FINAL REPORT

ITS Impacts Assessment for Seattle MMDI Evaluation: Modeling Methodology and Results

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ABSTRACT

At the request of the Joint Program Office (JPO) for Intelligent Transportation Systems (ITS) of the Federal Highway Administration (FHWA), Mitretek Systems has conducted a modeling analysis of ITS impacts in support of the Metropolitan Model Deployment Initiative (MMDI) evaluation program. The Mitretek modeling effort supports the evaluation of the Seattle model deployment, Smart Trek, through impact analysis in the areas of Advanced Traveler Information Services (ATIS), Advanced Traffic Management Systems (ATMS), and Incident Management Systems (IMS). Of particular interest to this modeling study (as well as the overall MMDI effort) is the quantification of likely impacts from data sharing or integrated control between functional areas (ATIS, ATMS, and IMS) and across jurisdictions. This document presents the methodology of the study and details findings for a mixed freeway/arterial corridor model drawn from the roadway network north of downtown Seattle. Impacts are characterized in terms of near-term peak period delay reduction, travel time reliability, changes in regional mode choice, corridor travel throughput, fuel consumption, emission rates, and other measures.

KEYWORDS: Intelligent Transportation Systems, Federal Highway Administration, benefits, modeling, simulation, Advanced Traveler Information systems, Advanced Traffic Management Systems, Metropolitan Model Deployment, evaluation, Smart Trek.

EXECUTIVE SUMMARY

At the request of the Joint Program Office (JPO) for Intelligent Transportation Systems (ITS) of the Federal Highway Administration (FHWA), Mitretek Systems has conducted a modeling analysis of ITS impacts in support of the Metropolitan Model Deployment Initiative (MMDI) evaluation program. The Mitretek modeling effort supports the evaluation of the Seattle model deployment, Smart Trek, through impact analysis in the areas of Advanced Traveler Information Services (ATIS), Advanced Traffic Management Systems (ATMS), and Incident Management Systems (IMS). Of particular interest to this modeling study (as well as the overall MMDI effort) is the quantification of likely impacts from data sharing or integrated control between functional areas (ATIS, ATMS, and IMS) and across jurisdictions. This document presents the methodology of the study and details findings for a mixed freeway/arterial corridor model drawn from the roadway network north of downtown Seattle. Impacts are characterized in terms of near-term peak period delay reduction, travel time reliability, changes in regional mode choice, corridor travel throughput, fuel consumption, emission rates, and other measures.

Background

Mitretek, in the JPO-sponsored study "Incorporating ITS into the Planning Process" predating the MMDI effort [2], developed an evaluation methodology and a set of network models of Seattle suitable for the assessment of ITS impacts at a subarea and regional level. When the MMDI evaluation program began, MMDI team leaders recognized that leveraging existing Mitretek modeling resources was a logical and efficient option in support of Smart Trek evaluation, especially given the long lead times and expense associated with large-scale simulation network development and calibration.

The previous Mitretek modeling study projected localized and regional impacts in the year 2020 from a range of potential transportation system improvements within a 120-square mile freeway/arterial corridor north of the Seattle central business district (Figure ES-1). However, the 2020 forecast year models and data sets were not constructed with MMDI projects in mind, and Mitretek had to modify and re-calibrate them to reflect the near-term MMDI evaluation effort. New travel demand was estimated for the North Corridor model based on a forecast for the 1997/1998 evaluation time frame. Calibration of the network for MMDI evaluation included a flow analysis as well as a calibration of within-peak travel time variation and day-to-day reliability of freeway travel.

The area represented by the North Corridor model features a highly utilized multi-modal transportation system, with significant travel delays during both the morning and evening peak travel demand period. Many of the ITS enhancements associated with the MMDI evaluation effort are planned or operational within the North Corridor; however, some are deployed outside the subarea and cannot be assessed with the North Corridor modeling system. Altogether, Mitretek modeling analysis in the North Corridor provides direct evaluation support to 13 of 26 projects in Seattle selected for evaluation as a part of MMDI ranging from ATIS provision, traffic signal control improvements, and incident management enhancements.

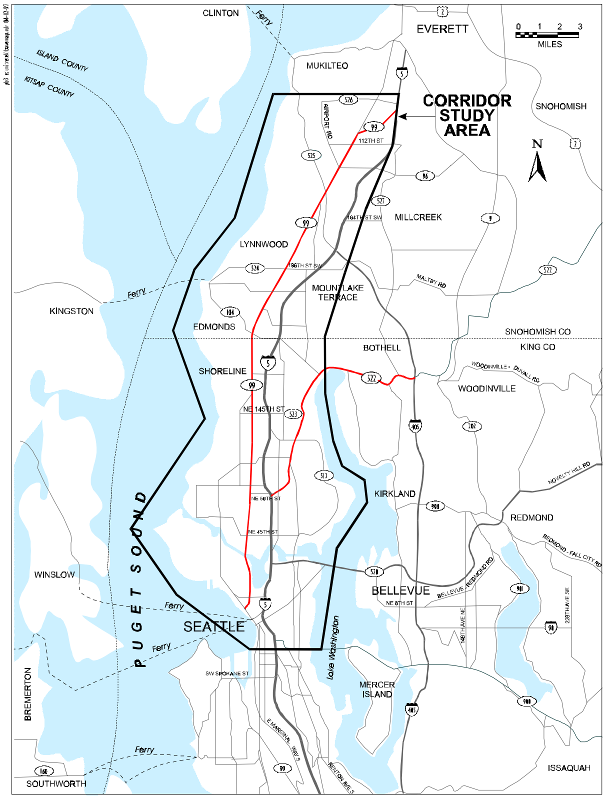

Figure ES-1. The Seattle North Corridor Study Area

Role of Modeling

The Mitretek modeling analysis effort for MMDI has focused on project features that are difficult to evaluate with direct field measurement. For example, during the evaluation period, overall travel demand rose concurrently with overall utilization of web-based ATIS. Differentiating these impacts would be problematic at best using the existing data collection methods in the Seattle area (primarily loop detectors). In cases like this, models are helpful in systematically and independently quantifying the impacts of concurrent factors such as rising travel demand or web-based ATIS usage.

Likewise, the modeling effort also assists local MMDI partners in projective analyses of interest regarding specific projects. For example, MMDI-related improvements in arterial data collection and archiving facilitate the development of coordinated inter-jurisdictional traffic signal plans along major arterial corridors. However, participating jurisdictions are reluctant to implement these plans until impacts to both local and through traffic can be estimated. In cases such as these, models are helpful in providing insight before a commitment to full implementation is made.

The focus of the modeling and simulation work is a reflection of the role it plays in supporting both national MMDI evaluation goals and the goals of the local Smart Trek participants. In support of the national evaluation, for example, the modeling work seeks to quantify relationships between rising ATIS market penetration and measures of overall system impacts such as throughput or energy consumption. Likewise, some experiments address more specific hypotheses of local interest. For example, in the traffic signal case discussed above, that integrated data collection, archiving and cross-jurisdictional cooperation have positive impacts on network efficiency both along and within the arterial corridor. In order to meet these goals, the intent of the Mitretek modeling effort is not to explicitly evaluate the impact of each MMDI project, although where such impacts can be reliably estimated these impacts will be highlighted. Rather, the focus is on testing hypotheses related to national or local goals, and on benchmarking impacts in Seattle from the deployment of newly integrated ITS capabilities in the MMDI time-frame.

Summary of Evaluation Approach

Mitretek has developed an ITS evaluation methodology, the Process for Regional Understanding and EValuation of Integrated ITS Networks (PRUEVIIN). It features a traditional four-step transportation planning model as well as a traffic simulation to capture regional and corridor-level ITS impacts. For this study, EMME/2 is implemented as the transportation planning model and INTEGRATION 1.5 is implemented as the simulation model. Transportation planning analyses typically deal with various infrastructure deployment plans or alternatives to meet forecast transportation needs for a particular corridor.

The performance of each alternative is evaluated using a combination of a planning model and a simulation. The regional planning model is employed to identify impacts on travel demand including trip distribution, mode choice and regional assignment. The regional travel demand model represents long-term adaptation by the travelers in the system to average conditions experienced in the peak period.

Measuring ITS impacts over a range of conditions is a key element in accurately calculating annualized impacts. As depicted in Figure ES-2, impacts analysis is often conducted under “normal” conditions: an assumption of invariant average travel demand, clear weather and no accidents in the roadway system. However, the reality of the urban travel is quite different from this notion of normality. In fact, ITS typically has a greater impact when unusual conditions prevail, i.e., snow, special events, and major incidents. Particular types of ITS enhancements may be beneficial in very different situations. Accounting for these ITS impacts under various conditions is critical for an accurate evaluation, as is identifying the relative frequency of each event.

Accordingly, the simulation is exercised through a series of 30 scenarios. Each scenario represents a particular combination of weather impacts, travel demand variation, as well as a pattern of incidents and accidents in the corridor. The scenarios were derived from a cluster analysis of traffic flow data (for variations in day-to-day travel demand) and weather/incident impacts (taken from historical archives). Each scenario has a probability of occurrence. The scenarios taken together comprise a representative year of operation. The use of representative day scenarios within the PRUEVIIN framework facilitates the analysis of system variability for ITS evaluation.

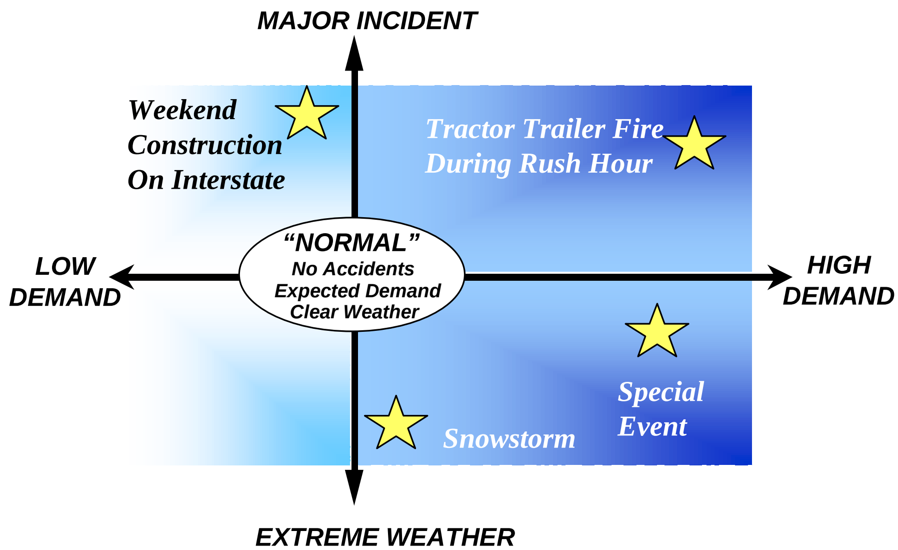

Figure ES-2. Potential Range of Conditions for ITS Evaluation

Simulation analysis over the representative year of operation allows for a meaningful linkage between the two modeling scales. Travel time impacts by scenario can be rolled into an annual average and compared with baseline travel in the regional model. These differences can then be analyzed to examine potential shifts in regional demand patterns. Examples of changes to trip patterns include changes in trip length, mode split, and shifting of demand between parallel corridors.

Evaluation of ITS Enhancements: Project Groupings

Project groupings are used to identify Smart Trek projects that utilize the same kinds of technologies or integrate similar traffic control components. Hypothesis are tested and impacts reported by project groupings, not by individual project. In some cases, projects are grouped because the impact of a single project acting in isolation has either no impact or an impact that cannot be measured in modeling. For example, the On-Scene Incident Video project alone has no impact unless it is coordinated through the WSDOT Northwest Region Transportation Management Center and linked to more effective incident management. In this case it is only natural to consider projects together when they support a particular ITS component or user service. Four project groupings are used here for the evaluation of ITS enhancements: ATIS, ATMS, IMS and Integration (enabling a range of potential integrated deployments between the ATIS and ATMS project groupings).

The ATMS grouping includes projects that serve to archive and consolidate arterial traffic data from a number of sources in a central location. The ATIS project grouping comprises a collection of pre-trip and en route information services presenting current congestion conditions based on real-time Washington State Department of Transportation (WSDOT) freeway detector data. The IMS grouping is composed of projects that (among other goals) seek to improve detection, response time, and freeway system efficiency under incident conditions. The Integration grouping contains only one project, ITS Backbone, which allows for data collected from arterial sensors for the purpose of traffic signal control to be utilized in support of ATIS. First, this cross-functional data sharing capability is evaluated with respect to improved ATIS real-time coverage in isolation from any changes to traffic signal control. Second, a cross-functional (ATIS/ATMS) integrated deployment is evaluated with concurrent improvements to traffic signal control as well as more comprehensive ATIS provision. This cross-functional deployment is called the Enhanced ITS alternative. The Enhanced ITS alternative is evaluated using both the regional and corridor simulation models to evaluate the potential "big-picture" impact of integrated ITS deployment on regional travel. All other analyses, or sensitivity analyses for ATIS, ATMS, and IMS stand-alone deployments are conducted within the simulation model alone. An overview of the experimental plan for this study is presented in Figure ES-3.

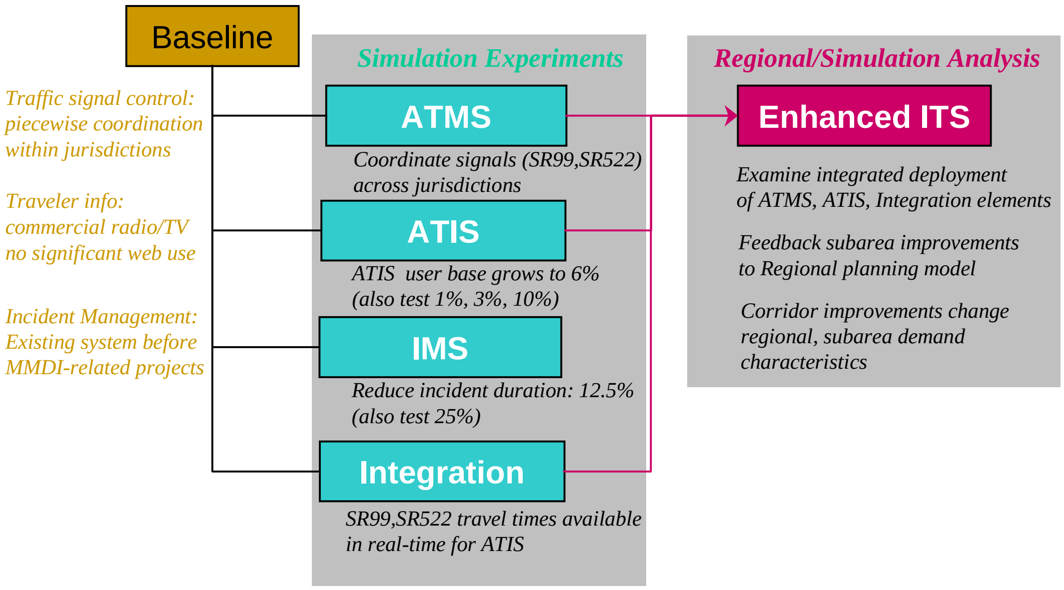

Figure ES-3. Experimental Overview

Measures of Effectiveness

Results are reported by project grouping. Each experiment is described in terms of hypothesis, experimental controls, network efficiency impacts (delay reduction and throughput), as well as energy and emissions impacts. Each experiment is compared with a uniform Baseline case; representing long-standing traveler information services and traffic management systems deployed in the corridor. For example, commercial traffic reporting and ramp metering control on I-5 are considered to be elements of the Baseline case.

Subarea Impact Measures: For network efficiency impacts, data is collected for all vehicles that begin trips in the network between 6:15 AM and 9:00 AM in the North Corridor. For these trips, average delay is calculated as the difference between the average travel time in each scenario and free-flow (50% of average demand, no accidents in the system, good weather) travel times. *Delay reduction* is calculated by expressing the difference in average delay between the Baseline case and the experimental case as a percentage of Baseline average delay. *Throughput* measures the number trips starting in the 6:15-9:00 time frame that can finish before the end of the peak period at 9:30 AM. Delay reduction and throughput measures are calculated for each scenario. An annualized figure is then calculated by computing a weighted average of across all scenarios. System *coefficient of variation* is calculated by examining the variability of travel time for similar trips in the system taken across all scenarios. This statistic is an indicator of the reliability of travel time in the corridor.

Speed and stops across the network are archived by link in each run of the simulation between 6:00 AM and 9:30 AM. Speed profiles are then normalized by total vehicle-kilometers of travel in the system to create the statistic *percentage of vehicle-kilometers of travel by speed range*. A similar technique is applied to stops estimated by the simulation at a link level. The *expected number of stops per vehicle-kilometer of travel* is the measure used in comparison with the Baseline case.

Link-level speed and stop data are used to drive an energy and emissions post-processor developed for MMDI evaluation at the Virginia Polytechnic Institute and State University [3]. Energy estimates are calculated *as total liters of fuel consumed*. Total emissions of *hydrocarbons* (HC), *carbon monoxide* (CO) and *nitrates of oxygen* (NOx) are also estimated. A related safety post-processor [4] utilizes total vehicle-kilometers and total vehicle-seconds of travel by speed range reported by the simulation to predict *total crashes* and *total fatal crashes*.

Subarea measures of effectiveness are obtained from simulation model runs. A paired t-test analysis is performed on each measure to determine the relative level of statistical significance of the results against inherent randomness in the simulation.

Regional Impact Measures: Regional impact measures are obtained from the regional four-step planning model runs. The impacts of corridor improvements on regional travel demand patterns are reported in terms of *transit mode share*, *auto mode share, trip length* and *trip speed*. Similar measures are also used to characterize travel demand originating in or traveling to or through the North Corridor. Additional travel demand attracted to the corridor because of improved performance is reported as *additional corridor demand*. Regional impact measures are only reported in the Enhanced ITS Alternatives Analysis.

ATIS Experiment: Hypothesis, Controls and Findings

Hypothesis: At an estimated near-term rate of ATIS usage, the provision of primarily pre-trip traveler information services containing more accurate, frequently updated quantitative freeway travel time estimates reduces overall travel delay and variability, improves system throughput, and reduces the total number of vehicle-stops.

Experimental Controls: The ATIS experiment attempts to capture current and projected near-term impacts on the North Corridor from the rising utilization of various traveler information services. MMDI projects represented in the ATIS experiment include Microsoft Sidewalk Traveler Information, Etak/Metro Traffic Control Traveler Information, Fastline Hand-held PC, Traffic Channel on Cable TV, WSDOT Web Page and Traffic Telephone Information Line. The simulation modeling used to evaluate ATIS impacts cannot differentiate between media employed to deliver similar messages at the same decision point in the trip. However, the model can discriminate based on whether the information is provided pre-trip or en route, the coverage area, and the level of message detail. An example of message detail is the difference between a variable message sign indicating “congestion ahead” versus a detailed quantitative assessment of delay with precise location ("current travel time for I-5 is 12.5 minutes between exit 3 and exit 4").

Traveler information services in the baseline case provide incident, construction, and other emergency road closure information on radio, TV, variable message signs and highway advisory radio, as they have been in Seattle for many years. In the ATIS case, visual displays of I-5 freeway travel congestion throughout the system are available, thereby allowing the traveler to more effectively gauge likely travel time for an intended trip. In the baseline case, route choice decisions are made under greater uncertainty about the delays associated with incidents, weather or recurrent bottlenecks. In the ATIS case, travel choices are made with lesser uncertainty because a current estimate of travel time is provided to the user. PSRC panel survey data (1997) indicates that 16% of travelers hear traffic reports pre-trip, primarily through commercial media. The assumption tested in this experiment is that pre-trip information users migrate to the collection of higher fidelity ATIS pre-trip services represented by the MMDI projects listed above. An overall higher-fidelity ATIS usage rate of 6% is used for this experiment (roughly 1 out of every three pre-trip information users) based on the extrapolation of PSRC panel survey rates and the website user session growth since the time of the survey. Since there is a great deal of uncertainty about this figure, a sensitivity analysis around the 6% figure is also conducted, included in the full report but not discussed here.

Table ES-1. System Efficiency Impacts, ATIS Experiment

Measure per Average AM Peak Period, North Corridor Subarea	Baseline	ATIS	Change	% Change
Vehicle-Hours of Delay	17,879	17,619	-260	-1.5%
Vehicle Throughput	209,372	209,382	+10	+0.0% (NS)
Coefficient of Trip Time Variation	.242	.236	-.006	-2.5%
Vehicle-Km of Travel	3,438,000	3,436,000	-2,000	-0.1% (NS)
Total Number of Stops	1,200,000	1,201,000	+1,000	+0.1% (NS)

(NS) = not statistically significant vs. baseline at 90% confidence level

Network Efficiency Impacts: The ATIS experiment indicates that the improvements modeled have limited but positive annual impact on overall system performance (Table ES-1). In each AM Peak Period, total system delay for the North Corridor is reduced by 260 vehicle-hours, a 1.5% reduction. An average of 10 additional vehicles per day traverse the network, although this increase is too small to be statistically significant. Travel is more reliable as travel time variation is reduced by 2.5%.

ATIS impact is highest in scenarios with poor weather, heavy demand, freeway accidents or any combination of these factors. Eighty percent of the total delay reduction attributable to ATIS improvements is accounted for in scenarios with a combined probability of 28%.

More precise freeway congestion information is consistently helpful to certain kinds of trips in the system. These are not the long freeway-based trips usually associated with ATIS but mid-range trips (18-25 km) within the subarea that cross I-5. An example of such a trip is from Edmonds to the University of Washington southeast across the corridor. These travelers can access I-5 at several exits or bypass it altogether when choosing from a set of relatively competitive alternative routes. Users of the pre-trip information service reduce their average delay by 3.9% (vs. 0.9% for the system) and have more reliable trips than non-users.

The impact on facility speed is indeterminate in nature. The amount of travel occurring in the system with fewer than 0.25 stops per kilometer increases by roughly 9 percent. A small improvement in expected stops per kilometer can be observed for freeway travel. Stops per kilometer on non-freeway facilities do not change significantly.

Table ES-2. Energy and Emissions Impacts, ATIS Experiment

Measure per Average AM Peak Period	Baseline	ATIS	Change	% Change
Fuel Consumption (l)	354,620	354,230	-390	-0.1% (NS)
HC Emissions (kg)	390.0	389.6	-0.4	-0.1% (NS)
CO Emissions (kg)	7043	7020	-23	-0.3% (NS)
NOx Emissions (kg)	846.2	843.9	-2.3	-0.3% (NS)

(NS) = not statistically significant vs. baseline at 90% confidence level

Energy and Emissions Impacts: The ATIS experiment resulted in a small decrease in subarea travel and a small increase in total vehicle stops. These changes translate into small positive impacts on subarea energy consumption and total emissions using the Virginia Tech post-processor (Table ES-2). Viewed against the inherent randomness in the simulation, however, none of these changes can be shown to be statistically significant.

Safety Impacts: The ATIS experiment indicates a decrease in the number of crashes by 0.6%. The reduction in crashes of all types is related to an overall increase in subarea travel speeds. The post-processor employed for the safety analysis generally predicts fewer crashes at higher speeds, but the risk of these crashes being fatal increases. In this case, the overall reduction in crashes also reduces fatal crashes. The expected number of fatal crashes over a ten year period was reduced from 114.9 to 114.4, a 0.4% decrease.

ATMS Experiment: Hypothesis, Controls and Findings

Hypothesis: Improvements in arterial signal coordination along SR99 and SR522 from jurisdictional cooperation and adjusting southbound progression speed for expected average queues at intersections improves corridor throughput and efficiency.

Experimental Controls: The ATMS experiment attempts to capture impacts on the North Corridor from a prospective re-timing of signals along two major arterials. This prospective re-timing is enabled by the North Seattle ATMS project, which archives detector data collected along the arterials at the Northwest TSMC.

Current signal timing plans along the two major arterials can be characterized as fixed-timing plans optimized for peak period flow with piece-wise coordination within jurisdictions. In the case of SR99, there are four jurisdictions; along SR522 there are two. Progression along the corridors is generally set close to posted speed limits. Signal timing plans based on these assumptions were implemented in the simulation as the default baseline plan.

Three distinct effects of this prospective re-timing project are modeled in the simulation as a part of this experiment:

- The impact of coordinating signals at major intersections from “top to bottom” along SR99 and SR522 without regard to the current jurisdictional boundaries.

- The coordination of minor signals along these same corridors at variable progression speeds between major intersections.
- The calculation of progression speeds between major intersections based both on speed limit and adjustment made to offset timings based on average peak-period queue length. The adjustment for queue dispersion along SR99 and SR522 was calculated using trial-and-error optimization under average travel demand.

Table ES-3. System Efficiency Impacts, ATMS Experiment

Measure per Average AM Peak Period, North Corridor Subarea	Baseline	ATMS	Change	% Change
Vehicle-Hours of Delay	17,879	16,661	-1,218	-7.0%
Vehicle Throughput	209,372	209,774	+402	+0.2%
Coefficient of Trip Time Variation	.242	.237	-.005	-2.1%
Vehicle-Km of Travel	3,438,000	3,455,000	+17,000	+0.4%
Total Number of Stops	1,200,000	1,167,000	-33,000	-2.7%

Network Efficiency Impacts: The ATMS experiment indicates that the improvements modeled have a measurable impact on overall system performance (Table ES-3). Total system delay for the North Corridor is reduced by 1,218 vehicle-hours in the AM peak period, a 7.0% annualized reduction. An average of 402 additional vehicles per peak period traverse the network, a 0.2% increase. Travel is slightly more reliable as travel time variation is reduced by 2.1%.

The impact of signal re-timing is broadly distributed over a range of scenarios. Eighty percent of the total delay reduction attributable to ATMS improvements is accounted for in scenarios with a combined probability of 67%. Highest delay reduction is realized in scenarios where the ratio of travel demand to network capacity is close to expectation. That high performance is located close to expectation is not surprising, given that the signal timing plans have been optimized for this condition. Improved performance is not seen in all scenarios, however, including some cases of marginally reduced throughput and increased delay. These negative impact cases occur in extreme high demand scenarios or in snow conditions, indicating that the signal timing plans optimized for average conditions may be less than optimal under extreme conditions.

The impact on facility speed is small but positive, particularly for urban arterials. Stops overall are reduced by 2.7%. Stops are reduced along urban arterial system, as expected, but freeway links also see a reduction in stops. This may be indicative of increased travel load being borne by the arterial system, freeing up capacity on the freeways.

Table ES-4. Energy and Emissions Impacts, ATMS Experiment

Measure per Average AM Peak Period	Baseline	ATMS	Change	% Change
Fuel Consumption (l)	354,600	355,600	+1,000	+0.3% (NS)
HC Emissions (kg)	390.0	392.6	+2.6	+0.7% (NS)
CO Emissions (kg)	7043	7116	+73	+1.0% (NS)
NOx Emissions (kg)	846.2	850.2	+4.0	+0.5% (NS)

(NS) = not statistically significant vs. baseline at 90% confidence level

Energy and Emissions Impacts: A reduction in overall stops does not fully compensate for the 0.4% increase in subarea travel in the emissions analysis (Table ES-4). Overall, small increases are indicated for fuel consumption and the three pollutants, but none of these increases are statistically significant when compared with the inherent randomness in the simulation.

Safety Impacts: Overall, the expected number of crashes decreased by 2.5%. The total number of fatal crashes projected over a ten-year period decreased by 1.1%, from 114.9 to 113.7. This reduction can be attributed to a shift from lower-speed travel (in particular for ATMS from the 32-40 kph range) to higher-speed travel (60-80 kph range).

