O} = o$.
$\mathbf{C}$	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 $n = \min\limits_{n' \in \mathbf{O}} \{\mathrm{F}(n')\}$; $\boldsymbol{a} = \mathrm{G}(n)$.
   b. if $n = d$, then GOTO Step 5.
   c. for each $n' \in \mathrm{S}(n)$:
      Let $\ell = (n, n')$ and $\boldsymbol{a}' = \boldsymbol{a} + c_\ell(\boldsymbol{a})$.
      if $n' \notin \mathbf{O} \bigcup \mathbf{C}$ then
         Set $\mathbf{O} = \mathbf{O} + n'$, GOTO (*).
      if $n' \in \mathbf{O}$ AND $\boldsymbol{a}' < G(n')$ then GOTO (*).
      if $n' \in \mathbf{C}$ AND $\boldsymbol{a}' < G(n')$ then
         Set $\mathbf{C} = \mathbf{C} - n'$, $\mathbf{O} = \mathbf{O} + n'$, GOTO (*).
      Else GOTO (**).
      (*) Set $G(n') = \boldsymbol{a}'$ 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 $G(d) - t^0$.

B. Reverse-Time Dynamic Program: \`D

\`D$\left(d, \boldsymbol{t}, c_\ell(t)\right)$: The subroutine takes the following arguments:

d	trip destination
$\boldsymbol{t}$	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:

$\mathbf{O}$	the set of open nodes, set $\mathbf{O} = d$.
$\mathbf{C}$	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 $\boldsymbol{t}$, $G(d) = \boldsymbol{t}$.
$P(n)$	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 $\mathbf{C}$ contains all nodes in the network, GOTO Step 5.
Otherwise, recover or calculate $G(n)\forall n \in \mathbf{O}$.

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

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

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

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

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

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

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

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

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

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

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

Else GOTO (**).

(*) Set $G(n') = \boldsymbol{a}'$ 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 $\boldsymbol{t} - G(n)$.

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

$\mathrm{T}'\left(\mathbf{P}_{o,d}, t^0, c_{\ell}\left(t^0\right)\right)$: 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.

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

$\mathrm{T}'\left(\mathbf{P}_{o,d}, t^0, c_{\ell}(t)\right)$: 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.

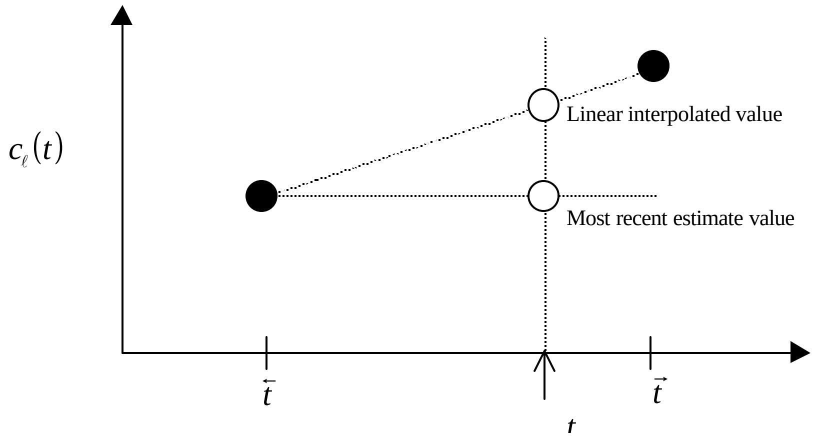
   $$\widehat{c}_{\ell}(t) = \widehat{c}_{\ell}(\bar{t}) + (t - \bar{t})\frac{\left(\widehat{c}_{\ell}(\vec{t}) - \widehat{c}_{\ell}(\bar{t})\right)}{(\vec{t} - \bar{t})} \qquad \text{(see Appendix E)}$$

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

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.

E. 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:

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