IMS Experiment: Hypothesis, Controls and Findings

Hypothesis: A reduction in incident duration improves throughput and efficiency.

Experimental Controls: In this experiment, we reflect system level impacts resulting from the ability of highway patrol, WSDOT, and emergency medical service providers to coordinate their response to incidents. Relevant MMDI projects include Regional Video Sharing, Incident Information Capture, On-Scene Incident Video, and Emergency Operations Center Coordination. Reaction to an incident may be characterized by detection time, response time (time to getting the first unit to the incident site), and time-to-removal. In this experiment, we assume that there is no change from the current incident detection and response times of 4 and 6 minutes, respectively. However, we do assume some reduction in incident duration because of increased coordination among responding agencies. Estimates in Seattle of such impacts are not currently available; however, we attempted to estimate this impact by using data from a similar study in Houston where a 25% reduction in incident duration was reported. Given the incremental nature of the MMDI-related enhancements relative to the existing incident management infrastructure in Seattle, a more conservative 12.5% incident duration reduction was selected for evaluation. These reductions were implemented only for accidents occurring along SR99 and I-5.

Network Efficiency Impacts: IMS impacts are concentrated in scenarios that have major incidents or large numbers of accidents on SR99 and I-5. Eighty percent of the delay reduction from improved IMS occurs in scenarios with a combined probability of roughly 5%. The timing and location of incidents are critical in terms of IMS effectiveness. Major disruptions on the freeway when combined with heavy demand or snow show the most significant impact. Benefit is highly concentrated, even in the freeway incident cases, among users traveling particular facilities at particular times. One may characterize IMS impacts as the most highly concentrated (of the three sensitivity analyses) in terms of geography, trip timing, and scenario. At the 12.5% incident duration reduction, however, no significant impacts can be measured for overall annualized delay or other impact measures. A sensitivity analysis at the 25% blockage duration reduction level showed an annualized reduction of roughly 90 vehicle-hours of delay per AM peak period.

Energy and Emissions Impacts: Small changes in energy and emissions impacts are indicated for the IMS experiment. These changes are so small, however, that they are statistically too small to measure over the inherent randomness in the simulation.

Safety Impacts: Small system-level changes in travel speed result in safety impacts that cannot be measured over the inherent randomness in the simulation.

Arterial Data for ATIS Integration Experiment: Hypothesis, Controls and Findings

Hypothesis: The provision of arterial travel time estimates from SR99 and SR522 to ATIS users improves overall system efficiency.

Experimental Controls: This experiment models the integration of data from arterial loop detectors along SR99 and SR522 into the freeway-based ATIS available on the WSDOT website and other media. The baseline case assumptions remain the same as in the ATIS and ATMS experiments. No changes to existing traffic signal control along the two arterials are modeled, the only change is that users of ATIS may now consider real-time estimates of congestion on the two arterial routes in addition to I-5 conditions when making travel decisions. We assume the arterial data is updated every 15 minutes and is provided as a combined estimate of both link travel time and intersection delay.

Table ES-5. System Efficiency Impacts, Arterial Data for ATIS Experiment

Measure per Average AM Peak Period, North Corridor Subarea	Baseline	ATIS (+ Arterials)	Change	% Change
Vehicle-Hours of Delay	17,879	17,308	-571	-3.4%
Vehicle Throughput	209,372	209,575	+203	+0.1%
Coefficient of Trip Time Variation	.242	.239	-.003	-1.2%
Vehicle-Km of Travel	3,438,000	3,443,000	+5,000	+0.2%
Total Number of Stops	1,200,000	1,134,000	-66,000	-5.5%

Network Efficiency Impacts: The provision of arterial data roughly triples the overall system impact of ATIS in the North Corridor. Vehicle hours of delay are reduced by 571, a 3.4% decrease. Vehicle throughput is also higher, with an additional 203 vehicles successfully traversing the network on average each AM peak period. Trip time reliability is improved by 1.2%. Total travel is slightly increased, while stops are decreased by 5.5%.

Overall, it is clear that the provision of travel time estimates on the primary alternatives to I-5 in the North Corridor allows travelers to make more efficient route choice decisions. Patterns of use are also changed – total freeway to arterial diversion decreases when the arterial data appears in ATIS. This is because unwarranted diversions away from the freeway are reduced given that travelers now have a more current accurate estimate of arterial performance.

Table ES-6. Energy and Emissions Impacts, Arterial Data for ATIS Experiment

Measure per Average AM Peak Period	Baseline	ATIS (+ Arterials)	Change	% Change
Fuel Consumption (l)	354,620	351,730	-2,890	-0.8%
HC Emissions (kg)	390.0	382.8	-7.2	-1.9%
CO Emissions (kg)	7043	6830	-88	-3.0%
NOx Emissions (kg)	846.2	820.6	-25.6	-3.0%

Energy and Emissions Impacts: A 5.5% drop in number of stops under relatively stable total travel results in across the board improvements in energy efficiency and emissions reductions. Most notably, a 3.0% reduction in total CO emissions and total NOx emissions is indicated, primarily the result of a reduction in high-speed stops. A smaller reduction is indicated for HC, while overall fuel consumption drops by 0.8%.

Safety Impacts: Overall, the expected number of crashes decreased by 1.0%. The total number of fatal crashes projected over a ten-year period decreased by 0.3%, from 114.9 to 114.6.

Enhanced ITS Alternatives Analysis: Hypothesis, Controls and Findings

Hypothesis: Implementing an integrated deployment combining ATIS and ATMS technologies improves system throughput and efficiency.

Experimental Controls: The Enhanced ITS Alternative is a prospective integrated deployment of the improvements made as a part of the ATIS and ATMS experiments. Thus, it features an improved signal coordination system on SR99 and SR522, and a user base of 6% of travelers using ATIS that includes both I-5 freeway congestion estimates as well as travel time estimates along SR99 and SR522. However, this alternatives analysis is different than the simulation experiments discussed thus far because it involves the utilization of regional and subarea modeling in the PRUEVIIN framework. With the presence of the regional model in the analysis, changes in corridor travel demand in response to system capacity improvements can be assessed. In this analysis, we have isolated the impacts of the Enhanced ITS alternative with and without changes to regional travel demand.

Regional Travel Impacts: Overall, the impacts of the improvements at the regional level are logical, but relatively small. A slight shift from transit to the auto modes (-0.14%) is seen due to the improvements. Trips are longer (+0.4%) and have improved speeds (+0.6%). There is also a diversion of roughly 1,000 trips during the AM peak period to the simulation area, primarily from the travel on I-405 to the east of the North Corridor. Thus, the travel demand with feedback seen in the subarea is 0.4% higher than without feedback, and these new trips introduced into the subarea are longer on average than in the baseline demand case.

Subarea Network Efficiency Impacts: A summary of network efficiency impacts associated with the Enhanced ITS alternative with feedback to the regional model is presented in Table ES-7. The integrated deployment reduces overall subarea delay by 6.1% while carrying additional 1,300 vehicles in the AM peak period. Subarea travel increases by 0.9% although total number of stops drops by 4.7%.

Table ES-7. System Efficiency Impacts, Enhanced ITS Experiment
(with feedback to regional model)

Measure per Average AM Peak Period, North Corridor Subarea	Baseline	Enh. ITS (with feedback)	Change	% Change
Vehicle-Hours of Delay	17,879	16,893	-986	-6.1%
Vehicle Throughput	209,372	210,704	+1,331	+0.7%
Coefficient of Trip Time Variation	.242	.241	-.001	-0.4%
Vehicle-Km of Travel	3,438,000	3,487,000	+49,000	+1.4%
Total Number of Stops	1,200,000	1,149,000	-51,000	-4.3%

Table ES-8. System Efficiency Impacts, Enhanced ITS Experiment
(no feedback to regional model)

Measure per Average AM Peak Period, North Corridor Subarea	Baseline	Enh. ITS (no feedback)	Change	% Change
Vehicle-Hours of Delay	17,879	16,534	-1,345	-7.8%
Vehicle Throughput	209,372	210,007	+635	+0.3%
Coefficient of Trip Time Variation	.242	.233	-.008	-3.3%
Vehicle-Km of Travel	3,438,000	3,453,000	+15,000	+0.4%
Total Number of Stops	1,200,000	1,144,000	-55,000	-4.6%

The impact of regional feedback can be seen by comparing these results against the Enhanced ITS analysis performed under baseline travel demand in Table ES-8. In this case, higher delay reduction is seen (7.8%) as well as a reduction in trip time variability (3.3%), while the increase in throughput is lower (0.3%). This result stems from the fact that under feedback to the regional model, the improvements in the subarea attract new demand to the improved facilities. The new demand raises the overall level of congestion in the network, resulting in increased throughput but lower delay reduction and higher trip time variability.

Table ES-9. Subarea Energy and Emissions Impacts, Enhanced ITS Experiment
(with feedback to regional model)

Measure per Average AM Peak Period	Baseline	Enh. ITS (w/feedback)	Change	% Change
Fuel Consumption (l)	354,620	355,130	+510	+0.1% (NS)
HC Emissions (kg)	390.0	387.8	-2.2	-0.6% (NS)
CO Emissions (kg)	7043	6955	-88	-1.3% (NS)
NOx Emissions (kg)	846.2	835.7	-10.5	-1.3%

(NS) = not statistically significant vs. baseline at 90% confidence level

<u>Subarea Energy and Emissions Impacts</u>: The combination of more subarea travel and reduced stops results in a mixed bag of energy and emissions impacts. A statistically significant reduction in NOx emissions is indicated (-1.3%). HC and CO emissions are also lower, although these changes do not meet the 90% confidence interval for statistical significance. Although total fuel consumption is slightly higher, tracking an increase in total travel, average vehicle fuel economy (miles per gallon) improves by 1.3% to 23.5 mpg from 23.2 in the Baseline case.

Safety Impacts: Overall, the expected number of crashes decreases by 1.9%. Total fatal crashes expected over a ten-year period in the corridor increases 0.8% from 114.9 to 115.8. This increase is a result of both higher travel speed and increased travel in the corridor. Fatal accident rates per million vehicle kilometers traveled actually decline 0.6%.

Discussion and Conclusions

A key feature of the MMDI evaluation effort is in the identification of benefits associated with the deployment of integrated ITS, rather than stove-pipe functional or jurisdictional systems. The Seattle MMDI deployment has examples of both functional (utilization of arterial congestion data for both traffic signal control and ATIS) and jurisdictional cooperation (traffic signal coordination along major arterial corridors). Based on the full range of assessments conducted in this study, some key observations can be made on the impact of integrated ITS systems.

The *benefit of jurisdictional cooperation for signal control* is illustrated in the impacts associated with the ATMS experiment. The combination of better data on arterial queue length in the AM peak and the coordination of signals at variable progression speeds (both major and minor) is projected to reduce system-wide delay by 7%. The subarea model available for this effort and the experiments performed are not detailed enough to produce a traffic signal timing plan that can be directly implemented in the field. However, for traffic engineers in Seattle, Lynnwood and other jurisdictions in the North Corridor, the 7% delay reduction provides a quantitative estimate of potential benefit that can be used in prioritizing the development of a detailed plan for SR99 or SR522. Further, the delay reduction figure demonstrates to local jurisdictions that cooperation on timing plans has a quantifiable potential benefit, bolstering an argument that was heretofore conjecture.

Another useful observation concerning jurisdictional cooperation for signal control is that although well-timed plans are generally beneficial, the range of conditions (particularly the combination of weather and travel demand variations) seen in the North Corridor cannot always be satisfied with a single fixed plan. A case can be made, therefore, that *even more benefit could reasonably be expected if alternative plans could be implemented* for particular observed conditions. For example, a coordinated plan with shorter cycle lengths and faster progression speeds could be developed for light demand conditions. This signal control strategy would require cooperation between jurisdictions on a day-to-day basis to select the appropriate coordinated plan from a list of approved alternatives.

ATIS has largest impact during conditions associated with the worst congestion: heavy demand, major accidents or extreme weather. Eighty percent of the total delay reduction from ATIS is accounted for a set of scenarios with a combined probability of 28%. This set is composed of scenarios with either heavy demand, a major accident, extreme weather, or a combination of these factors. ATIS effectiveness under these conditions is reflected in its impact on travel time variability. In the ATIS experiment an average of 260 hours of vehicle delay is eliminated each AM peak, compared with 1,218 hours in the ATMS experiment. However, the ATIS impact on annual travel time variability (-2.5%) is larger than the ATMS experiment (-2.1%).

Integrating arterial congestion data with freeway-based ATIS clearly improves the effective utilization of ATIS by the travelers modeled in the North Corridor. The delay reduction associated with a 6% usage rate in the AM peak more than doubles from 1.5% to 3.4% when congestion data on parallel arterial facilities (SR99 and SR522) is made available to ATIS. User delay reduction is similarly enhanced. This larger impact should be interpreted understanding the focus of the evaluation network on corridor-specific travel. Travelers planning for long trips from the extreme north to south within the Puget Sound region, e.g. Everett to Tacoma, have freeway-to-freeway alternatives (I-5 vs. I-405) that are not represented by the current North Corridor model. The range of choices is limited to the corridor level (SR99 vs. I-5), so we expect some underestimation of benefit for these types of trips. Providing arterial congestion data is likely more useful for the inter-corridor, moderate length trip maker (e.g., Edmonds to the University of Washington campus) than for the long regional trip maker.

Another goal for MMDI evaluation is to *quantify the overall system impacts of integrated ITS compared with isolated deployments of ITS functional components*. An examination of the conditions where benefit can be expected from each functional component is illustrative of how these functional components may be interacting. For example, IMS and ATIS have highest impact in many of the same situations, primarily corresponding to freeway incident cases and extreme weather cases. Traffic signal control impacts are insensitive to incidents and have highest impact where the ratio of travel demand to roadway capacity is close to expectation. In scenarios where impact by functional component overlaps, impacts from adding in a new functional component is diluted by the simple fact that there is less delay to eliminated.

At the corridor level, projected energy and emission impacts associated with MMDI-related ITS enhancements are small and indeterminate. Overall energy consumption in the corridor is projected to increase as additional travel demand is drawn into the more efficiently operating corridor roadway system. However, fuel economy (on a miles-per-gallon basis) within the corridor is slightly improved because of reduced stop-and-go traffic conditions. Overall emissions of pollutants (HC, CO, and NOx) are generally slightly lower, but in many cases these reductions are too small to be statistically significant. A key observation is that the smoother traffic flow (defined in terms of stops/vehicle-km) associated with MMDI-related ITS enhancements improve corridor throughput without an increase in overall emissions.

Projected corridor-level safety impacts are small but positive. Using an analysis of travel speed and crash rates, the MMDI-related ITS enhancements generally produce slightly higher travel speeds and hence less frequent crashes. Although the proportion of all crashes that involve at least one fatality increases with travel speed, the overall number of fatal crashes typically remains steady because of the overall reduction in total crashes.

Another observation that can be made is that the impacts associated with the Enhanced ITS alternative are relatively small when compared with the impacts projected for fully integrated end-state ITS deployments like the one tested in the Seattle 2020 analysis. The difference in impact is reflective of the significant difference in how much ITS is deployed in each case. For example, the 2020 ITS Rich alternative features comprehensive adaptive ATMS arterial control, integrated freeway/arterial surveillance supplemented by probe vehicles for ATIS, and higher usage rates for advanced pre-trip and en-route traveler information services. The Enhanced ITS alternative is best viewed as an evolutionary step towards such a fully integrated ITS deployment.

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SECTION 1: INTRODUCTION

The purpose of this document is to present the methodology and findings of a modeling study conducted by Mitretek Systems in support of the evaluation of the Metropolitan Model Deployment Initiative (MMDI) program. This section describes the background of the study, the objectives of the experimental plan, the role of modeling with respect to national and local evaluation goals, and the schedule of major deliverables for the Mitretek modeling effort.

In February 1998, the ITS Joint Program Office (JPO) directed Mitretek to prepare a modeling study plan to support its ongoing evaluation effort for the Seattle MMDI deployment. The inclusion of Mitretek as direct support to the Seattle MMDI evaluation was made in light of time and resource constraints associated with the delivery of a national-level MMDI evaluation report in 1999. Mitretek, under the aegis of another JPO-sponsored effort predating the MMDI effort, had already developed a set of network models of Seattle suitable for the assessment of ITS impacts at a subarea and regional level. Leveraging existing Mitretek modeling assets allowed MMDI evaluation resources to be concentrated elsewhere, particularly given the time and effort associated with large-scale simulation network development and calibration.

The previous Mitretek modeling case study projected ITS impacts in the year 2020 from a range of potential transportation system improvements within a 120-square mile corridor north of the Seattle central business district. However, the 2020 forecast year models and data sets were not constructed with MMDI projects in mind, and Mitretek had to modify and re-calibrate them to reflect the near-term MMDI evaluation effort. A brief overview of the modeling framework, data sets, and scenario sets developed for that effort and their usefulness to the MMDI evaluation is presented in Section 1.1.

Given a set of resource constraints and the master schedule associated with the national MMDI evaluation program, Mitretek developed a plan in April 1998 [1] to tailor the existing the 2020 evaluation framework and data sets for the MMDI evaluation effort. The experimental design associated with that evaluation plan has been implemented with only minor changes. The experimental design attempts to deal with ITS impacts on two levels. First, through a set of simulation experiments referred to here as sensitivity analyses, hypotheses integral to the isolated deployment of projects in similar functional groupings (e.g., Advanced Traveler Information Systems (ATIS), Traffic Signal Control, Incident/Emergency Management, and Transit Applications) are explored. The sensitivity analysis is based solely on subarea simulation analysis. Second, interactions between projects deployed concurrently plus the impact on overall regional travel demand are examined through an integrated before-and-after alternatives analysis. The alternatives analysis features employs both subarea simulation and a regional planning model to assess impacts.

The Mitretek modeling analysis effort for MMDI has focused on project features that are difficult to evaluate with direct field measurement. For example, during the evaluation period, overall travel demand rose concurrently with overall utilization of web-based ATIS. Differentiating these impacts would be problematic at best using the existing data collection methods in the

Seattle area (primarily loop detectors). In cases like this, models can be helpful in systematically and independently quantifying the impacts of rising travel demand or web-based ATIS.

Likewise, the modeling effort also assists local MMDI partners in projective analyses of interest regarding specific projects. For example, MMDI-related improvements in arterial data collection and archiving facilitate the development of coordinated inter-jurisdictional traffic signal plans along major arterial corridors. However, participating jurisdictions are reluctant to implement these plans until impacts to both local and through traffic can be estimated. Here models are helpful in providing insight before a commitment to full implementation is made.

The focus of the modeling and simulation work is a reflection of the role it plays in supporting both national MMDI evaluation goals and the goals of the local partners. In support of the national evaluation, for example, the modeling work seeks to quantify relationships between rising ATIS market penetration and measures of overall system impacts such as throughput or energy consumption. Likewise, some experiments address more specific hypotheses of local interest. For example, in the traffic signal case discussed above, that integrated data collection, archiving and cross-jurisdictional cooperation have positive impacts on network efficiency both along and within the arterial corridor.

In order to meet these goals, the intent of the Mitretek modeling effort is not to explicitly evaluate the impact of each MMDI project, although where such impacts can be reliably estimated these impacts will be highlighted. Rather the focus is on testing hypotheses related to national or local goals, and to benchmark progress made in Seattle from the deployment of newly integrated ITS capabilities in the MMDI time-frame.

Altogether, Mitretek modeling analysis in the North Corridor provides direct evaluation support to 13 of 26 Seattle MMDI projects ranging from ATIS provision, traffic signal control improvements, and incident management enhancements.

1.1 MMDI Evaluation and the 2020 Seattle North Corridor Case Study

Mitretek, at the request of the FHWA ITS JPO has been conducting a study unrelated to the MMDI effort entitled “Incorporating ITS into the Planning Process”[2]. As a part of that effort, Mitretek developed an ITS evaluation methodology for use within the constraints of the Major Investment Study (MIS) process applied in traditional transportation planning. This evaluation methodology has been dubbed the Process for Regional Understanding and EValuation of Integrated ITS Networks (PRUEVIIN). The PRUEVIIN framework has been applied in a case study of the Seattle metropolitan area for the 2020 time frame. Mitretek’s general approach in support of the Seattle MMDI evaluation has been to adapt the models and data sets associated with the Seattle 2020 effort, efficiently and in a timely manner, to address the specific concerns of the Seattle MMDI evaluation effort.

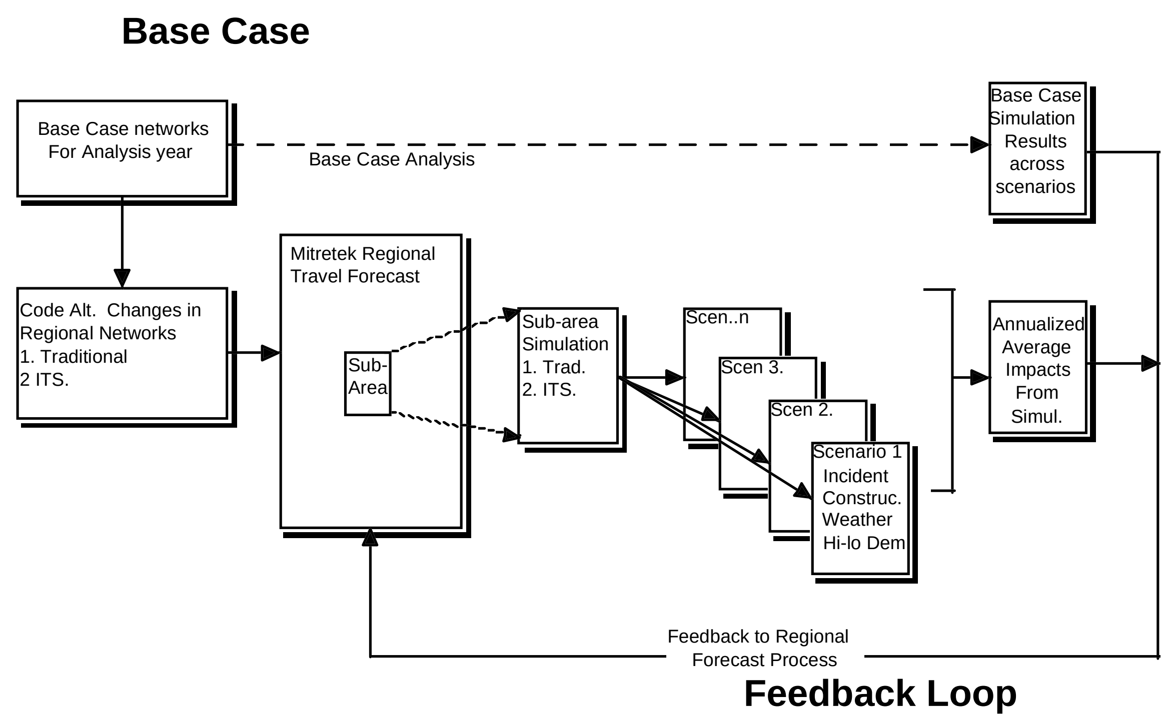


Figure 1-1. Evaluation Framework

Mitretek's PRUEVIIN framework features a traditional four-step transportation planning model as well as a traffic simulation to capture regional and corridor-level ITS impacts (Figure 1-1). MIS-style analyses typically deal with meeting transportation needs for a particular corridor. In the Seattle 2020 effort, the corridor under study (dubbed the Seattle North Corridor) is a roughly 120 square-mile corridor running north from downtown Seattle to Everett, WA bounded by Puget Sound on the west and Lake Washington on the east. The North Corridor data set models 350,000 vehicles traversing a network containing over 2,200 links. Transportation facilities in the corridor were identified and coded in the two models based on projections of infrastructure and travel demand associated with the 2020 forecast year for the morning peak period (6:00 AM – 9:30 AM).

Each alternative's performance is evaluated using a combination of regional planning model and the subarea simulation model. The regional planning model is employed to identify impacts on travel demand including trip distribution, mode choice and regional assignment. The regional travel demand model represents long-term adaptation by the travelers in the system to average conditions experienced in the peak period.

Traffic simulation is employed within the boundaries associated with the North Corridor subarea. The role of the simulation is to capture effects associated with the day-to-day and within-day variation in conditions associated with peak period travel. To this end, the simulation is exercised through a series of 30 representative scenarios. Each scenario describes a particular combination of weather impacts, travel demand variation, as well as a pattern of incidents and accidents in the system. The scenarios were derived from a cluster analysis of the traffic flow data (for variations in day-to-day travel demand) and weather/incident impacts (taken from historical archives). Each scenario has a weight or probability of occurrence and the scenarios taken together comprise a representative year of operation.

Simulation analysis over the representative year of operation allows for a meaningful linkage between the two modeling scales. Impacts by scenario can be rolled into an annual average and compared with baseline travel in the regional model.

The fact that North Corridor network data sets had been developed, tested and calibrated as a part of the previous study proved of great benefit to the Seattle MMDI evaluation since the time-consuming task of generating a network was avoided. Since schedule and budget constraints precluded new network generation, simulation analysis in support of the MMDI evaluation was necessarily confined to the North Corridor subarea. The majority of Seattle MMDI projects are deployed within the North Corridor, although some projects are not present in the corridor whatsoever. The eight projects not present in the corridor are not modeled in this study.

Results from this study should be understood in context of the North Corridor impacts. The mix of ITS technologies, congestion levels, weather and other factors seen in the North Corridor are representative of the Seattle region. While representative, the North Corridor impacts should not be viewed as the sum total of MMDI-related impacts. Similarly, extrapolation of subarea impacts in the estimation of overall regional impacts should be conducted with close consideration of the particular attributes of the North Corridor.

1.2 Relationship of Mitretek Modeling and Seattle MMDI Projects

Project	Project Title	Dropped By MMDI	Mitretek Project Groupings: ATMS	ATIS	IMS	Integ.	Not Modeled
SE-1	North Seattle ATMS		●				
SE-2	Eastside ATMS						●
SE-3	Southside ATMS						●
SE-4	Seattle ATMS						●
SE-5	SeaTac Airport TMS						●
SE-6	Bellevue TMS						●
SE-7	Northwest TSMC		●				
SE-8	Olympic TSMC						●
SE-9	Regional Video				●		
SE-10	Bartizan	●					
SE-11	XYPoint	●					
SE-12	Incident Capture				●		
SE-13	Incident Video				●		
SE-14	Emergency Ops Center				●		
SE-15	King County AVL						●
SE-16	AVI Bus Signal Priority						●
SE-17	Microsoft Sidewalk			●			
SE-18	Etak/Metro Traffic			●			
SE-19	Fastline HPC			●			
SE-20	Cable TV			●			
SE-21	WIN Kiosks	●					
SE-22	Seattle Center Parking						●
SE-23	Riderlink/Busview						●
SE-24	King Co. Transit Display						●
SE-25	WS Ferries ATIS						●
SE-26	WSDOT Web Page			●			
SE-27	Traffic Telephone			●			
SE-28	Dynamic Rideshare						●
SE-29	ITS Backbone					●	
	Total	**3**	**2**	**6**	**4**	**1**	**13**

Table 1-1. Mitretek Modeling and Seattle MMDI Projects

Table 1-1 identifies analysis performed versus the April 1998 plan in terms of Mitretek modeling activity with respect to each of the 29 ITS projects evaluated as a part of MMDI. Three projects (XYPoint, Bartizan, and WIN Kiosks) have been dropped from the Seattle MMDI. Of the remaining 26, 13 are supported by this modeling effort directly and have results in this document. These 13 projects fall under the ATMS, ATIS, IMS, and Integration project groupings. A fifth project grouping, Transit (included in the April 1998 plan but dropped here), has five components (SE-15 King County AVL, SE-16 AVI Bus Signal Priority, SE-23 Riderlink/Busview, SE-24 King County Transit Display, and SE-28 Dynamic Rideshare) considered for evaluation through Mitretek modeling. Due in part to a lack of field results and time and resource constraints, this project grouping is not modeled or reported on here.

Results from the North Seattle ATMS project (SE-1) have indirect bearing on four other arterial traffic management projects (SE-2,3,4,6) since they have similar function but are deployed in different geographic areas. Mitretek modeling does not address another four projects beyond the SE-2,3,4,6 ATMS grouping. In each case this is because the projects are wholly outside of the North Corridor study subarea and have no functional analogs within the subarea.

The project groupings are used to identify projects that utilize the same kinds of technologies or integrate similar traffic control components. Hypothesis and impacts associated with projects within a grouping are performed using similar techniques, detailed in Section 3. In some cases, projects are grouped because the impact of a single project acting in isolation has either no impact or an impact that cannot be measured in the simulation. For example, the Incident Video project (SE-13) alone has no impact unless it is coordinated through the Northwest TSMC (SE-7) and linked to more effective incident management. In this case it is only natural to consider these projects together when they support a particular ITS component or user service.

The ATIS project grouping is further differentiated into two subgroups: pre-trip and en route ATIS services. The PRUEVIIN framework cannot discriminate effectively between two media being employed to deliver similar messages at the same decision point in a trip. For example, the data viewed pre-trip on Cable TV (SE-20) or Microsoft Sidewalk (SE-17) is based on the same real-time source as the WSDOT web-site (SE-26). However, the simulation model can differentiate between the same data being presented pre-trip versus en route, for example, highlighting differences between Fastline PC (SE-19) and the Cable TV (SE-20).

In summary, the ATMS grouping includes projects that serve to archive and consolidate arterial traffic data from a number of sources in a central location. The ATIS project grouping comprises a collection of pre-trip and en route information services presenting current congestion conditions based on real-time WSDOT freeway detector data. The IMS/EMS grouping is composed of projects that (among other goals) seek to improve detection, response time, and freeway system efficiency under incident conditions. The Transit grouping is a collection of transit-related improvements intended to provide real-time information to bus riders or to improve the management capabilities of transit operators. The Integration grouping contains only one project, ITS Backbone (SE-29), that allows for data collected from arterial sensors for the purpose of traffic signal control to be utilized in support of ATIS.

1.3 Alternatives Analyses and Sensitivity Analyses

The PRUEVIIN framework is designed to support alternatives analysis. That is, a set of well-defined alternatives is proposed as potential solutions to meeting projected corridor travel demand. These alternatives may contain specific ITS components as well as traditional infrastructure construction components. Corridor level impacts of each alternative are predicted by the use of the meso-scale traffic simulation. Regional travel demand impacts are predicted by the traditional four-step regional planning model. A limited feedback mechanism is used between the two models to reflect changes in average or perceived corridor conditions that may impact regional travel considerations.

For the Seattle 2020 analysis, a strict alternatives analysis was sufficient to meet all the goals of a 20-year forecasting effort. However, a direct application of an alternatives analysis was less appropriate for the needs of MMDI evaluation. First, the set of enhancements to the current ITS infrastructure in Seattle that the MMDI projects represented did not easily fit the well-defined in-or-out precepts of direct alternatives analysis. In many cases, the MMDI projects represented the connecting together of isolated capabilities or the incremental extension of existing technologies. In some cases, the impact of these data-sharing capabilities were not implemented as a part of MMDI, but established a necessary condition for any future implementation. For this reason, the before and after alternatives considered for the MMDI evaluation are “Baseline” and “Enhanced ITS.” The Enhanced ITS alternative (defined in detail in Section 3.4) represents a combination of improved ITS capabilities deployed in the MMDI deployment time-frame, an increase in users of web-based ATIS, and a set of projective improvements to signal coordination facilitated but not implemented during the MMDI time frame.

Finally, a direct application of the alternatives analysis does not meet the MMDI evaluation goal of providing impact measures on specific hypotheses. The alternatives analysis of the Baseline and Enhanced ITS cases provides estimates of overall corridor-level and regional level impacts from concurrent deployment of MMDI-related improvements. In order to meet the local and national-level MMDI evaluation requirement for testing a number of specific hypotheses, a range of sensitivity analyses have also been conducted. These sensitivity analyses consider the corridor simulation alone without runs or interaction with the regional model (and are also referred to in this document as “simulation experiments”). Since feedback to the regional model significantly increases the computational load associated with each experiment, and cannot be performed within the national MMDI master schedule, feedback is only performed for the alternatives analysis. That said, the two-pronged strategy (alternatives plus sensitivity analysis) helps to meet the need for both individual project analyses and a desire to evaluate the “big-picture” impact of integrated MMDI deployment on regional travel. The regional impact is particularly important for meaningful analysis of energy and emissions impacts.

1.4 Deliverables of the Mitretek Seattle MMDI Evaluation Effort

This document represents a draft final report deliverable to the JPO by 30 June 1999. This draft final report updates the interim report delivered 1 January 1999 and draft executive summaries delivered 14 May 1999 and 10 June 1999. The contents of this report are organized to conform to the structure of MMDI site-reports and national-level MMDI evaluation reports, and may appear wholly or in part in those documents.

SECTION 2: APPROACH, METHODOLOGY AND MODEL CALIBRATION

This section presents detail on changes to the PRUEVIIN framework for MMDI evaluation; the set of 30 representative scenarios used to estimate annual impacts; the role of field data and survey results, traveler expectation modeling; and the results of calibration in both the regional planning model and the subarea simulation.

2.1 Modifications to the PRUEVIIN Framework

For MMDI evaluation, the PRUEVIIN methodology has been modified slightly from the technique used in the Seattle 2020 alternatives analysis. First, in that analysis, impacts in eight of 30 representative day scenarios were estimated using simple interpolation techniques. For MMDI, all 30 scenarios are run in the simulation and no interpolation is used. Second, for this study, no real-time mode choice is modeled. Recent survey data (see below) indicates that only 1% of current commuters consider mode choice when viewing real-time congestion reports. Mitretek testing indicates that, at this level of utilization, the impacts of such choices are too small to be measured against background randomness in the simulation model.

2.2 Measures of Effectiveness

For each experiment, measures of effectiveness (MOEs) for several of the JPO-designated Few Good Measures (FGM) are calculated. In the corridor subarea, simulation outputs are analyzed to compute the network efficiency measures average system delay and total vehicle throughput. Throughput is defined as the number of trips selected from the total traveler population that can complete trips within the AM peak period modeled. Other measures calculated include the coefficient of variation associated with day-to-day travel variability, the number of severely delayed trips (more than 15 minutes of delay or 150% of expected travel time). Similar statistics may be reported for each of the various traveler classes (for example, Fastline PC users or travelers guided by pre-trip information from the WSDOT Website). For the region, Mitretek will report the following MOEs: total VMT and VHT, mode share, accessiblity (a measure of transit service breadth) and average travel time. Details of network efficiency MOE calculation are provided in the introduction of Section 4.

For energy and emissions estimates, Mitretek has employed a post-processing analysis of simulation link-level speed and stop data. The relationships between travel speed, stops, and energy and emission rates were developed at the Virginia Polytechnic Institute and State University (Virginia Tech) as a part of the national MMDI evaluation effort [3]. The introduction of stop data as well as speed data into the energy and emissions analysis represents an advance in the current state-of-the-art. The new technique applied here for the Seattle MMDI evaluation is consistent with ongoing energy and emissions impact assessments associated with the MMDI in Phoenix and San Antonio. Details on how this methodology is applied in this study are presented in Section 2.9.

A related safety post-processing technique (also developed at Virginia Tech) [4] is employed to predict total crash and fatal crash rates. This safety analysis utilizes a stratification of corridor-level travel by speed range as input and applies speed-sensitive crash rates from national statistics. Details on how this methodology is applied in this study are presented in Section 2.10.

2.3 Scenario Set

The set of evaluation scenarios developed for the Seattle North Corridor are composites of several kinds of data collected during the study and are based on conditions seen in the morning peak period (6:00 AM - 9:30 AM). Three sources of system variability were investigated: the impact of incidents and accidents on localized network capacity, the impact of weather (including fog and visibility effects) on global network capacity, and variation in day-to-day travel demand.

Data on accidents was collected and analyzed from a number of sources. In the Seattle region, the impact of accidents are tracked and recorded in two databases depending on accident severity. Incidents are the most severe form, involving an hour or more of Washington State DOT activity to clear. Accidents are all events (including shoulder and partial lane blockages) recorded by the State Patrol. Various types of records were examined in the period 1991-1998. From these records, a cluster analysis of incident temporal and geographic position was performed. These in turn lead to the development of probabilistic distribution of accidents of varying severity for use in the evaluation scenarios. In the simulation analysis, accidents (including incidents) are modeled as temporal reductions in link capacity.

Similarly, a weather analysis was performed based on hourly weather observations over the period 1994-1995. Three conditions are incorporated into the evaluation scenarios: clear, rain and snow/frozen. Rain also includes limited visibility impacts of fog. In the simulation analysis, these impacts are modeled as global reductions in network maximum travel speed, capacity and speed at capacity. The reduction values selected in each case are consistent with Highway Capacity Manual (HCM) estimates and several publications on weather impacts. [5,6,7]

Finally, the variation in corridor travel demand was estimated from observed flow rates at a set of freeway and arterial detector stations throughout the area. These peak-period flow rates were analyzed over all weekdays in the years 1994-1995 to identify patterns of variation. These variation factors are included in the simulation model through uniform scaling up or down of origin-destination flow rates.

The scenario set represents a cross-section of the conditions seen in the AM peak period using the three data sets (incidents, weather and demand variation) and is illustrated in Figures 2-1 and 2-2. These figures show the 30 scenarios organized in two dimensions by changes in roadway supply and travel demand. The relative size of the boxes for each scenario reflects the probability of occurrence, that is, the larger the box the more likely that particular scenario is to occur.

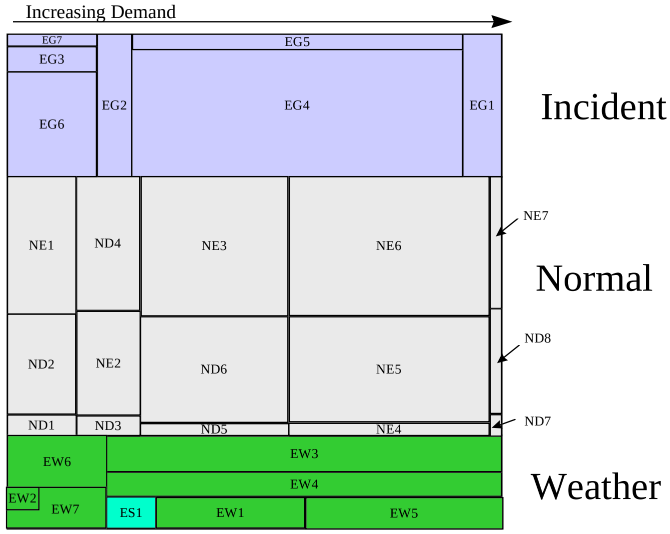


Figure 2-1. Evaluation Scenarios Shaded by Roadway Supply Impacts

In Figure 2.1, the scenario mapping is shaded by impacts in roadway supply into three subgroups: Incident (scenarios with good weather and more than 9 accidents), Normal (good weather and fewer than 9 accidents), and Weather (rain or snow). The relative intensity of the disruption increases as one moves from scenarios in the center of the mapping to the top or bottom edges of the mapping.

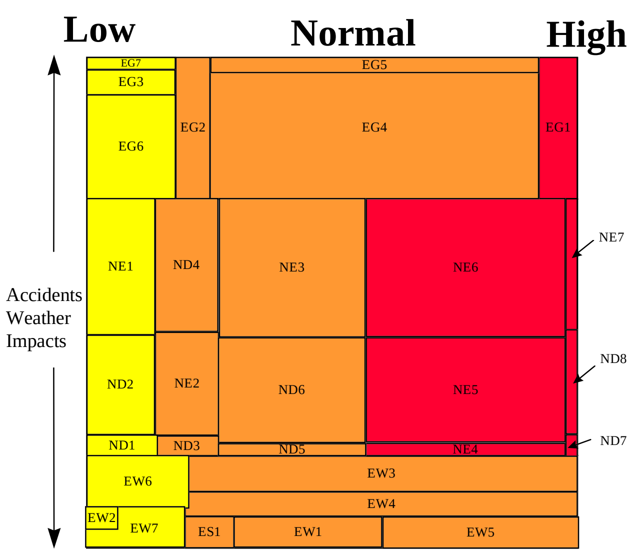


Figure 2-2. Evaluation Scenarios Shaded by Travel Demand Impacts

Figure 2-2 presents the same mapping but has been shaded to reflect changes in travel demand with respect to the average conditions observed. Again, three subgroups are presented: Low (a 10% reduction or lower in expected demand), Normal (demand within plus/minus 10% of average), and High (a 10% or higher than expected demand pattern). The relative deviation from expected demand increases as one moves from scenarios in the center of the mapping to the left or right edge of the mapping.

Mappings of this type allow for two important analyses to be performed on model outputs. First, quantified impact measures (say travel time) in each scenario can be multiplied by the likelihood of the scenario and an average annual impact computed. These point estimates of average conditions are critical for both interaction with the regional model, as well as in modeling the impact of advanced traveler information systems or determining the effectiveness of signal timing plans. Second, the mappings themselves can be color-coded by ITS impact to illustrate the conditions under which ITS components provide the most significant impacts.

2.4 Field Data Sources and Survey Findings

A range of data sources has been utilized for the purposes of this study: data detailing project deployments; data on market penetration and customer response; and data on observed travel times and flows in the system.

First, detailed data on the MMDI projects themselves have been collected from WSDOT and other local sources. These data points identify the detector locations, jurisdictional boundaries for traffic signal control, VMS location and control, and other factors. How these data points are included in the analysis is detailed in Section 3.

Second, the primary source of data on market penetration and traveler response to information provision is the 1997 PSRC panel survey data. Jane Lappin (Volpe) and other researchers from the MMDI evaluation effort provided a useful summary of the survey results [8] with respect to ITS issues. Again, the details of how this data is utilized in the modeling effort appear in Section 3. Additional data from ongoing customer satisfaction survey work for MMDI is expected later in 1999. When this data becomes available, Mitretek plans to review ATIS-related simulation parameters as well as ATIS modeling approach in light of any new findings. However, any additional analysis work related to these new findings will be reported in a separate follow-on study and not incorporated into a revision of this report.

Third, travel time and flow data have been analyzed to provide a calibration data set for the subarea simulation model. The details of that data set and the calibration process are described in Section 2.7.

2.5 Traveler Expectation Modeling in PRUEVIIN

We characterize the provision of real-time information to travelers as attempts to bridge an “information gap” between the conditions that travelers expect to see when they make travel decisions and the actual current conditions of the system. Without any outside information, travelers only know the state of the network that they can visually inspect and make decisions based on experiential knowledge of typical network conditions. In our study, we use travel-time as a surrogate for overall traveler utility (within the same mode of travel). What this means is that travelers are assumed to seek generally faster time paths in the network when such paths can be identified based on known conditions and experiential knowledge base.

When travel-time information is provided to the traveler, the impact of that information must be considered in light of its source, the precision of the estimate, and the breadth of the network covered by the message. Finally, how that information is utilized depends on how knowledgeable the traveler is about congestion in the system.

Currently, travel time information is collected along the I-5 freeway within the corridor and centrally archived. This archive is utilized by public-sector agencies through Highway Advisory Radio (HAR), variable message signs (VMS), and an internet-based pre-trip planning service to provide travel time information or simple warnings to travelers in the system. For example, in response to a "Congestion Ahead" VMS message, an experienced traveler is more likely to divert from the freeway than a traveler unfamiliar with the network. Further, this experienced traveler is likely to choose a more efficient diversion route based on a presumably richer and more comprehensive knowledge of network conditions. If new detectors broaden the coverage of information or new services provide more precise estimates of delay, then travelers will have more detailed or more comprehensive information on which to base travel decisions.

In order to capture these differences, an expectation-setting process is required to meet two key analytical goals. First, a series of habitual routes have to be established which describe the paths typically taken by travelers in the system. Second, the travel times associated with these expected network conditions must be determined. Note that for our notion of expectation to hold, these two representations must be consistent -- that is, if vehicles traverse these habitual routes they will experience the expected travel times. Conversely, if vehicles traverse the network according to fastest paths associated with the expected travel times they will follow their habitual routes.

The expectation-setting technique employed in the Seattle network is an extension of the SAVaNT simulation feedback method developed by at the University of Michigan [9,10,11]. The expectation-setting framework is illustrated in Figure 2-3. Simulation input data corresponding to a clear weather, no incident and average travel demand day is input to the traffic simulation. All vehicles are set as if they are probe vehicles and report travel times to a central facility. A mix of familiar and unfamiliar drivers is generated for the simulation. In this first run, dynamic fastest-path routes for familiar drivers (i.e., commuters) are identified using an internal multi-path feedback strategy. This strategy computes a new set of fastest paths for 20% of commuter traffic every 400 seconds. A second group is provided fastest paths 400 seconds later, and so on until five groups of vehicles have been routed. After all subgroups have been updated once, the process begins again with the first subgroup. The result is that every vehicle is re-routed at 2000 second intervals based on complete network travel time information. Recall that this simulation run represents the average or expected network conditions. Thus, the internal route adjustment process reflects a familiar driver's adjustment in network congestion experienced on a recurring basis at different points and times.

This first run produces a set of habitual commuter routes. These routes provide paths for each subgroup from any node in the network to its ultimate destination based on 2000-second intervals. For the corridor network modeled in Seattle, this is a 70+ MB file. At this point, however, the routing table is based on network conditions associated with only the first run and not on equilibrated expectation. To achieve this goal, 10% of the vehicles are instructed to follow not the habituated paths but the fastest paths associated with a historical link travel time profile updated every 15 minutes. An iterative process is seeded with the results from the initial run. As the process iterates, the historical link travel time profile is updated. This iterative process continues until the aggregate performance of the vehicles routed based on historical information is statistically equivalent to that of the vehicles based on fixed routes.

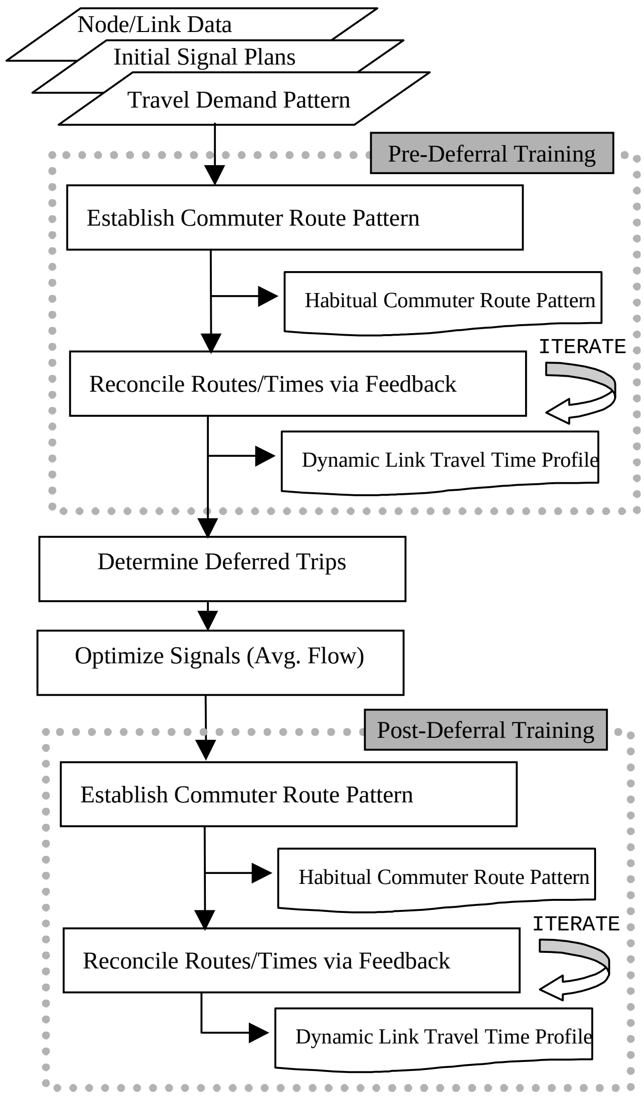


Figure 2-3. Expectation-Setting Process

Next, a subset of trips is identified for potential deferral to an off-peak time. This step was developed for the Seattle 2020 network when it became clear that travel between particular origins and destinations became highly congested at certain times in the peak period. When the average travel speed between points in the network dropped below the 10-km/hr threshold, a fraction of the total trips between these points was removed from the trip table depending on the magnitude of the delay. The deferral process, in combination with the regional travel demand model, produces higher expected travel demand for alternatives with the highest non-incident capacity. In the 2020 case study, the amount of travel deferred was typically small (2-5% of travel depending on the alternative). Less than 1% of travel demand is deferred at 1998 congestion levels.

After deferral, travel demand is lower and overall network congestion is lower. Therefore, the habituated route patterns of the commuter population determined in the Pre-Feedback Training process (based on the higher, pre-deferral demand) are no longer accurate. In order to compensate for this change, experienced commuters are re-trained a second time using the same iterative feedback technique utilized before the deferral process. The result is the generation of a routing file and a travel time file that are consistent with one another and conforms to expectation.

Unlike commuters, the unfamiliar driver's knowledge base does not contain any information on average temporal and geographic distribution of congestion. Routes are determined for these drivers based on estimates of uncongested travel times. The process represented here is map-scanning by travelers who imprecisely reckon their best route based on facility class and distance. The data model representing the knowledge base of the unfamiliar driver has the same structure as the commuter model, but contains less detailed, less accurate estimates of link travel times. Rather than a set of 15-minute estimates of link travel time, a single static estimate is calculated using free-flow (uncongested) travel time plus a uniform error. Routes are selected from this data model using a fastest-path calculation.

2.6 Network Calibration Initial Data Sets

As outlined in the April 1998 evaluation planning document [1], Mitretek considered several options for the development of a representative present-day network and travel demand pattern from the data sets used in the 2020 Seattle case study. Mitretek had in hand a 1990 network data set both at the regional and subarea level for the purposes of validation and calibration of simulation parameters in the data set. That calibration data set contained the following elements:

- modified regional (EMME/2) network
- regional 1990 demand files (circa 1995)
- modified and validated regional process (circa 1995)
- INTEGRATION 1.5x 1990 corridor network
- INTEGRATION 1.5x 1990 corridor demand files

The data set was calibrated against link flow data collected over the calendar years 1994-1995 and time-variant travel time estimates for freeway trips during an eight-month period in 1997. The target in this case was to replicate within-day travel time variation for the AM peak period under average demand, clear weather, and no accident conditions.

In order to develop a present day (1997/1998) network representation for the Baseline alternative, Mitretek examined three options. The first option is to use the 1990 networks (regional and corridor) as is, with overall travel demand factors adjusted upward based upon regionally accepted zonal growth rates to match 1998 travel demand estimates. Other options included systematic examination of differences between current Puget Sound Regional Council data sets or a complete re-calibration of both regional and subarea models.

Given the time constraints and the amount of analysis planned, Mitretek chose the first option. Section 2.7 describes the process by which Mitretek developed the 1997/1998 Baseline regional networks and travel demand using option one. Section 2.8 describes the resulting impacts on the subarea simulation travel demand as well as the results of comparing observed archived travel time data and simulated travel time data on an annual basis.

2.7 1998 Regional Planning Network Development

Section 1 provided a brief overview of the Process for Regional Understanding and Evaluation of Integrated ITS Networks (PRUEVIIN) for evaluating improvements in a transportation corridor (see Figure 1.1, a detailed description of the PRUEVIIN process and its application in a 2020 Seattle Case Study is provided in Mitretek 1998 [2]). In PRUEVIIN each alternative's performance is evaluated using a combination of two forecasting processes: (1) A regional "planning" level four-step travel forecasting process; and (2) A sub-area simulation and representative day analysis. The regional planning analysis represents the recurrent/average conditions "perceived" by travelers and the impacts that changes in these conditions have on regional travel patterns and demand within the analysis period (i.e. AM peak period). This information is then fed into the sub-area simulation and representative day analysis to capture the effects of within day and day-to-day variation, system operational response to conditions, and the value of information to travelers. In order to evaluate the impacts of improvements in a corridor the analysis is carried out for a base case (without the improvements) and one or more alternatives (with improvements).

This section provides an overview of the development of the 1997/1998 Baseline networks and travel demand for the Seattle MMDI Evaluation. Several options for this development were described in the previous section. As stated, the first option was chosen given the time schedule and data availability. This consisted of:

- Installing and verifying the available regional four-step travel forecasting process. The process used is an extension of the Puget Sound Regional Council (PSRC) process developed for Mitretek's previous work on Incorporating ITS into Corridor Planning: Seattle Case Study [2]
- Establishing the Baseline networks and transportation system representation. The previously developed 1990 networks system characteristics were used [2]
- Updating the socioeconomic (e.g. zonal population, employment, income) and other exogenous inputs to 1997/1998 conditions

- Executing the 1997/1998 travel forecasts and providing the resultant travel demand to the sub-area simulation process

Each of these is briefly discussed below. A request for updated 1997/1998 information (networks, demographic data, models) was made to the Seattle MMDI Evaluation liaison with a heads up to PSRC in early August. The formal request was made to PSRC on September 18th. PSRC was in the middle of a model and forecast update and could not respond with official numbers until later in the year. It was therefore decided to derive "best guess" estimates of 1997/1998 inputs using data that could be obtained from available sources (see below). The results described in this report are based upon these "best guess" inputs. PSRC did respond to the data request on 24 November 1998 providing updated 1995 and 2000 networks, demographic and trip generation files, and regional model (EMME/2) macros and parameters. This response was too late to be incorporated into the ongoing Mitretek modeling effort. A detailed comparison of those files against the "best guess" inputs was not undertaken but initial tests indicate that the inputs are not dissimilar.

Regional Travel Forecasting Process: The regional travel forecasting process represents average recurring characteristics and conditions in a transportation network/system. It then captures and forecasts travelers responses to these "expected" conditions. An extension of the Puget Sound Regional Council's (PSRC) Regional Travel Modeling Process (EMME/2 travel forecasting package macros and programs; base transportation networks; and demographic files as obtained from PSRC in October 1996) developed for the Seattle Case Study [2] was adopted as the initial starting point for the regional travel forecasting system used in this study. The PSRC forecasting process is a "traditional four step" travel forecasting process (i.e. 0. Land use/socio-economic forecasting and data preparation, 1.Trip Generation, 2. Trip Distribution, 3. Mode Split, and 4. Assignment) and described in detail elsewhere [12,13]. Only slight modifications were made to the PSRC (circa, 1996) process for the Seattle Case Study to account for additional network detail required by the subarea simulation and to provide consistent "seed" network characteristics across all alternatives. The model development is described in detail in the Seattle Case Study documentation [2]. Also, for the current study a "growth factoring" process was used to expand the 1997/1998 productions and attractions from 1990 instead of the PSRC's more complex iterative Land use /demographic/ trip generation procedure used for forecasting into the future.

The resultant regional travel forecasting process used for this study is shown in Figure 2-4, Regional Travel Forecasting Process for Seattle MMDI Evaluation. As shown in the figure to produce an alternative's regional forecast, the alternative is coded and trip generation is performed. Then the trip distribution, mode split, and assignment steps are carried out. The assignment results are then fed back to mode split and trip distribution. Typically, 3.5 full feedback iterations are performed (iteration 0 assigns a seed trip table to obtain initial congested times for trip distribution and mode split). As stated, one slight modification to the PSRC model setups has been made for consistency across the alternatives. The study process starts with the same "seed trip tables" for each alternative. For the Seattle MMDI Evaluation these were the 1990 validated trip tables from the previous Mitretek Seattle case study [2].

The development of the 1997/1998 inputs to the regional forecasting process: the networks, socioeconomic, and other data are described next.

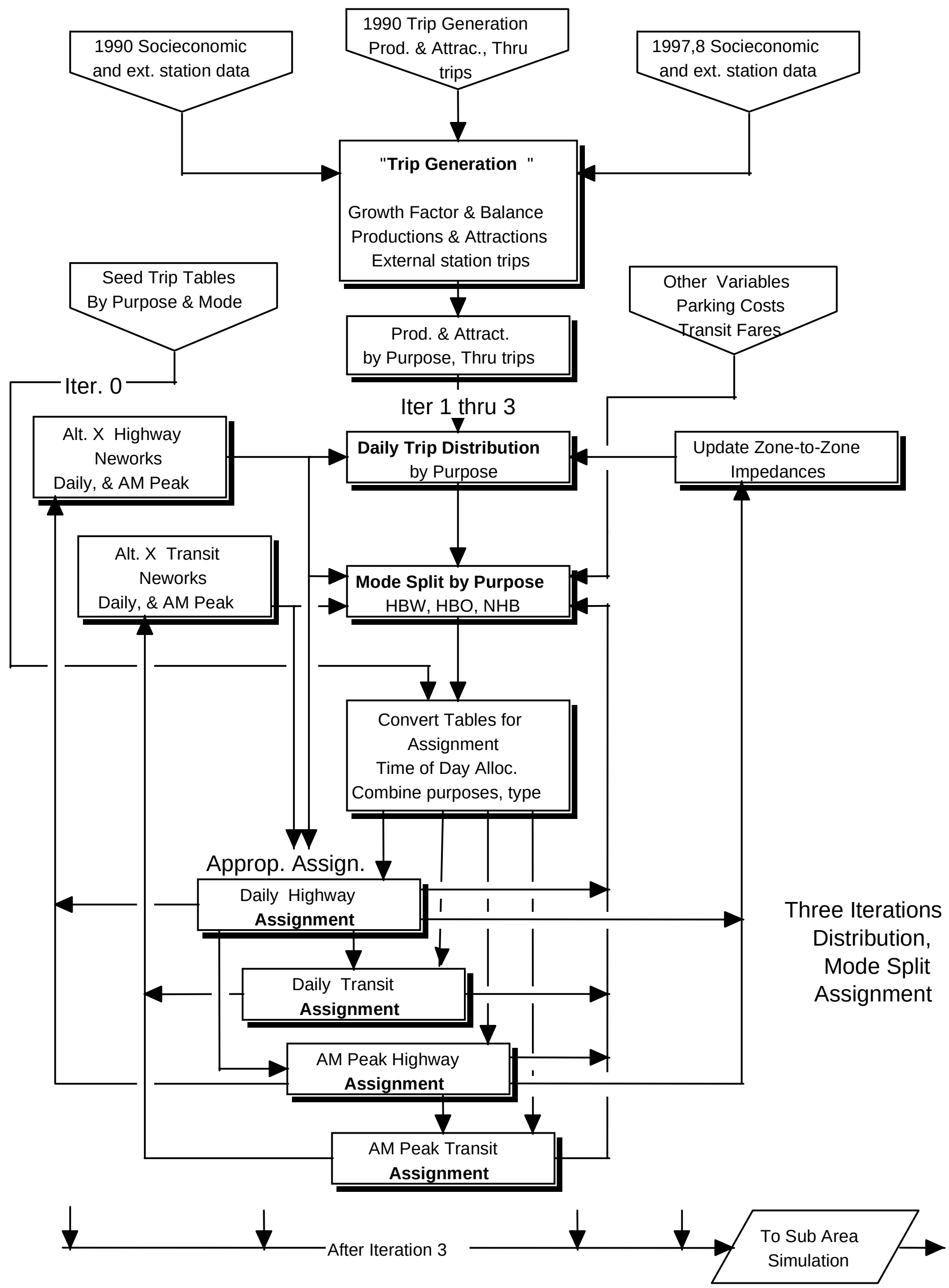
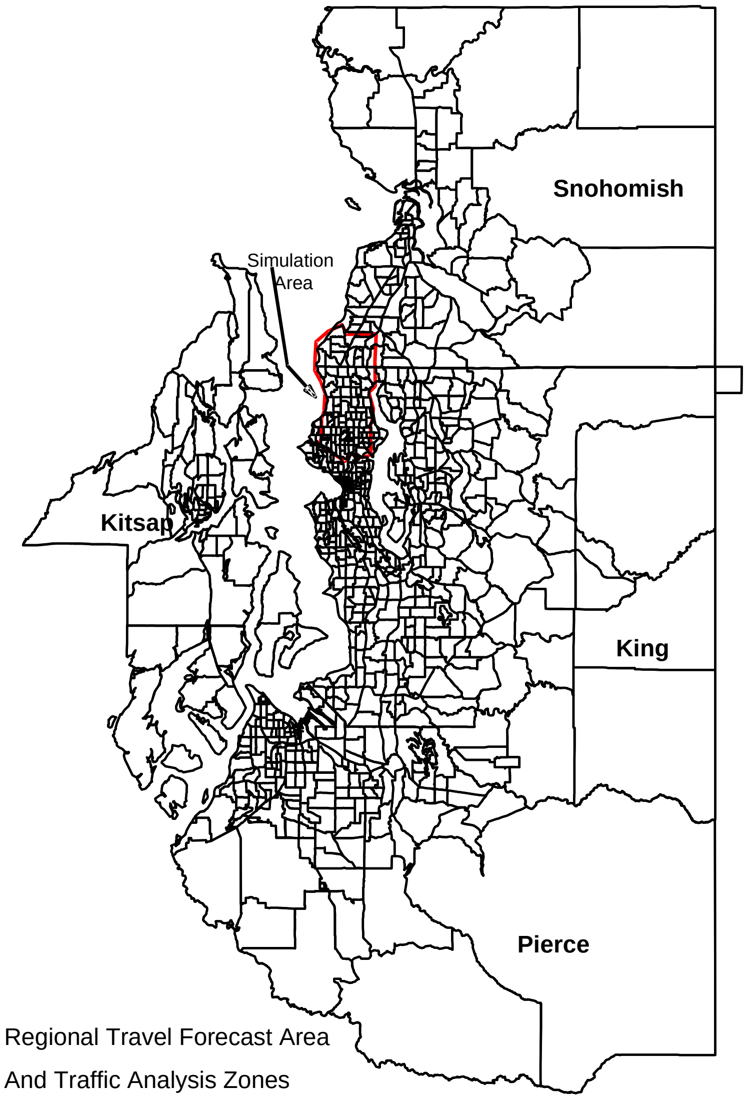
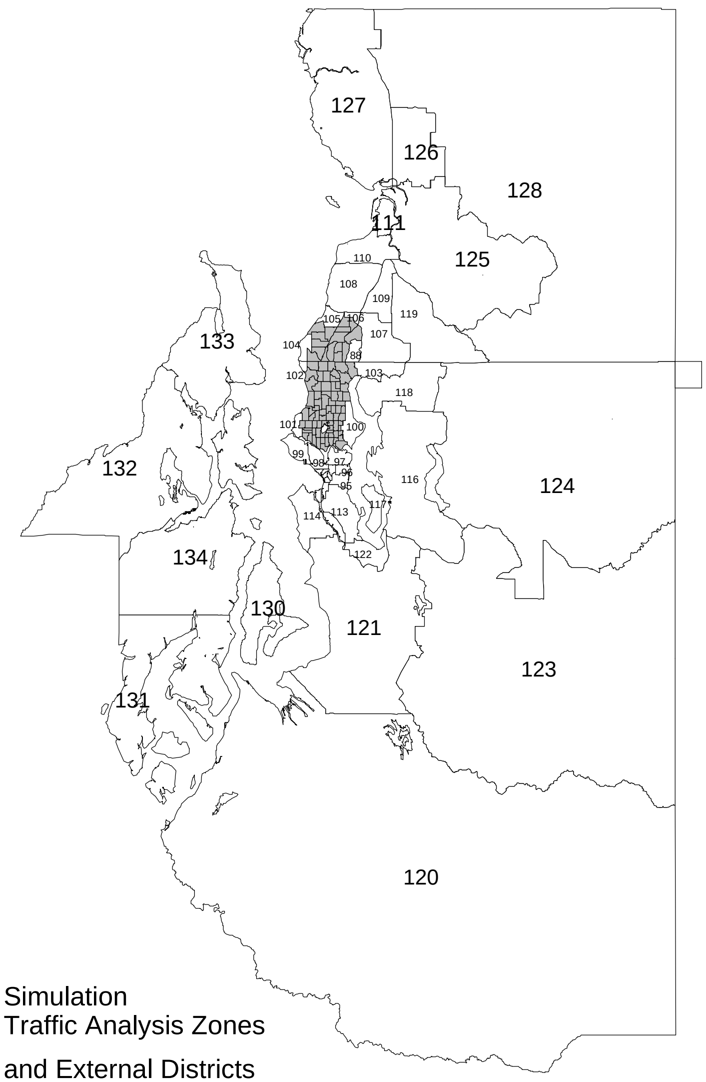


Figure 2-4. Regional Travel Forecasting Process, Seattle MMDI Evaluation

Transportation Network and System Representation: In regional and subarea simulation forecasting processes travel demand is represented by calculating trips between traffic analysis zones. Trips (both vehicle and person) are assigned a route over the transportation network based upon the characteristics of each segment (length, capacity, time, delay function). Figures 2-5 and 2-6 show the regional and subarea simulation zone systems and networks used for the Seattle MMDI Evaluation. At the initiation of the modeling effort current year (1197/998) networks were not available for the region. A cursory review of transportation improvements within the simulation corridor was consequently made. Based upon this review it was decided that the 1990 networks developed and validated as part of the previous Mitretek Seattle case study for incorporating ITS into corridor analyses would provide a good representation of the corridor baseline conditions for the MMDI evaluation.



Regional Travel Forecast Area
And Traffic Analysis Zones



Simulation
Traffic Analysis Zones
and External Districts

Figure 2-5. Regional and Subarea Zone Systems

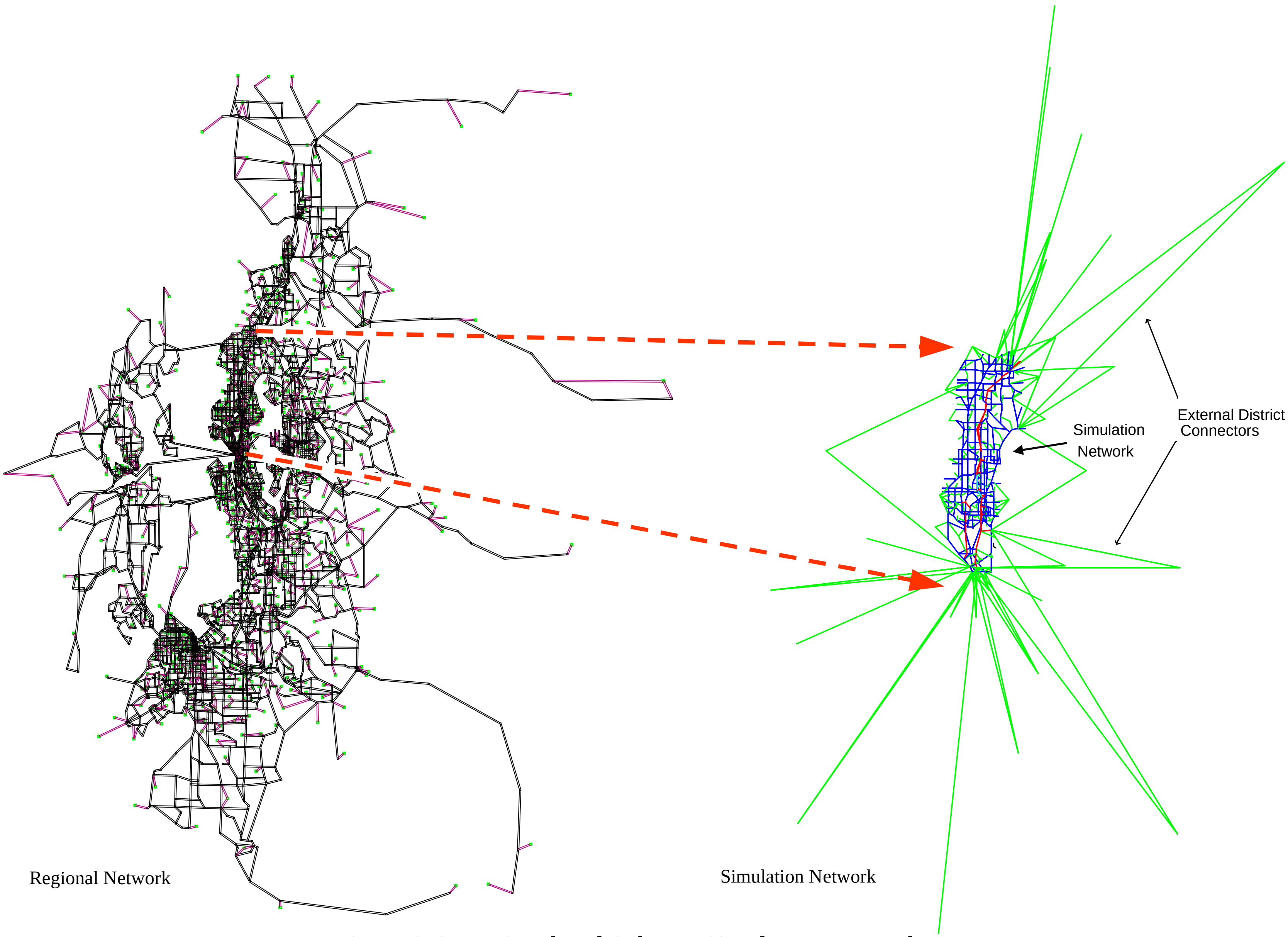


Figure 2-6. Regional and Subarea Simulation Networks

A summary of the development of these networks and their characteristics follows.

As shown in Figure 2-5 the regional forecasting system represents the travel in the four counties of the PSRC region (King, Snohomish, Pierce, and Kitsap). This area is represented using 832 internal traffic analysis zones and 18 external stations for a total of 850 zones. Within the simulation subarea the zones are the same as in the regional process (96 zones). It is very important to capture each person's complete trip from start to finish when examining the impacts of improved information (ATIS) in simulation. For the subarea simulation the entire 4 county model region is therefore maintained, however, as the distance from the simulation area increases the detailed regional zones are aggregated into 38 larger external districts. The subarea simulation uses 134 total zones to represent the region. Any trip that in the regional process goes to, from or through the simulation area is siphoned off and converted for input into the simulation process.

Figure 2-6 shows how the transportation network is also focused from the regional to the subarea simulation processes. The network within the simulation area should be the same for both the subarea simulation and regional modeling processes to minimize differences in results caused solely by inconsistencies in the transportation system's representation within each process. Consequently, the regional network coding was enhanced within the simulation area to meet the requirements of the simulation system. This enhancement included detailed coding of interchanges and the addition of new functional classifications and coding conventions to address ramp meters, HOV bypass lanes, limited access express facilities (SR99), and different types of HOV service (diamond lane, barrier separated, and arterial). The network coding modifications are described in detail in [2]. For each of the external district connectors the time and distance it takes to reach the simulation area from the external district in the regional model is coded.

Table 2-1 provides a summary of the network characteristics for both the regional forecasting model and subarea simulation networks used in the Baseline alternative. These networks provide the base upon which the Enhanced ITS alternative improvements are coded.

	Regional Network			Subarea Simulation Network		
Facility Type	Link Miles	Lane Miles	Capacity Miles	Link Miles	Lane Miles	Capacity Miles
Freeways and Expressways	1,139	2,418	4,038,991	76	220	378,645
Urban Arterials	1,360	2,192	2,285,944	278	494	525,305
Rural Arterials	5,355	6,604	6,857,640	182	279	281,707
Ramps	27	29	33,307	18	19	22,108
Zonal, External District Connections	2,112	4,151	4,296,674	2,271	4,542	4,542,380
Total	9,993	15,394	17,512,555	2,825	5,554	5,750,145

Table 2-1. Seattle MMDI Baseline Alternative Network Characteristics

<u>Socioeconomic and Other Exogenous Inputs:</u> The demographic growth throughout the region; increase in external – internal and through trips; and change in special generators and other exogenous inputs, determine the trip generation and travel patterns that the transportation system must serve. The interrelationships between land use, transportation system congestion, and travel demand are complex and PSRC has a sophisticated feedback process to capture them, develop zonal level demographic data and trip generation, and to verify the results (see [12,13]). During

the summer and fall of 1998 PSRC was carrying out this process to update their estimates and current (1997/1998) data were not available. It was therefore decided to use the data that was available to create "Best Guess" estimates of the inputs required by the regional forecasting model.

One of the key inputs to the process is the zonal level growth in households and population. Households and their characteristics are the primary factors in determining the trips "produced" by each zone. While zonal level data was not available, PSRC had recently released population and household estimates for 1990 and 1997 by census tract for the four county region. A zone-to-tract table of equivalency was developed and the PSRC 1997 data merged with previously obtained 1990 zonal population and household estimates (Mitretek Seattle Case Study 1990 Validation [2]). This allowed new 1997 zonal population and household estimates for each zone to be derived. Table 2-2 provides a county level summary of the change for both population and households. As can be seen the region's households grew 13.24% in seven years. More significant were the high growth rates in the outer counties increasing commute distances and the stress on the commuter routes to the major employment areas. With the change in households, the distribution of income within each zone was assumed to remain the same from 1990 to 1997.

Employment by type is the primary factor used to determine the trips attracted to each zone.

	Population				Households			
County	1990	1997	Change	% Change	1990	1997	Change	% Change
1. King	1,507,320	1,646,226	138,906	9.22%	615,055	674,597	59,542	9.68%
2. Snohomish	465,642	551,181	85,539	18.37%	171,618	203,837	32,219	18.77%
3. Pierce	586,203	674,309	88,106	15.03%	214,657	249,232	34,575	16.11%
4. Kitsap	189,732	229,585	39,853	21.00%	69,262	84,625	15,363	22.18%
Grand Total	2,748,897	3,101,301	352,404	12.82%	1,070,592	1,212,291	141,699	13.24%

1990 estimates from zonal level model demographic file "1990TAZF.WK1" (PSRC Oct. 1996)

1997 estimates from tract level "Population and Household Estimates" file "pop97.xls" (PSRC Sep. 1998)

Table 2-2. " Best Guess" Population and Household Trends

Employment is more difficult to track and estimate than other demographic data because of the many definitions of "employment" that are used by different data sources. Consistent definitions and data coverage must exist across data sets in order to analyze trends and develop new estimate. Consequently, even though there were PSRC 1997 estimates of employment covered under Washington State's unemployment insurance programs, consistent information for 1990 could not be found. The WSDOT Planning Office was able to provide a secondary data set of previously developed zonal employment information for 1990,1995, and 2010. This information was used to interpolate a set of "Best Guess" 1997 zonal employment estimates. These estimates and their implied growth from 1990 are shown in Table 2.3. As shown employment is also increasing at a rapid rate throughout the region and like the demographic growth is also concentrated in the outer counties. Employment grew 10.37% for the region from 1990 to 1997, which is slightly less than household and population growth.

	Employment				1990 to 1997	
County	1990	1995	1997	2010	Change	% Change
1. King	1,024,776	1,064,486	1,103,037	1,353,620	78,261	7.64%
2. Snohomish	176,750	197,974	207,904	272,453	31,154	17.63%
3. Pierce	235,759	261,027	269,523	324,750	33,764	14.32%
4. Kitsap	82,267	94,095	96,627	113,084	14,360	17.45%
Grand Total	1,519,552	1,617,581	1,677,091	2,063,907	157,539	10.37%

1990, 1995, 2010 estimaes from zonal level land use file "landuse.xlw" (WSDOT 1997)

1997 estimates interpolated from 1995 and 2010 estimates

The other significant determinant of transportation system use within in a region is the amount of travel that crosses its borders from “external” sources, or stations. This travel may either be occur to and from the region, or represent the trips through the area on their way to some other destination. To derive the growth in these trips the Average Annual Daily Traffic (AADT) count data was obtained from WSDOT for 1990, and 1993 through 1996. This information was used to make a “Best Guess” on the 1997 AADT for each external station. The 1997/1990 growth ratio was calculated. This growth ratio was used to expand the internal-external productions and attractions associated with each external station.

External stations			AADT From WSDOT Count Books							AADT Estimated	Ratio
County	TAZ	Location	1990	1991	1992	1993	1994	1995	1996	1997	97/90
Pierce	833	I-5 to Olympia	79900			86000	88000	90000	92000	94000	1.176
	834	SR-507 to Yelm	10100			12000	14000	14000	14000	14000	1.386
	835	SR-7 to Morton	3800			3800	4000	4100	4100	4200	1.105
	836	SR-706 to Longmire	1550			1700	1800	1800	1800	1800	1.161
	837	SR-123 S.of Cayuse Pass	810				845	730	883	910	1.123
	838	SR-410 E. of Chinook Pass	5600			5700	5800	6000	6000	6200	1.107
King	839	I-90 to Snoqualmie Pass	21400				26000		27000	27500	1.285
Snohomish	840	SR-2 to Stevens Pass	4259			4700	4700	4600	4700	4700	1.104
	841	SR-92 to Monte Christo	8900			9900	10000	11000	11000	11300	1.270
	842	SR-530 N. of Darrington	3400						3800	3866	1.137
	843	SR-9 N. of Arlington	1200			1500	1500	1500	1500	1500	1.250
	844	I-5 to Mt. Vernon	40000			45000	46000	48000	48000	49000	1.225
	845	SR-530 N. of Starwood								1.27 hh growth in 754 1.16 emp growth in 754	1.250
	846	SR-532 to Camano Island	11600			13000	14000	14000	15000	15700	1.353
	847	Mukilteo Ferry to Whidbey Island (SR 525)	5200			5900	6000	6300	6400	6500	1.250
Kitsap	848	Hood Canal Bridge (SR-104)	11424			13000	14000	14000	14000	14000	1.225
	849	SR-3 to Belfoir	11300				10000	10000	10000	10000	0.885
Pierce	850	SR-302 E. of SR-3	1850			1100	2000	2000	2000	2000	1.081

Table 2-4. External Station Traffic Growth

Through trips also travel through the external stations. They, however, cannot simply be expanded by the growth rate at each of their ends because this often leads to inconsistencies. If the external station at one end of the trip has a growth ratio of 1.5 and the station at the other end of the trip has a ratio of 1.1 they can’t both be consistently applied. Consequently, an “Iterative Proportional Fitting (IPF)” method was used to expand the through trips and maintain the external station growth rates as closely as possible (see [14]). This caused an increase in through vehicles trips from 5,203 in 1990 to 6,250 in 1997, a 20.12 % increase. This increase is on average consistent with the growth in external station volumes shown in Table 2-4.

The last updates to the exogenous regional model inputs made were the modifications to the special generator trips. Special generators are activity centers, or areas, which create trips and travel patterns very different from other areas in the region. The PSRC regional process treats the Sea-Tac Airport, Fort Lewis/Mchord, the Seattle Center, the Kingdome, and the Tacoma

Dome as special generators. For 1997/1998 one third of the change in trips from 1990 to 2020 was assumed. This is similar to the accelerated early growth during this period seen for trip generation overall. All of the other inputs, such as parking costs and transit fares were assumed to grow with inflation, or remain constant.

Best Guess 1997/1998 Baseline Travel: The socioeconomic, external station, and other exogenous inputs were used to develop the 1997/1998 estimates of trip productions and attractions by trip purpose which are then used to carryout the regional travel forecasting process shown in Figure 2-3. For each zone the productions for the Home Based Work, College, Home Based Other, and School trips were grown based upon the percentage change in households. The attractions for each trip purpose were grown based upon the change in both households and employment and their relative contribution in the PSRC trip generation formulas. The productions in each zone for the Non-Home Based and Commercial Vehicle trips were set equal to the attractions. Then for each trip purpose the attractions were "balanced" to the productions since for the region they must always be equal. The results of this "Trip Generation" Process are shown in Table 2-5. As expected, the overall growth in trips of 13.45% between 1990 and 1997 is similar to the growth in households.

Summary results of the Enhanced ITS (1997/1998) travel demand produced by carrying out the trip distribution, mode split, assignment, and feedback process are shown in Tables 2-6 through 2-8. Table 2-6 provides a summary of the daily person and vehicle trips by mode for 1990 and the Baseline. From 1990 to the Baseline there is a slight shift from transit to auto modes reflected by the lower growth in the transit trips. The transit trips grow at 2.48%. Within the auto modes there also seems to be a slight shift to non-carpool vehicle trips reflected by a 13.62% growth in these trips and only an 11.98% growth in carpool trips. These shifts are understandable given that the outer counties are growing at a much faster rate than the North Corridor. More trips are being produces in areas where the only option is auto and it is difficult to carpool.

Regional Travel: Daily Person and Vehicle Trips

	Measure	1990	1997 MDI Baseline	Change	% Change
Daily Trips					
	Non-Carpool Vehicle trips	7,638,754	8,679,492	1,040,738	13.62%
	Carpool Vehicle Trips	11,291	12,643	1,352	11.98%
	Transit Person Trips	247,714	253,861	6,147	2.48%

Table 2-6. Daily Person and Vehicle Trip Comparison (1990-1997)

Daily Trip Productions And Attractions *				
Trip Purpose	1990	1997	Change	% Change
Home Based Work	1,813,125	2,062,372	249,247	13.75%
College	142,866	162,013	19,147	13.40%
Home Based Other	4,147,054	4,737,266	590,212	14.23%
School	203,805	234,969	31,164	15.29%
Non-home Based	2,854,087	3,239,356	385,269	13.50%
Commercial Vehicle	1,015,057	1,131,455	116,398	11.47%
Through (O/D format)	5,203	6,250	1,047	20.12%
Grand Total	10,181,197	11,573,681	1,392,484	13.68%

* After "balancing" trip productions equal trip attractions for each purpose

Table 2-5. Daily Trip Generation Comparison (1990-1997)

Similar trends are seen in the AM Peak Period travel shown in Table 2-7. The growth rates are slightly higher than for daily travel, however, transit and carpools are still growing at a less rapid rate than non-carpool vehicle trips. The AM Peak period was already congested and is only more so given a 14.06% growth from 1990 to 1997 shown in Table 2-7. This is especially true for corridors such as the North Corridor that are geographically bound, have increasing commuter travel through them, and have limited transportation capacity expansion options.

Regional Travel: AM Peak Period Person and Vehicle Trips By Mode				
Measure	1990	1997 MDI Baseline	Change	% Change
Non-Carpool vehicle trips	1,340,565	1,529,112	188,547	14.06%
Carpool vehicle trips	8,468	9,483	1,015	11.99%
Transit person trips	70,571	72,504	1,933	2.74%

Table 2-7. AM Peak Period Person and Vehicle Trip Comparison (1990 –1997)

Once the regional travel process is carried out the trips to, from and through the subarea are siphoned off and fed to the subarea simulation analysis. Table 2-8 summarizes the 1990 and 1997/1998 Baseline trips that are provided to the simulation analysis. As shown the percent growth in regional vehicle trips is higher than those that go to, from, or through the simulation area. This is the result of two factors. First, the already mentioned growth in the outer areas will lead to relatively more of the vehicle trips being created there than in the simulation area. Second, the simulation area's facilities (I-5, SR-99, SR 522) were already congested in 1990. There is not as much ability to absorb additional trips without significant delays in the simulation area as there may be in other corridors, especially at bottlenecks such as the bridge crossings of the Seattle Ship Channel. In effect, diversion away from the North Corridor is taking place which creates latent demand for ITS and other improvements when they do occur.

AM Peak Period Regional & Simulation Area Vehicle Trips				
	1990	1997 MDI Baseline	Change	% Change
Regional SOV	1,340,565	1,529,112	188,547	14.06%
SubArea SOV	237,262	256,520	19,258	8.12%
% SubArea SOV	17.70%	16.78%		
Regional HOV	8,468	9,483	1,015	11.99%
SubArea HOV	2,059	2,230	171	8.31%
% SubArea HOV	24.32%	23.52%		

Table 2-8. AM Peak Period Simulation Area Trips Comparson, 1990 to 1997

2.8 1998 North Corridor Subarea Simulation Calibration

The development of the regional planning network for the 1998 time frame produces travel demand estimates for the AM Peak, and in particular, a demand pattern of travelers who utilize the North Corridor subarea. This travel demand pattern for the AM peak period in the subarea (corridor) was then converted for use in the traffic simulation. Time-variant modifications to the subarea demand pattern were calibrated to data describing trip time variability. This calibration exercise is important because if system variability is overstated, then benefits associated with adaptive control or ATIS will likely be overstated. Likewise, if system variability is understated, then the benefits of ITS technologies will likely be understated.

A key modification that has to be made to baseline travel demand pattern obtained from the regional model is the introduction of a time-variant, within-peak travel demand profile. The regional model assumes uniform travel rates between every origin and destination in the system over the 6:00-9:30 AM peak period. Mitretek, based on experience with calibrating the 1990 North Corridor model, had observed that a "peak-within-the-peak" period demand profile is more representative of the real world and is required to produce more realistic within-period travel time variation.

The primary data source for calibrating the within-peak travel time came from estimates of travel time delivered by the Microsoft Sidewalk [15] service at regular intervals in the AM peak period over a 16 month period from June 1997 to October 1998 [16]. Estimated travel times between the Alderwood Mall and Mercer Street exits (both northbound and southbound) on I-5 were logged every 30 minutes in the 6:00-9:30 AM peak period. These two points are located near the northern (Alderwood Mall) and southern (Mercer Street) boundaries of the simulation subarea. Although this data is indicative of travel times only along the freeway and provides no data on arterial travel, the number of observations over the 16-month period provided sufficient data to characterize the variability along the most important facility in the North Corridor. A reduced sample set was selected from the raw data to remove days with missing or unreliable data points, as well as to eliminate any bias introduced by having collected data over two June-October periods. In all, 80 days of data were used to create the calibration sample set.

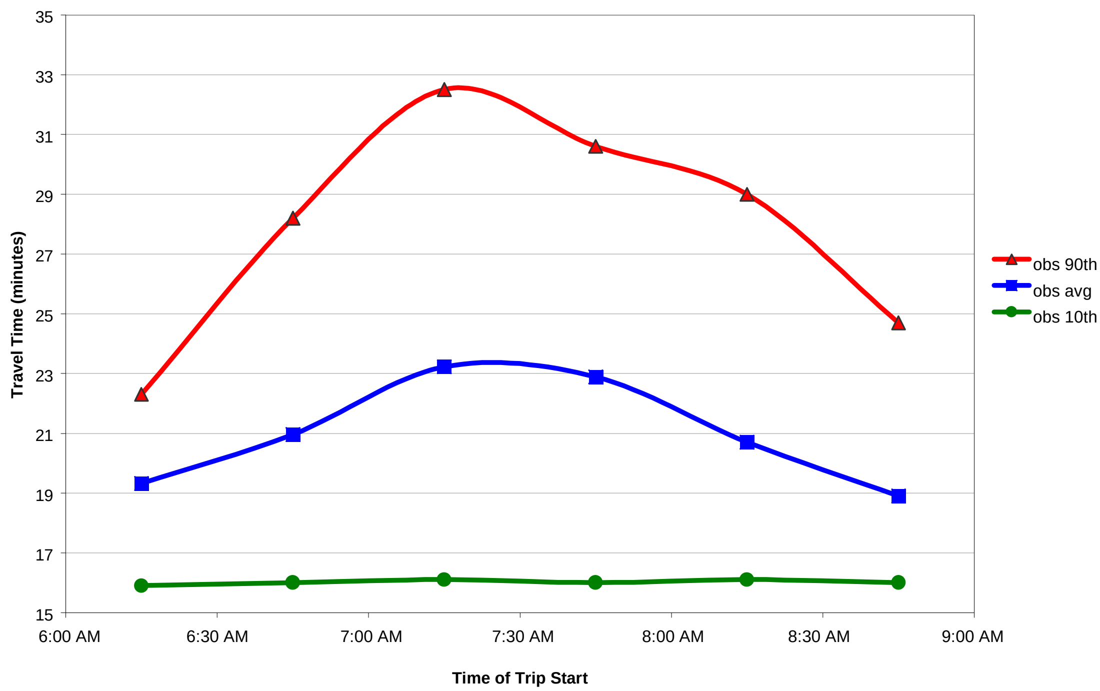


Figure 2-7. Calibration Data for Within-Day and Day-to-Day Variability (Seattle Sidewalk Estimates)

The calibration data for southbound (peak direction) travel between Alderwood Mall and Mercer Street on I-5 is illustrated in Figure 2-7. Average travel time between these two points (a roughly 14 mile trip) ranged from just over 19 minutes at the start of the peak period peaking to 23 minutes in the 7:00-8:00 AM period. This peak travel time then subsides, returning to a 19 minute trip at the end of the peak period (9:30 AM).

Other important calibration information can be generated from this travel time data set (illustrated in Figure 2-7). First, travel times in each period are rank-ordered from lowest-to-highest and a percentile analysis performed to quantify the variability of travel between the two points. At the 10th percentile, representing uncongested conditions, there is no discernable peak and travel time remains flat at roughly 16 minutes. At the 90th percentile, representing highly congested conditions seen for the trip during the year, travel time peaks to near 33 minutes in the 7-7:30 AM time period. Maximum reported travel time (not plotted) was more than 70 minutes.

The Sidewalk estimates are not as accurate as data provided from a dedicated probe-vehicle travel time study because they are based on link detector data. However, the travel time estimates were within 10% of travel times collected by Mitretek in a single-day experiment under relatively low-demand conditions using a GPS-based automated travel time collection device. Further experiments to test the accuracy under heavy-demand or incident cases were not possible given time and resource constraints. Although not a perfect measure, after some elimination of missing or unreasonable data, the data served its purpose of characterizing within-period travel-time variability for the calibration of the simulation model.

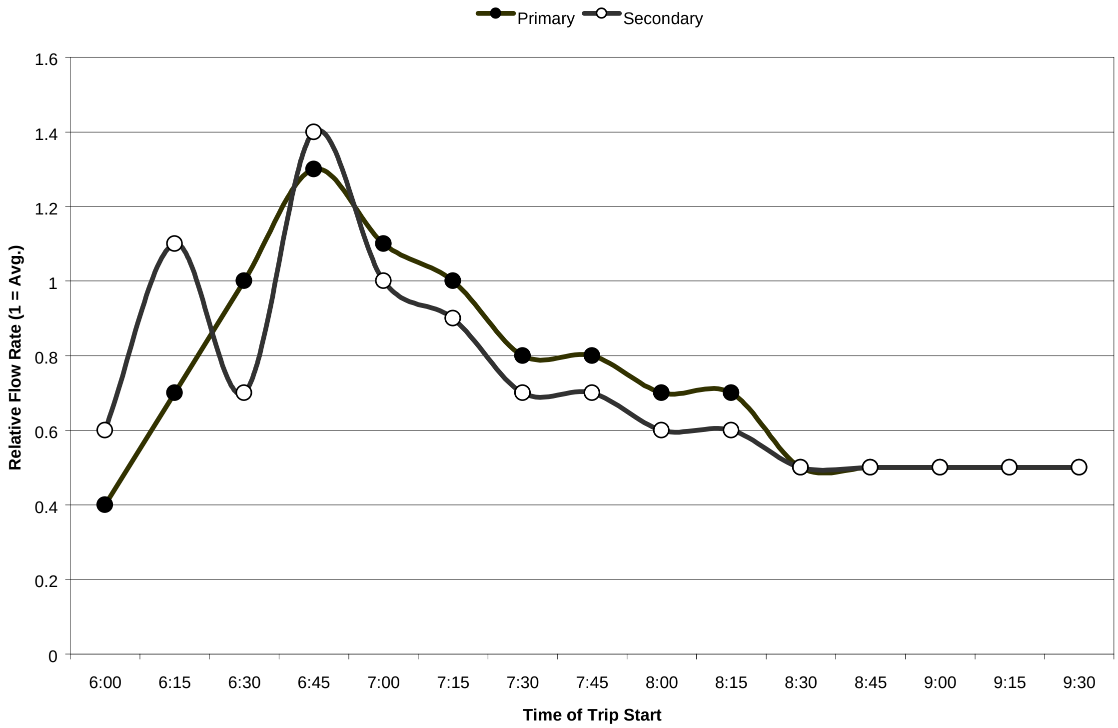


Figure 2-8. Primary and Secondary AM Peak Period Travel Demand Patterns

The precise timing and peaking of the travel demand pattern was the primary parameter used in the calibration of within-day travel time. A default peaking pattern was developed based on empirical data in the Highway Capacity Manual [17], and then adjusted to create a primary pattern for all origin-destination pairs. Application of this primary pattern in the training process (discussed above in Section 2.5) overloaded the freeway in the early peak period (6:30-7:00). Because of oscillation in the simulation multi-path route selection algorithm under the primary pattern, a modified pattern was applied for selected origin-destination pairs located directly along the I-5 facility. This secondary pattern satisfactorily compensated for the early-peak oscillation. The number of vehicles affected by this secondary pattern represent less than 5% of overall travel demand. The primary and secondary time-variant demand patterns are illustrated in Figure 2-8.

Although the calibration of within-day travel time in the training process is important in establishing reasonable habituated routings and travel time profiles, the calibration of day-to-day travel times requires a complete set of runs over the 30 representative day scenarios (described above in Section 2.3). In Figure 2-9, results from the analysis of the Baseline alternative are presented. For this analysis, four full AM peak simulation runs were conducted for each representative day scenario under different random seeds. From these 120 simulated days, average and percentile travel times can be calculated similarly to the analysis conducted on the Sidewalk calibration data. In the case of the representative day scenarios, each scenario's contribution is non-uniformly weighted in contrast to the calibration data which weights each observed day equally.

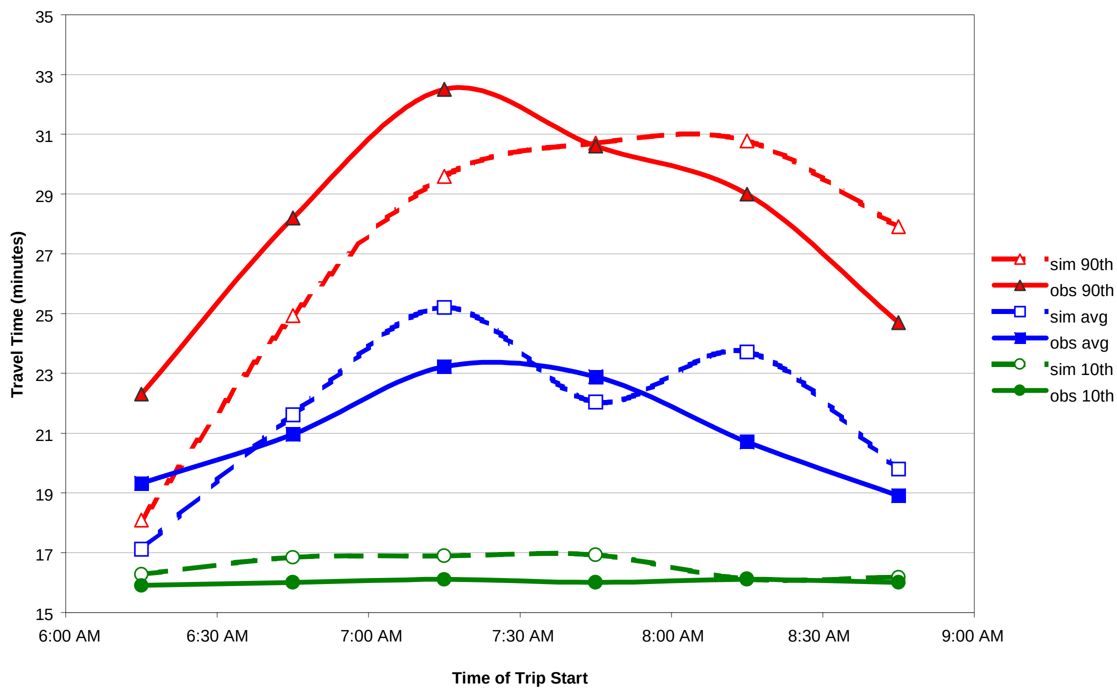


Figure 2-9. System Variability Calibration Southbound I-5, Alderwood Mall to Mercer Street

Figure 2-9 illustrates that the variability seen in the calibration data and in the simulated data are quite similar. The calibration target data is again presented as in Figure 2.7 as the solid line with solid data symbols. Average travel time in the simulated data rises from 17 minutes to 25 minutes, peaking in the 7:00-7:30 AM period, then drops off to 19 minutes by the end of the AM peak period. Congested travel times at the 90th percentile peak at 31 minutes, while uncongested travel times range between 16-17 minutes. One may observe that simulated travel times in the 8:00-8:30 AM period is 1.5-2.5 minutes higher than the calibration data, and that the 90th percentile simulated data is lower in the early peak 7:00-7:30 AM period. Especially for the 90th percentile travel times here are strongly influenced by the timing and position of incidents along the I-5 freeway. This observation likely indicates that the incident profiles from 1993-94 had more, or more serious, accidents on the freeway later in the peak period than those occuring over the calibration data period, 1997-98.

The calibration of the network for within-day and day-to-day conditions is a critical factor in establishing the capability to assess ITS impacts using simulation. This effort for the Seattle MMDI network represents the most comprehensive and detailed large network calibration conducted to date for ITS impacts assessment.

2.9 Energy and Emissions Assessment Methodology

Mitretek calculated energy and emissions estimates by post-processing simulation data from the PRUEVIIN framework through an estimation process developed at Virginia Polytechnic Institute and State University (Virginia Tech). The energy and emissions estimation process combines average link statistics from the simulation model with energy and emission rates associated with travel speed and stop frequency. Simulated travel speed and stop frequencies are obtained for in each evaluation scenario. Each of these estimates represents a composite of results from four random seeds. The multiple-seed approach allows any energy and emissions impact indicated for the ITS strategies tested to be compared statistically against the inherent randomness in the simulation. Annualized speed and stop profiles of travel are generated by taking the weighted sum of all the scenario impacts. Annualized energy and emissions impacts are then calculated by applying the Virginia Tech rates against the annualized speed and stop profiles. The analysis enabled by the Virginia Tech energy and emissions rate data is new in that it explicitly considers stops as well as travel by speed range in its calculation of impacts. The rate tables allows an examination of tradeoffs between increased travel and smoother, higher speed travel associated with improvements to roadway system efficiency.

The remainder of this section will first describe some of the details and assumptions made in the Virginia Tech energy and emissions rate data. The latter part will describe the statistical T-tests that were conducted on the four seeds of each experiment and the alternative. A flow chart of the energy and emissions estimation process can be found in Figure 2-10.

Virginia Tech Energy and Emissions Data: The following description of the model was taken from the Virginia Tech documentation [3]:

> *The model computes the fuel consumption rate and emission rates of hydrocarbon (HC), carbon monoxide (CO) and oxides of nitrogen (NOx) of that vehicle on a per kilometer basis. The calculations are made for various scenarios considering different average speeds and number of stops per kilometer.*
>
> *For each vehicle, the following combinations of vehicle average speed and number of stops per kilometer are considered:*
> *Vehicle average speed ranging from 10 to 120 km/h, with a 10 km/h increment, and*
> *Number of stops per kilometer ranging from 0 to 1, with a 0.25 stop/km increment.*
>
> *The calculations are made on the basis of the following assumptions:*
> *Vehicle deceleration rate is assumed to be –3 m/s2 (-10.8 km/h-s).*
> *Vehicle acceleration rate is assumed to correspond to 50 percent of the vehicle's maximum sustainable acceleration at any given speed.*
> *A linear relationship is used to model the relation between speed and maximum acceleration.*
> *Fuel consumption and pollutant emissions are calculated assuming that each vehicle makes one full stop during a one-kilometer trip.*
> *Changes in the number of stops per kilometer are reflected in the calculations in two ways. First, a higher number of stops per kilometer result in the use of a higher travel speed from which the stop is made. An increased cruise speed is used to ensure that stopping vehicles would travel the one-kilometer roadway segment in the same amount of time as vehicles making no stop and traveling continuously at the specified average speed. Second, linear interpolation is used to adjust the total fuel consumption and emissions for trips including*

more or less than one stop per kilometer. For example, only half of the total calculated consumption and emissions during the deceleration and acceleration periods is assumed incurred in scenarios with only 0.5 stops per kilometer. Similarly, twice the calculated amounts are considered incurred in scenarios with 2 stops per kilometer.

Actual energy and emissions data was used as an input to the model. This data was a composite of eight different vehicles, and was provided to Virginia Tech by the Oak Ridge National Laboratory. Other experimental data sets at Georgia Tech and UC Riverside were considered; however, Oak Ridge was the only party that made their data available for third party use. The following is a list of the vehicles that were used in the composite:

1988 Chevrolet Corsica
1994 Oldsmobile Cutlass Supreme
1994 Oldsmobile Eighty Eight
1995 Geo Prizm
1993 Subaru Legacy
1994 Mercury Villager
1994 Jeep Grand Cherokee
1994 Chevy Pickup Silverado

Charts depicting the speed and stop range relationships for fuel use and emissions can be found in Appendix A. They show the effects of vehicle speed and the number of stops per kilometer on fuel use and emissions. In general, increases in speed and stops per kilometer cause fuel use and emissions to increase. The following paragraph goes into the sensitivities of fuel usage and emissions in greater detail.

Figure A-1 presents the sensitivity of the energy consumption rates to travel speed and stop rate. For example, there is high fuel consumption in the 0-10 km/h speed range. However, fuel usage rapidly decreases to about the 40-50 km/h range. Fuel usage then begins to rise and the difference in fuel use among the various stop ranges becomes more apparent as the vehicle speeds increase.

For HC, increases in speed have a more dramatic effect. (Figure A-2) Once vehicles reach the 50-60 km/h speed range, HC emission increases become very substantial. Also, the differences among stop ranges become greater beginning at the same 50-60 km/h range. For CO and NOx (Figures A-3 and A-4), the emission charts follow the same pattern as in HC.

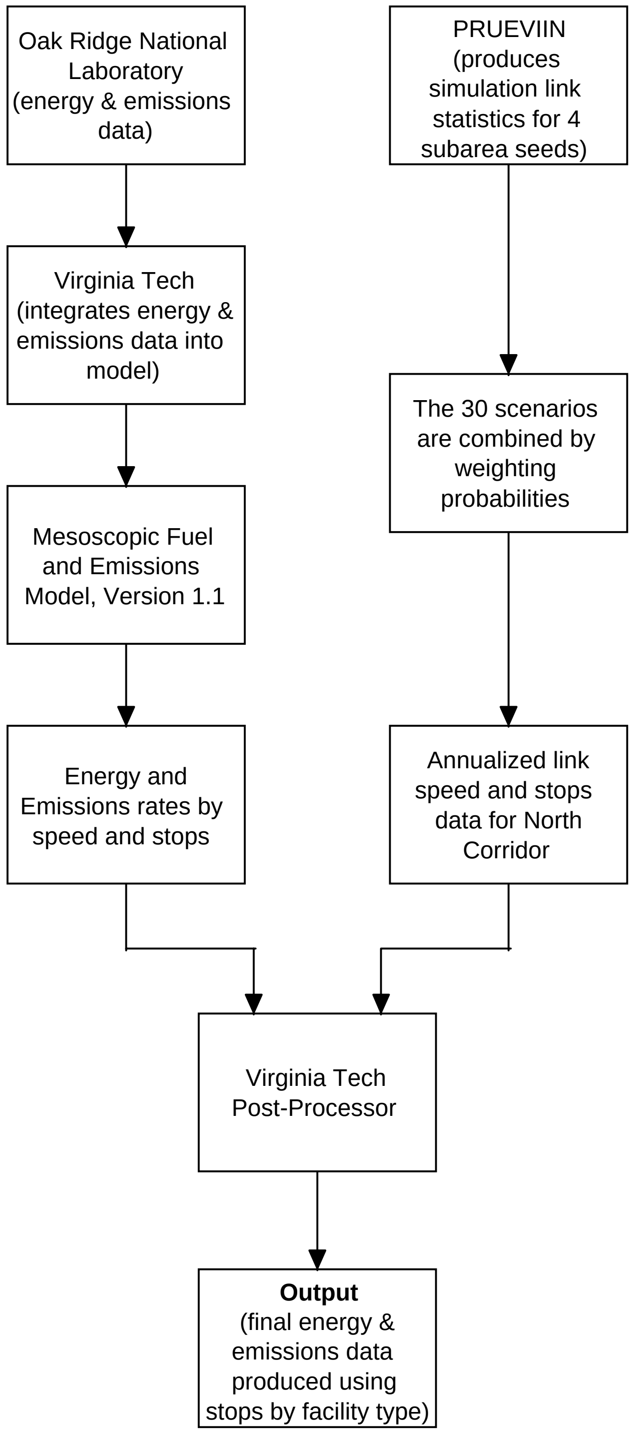


Figure 2-10. Energy and Emissions Impacts Assessment Process

One inconsistency between the Virginia Tech analysis using a single representative vehicle and the aggregated simulation data did arise during the analysis. At higher speeds (80+ km/h), it is physically impossible for a single vehicle to average a high number of stops per kilometer, although aggregated data may still have valid data in that range. For example, it is not possible for a vehicle to average a speed of 90 km/h and still make 0.80 stops per kilometer. Therefore, the Virginia Tech analysis did not produce any data for these particular instances. However, aggregated simulation data did produce some travel in these ranges. For example, a few slow-moving vehicles with a high number of stops combined with other fast-moving vehicles with no stops generate profiles of speeds and stops that a single vehicle cannot. Thus, wherever the model did not provide energy and emissions data, estimated data was taken from the closest stop range. For example, the Virginia Tech analysis was able to produce data for 0.50 stops per vehicle kilometer at an average speed of 90 km/h. This data was then inserted for the missing rates at 0.80 stops per vehicle kilometer at 90 km/h. Because less than 0.5% of the vehicle kilometers in the simulation model lacked energy and emissions data, this estimation method had little impact on the overall results. The energy and emissions charts in Appendix A show where the Virginia Tech analysis did not produce data at the higher speed and stop ranges.

Statistical T-tests: Statistical T-tests were performed to test whether the results of the experiments or the alternative were related to the results of the Baseline. The T-tests found the probability that the mean of the experiments and alternative were related to the mean of the Baseline. This was done for Fuel Use and the emissions categories along with the Number of Stops and Vehicle Kilometer of Travel. The process in computing the T-test results differed from computing the fuel and emissions output in that the four seeds were left separate. They were not combined for each scenario, but rather the scenarios were averaged together for each seed. The seeds were then used for a paired T-test with a one-tail distribution. A confidence level of 90% was used. Any T-test results that fell below the confidence level were considered to be possibly unreliable. The outcome of the T-tests are reported in Section 4 alongside the energy and emission impacts of each experiment.

2.10 Safety Impacts Assessment Methodology

Seattle crash statistics were calculated for each of the four sensitivity analyses an the alternatives analysis. The simulation output required to calculate crash statistics are total million vehicle kilometers traveled and total vehicle seconds traveled.

The vehicle-kilometers and vehicle-seconds are fed into a series of coefficients provided by the Virginia Tech Center for Transportation Research. The coefficients are used to calculate total number of crashes using either vehicle-kilometers or vehicle-seconds. Virginia Tech also provided coefficients that calculate severity of crash and severity of injury using either vehicle-kilometers or vehicle-seconds. Using these coefficients, crash probability, total number of crashes, fatal crash probability, and total number of fatal crashes could then be calculated.

The baseline crash statistics are compared against each of the strategies to determine if overall crashes rates or fatal crash rates rose or dropped. They were also compared by six different speed ranges and by facility. The changes in total crashes or fatalities are very small when reviewed for one morning rush hour, so these statistics were looked at based upon a ten-year period.

In addition, because of the slight variations in total crashes and total fatalities when reviewing comparisons, a paired t-test analysis was conducted to determine whether the changes were significant or just random variation. The crash statistics were also compared to other data sources to determine their validity.

<u>Simulation Output:</u> Four seeds were used to generate random simulations for each strategy. Thirty simulations were run for each of the seeds. The thirty simulations are then combined using weighted averages to create an average simulation output for each seed. This averaged output represents what Seattle traffic would be like on any given day of the year.

The simulation creates a text file giving the total vehicle seconds and total vehicle kilometers that are traveled on each link in the model. The data is analyzed using a post processor that both rolls up the numbers and calculates the crash statistics (described below).

<u>Virginia Tech Coefficients</u>: As part of the Metropolitan Model Deployment Initiative (MMDI) evaluation, the Center for Transportation Research at Virginia Tech developed coefficients used to calculate crash data[4]. The four types of coefficients are crashes per vehicle-kilometer, crashes per vehicle-second, probability of damage and probability of injury. These coefficients are further broken down by speed range. They are not broken down by facility type, so these coefficients do not explicitly account for different accident levels on freeways versus arterial roads. The coefficients account for stops in the speed ranges, but the equations themselves do not have a variable to account for stops, therefore the number of stops in each simulation are not dealt with. This differs from the energy and emissions analysis where stop rates were directly used as inputs to the impacts estimation process.

Virginia Tech used the following calculations to create the crash rates given travel in certain speed ranges:

<u>Eq. 2.10-1</u>

$$r_s = \exp(c_1 v + c_2)\text{, where}$$

r_s = crash rate per million vehicle seconds of exposure

v = travel speed, c_1, c_2 = coefficients supplied by Virginia Tech

<u>Eq. 2.10-2</u>

$$r_k = \frac{r_s}{(1.6v)(3600)}\text{, where}$$

r_k = crash rate per million vehicle-kilometers of travel

These coefficients expect velocity to be in miles/hour, so metric conversions have to be done to obtain the correct output.

The following crash rates results from the calculations:

	Crashes/ million veh-sec	Crashes/ million veh-km
0-32 kph	0.05946	6.68944
33-40 kph	0.05376	4.83816
41-60 kph	0.04178	2.50664
61-80 kph	0.03247	1.46102
81-100 kph	0.02523	0.90834
100+ kph	0.02169	0.69716

Table 2-9. Crash Rate Coefficients

These numbers generally coincide with the rule of thumb that there are fewer crashes at higher speed than at lower speeds.

The following calculations were used to obtain damage probabilities:

Eq. 2.10-3

$$d_i = c_{(i,1)} + c_{(i,2)}v + c_{(i,3)}v^2 + c_{(i,4)}v^3 \text{, where}$$

d_i = damage by index category (none, minimal, moderate, severe)

The coefficients $c_{(i,k)}$ are coefficients supplied by Virginia Tech, indexed by i for severity. The resulting values are then normalized to 1 to create damage probabilities.

The following damage probabilities result from the calculations:

	no damage	minor	moderate	major
0-32 kph	1.93%	55.82%	24.59%	17.66%
33-40 kph	4.66%	43.03%	30.32%	22.00%
41-60 kph	6.63%	37.48%	32.91%	22.98%
61-80 kph	4.71%	48.95%	28.09%	18.26%
81-100 kph	2.86%	50.41%	27.98%	18.75%
100+ kph	3.46%	35.53%	35.09%	25.92%

Table 2-10. Damage Probabilities

These damage probabilities are not as clear as the accident rates, however, the data does generally indicate lower speeds have a high ratio of minor damage than higher speeds.

The following calculations were used to obtain injury probabilities:

Eq. 2.10-4

$$I_j = b_{(j,1)} + b_{(j,2)}v + b_{(j,3)}v^2 + b_{(j,4)}v^3 \text{, where}$$

I_j = injury probability by index category (minimal, non-incapacitating, incapacitating, fatal)

Coefficients $b_{(j,k)}$ are coefficients created by Virginia Tech, indexed by j for injury severity. The resulting values are then normalized to 1 to create injury probabilities.

The following injury probabilities result from the calculations:

	no inj	minor	non-incap	incap	fatal
0-32 kph	52.87%	14.90%	23.12%	8.88%	0.23%
33-40 kph	52.87%	14.90%	23.12%	8.88%	0.23%
41-60 kph	50.63%	18.86%	17.88%	12.10%	0.53%
61-80 kph	52.14%	20.78%	15.64%	10.85%	0.59%
81-100 kph	52.75%	18.36%	15.25%	12.44%	1.20%
100+ kph	50.51%	13.68%	15.42%	18.18%	2.21%

Table 2-11. Injury Probabilities

The results generally indicate there are more fatalities at higher speeds than at lower speeds. As a whole, fatalities are very infrequent in comparison to other injuries.

Post-Processor (CRASH): As previously stated, 30 simulations were performed for each seed in a given strategy. These simulations were then combined to come up with a weighted average simulation for each seed. The output is vehicle-kilometers and vehicle-seconds by speed and by link. In order to group the results by speed bin and facility type, a post processor was written to use the coefficients and calculate crashes and fatalities.

CRASH is a FORTRAN program built by Mitretek to input the simulation results and calculate crash statistics using the Virginia Tech coefficients. CRASH calculates crash and injury statistics using both vehicle-kilometers and vehicle-seconds. Calculating statistics using differing inputs will result in two different answers, however, it gives an idea of what range that benefits can be expected for each strategy.When the simulation results were processed using CRASH, the following information was calculated from the post-processor:

	Number of Crashes		**Number of Fatal Crashes**		**Percentage of Fatal Crashes**	
Speed Range	**Million veh-sec**	**Million veh-km**	**Million veh-sec**	**Million veh-km**	**Million veh-sec**	**Million veh-km**
0-32 kph	5.48	3.15	0.013	0.007	0.10%	0.073%
32-40 kph	2.05	1.87	0.005	0.004	0.04%	0.042%
40-60 kph	3.48	3.02	0.018	0.016	0.14%	0.167%
60-80 kph	1.03	0.86	0.006	0.005	0.05%	0.052%
80-100 kph	0.73	0.65	0.009	0.008	0.07%	0.083%
100+ kph	0.06	0.05	0.001	0.001	0.007%	0.010%
Per morning rush hour:	**12.83**	**9.60**	**0.052**	**0.042**	**0.407%**	**0.435%**

Table 2-12. Crash Probabilities by Speed Range, Baseline Case

	Number of Crashes		Number of Fatal Crashes		Percentage of Fatal Crashes	
Facility Type	**Million veh-sec**	**Million veh-km**	**Million veh-sec**	**Million veh-km**	**Million veh-sec**	**Million veh-km**
Freeway	0.78	0.66	0.005	0.004	0.040%	0.046%
Expressway	0.26	0.23	0.002	0.001	0.012%	0.014%
Urban Arterial	3.40	2.43	0.011	0.008	0.087%	0.087%
Rural Arterial	3.77	2.47	0.012	0.009	0.093%	0.089%
Per morning rush hour	**8.21**	**5.79**	**0.030**	**0.023**	**0.230%**	**0.236%**

Table 2-13. Statistics by Facility Type, Baseline Case

Verification of the results is difficult because most available corroborating data is usually composed of national averages. Source data for studies can also be from past years and may not reflect the current year situation. However, if the simulation results are relatively close to national averages we gain some confidence in the estimation technique.

The National Highway Traffic Safety Administration (NHTSA) released a Traffic Safety Facts report in December 1997 [18]. This is a compilation of nationwide traffic statistics for 1996. The data was not broken down to a fine enough detail to compare directly to King County, Washington, however, the report does indicate the following national statistics:

	% of Crashes that are Fatalities	Crashes/ Million veh-km	Fatal Crashes/ Million veh-km
*National	0.546%	1.71	0.009
Baseline	0.407%	3.73	0.015

*Source: Traffic Safety Facts 1996, section 1996 National Statistics

Table 2-14. National Crash Averages Compared to Baseline

The baseline fatality percentage obtained from post-processing simulation data is 0.1% lower than the national average obtained from NHTSA. The few fatalities that occur in crashes can contribute to the wide differences in results. The national crash and fatality rate is higher, which leads to the assumption the baseline is undercounting. However, the Traffic Safety Facts 1996 also had crashes broken down in time periods. This would make it easier to compare the baseline to a fairer starting point. It did not have vehicular-miles or vehicular-seconds broken down, so only the percentage of fatal crashes is calculated:

	% of Crashes that are Fatalities
*National	0.356%
Baseline	0.407%

*Source: Traffic Safety Facts 1996, Chapter 2-Crashes, Table 24

Table 2-15. National Percentage of Crashes Compared to Baseline (6AM – 10AM only)

This is a more credible number because the national average is now underestimated. This can be attributed to the fact national statistics include highway driving and driving outside of cities, which can reduce the average. Traffic Safety Facts can be obtained from the NHTSA website at http://www.nhtsa.dot.gov/people/ncsa/TSF96.html.

The National Highway Transportation Safety Authority maintains an online database called the Fatal Accident Reporting System (FARS) [19]. FARS can be used to compare fatality statistics for King County. These results can still be different from the simulation because King County contains part of downtown Seattle and some outlying areas, so the exact pattern is not the same. Another problem is FARS counts actual fatalities, not accidents involving fatalities. However, each record shows what accident it was involved in, so duplicate accidents can be removed

FARS was queried for calendar year 1997 data, Washington State, for all fatalities between 6:00 AM and 10:00 AM.

	Annual Fatal Crashes
FARS	14
Baseline	11.4

Table 2-16. Comparison of FARS Fatal Crashes to Baseline for King County

The annual fatal crashes according to the simulation is slightly lower than the 1997 fatal crashes for King County. However, it is close if considering some of the accidents could have occurred out of the North Corridor subarea.

SECTION 3: EXPERIMENTAL DESIGN

This section presents detail on the modeling experiments conducted in support of the Seattle MMDI effort. Section 2 presented the evaluation framework and the calibration of the Baseline case. Understanding the assumptions of the Baseline case is critical when examining the four MMDI-related experiments presented in this section. Four simulation experiments (sensitivity analyses) follow the three project groupings in isolation (ATIS, ATMS, IMS, and Arterial Data for ATIS). A linked regional model-simulation analysis examines a prospective concurrent deployment of the ATMS and Arterial Data for ATIS experimental controls (Enhanced ITS).

The parameters selected in the Baseline case are considered the default values in any experiment where a set of control parameters is varied. For example, in the experiments isolating the impact of coordinated traffic signal control (ATMS), the Baseline parameter setting for various advanced traveler information usage levels (e.g., usage of web-based pre-trip planning services set to 0%) is utilized.

For the estimation of market penetrations for ATIS, precise quantification of actual usage rates cannot always be made. Model inputs generally do not accept ranges of values or allow for uncertainty in parameter estimation. In order to resolve this issue, Mitretek makes a reasonable estimate for all model parameters given currently available data. Where these parameters are used as controls within an experiment, a range of values is examined in a sensitivity analysis. While this effort does not more precisely quantify the parameter, it does indicate what range of impacts are associated in the area of uncertainty around a particular parameter choice.

As pointed out in Section 1.4, the majority of Seattle MMDI projects were focused on system integration or expansion, i.e., the connecting together of isolated capabilities or the incremental extension of existing technologies. Because of this, the Baseline case should not be misconstrued as representing a “No ITS” case, especially given the fact that the North Corridor itself contains a highly instrumented freeway segment (I-5) with advanced control and traveler information systems. In fact, many of these technologies have been in place for several years (e.g., ramp metering). With this in mind, the experiments have been designed to illustrate impacts of ITS after MMDI-related enhancements have been or could be implemented.

The “could be implemented” phraseology here refers to the fact that some projects enabled but did not enact a change in system control in the North Corridor. For example, the archiving of arterial data facilitated by the North Seattle ATMS (SE-1) allows WSDOT to comprehensively examine and test new traffic signal control patterns. To date, new plans based on the data have not been developed nor have jurisdictions along the arterial corridors agreed to implement a new plan. Again, the impact of these data-sharing capabilities were not implemented as a part of MMDI, but established a necessary condition for any future implementation. The ATMS modeling effort seeks to predict the potential impacts of implementing a new optimized signal control plan. In each experimental plan description, such projective assumptions are clearly itemized.

The “after” condition alternative, Enhanced ITS, represents a combination of improved ITS capabilities facilitated within the MMDI deployment time frame. These enhanced capabilities comprise the concurrent deployment of the ATMS and Arterial Data for ATIS enhancements examined in isolation as a part of the four sensitivity analyses. More specifically, these control parameters include an increase in users of detailed, real-time freeway travel-time information with expanded coverage to two parallel arterial facilities (Arterial Data for ATIS), and a set of projective improvements to signal coordination (ATMS).

The results in Section 4 cover impacts over all scenarios using the default control parameters associated with the Baseline and the Enhanced ITS alternative. For ATIS, this implies a 6% market penetration for high-fidelity pre-trip traveler information. For the IMS analysis, this implies a 12.5% reduction in incident duration. In addition, sensitivity analyses on these parameters is also included. For the ATIS experiment, market penetration rates of 10%, 3%, and 1% are also tested. Likewise, a 25% reduction in incident duration is considered.

3.1 Baseline Case Description

Project Grouping	**Relevant Baseline Infrastructure**	**Seattle MMDI Projects Represented in Enhanced ITS Alternative**
Traveler Information Services (ATIS experiment)	Traffic reports on commercial radio, TV reports	Microsoft Sidewalk (SE-17) Etak/Seiko/Metro (SE-18) Fastline HPC (SE-19) Cable TV (SE-20) WSDOT Web Page (SE-26) Traffic Telephone (SE-27)
IMS/EMS Freeway Management (IMS experiment)	Shoreline TSMC freeway management capabilities, including ramp metering and VMS on I-5	Regional Video (SE-9) Incident Capture (SE-12) Incident Video (SE-13) Emergency Ops Center (SE-14)
Traffic Signal Control (ATMS experiment)	Fixed time-of-day plans	North Seattle ATMS (SE-1) Northwest TSMC (SE-7)
Arterial Data Integration with ATIS (Integration)	None	ITS Backbone (SE-29)

Table 3-1. North Corridor ITS Services in the Baseline Alternative

Table 3-1 summarizes the Baseline alternative. ITS deployments in the region have enhanced the scope and availability of traveler information services, freeway management, traffic signal control, and transit information services. Some of these enhancements predate the MMDI effort, some are unrelated to MMDI, some are MMDI projects. Some cases, like the WSDOT ATIS web site, are experiencing rapid growth in user base. Table 3-1 also shows how we have split up these capabilities into the categories of Baseline capabilities and MMDI-related enhancements.

<u>Traveler Information Services</u>. Incident, construction, and other emergency road closure information have been reported on radio, TV, variable message signs, and highway advisory radio for several years. Accordingly the use and operation of these advisory services is modeled

in the Baseline alternative. Figure 3-1 shows the physical locations ([20]) of the VMS modeled as a part of the North Corridor subarea. The same signs are present in all experiments. The modeling of these devices is described in Section 3.2.

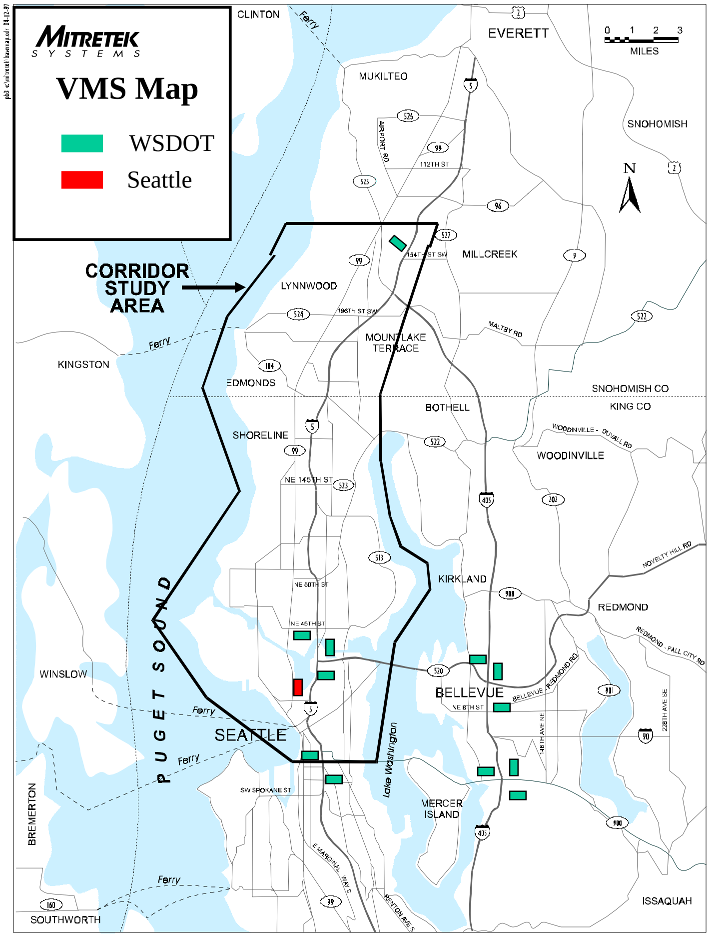


Figure 3-1. VMS Modeled in the North Corridor Subarea

<u>IMS Freeway Management</u>. WSDOT has been operating an advanced freeway management system in the region for several years [21]. Most sections of the major freeways are instrumented with loop detectors every half-mile in most sections and some sections with greater density. This data is communicated to the WSDOT Traffic System Management Center (TSMC) where it can be fused to provide a comprehensive picture of current regional traffic conditions, control ramp metering systems, and disseminate information through variable message signs, HAR, and Metro Traffic. We model these capabilities of the WSDOT TSMC in the Baseline.

In the subarea simulation current travel time information is only available for links assumed to be under surveillance. Surveillance devices in the North Corridor are either loops or CCTV cameras. Only CCTV equipped roadways or those equipped to send count data back to the TSMC are modeled as being under surveillance. Other roadways, such as those with only presence detectors that actuate traffic signals, are assumed to be without surveillance.

In the Baseline alternative we include only the surveillance infrastructure currently sending information to the WSDOT TSMC. I-5, I-90, SR-99 south of 45th Street, the Evergreen Point Floating Bridge, the Lacey V. Murrow Bridge, and the Ship Canal Bridge are under surveillance ([21]). All associated on-ramps are also assumed to be under surveillance. Figure 3-2 shows these surveillance assumptions on a map.

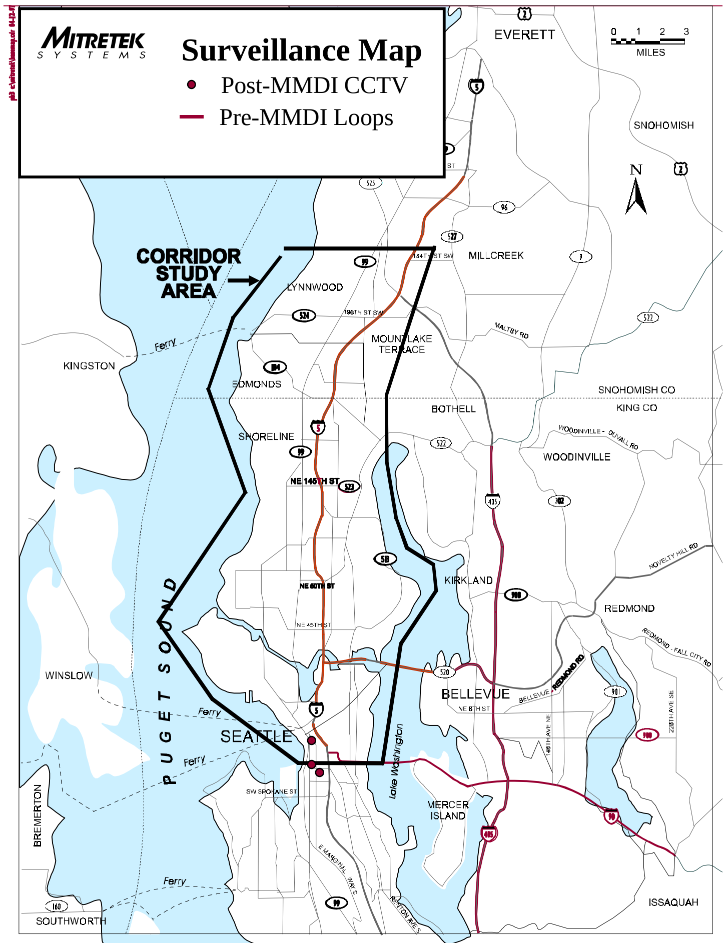


Figure 3-2. North Corridor Surveillance Infrastructure

<u>Traffic Signal Control</u>. Signal control in the Baseline case is characterized as fixed, time-of-day control within jurisdictional boundaries [21,22]. Although simple actuation is a feature at some intersections, no adaptive control systems (like SCOOT) are present in the corridor. A FHWA-sponsored RT-TRACS adaptive control field test currently underway just outside the subarea in Bothell, WA is not considered as a part of either the Baseline case or the Enhanced ITS case.

<u>Arterial Data Integration with ATIS</u>. The provision of real-time congestion information from major arterials to ATIS providers is not a feature of the Baseline case.

Section 3.2 Sensitivity Analysis: ATIS Experiment

Hypothesis: *Provision of traveler information containing more accurate, frequently updated quantitative freeway travel time estimates improves throughput and efficiency.*

Characterization and Data Sources: The ATIS experiment highlights the impact of several internet-based mobile and desktop information sources. Traffic information is also now available through Microsoft's Seattle Sidewalk website (http://trafficview.seattle.sidewalk1.com/), WSDOT's public website (http://www.wsdot.wa.gov/), a message watch sold by Seiko, and a handheld personal computer (HPC) sold by Fastline (http://www.fastline.com/).

In addition to these internet-based services, the University of Washington provides improved traffic information on cable TV (channel 27). The web-based services, cable TV, and the Fastline HPC currently provide maps of the regional freeway system. The freeways are color coded to reflect current congestion levels. The levels are estimated from flow and speed data obtained every 20 seconds through WSDOT's extensive freeway surveillance infrastructure. The web sites also provide views from more than fifty CCTV cameras, as well as incident and construction reports. The Seiko message watch provides only incident reports. The reports are encoded in a particular numeric format that must be known by the user.

Table 3-2 states the key attributes and corresponding descriptors that categorize the information services. Both the availability of field data and the modeling capabilities of EMME2 and INTEGRATION inform our choice of key attributes.

Key Attribute	**Descriptors**
Access type	*Pre-trip/En-route*
Congestion Information Quality	*High fidelity: quantitative, regional LOS or travel time* *Low fidelity: qualitative, localized congestion information*
Facilities covered	*Freeways only/Freeways and state routes only/ All roads*
Incident Reports	*Yes/No*
Construction Reports	*Yes/No*
Update frequency	*Time in minutes*
Usage	*Percentage of travelers*

Table 3-2 Differentiating Traveler Information Services

Access type is significant because some traveler information sources can be accessed only at the point of origin (denoted by pre-trip), e.g., TV reports, whereas others can be accessed during the trip, e.g. radio. Therefore the access type of the information source used by a driver determines the propensity of the driver to re-route during a trip. Congestion information quality is perhaps the most important factor distinguishing the newer information sources included in the ATIS experiment from the older sources modeled in the Baseline. Sources with low fidelity congestion information quality tend to restrict themselves to reporting incidents, construction, and special events and some limited description of the congestion in the neighborhood of the incident. The high fidelity sources on the other hand provide visual displays of travel conditions in the system as a whole, thereby allowing the user to more effectively gauge the likely travel time for the entire trip. The information sources also differ in terms of the roadway facilities they report about. We refer to this as coverage. High fidelity congestion information from Cable TV and the web-based services is currently restricted to the freeway system only. The low fidelity information sources providing incident, construction, and event reports cover the freeways and all the state routes in the region. Most of the high fidelity information sources also provide incident reports. Table 3-3 classifies all traveler information sources by access type, congestion information quality, and coverage.

The classification in Table 3-3 is based on data gathered from different traveler information sources. Mitretek collected limited primary data ([16]) to understand the characteristics of some of the information sources. In particular we monitored the WSDOT web page, KIRO710 FM real-time web radio, and traffic telephone during the AM peak period on five weekdays. The data collected was analyzed to estimate the operating characteristics of the different sources. The impressions so formed were then compared with information obtained from WSDOT ([23]). The two sources of data were in agreement on all major points. We also visited Metro Traffic in the city of Seattle to better understand the process of generating radio traffic reports. Operating characteristics of the Seiko Message watch were obtained from ([24]).

	Low Fidelity Information	**High fidelity Information**
Pre-trip Access	Traffic Telephone TV Reports *Coverage: Freeways and state routes*	Desktop: WSDOT web Desktop: Sidewalk Cable TV Map *Coverage: Freeways*
En-route Access	Traffic Telephone (Cell) Radio, VMS *Coverage: Freeways (all), state routes (telephone, radio)*	Fastline HPC Seiko Message Watch *Coverage: Freeways*

Table 3-3. Classification of Traveler Information Sources

Two other features of the information sources that are important to the PRUEVIIN models are the dynamic responsiveness of the information and the usage of the source. The dynamic responsiveness of the information source is modeled by the interval at which it is updated. Most of the high fidelity sources are updated faster than every two minutes ([23]). These sources derive their information from WSDOT's freeway loop data that sends new counts to the TSMC every 20 seconds. The different high fidelity information sources process and package this data in different ways to make it suitable for users. Incident information is derived from reports created by highway patrol, WSDOT operators monitoring CCTV cameras, and individuals calling Metro Traffic. Radio traffic reports are typically broadcast every 10 minutes ([21,23]), traffic telephone recordings are updated at a comparable frequency, VMS signs and the Seiko watch are event-driven, reporting incidents as and when they occur ([25]). Table 3-4 summarizes the update intervals.

ATIS Service	Reports	Update Interval	Usage
WSDOT web	Incident: Yes Construction: Yes	< 2 min	300,000 hits per day (1998) 0.5 % of commuters (1997)
Sidewalk	Incident: Yes Construction: Yes	< 2 min	Unavailable
Cable TV	No	< 2 min	Unavailable
Fastline HPC	No	< 2 min	Low
Seiko watch	Incident: Yes	As needed	Low
Radio	Incident: Yes	10 min	49 % of commuters*
TV reports	Incident: Yes Construction: Yes	10 min	16 % of commuters
Traffic telephone	Incident: Yes Construction: Yes	5-10 min	Low (< 500 calls in AM peak)
VMS	Incident: Yes Construction: Yes	As needed	20% of commuters
HAR	Construction: Yes	As needed	49 %*

*HAR, commercial radio rates cumulative

Table 3-4. Classification of Seattle MMDI Traveler Information Sources

Table 3-4 also summarizes the usage data ([26,27,28]). At the time of this report, Microsoft is not sharing data on usage of the Seattle Sidewalk website. The cable TV traffic channel has been recently deployed and some survey data on its usage should be available in the near future. There are probably a few (less than 100) message watch users in the region. Thus its current or projected near-term impact is expected to be quite small. The current market penetration of the Fastline HPC is also small. Available data indicates that weekday AM traffic telephone call volume is less than five hundred calls per AM peak period. Since there are over 250,000 travelers in the North Corridor AM peak period the impact of traffic telephone may also be expected to be small. Small system-level impacts are difficult for discern above background randomness in a large simulation model like the North Corridor network. As a rule of thumb, the North Corridor simulation model requires at least a roughly 1% market penetration to generate a statistically significant impact.

As a part of the MMDI evaluation, Batelle researchers and WSDOT have been tracking web-site usage over the period May 1998-May 1999.. The web usage numbers in Table 3-4 are based on preliminary findings from that effort. More detailed breakdowns of these numbers by day, time, kind of information accessed, user type, etc., will be available later in 1999. The usage seems significant enough to measurably affect traffic flow in the region. Moreover, its usage seems to be growing rapidly. The radio, TV, and VMS usage data is obtained from [26].

Control Parameters: The subarea simulation supports the concurrent use of multiple driver and device classes that differ in their travel time information sources and routing algorithms ([29]). To model the operation of the North Corridor when loaded by drivers having different sources of information and access to different infrastructural facilities such as HOV lanes or VMS signs, we create five driver and two device classes (discussed later) as follows.

- Drivers without dynamic information (Class 1,2,3)
  - Class 1 (SOV commuters): Route themselves by habitual path determined during network training/calibration process (see Section 2.5).
  - Class 2 (HOV commuters): Route themselves onto the minimum travel time path, including HOV lanes, by historical information.
  - Class 3 (Unfamiliar drivers) : Route themselves via imprecise estimation of travel times based on roadway class.
- Drivers with dynamic pre-trip information (Class 4,5)
  - Class 4 (Low fidelity): Route themselves at the origin by incident reports and historical information.
  - Class 5 (High fidelity): Route themselves at the origin by flow map, incident reports, and historical information.

Table 3-5 describes the percentage of total AM peak period demand assigned to each driver class. The PSRC panel survey [26] indicates that 16% of the commuters watch TV reports prior to their morning commute. Since this is pre-trip low-fidelity information we assign this percentage to class 4 in the Baseline alternative. Although table 3-3 indicates that traffic telephone is also pre-trip low-fidelity, field data indicates that its usage may be neglected without appreciable error. Thus the remaining 84% of drivers are assigned to classes 1, 2, and 3 in the Baseline. The new class of drivers in the Enhanced ITS alternative is class 5.

The biggest component of class 5 population is estimated based on usage of the WSDOT and Sidewalk web pages. The PSRC panel survey ([26]) indicates that web page usage prior to the morning commute is of the order of 0.5 %. However, WSDOT published data ([28]) indicates usage of this service is rapidly growing, including a reported hit rate of 300,000 hits per day. If We assume that this figure is valid for normal weekdays and one-third of the hits occur during the weekday AM peak. At a rate of 2 hits per traveler, these 100,000 hits represent a population of 50,000 travelers. Further, the trips through the North Corridor represent roughly one-sixth of total travel in the region, so we estimate just over 8,000 travelers in the North Corridor AM peak utilize the WSDOT web page (a roughly 3% market penetration). Another equally large group (3% of travelers) is assumed to be looking at data pre-trip either on the Cable TV station or through Microsoft Sidewalk site.

Thus, in the absence of more detailed user statistics we assign the estimated 6% to class 5 in the ATIS experiment. In the ATIS experiment, we examine the impact of a wider range of market penetrations: 1%, 3%, 6% and 10%. We have also assumed that the 6% in class 5 are drawn predominantly from the low-fidelity pre-trip information users and less from those who use no information at all, i.e., classes 1, 2, and 3 (see Table 3-5).

	Class 1	Class 2	Class 3	Class 4	Class 5
Baseline	84 %			16 % (TV)	0%
Enhanced ITS	84 %			10% (TV)	6 % (web)

Table 3-5. Percentage of Total AM Peak Demand by Driver Class

Since drivers of all classes may have access to information from VMS signs or radio en-route we define two device classes. At specific nodes in the network, drivers of all classes probablistically respond to radio congestion reports (Device class 1) or VMS alerts (Device class 2) for a specified period of time (see figure 3-3). Both devices are assumed to provide low fidelity information. Accordingly, during the period of influence drivers are assumed to route themselves onto the minimum travel time path based on their experiential travel time data and a large delay associated with the advisory alert. The two device classes differ in the following respects. Class 1 devices are only modeled on links that physically correspond to a roadway with a VMS sign on it ([29]). Class 2 devices are modeled as being present at all nodes since there is total regional radio coverage. Furthermore probability of response is class specific and denoted by Pradio and Pvms respectively.

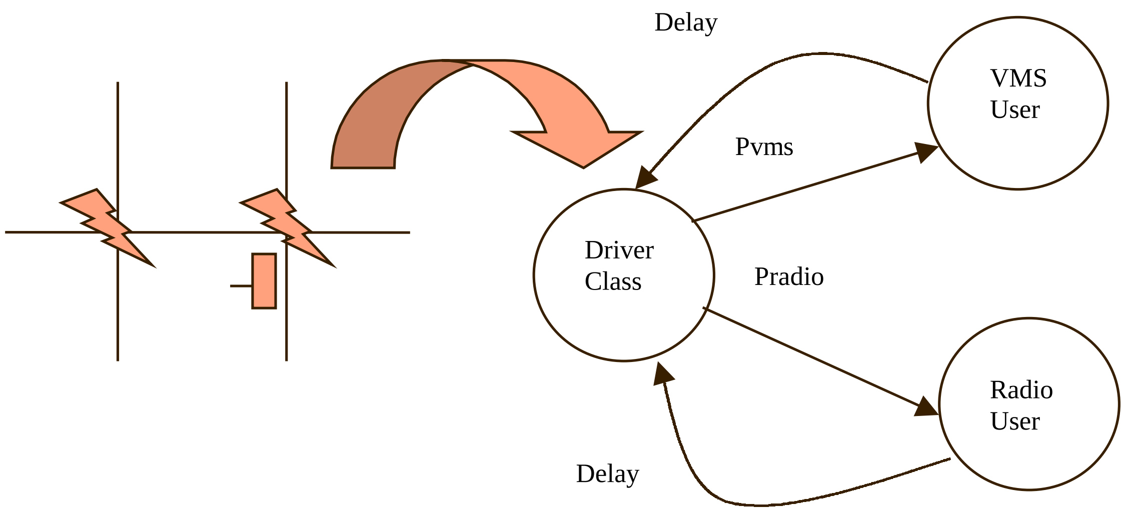


Figure 3-3. Response to Device Classes

The number of responders is calibrated to results of the PSRC panel survey [26]. The probability Pvms is chosen so that 20% of the drivers in the AM peak period respond to VMS alerts at least once during a calendar year. Likewise the probability Pradio is chosen so that 49% of the drivers become radio listeners at least once in the same time frame. In each scenario run, the simulation reports the number of responders by origin-destination pair. Annual usage data is calculated by first finding the maximum number of responders over all scenarios for each origin-destination. These maximums are then summed over across the range of origin-destination pairs in the demand pattern.

Since driver and device classes differ in the type of information used for routing, it is important to model the distinctions between historical, roadway class, low fidelity, and high fidelity information in INTEGRATION. All information used for routing in INTEGRATION is in the form of time slice specific link travel time vectors. Table 3-6 describes the distinctions between the different kinds of information.

Information type	Travel time model
Roadway class information	Freeflow link travel time (LTT).
Historical information	LTT vectors by time slice generated by the training process.
Low fidelity information	Historical travel time for non-incident links Large travel time values for incident links.
High fidelity information	Historical travel time for links without surveillance. Current travel time with random error for links with surveillance.

Table 3-6. Modeling Information Quality

In the case of low fidelity information, the large travel time value on the incident links is chosen to route the driver class away from the incident link and onto reasonable alternative paths. In the case of high fidelity information the travel time used for routing is assumed normally distributed with the mean set at the current link travel time and a coefficient of variation of 10%. High fidelity travel time estimates are only made available for links under surveillance – in this case the freeway links of I-5.

Under these conditions of enhanced ATIS capability, 120 individual simulation runs (30 scenarios x 4 random seeds) were conducted. An additional 360 runs were conducted in the market penetration sensitivity analysis. Travel time and throughput of the system is then compared against the travel time and throughput characteristics of the Baseline case. Results of this experiment are presented in Section 4.1.

3.3 Sensitivity Analysis: ATMS Experiment

<u>Hypothesis</u>: *Improvements in arterial signal coordination from jurisdictional cooperation and more detailed data on queue size improves throughput and efficiency.*

<u>Characterization and Data Sources:</u> Within the North Corridor subarea there are 135 major signalized intersections as well as a much larger number of additional intersections controlled by traffic signals. A major intersection is defined as the intersection of two facilities represented in the regional planning model. Based on data taken from the North Seattle ATMS document and interviews with WSDOT staff [22], we characterize the Baseline traffic signal control in the North Corridor as fixed, time-of-day control.

Fixed refers to plans developed by the controlling jurisdiction, based on average peak or off-peak demand, that cannot be changed in real-time. In some cases, these plans may be updated as often as monthly or quarterly, however they are not changed based on 15-minute or 30-minute updates of arterial queue lengths or other link performance metrics. No adaptive control is modeled in the Baseline, although simple actuation is a feature at some intersections. Time-of-day indicates that for high-volume arterials, there is often a morning and evening peak plan rather than a generic peak period plan. Typical cycle lengths, phase splits and other data in the area are taken from the North Seattle ATMS document.

Two important arterials in the subarea are SR99 (running parallel to and just west of the I-5 freeway) and SR522 (carrying traffic from the northern edge of Lake Washington to its southern terminus with I-5). These arterials are of significant length and both pass through several jurisdictional boundaries where the responsibility for setting timings changes. Within the North Corridor subarea, SR99 has three such boundaries, SR522 one. In the morning peak period, signals along these two arterials are generally timed for speed limit progression. Some exceptions occur by jurisdiction. Although an exhaustive analysis of signal plans was not undertaken, this characterization of the timing plans is supported by a series of GPS-floating car travel time runs collected along SR99 by Mitretek in 1997.

Control Parameters: Three distinct effects of a projective North Seattle ATMS signal retiming project are modeled in the simulation as a part of this experiment:

1. The impact of coordinating signals at major intersections from “top to bottom” along SR99 and SR522 without regard to the current jurisdictional boundaries.

2. The coordination of minor signals along these same corridors at progression speeds selected between major intersections.

3. The calculation of progression speeds between major intersections based both on speed limit and average queue length measured at each approach to a major intersection.

Major Intersections/Progression Speeds: The North Corridor simulation network models 135 major arterial intersections. A single node connecting at least two roadway segments models each of these intersections. The version of INTEGRATION employed for this effort is meso-scale and correspondingly does not explicitly model lane position or gap acceptance. INTEGRATION does however, model cycle length, phase split, and offset for each approach to an intersection. In addition, detailed tracking of turning movements are not directly modeled. Other aspects not directly modeled include turn pocket length, gap acceptance for permissive left hand turns, and permitted left-hand turn phases. Signal plans developed within the North Corridor model must therefore be viewed within the limitations of the model to represent those plans. While the details of individual intersections are not directly modeled, there is explicit representation of signal coordination along a corridor.

Thus, using the offset characteristic in the signal control model, the analyst may examine the effectiveness of linking strings of intersections at various progression speeds. In the ATMS case, we assume that a traffic engineer developing a “top-to-bottom” coordination of SR99 and SR522 would have access to an extensive database of AM peak queue lengths along these corridors. This data, heretofore unavailable, would allow our hypothetical engineer the ability to set signal offsets so that standing queues at intersections would be in motion by the time the first platoon of vehicles from an upstream intersection arrived.

Minor Intersections. There are also a great number of minor signalized intersections on the ground in Seattle, Lynnwood, and in other jurisdictions of the North Corridor subarea. These minor intersections do not have corresponding intersections in the regional model database obtained from the PSRC. Coordinating these minor signals, however, will provide improved throughput and/or improved travel time along our major arterial corridor. Improvements of this type are modeled indirectly through adjustment to link parameters within the subarea simulation network. For example, stretches of SR99 have a number of minor signals allowing access to commercial development along its length. Many of these lights are already coordinated with respect to mainline speed limit progression. The amount of adjustment to these link parameters is adapted from a previous Mitretek modeling studies examining the relationship between signal density and benefit of coordination. [2,30]

Baseline Signal Timing Plan: SR99 and SR522. In the Baseline case, an initial comprehensive signal plan was implemented. Where data specific to traffic signal control could not be obtained, Webster's formula for isolated intersections based on approach volumes under average travel demand was applied to set cycle length and phase split. Speed limit progression was then implemented along 14 major arterial corridors, including SR99 and SR522. Breaks in this signal coordination were implemented at jurisdictional boundaries for SR99 and SR522 and calibrated using floating-car data collected in the AM peak. No improvement to link capacity or free-speed is coded for improvements to minor intersection signal coordination. The resulting signal plans for SR99 and SR522 are shown in Tables 3-7 and 3-8, respectively.

Intersection with SR99	**Offset at Speed Limit Progression (seconds)**
188th St. SW	0
SR524	*0*
212th St. SW	105
220th St. SW	44
76th Ave. W	88
238th St. SW	9
185th St.	44
175th St.	*0*
155th St.	96
145th St.	*0*
Roosevelt Way N	14
130th St.	96
105th St.	110
85th St.	105
Green Lake Dr. N	3
80th St.	28
W. Green Lake Dr.	64

Table 3-7. Baseline SR99 Major Signal Coordination

Intersection with SR522	Offset at Speed Limit Progression (seconds)
Ballinger Way	0
155th St.	110
150th St.	0
145th St.	27
125th St.	54
15th Ave. N	69
80th St.	27
Roosevelt Way	42

Table 3-8. Baseline SR522 Major Signal Coordination

ATMS Experiment Signal Timing Plan for SR99 and SR522. In the ATMS experiment, the signal-timing plan developed for the Baseline case was modified to reflect changes at major intersections. Rather than a "top to bottom" coordination at the speed limit, however, the average queue length seen at each approach is taken into consideration in the calculation of progression speed.

Average queue length at each intersection, although an important metric, does not precisely define the most effective progression speed. Across a 3.5-hour peak period, the average queue length may be realized precisely on approach only on rare occasion. In fact, if one considers a simple bimodal distribution, the average may actually never reflect a single observed data point. For this reason, Mitretek conducted a limited off-line optimization analysis isolating the performance of SR99 and SR522 varying the amount of delay allocated to each queued vehicle seen on average in the peak period.

Employing the simulation at average travel demand, clear weather, and no accidents in the system, a reduction in progression speed was tested for 0.0, 0.25, 0.5, 0.75, and 1.0 seconds per queued vehicle seen on an approach. Independent tests were performed for SR99 and SR522. Travel time top-to-bottom in each corridor was used to evaluate each plan. In the end, a delay allowance of 1.0 seconds for SR99 and 0.25 seconds for SR522 provided the most effective progression speeds.

The resulting signal plans for SR99 and SR522 are shown in Tables 3-9 and 3-10, respectively, based on a corridor-wide cycle length of 120 seconds.

Intersection with SR99	Offset at Speed Limit Progression (seconds)	Offset With Queue Release (seconds)
188th St. SW	0	0
SR524	62	101
212th St. SW	47	118
220th St. SW	106	16
76th Ave. W	30	118
238th St. SW	59	58
185th St.	75	38
175th St.	27	25
155th St.	24	37
145th St.	78	13
Roosevelt Way N	92	31
130th St.	54	113
105th St.	68	8
85th St.	63	4
Green Lake Dr. N	81	26
80th St.	106	51
W. Green Lake Dr.	22	89

Table 3-9. Enhanced ATMS SR99 Major Signal Coordination

Intersection with SR522	Offset at Speed Limit Progression (seconds)	Offset With Queue Release (seconds)
Ballinger Way	0	0
155th St.	59	68
150th St.	75	86
145th St.	102	0
125th St.	9	38
15th Ave. N	24	70
80th St.	102	48
Roosevelt Way	117	67

Table 3-10. Enhanced ATMS SR522 Major Signal Coordination

Minor signal coordination improvements were also implemented at the link level. Based on a previous Mitretek study of signal density and the impacts of coordination, changes to link free-flow speed, speed-at-capacity, and capacity are coded. These three parameters define a particular speed-flow relationship for each link in the meso-scale INTEGRATION simulation. Table 3-11 presents these link-level changes for SR99 and SR522. Note that links representing SR522 have a higher impact than for SR99 because of the higher density of minor intersections along SR522 relative to SR99.

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Facility	Free-Flow Speed	Speed at Capacity	Capacity
SR99	3%	1%	1%
SR522	6%	2%	2%

Table 3-11. Link-Level Modifications For Minor Signal Coordination

The ATMS sensitivity analysis is evaluated using 120 individual simulation runs (30 scenarios x 4 random seeds), and compared against the travel time and throughput characteristics of the Baseline case. Results of this experiment are presented in section 4.2.

3.4 Sensitivity Analysis: IMS Experiment

Hypothesis: *A reduction in incident blocking time improves throughput and efficiency.*

Characterization and Data Sources: In this experiment, we reflect system level impacts resulting from the ability of highway patrol, WSDOT, and emergency medical service providers to coordinate their response to incidents. The scenario set developed for the North Corridor contains a representative set of accidents and incidents. This data set is detailed in Appendix B and provides information in incident location, onset and duration.

Reaction to an incident may be characterized by detection time, response time (time to getting the first unit to the incident site), and time-to-removal. In this experiment, we assume that there is no change from the current incident detection and response times of 4 and 6 minutes, respectively [21]. However, we do assume some reduction in incident duration because of increased coordination among responding agencies. Estimates in Seattle of such impacts are not currently available, however, we attempt to bracket this impact by using data from a similar study in Houston where a 25% reduction in incident duration was reported. A reduction of 12.5% is tested as the default value because of the incremental nature of the IMS improvements in Seattle, rather than the no-IMS vs. IMS case tested in Houston. The 25% value is tested as a sensitivity analysis.

Control Parameters: Incidents occurring along I-5 or SR99 have durations reduced by 12.5%. See Appendix B for a listing of representative scenarios with incidents on these links.

Under these conditions of reduced incident duration, 240 individual simulation runs (30 scenarios x 4 random seeds x 2 duration reduction levels) were conducted. Travel time and throughput of the system is then compared against the travel time and throughput characteristics of the Baseline case. Results of this experiment are presented in section 4.3.

3.5 Sensitivity Analysis: Arterial Data for ATIS

Hypothesis: *The provision of arterial travel time estimates from SR99 and SR522 to ATIS users improves overall system efficiency.*

Characterization and Data Sources: This experiment models the integration of data from arterial loop detectors along SR99 and SR522 into the freeway-based ATIS available on the WSDOT website and other media. We model the impact of the ITS Backbone project to integrate arterial detector congestion data into the traveler information services assumed to be operating in the ATIS experiments. In the Arterial Data for ATIS experiment we add surveillance on the rest of SR-99 north of Green Lake. South of Green Lake, SR99 is an expressway facility and is not assumed to be under surveillance. In addition, SR 522 between I-5 and Bothell is considered to be under surveillance.

The baseline case assumptions remain the same as in the ATIS and ATMS experiments. No changes to existing traffic signal control along the two arterials are modeled, the only change is that users of ATIS may now consider real-time estimates of congestion on the two arterial routes in addition to I-5 conditions when making travel decisions. We assume the arterial data is updated every 15 minutes and is provided as a combined estimate of both link travel time and intersection delay.

Control Parameters: Control parameters are set as in the ATIS experiment (see Section 3.3). However, the set of links assumed to be under surveillance has expanded to include SR99 and SR522 as well as I-5. High-fidelity ATIS users may now consider travel time estimates from all three facilities when considering fastest routes.

Under the conditions of improved surveillance and provision of arterial congestion estimates to ATIS, 120 individual simulation runs (30 scenarios x 4 random seeds) were conducted. Travel time and throughput of the system is then compared against the travel time and throughput characteristics of the Baseline case. Results of this experiment are presented in section 4.4.

3.6 Alternatives Analysis: Enhanced ITS

Hypothesis: *Implementing the ATIS, Arterial Data for ATIS, and ATMS improvements concurrently improves system throughput and efficiency.*

Characterization and Data Sources: The Enhanced ITS Alternative is a combination of the improvements made as a part of the Arterial Data for ATIS and ATMS experiments. Thus, it features an improved signal coordination system on SR99 and SR522 and the introduction of the quantitative freeway condition data to pre-trip planners (representing 6% of all travelers). However, this alternatives analysis is different than the four simulation experiments that precede it because it involves the full utilization of regional and subarea modeling in the PRUEVIIN framework. Because of the presence of the regional model in the analysis, travel demand in the corridor changes in response to improvements made to system capacity in the corridor.

Control Parameters: Simulation parameters are set as in the Arterial Data for ATIS and ATMS experiments. Toggles controlling the provision of current travel time estimates to ATIS providers are switched to on for segments of SR99 and SR 522.

Travel demand in the corridor is slightly higher from a pre-feedback initial run of the regional planning model. A side experiment was conducted in the simulation model to estimate the effect of steady-state improvements to traffic signals along SR99 and SR 522. Based on these experiments, the following link-level improvements are made to the regional model, illustrated in Tables 3-12 and 3-13.

Component	Free Flow Speed	Link Capacity
Major Signal	2%	3%
Minor Signal	3%	1%
Total Impact	5%	4%

Table 3-12. Enhanced ITS SR99 Link-Level Improvements for Regional Model

Component	Free Flow Speed	Link Capacity
Major Signal	1%	0%
Minor Signal	6%	2%
Total Impact	7%	2%

Table 3-13. Enhanced SR522 ITS Link-Level Improvements for Regional Model

The results indicate that full coordination along SR99 from the current four segments to one unified segment is a more significant impact than unifying the two segments of SR522. Further, the relatively low density of minor signals on SR99 makes this component of lesser impact than the major signals. The situation is reversed for SR522, where the higher density of intermediate signals accounts for a larger share of impact than the corridor coordination. Note also that the impacts in the regional model differ from the parameters selected for the subarea simulation. This is because the simulation models the major signals explicitly. Impacts from minor signals are consistent in the two models, however.

When these link-level improvements (Tables 3-11, 3-12) are coded at the regional level, travel demand patterns redistribute themselves to take advantage of the improvements. Whereas there is no change to overall regional person-trips (assumed fixed), there are some changes in steady-state demand patterns, redistributing trips into the North Corridor subarea.

This change to regional trip patterns results in an overall increase of 0.42% in subarea travel demand. This represents the drawing in of around 1,000 vehicles into the North Corridor subarea. Travel is also slightly longer (0.38%) reflecting impacts within trip distribution at the regional level. The number of regional HOV and Transit trips drops slightly (-0.18%). Overall, regional travel demand may be characterized as a little longer, but little change in overall travel time.

The Enhanced ITS alternative is evaluated through 120 individual simulation runs (30 scenarios x 4 random seeds). Travel time and throughput of the system is then compared against the travel time and throughput characteristics of the Baseline case. Results of this experiment are presented in section 4.5.

SECTION 4: RESULTS

This section presents results from the four sensitivity analyses (ATIS, ATMS, IMS and Arterial Data for ATIS) and the alternatives analysis (Enhanced ITS). Measures of effectiveness for the subarea simulation are calculated in both the sensitivity analysis and the alternatives analysis. Regional MOEs are calculated only for the alternatives analysis. Subarea MOEs are calculated from either trip-based data or link-based data.

Subarea Impact Measures: For network efficiency impacts, data is collected for all vehicles that begin trips in the network between 6:15 AM and 9:00 AM in the North Corridor. For these trips, average delay is calculated as the difference between the average travel time in each scenario (for scenario descriptions, see Section 2.3) and free-flow (50% of average demand, no accidents in the system, good weather) travel times. *Delay reduction* is calculated by expressing the difference in average delay between the Baseline case and the experimental case as a percentage of Baseline average delay. *Throughput* measures the number trips starting in the 6:15-9:00 time frame that can finish before the end of the peak period at 9:30 AM. Delay reduction and throughput measures are calculated for each scenario. An annualized figure is then calculated by computing a weighted average of across all scenarios. System *coefficient of variation* is calculated by examining the variability of travel time for similar trips in the system taken across all scenarios. This statistic is an indicator of the reliability of travel time in the corridor.

Speed and stops across the network are archived by link from each run between 6:00 AM and 9:30 AM. Speed profiles are then normalized by total vehicle-kilometers of travel in the system to create the statistic *percentage of vehicle-kilometers of travel by speed range*. A similar technique is applied to stops estimated by the simulation at a link level. The *expected number of stops per vehicle-kilometer of travel* is the measure used in comparison with the Baseline case.

Link-level speed and stop data are used to drive an energy and emissions post-processor developed for MMDI evaluation at Virginia Tech (see Section 2.9). Energy estimates are calculated *as total liters of fuel consumed*. Total emissions of *hydrocarbons* (HC), *carbon monoxide* (CO) and *nitrates of oxygen* (NOx) are also estimated. A related safety post-processor (described in Section 2.10) utilizes total vehicle-kilometers and total vehicle-seconds of travel by speed range reported by the simulation to predict *total crashes* and *total fatal crashes*.

Subarea measures of effectiveness are obtained from simulation model runs. A paired t-test analysis is performed on each measure to determine the relative level of statistical significance of the results against inherent randomness in the simulation.

Regional Impact Measures: Regional impact measures are obtained from the regional four-step planning model runs. The impacts of corridor improvements on regional travel demand patterns are reported in terms of *transit mode share*, *auto mode share*, *trip length* and *trip speed*. Similar measures are also used to characterize travel demand originating in, traveling to, or traveling through the North Corridor. Additional travel demand attracted to the corridor because of improved performance is reported as *additional corridor demand*. Regional impact measures are only reported in the Enhanced ITS Alternatives Analysis.

4.1 ATIS Experiment

Overall, the ATIS experiment indicates that the improvements modeled have limited but positive impact on system performance. This improvement is highest in scenarios where the network is experiencing a combination of heavy demand and weather impacts and/or freeway accidents. One observation that can be made is more precise freeway congestion information is consistently helpful to certain O-D pairs in the system. These are not the long freeway-based trips usually associated with ATIS but mid-range trips (18-25 km) within the subarea that cross I-5. A trip from Edmonds to the University of Washington southeast across the corridor is an example of a mid-range trip where ATIS is consistently helpful. These travelers can access I-5 at several junctures or bypass it altogether when choosing from a set of relatively competitive alternative routes.

For the ATIS-related sensitivity analysis, both system impacts and travel impacts on users and non-users of ATIS are tabulated. Section 4.1.1 presents the system-level impacts, while Section 4.1.2 presents a comparative analysis of travel characteristics of the various traveler classes modeled in the subarea simulation.

4.1.1 System Impacts

<u>Delay Reduction</u> (Figure 4-1). Statistically significant impacts can be observed in four scenarios featuring higher-than-expected demand in combination with either weather impacts or freeway accidents. On an annual basis, delay is reduced by 260 hours (0.08 minutes per vehicle) per AM peak period. This represents an annualized system delay reduction of 1.5% compared to the Baseline case.

<u>Throughput</u> (Figure 4-2). Statistically significant impacts on throughput are observed for scenarios HD1 and HD3. These scenarios feature 20% heavier-than-expected travel demand and clear weather conditions. On an annual basis, throughput remains flat. Roughly 10 additional vehicles complete trips in the peak period over the Baseline case, but this increase is too small to be statistically significant.

<u>Coefficient of Variation</u>. The Baseline case coefficient of variation is 0.242. Applying this to a trip with an expected duration of one hour, a traveler would have to budget 1.40 hours (84 minutes) to arrive at his/her destination on-time 95% of the time. The value obtained in the ATIS experiment is 0.236, indicating that travel has become slightly more predictable across the system. Under the constraints of our hypothetical one-hour trip, the amount of time needed to budget to be on-time 95% of the time is 83 minutes, a 2.5% reduction in trip time variability.

<u>Percentage of Vehicle-Kilometers of Travel By Speed Range</u> (Figure 4-3). The impact on facility speeds is small and indeterminate in nature. Some increase can be observed in high-speed arterial travel (80+ kph), as well as a small shift in freeway travel from the 80-100 kph range to the 60-80 kph range. These differences are likely smaller than the inherent randomness in the simulation.

Expected Number of Stops per Vehicle-Kilometer of Travel (Figure 4-4). Mixed impact on stops per vehicle-km of travel is indicated. Freeway facilities see smoother travel while expressway and arterial facilities see an increased rate of stops. Overall number of stops in the ATIS experiment compared to the Baseline case is slightly higher (+0.1%), although this impact is not statistically significant.

Market Penetration Sensitivity Analysis. Sensitivity to the default market penetration rate of 6% for high fidelity ATIS was tested at the 1%, 3% and 10% level. Impact on system performance is shown in Table 4-1. Larger market penetration yields higher delay reduction in the system, although the marginal rate of improvement declines as we move to higher market penetrations. Ever-larger pools of travelers receiving and acting on the same information explain this result. As the size of the pool of responding travelers increase, diversion routes may become congested with the diverting traffic. Throughput impacts are not statistically significant, although the lower market penetrations (1%, 3%) tended to generate larger throughput increases than larger market penetrations (6%, 10%).

Measure per Average AM Peak Period, North Corridor Subarea	ATIS 1%	ATIS 3%	ATIS 6%	ATIS 10%
% Delay Reduction	0.8%	1.3%	1.5%	2.1%
Hours of Delay Reduction	136	222	260	362
%Throughput Increase	0.08% (NS)	0.10% (NS)	0.00% (NS)	0.03% (NS)
Throughput Increase (veh)	161	203	9	66

(NS) = not statistically significant vs. baseline at 90% confidence level

Table 4-1. Market Penetration Sensitivity Analysis: Delay Reduction and Throughput

4.1.2 User Impacts

Subarea travel time for high-fidelity pre-trip ATIS have travel times that are roughly 0.2 minutes faster than average baseline travel time (18.9 minutes versus 19.1 minutes). One interesting observation is that low-fidelity travelers have slightly worse travel time performance than information non-users (19.4 versus 19.1 minutes). The poor performance of the low-fidelity respondents may be indicative of travelers making route choices under high uncertainty. An example of this is unwarranted freeway-to-arterial diversion when a minor freeway accident is reported on commercial radio.

Over a year of travel in the morning peak period in the North Corridor, the average traveler experiences a total of 17 hours of delay in the Baseline case. Users of web-based pre-trip ATIS in this experiment cut that delay by 40 minutes over a year to 16 hours and 20 minutes. This represents a 4% reduction in overall recurrent and non-recurrent delay for users of the service.

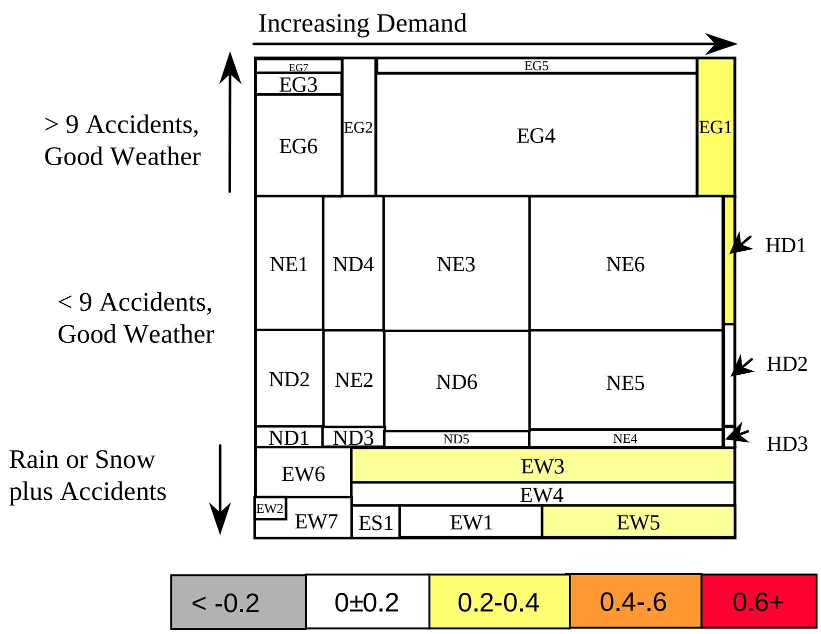

Figure 4-1. Minutes of Delay Reduction: ATIS vs. Baseline

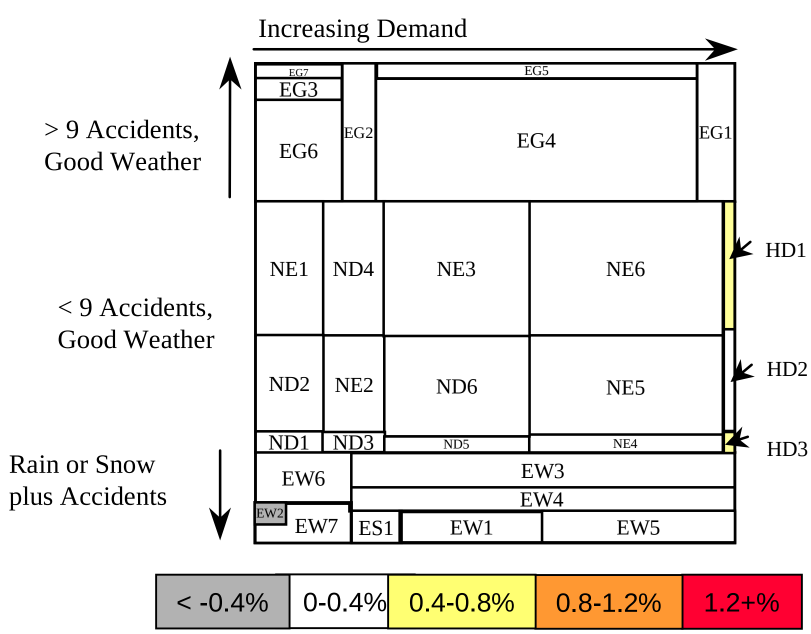

Figure 4-2. Percent Increase in Vehicle Throughput: ATIS vs. Baseline

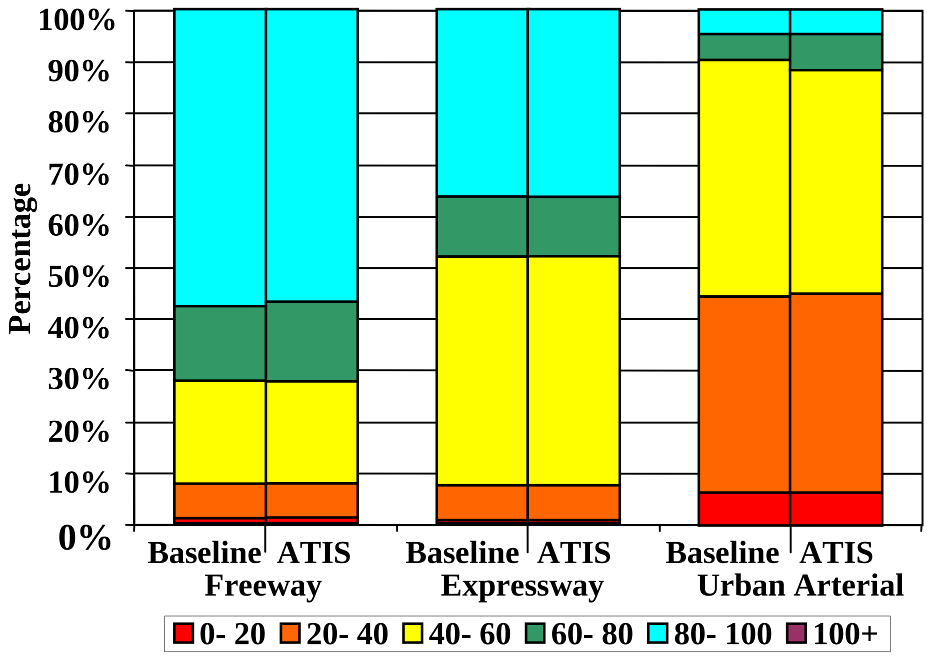

Figure 4-3. Percentage of Vehicle-Km by Speed Range (kph): ATIS vs. Baseline

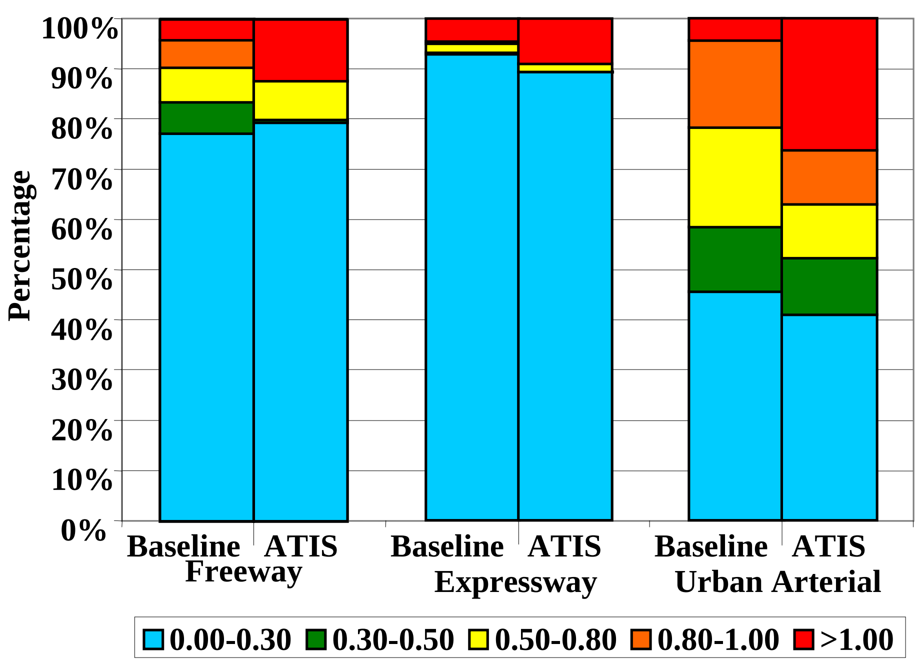

Figure 4-4. Expected Number of Stops Per Vehicle-Km: ATIS vs. Baseline

Energy and Emissions Impacts:

	Number of Stops	Vehicle km of Travel	Fuel Use	Total HC	Total CO	Total NOx	Avg Fuel Use
			kL	kg	kg	kg	kmpl
Base	1,199,677.5	3,438,362.5	354.62	390.04	7043.14	846.19	9.70
ATIS	1,201,382.0	3,435,676.8	354.23	389.61	7020.30	843.86	9.70
Diff.	1,704.5	-2,685.7	-0.39	-0.43	-22.84	-2.33	0.00
% Diff.	0.14%	-0.08%	-0.11%	-0.11%	-0.32%	-0.28%	0.00%
T-test	91.07%	67.95%	66.26%	59.34%	56.22%	75.98%	

Table 4-2. Energy and Emissions Impact Summary: ATIS vs. Baseline

As shown in Table 4-2, ATIS had little impact to the number of stops with an approximate 0.14% increase from the Baseline. There was also little impact to vehicle km of travel, fuel usage, and emissions. However, except for the total stops figure, none of the results can be considered significant according to statistical T-tests. As described in Section 2.9, the T-tests found the probability that the mean of ATIS was unrelated to the mean of the Baseline. A confidence level of 90% was used.

Facility	**Group**	**Speed (>60 km/h)**	**Stops (>0.5)**
Freeway	ATIS	72.4%	19.97%
	Baseline	72.2%	19.22%
Expressway	ATIS	48.0%	10.54%
	Baseline	48.1%	11.79%
		Speed (>30 km/h)	**Stops (>0.5)**
Urban Arterial	ATIS	77.9%	47.77%
	Baseline	80.3%	47.04%
Rural Arterial	ATIS	73.0%	38.72%
	Baseline	73.5%	39.56%

Table 4-3. Speed and Stop Range Comparison: ATIS vs. Baseline

A comparison of speed and stops impacts is instructive in identifying on which facilities we may expect to see changes in energy consumption or emission rates. The *Freeway* in ATIS had a slightly higher percentage of vehicle km at higher speeds (60+ kph) and more frequent stops than the Baseline. This indicates increased fuel usage and emissions. The *Expressway* had a slightly smaller percentage of vehicle km at higher speeds (60+ kph) and less frequent stops than in the Baseline. This indicates reductions in fuel usage and emissions. The *Urban Arterial* (King County arterials) had slightly less vehicle km at the higher speeds (30+ kph) but more frequent stops than in the Baseline. Nevertheless, it had reductions in ATIS for both fuel usage and emissions. The *Rural Arterial* (Snohomish County arterials) had fewer vehicle-km at the higher speeds (30+ kph) and less frequent stops than in the Baseline. This would support the reductions in fuel usage and emissions. However, none of the ATIS results passed the statistical T-tests so any conclusions must be taken with this in mind.

Safety Impacts: The number of crashes (Table 4-4) shows a marked decrease in the 32-40 kph speed range across both calculations. Overall, the reduction is approximately 0.6 to 0.7 percent. This is small reduction translates to approximately 100 crashes every ten years.

	using million veh-sec			using million veh-km		
	Baseline	ATIS	Percent Difference	Baseline	ATIS	Percent Difference
0-32 kph	5.48	5.54	1.09%	3.15	3.22	2.22%
32-40 kph	2.05	1.88	-8.29%	1.87	1.69	-9.63%
40-60 kph	3.48	3.49	0.29%	3.02	3.03	0.33%
60-80 kph	1.03	1.05	1.94%	0.86	0.88	2.33%
80-100 kph	0.73	0.74	1.37%	0.65	0.66	1.54%
100+ kph	0.06	0.05	-16.67%	0.05	0.05	0.00%
per morning rush hour	**12.83**	**12.75**	**-0.62%**	**9.60**	**9.53**	**-0.73%**
Annual	**2,823**	**2,805**		**2,112**	**2,097**	
Over ten years	**28,226**	**28,050**		**21,120**	**20,966**	

Table 4-4. Crash Analysis: ATIS vs. Baseline

Fatal crashes (Table 4-5) were reduced, but only by less than half a crash every ten years. The savings in fatal crashes are not statistically significant.

	using million veh-sec			using million veh-km		
	Baseline	ATIS	Percent Difference	Baseline	ATIS	Percent Difference
per morning rush hour	0.05222	0.05202		0.04176	0.04174	
Annual	11.4880	11.4444		9.1872	9.1831	
Ten years	114.9	114.4	-0.38%	91.9	91.8	-0.04%
Percentage of Total Crashes	0.407%	0.408%	0.25%	0.435%	0.438%	0.69%

Table 4-5. Fatal Crash Analysis: ATIS vs. Baseline

	Veh-Sec	Veh-km	Crashes (m veh-sec)	Crashes (m veh-km)	Fatal Crashes (m veh-sec)	Fatal Crashes (m veh-km)
ATIS	97.8%	75.7%	97.1%	66.5%	50.0%	69.8%

Table 4-6. Statistical Confidence Levels for Safety Impacts: ATIS vs. Baseline

The t-test results in table 4-6 confirm that any impact of ATIS is difficult to discern from random variation in the experiment. Four out of the six indicators tested show a percentage well below a ninety percent confidence level.

4.2 ATMS Experiment

Overall, system level improvements from the ATMS experiment are larger than the ATIS experiment, but this impact is concentrated among trips that typically use either SR99 or SR522. The largest impact is seen in system delay reduction, concentrated in scenarios where travel demand is higher than expected or when system capacity is reduced by weather impacts. No sensitivity to delay from accidents or incidents is indicated. This performance pattern is not surprising, given that the fixed signal timing plans have been optimized for near-normal conditions and cannot adjust to accidents or incidents. Improved throughput performance is not seen in all scenarios, indicating that the signal timing plans optimized for average conditions may be less than optimal under some extreme condition scenarios.

Delay Reduction (Figure 4-5). Highest impact on delay reduction occurs in scenarios where demand close to expectation and the weather is rainy (EW1, EW3). Impact across scenarios is relatively broad, with statistically significant impact on overall corridor delay seen in all but the lowest-demand (and hence lowest delay) scenarios. On an annual basis, delay is reduced by 1,218 hours (0.36 minutes per traveler) per AM peak period. This represents an annualized system delay reduction of 7.0% compared to the Baseline case.

Throughput (Figure 4-6). Impact on throughput is mixed bag of small improvements and reductions. Throughput impact outside of heavy demand and weather cases is negligible. On an annual basis, throughput is improved by 0.19%, corresponding to roughly 402 additional vehicles able to complete trips in the peak period over the Baseline case.

Coefficient of Variation. The Baseline case coefficient of variation is 0.242. Applying this to a trip with an expected duration of one hour, a traveler would have to budget 1.40 hours (84 minutes) to arrive at his/her destination on-time 95% of the time. The value obtained in the ATIS experiment is 0.237, indicating that travel has become slightly more predictable across the system. Under the constraints of our hypothetical one-hour trip, the amount of time needed to budget to be on-time 95% of the time is 83 minutes, a 2.1% reduction in trip time variability

Percentage of Vehicle-Kilometers of Travel By Speed Range (Figure 4-7). The impact on facility speeds is small and indeterminate in nature. Freeway speeds in the higher ranges appear to have slowed somewhat, while a slight increase in higher-speed arterial travel is indicated.

Expected Number of Stops per Vehicle-Kilometer of Travel (Figure 4-8). Positive impacts in terms of traffic smoothing are indicated for the urban arterial system, as well as a smaller impact for freeway links in the network. The smoother arterial travel is related to the improved coordination of traffic signals along SR99 and SR522, which see the largest reduction in stops per kilometer of any arterial facilities. Overall, the number of stops in the corridor drop by 33,000 per AM peak period, a 2.7% decrease.

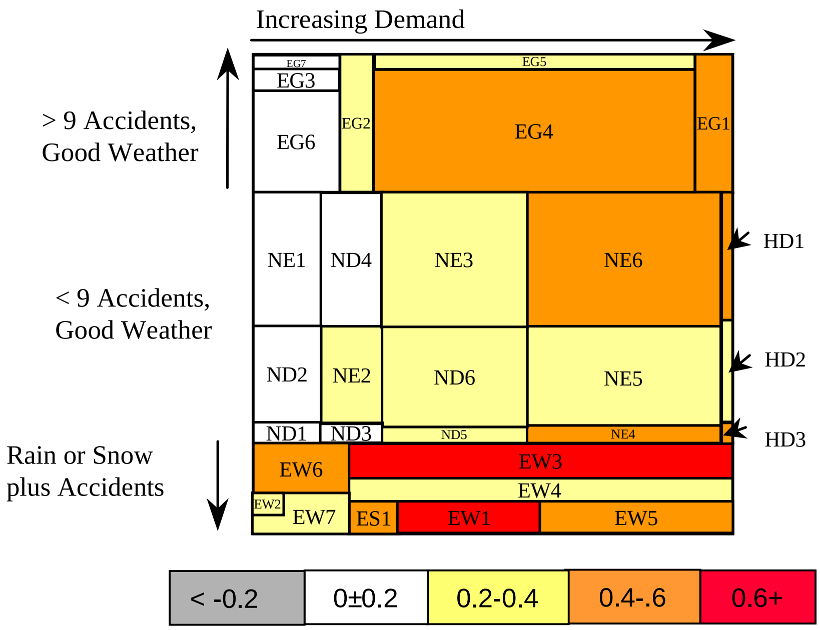

Figure 4-4. Minutes of Delay Reduction: ATMS vs. Baseline

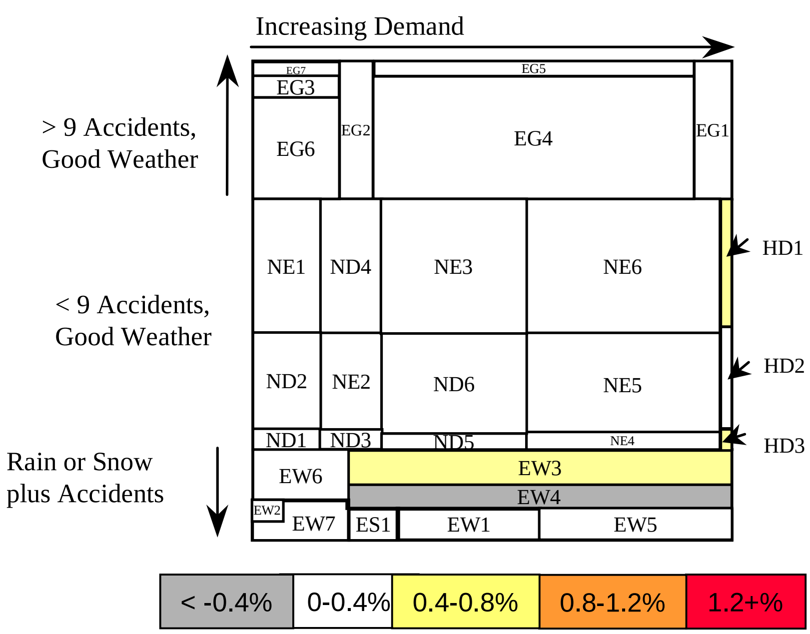

Figure 4-5. Percent Increase in Vehicle Throughput: ATMS vs. Baseline

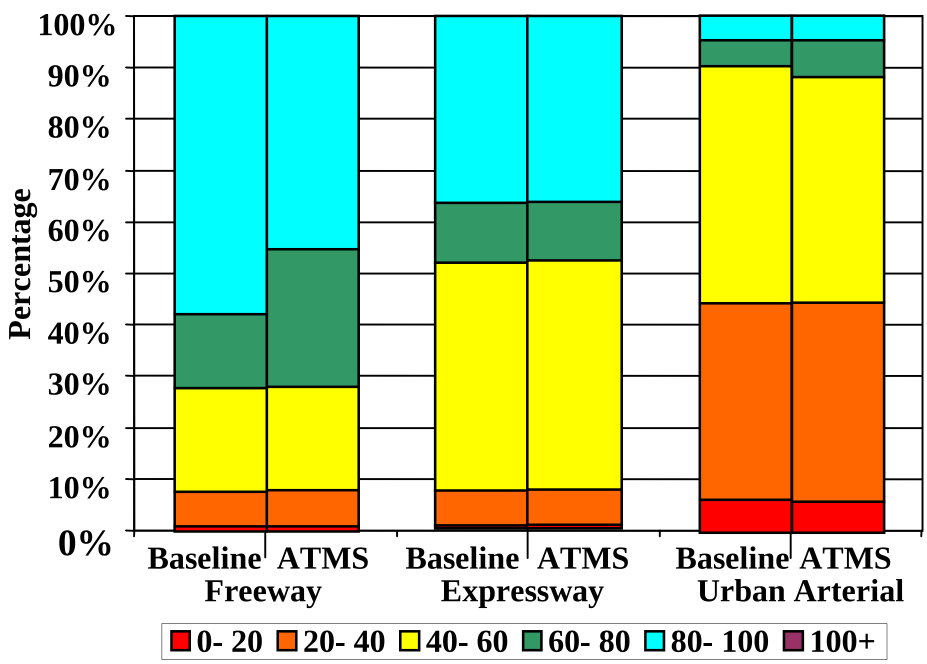

Figure 4-6. Percentage of Vehicle-Km by Speed Range (kph): ATMS vs. Baseline

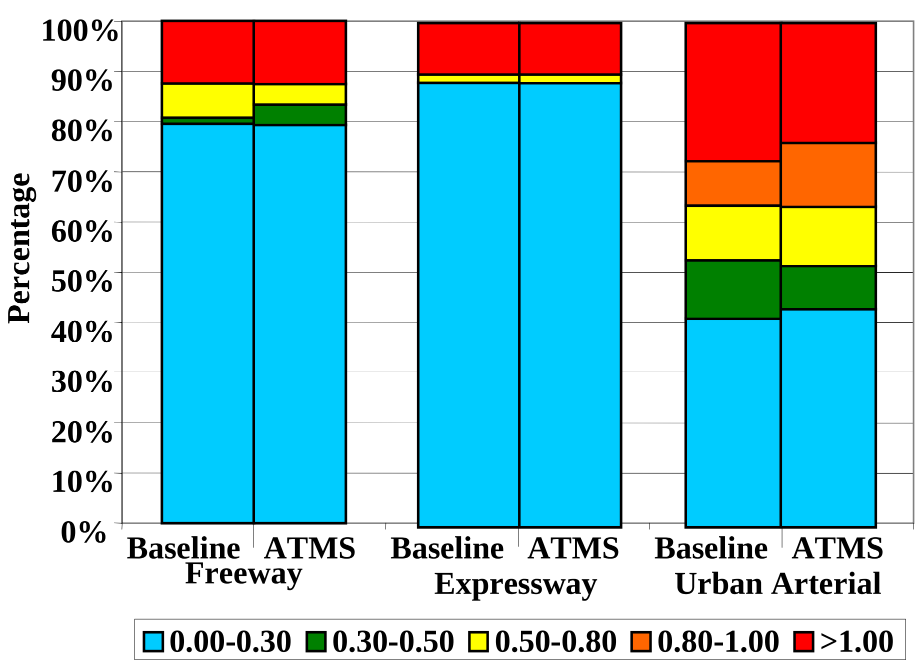

Figure 4-8. Expected Number of Stops Per Vehicle-Km: ATMS vs. Baseline

<u>Energy and Emissions Impacts:</u>

	Number of Stops	Vehicle km of Travel	Fuel Use	Total HC	Total CO	Total NOx	Avg Fuel Use
			kL	kg	kg	kg	kmpl
Base	1,199,677.5	3,438,362.5	354.62	390.04	7043.14	846.19	9.70
ATMS	1,166,823.0	3,455,312.0	355.61	392.61	7116.26	850.15	9.72
Diff.	-32,854.5	16,949.5	0.99	2.57	73.12	3.96	0.02
% Diff.	-2.74%	0.49%	0.28%	0.66%	1.04%	0.47%	0.21%
T-test	99.35%	99.23%	64.75%	52.87%	80.97%	58.59%	

Table 4-7. Energy and Emission Impacts Summary: ATMS vs. Baseline

As shown in Table 4-7, ATMS had some impact on the number of stops (2.74% decrease from the Baseline). However, there was little impact to vehicle km of travel, fuel usage, and emissions. According to statistical T-tests, neither the fuel usage nor the emissions results are significant. As described Section 2.9, the T-tests found the probability that the mean of ATMS was unrelated to the mean of the Baseline. A confidence level of 90% was used.

Facility	**Group**	**Speed (>60 km/h)**	**Stops (>0.5)**
Freeway	ATMS Baseline	72.0% 72.2%	16.60% 19.22%
Expressway	ATMS Baseline	47.7% 48.1%	11.90% 11.79%
		Speed (>30 km/h)	Stops (>0.5)
Urban Arterial	ATMS Baseline	80.4% 80.3%	48.19% 47.04%
Rural Arterial	ATMS Baseline	75.6% 73.5%	37.10% 39.56%

Table 4-8. Speed and Stop Range Comparison: ATMS vs. Baseline

An analysis of travel speed and stop rates by facility was also conducted to identify if energy and emissions impacts were concentrated on particular facility types. The *Freeway* in ATMS had a slightly smaller percentage of vehicle km at higher speeds (60+ kph) and less frequent stops than in the Baseline. This would support the decreases in fuel usage and NOx; however, it does not support the increases in HC and CO. The *Expressway* had increases for fuel usage and emissions. This would imply that the increase in frequent stops overrides the reduction in vehicle km at higher speeds. The *Urban Arterial* had slightly more vehicle km at higher speeds (30+ kph) and more frequent stops than in the Baseline. This would support the increases in Fuel Use, HC, and CO; however, there is a decrease in NOx. The *Rural Arterial* had more vehicle km at higher speeds (30+ kph) but less frequent stops than in the Baseline. There is a reduction in fuel use; however, the emissions are higher. It could be implied that fuel is more sensitive than emissions to a reduction in frequent stops. However, none of the ATMS results passed the statistical T-tests so any conclusions must be taken with this in mind.

Safety Impacts: Results from the ATMS experiment indicates a more substantial impact on safety than the ATIS experiment. In the ATMS experiment, between 300 to 700 fewer crashes are predicted over a ten year period (Table 4-9), depending on whether exposure (veh-sec) or travel (veh-km) are used to predict crash probabilities. There are significant decreases in the 32-40 kph speed range and in the 80-100 kph speed range. However, there is also a large increase in the 60-80 kph speed range that curtails the additional benefits of ATMS.

	using million veh-sec			using million veh-km		
	Baseline	ATMS	Percent Difference	Baseline	ATMS	Percent Difference
0-32 kph	5.48	5.17	-5.66%	3.15	3.02	-4.13%
32-40 kph	2.05	1.84	-10.24%	1.87	1.67	-10.70%
40-60 kph	3.48	3.53	1.44%	3.02	3.07	1.66%
60-80 kph	1.03	1.26	22.33%	0.86	1.06	23.26%
80-100 kph	0.73	0.65	-10.96%	0.65	0.57	-12.31%
100+ kph	0.06	0.06	0.00%	0.05	0.05	0.00%
per morning rush hour	**12.83**	**12.51**	**-2.49%**	**9.60**	**9.44**	**-1.67%**
Annual	**2,823**	**2,752**		**2,112**	**2,077**	
Over ten years	**28,226**	**27,522**		**21,120**	**20,768**	

Table 4-9. Crash Analysis: ATMS vs. Baseline

	using million veh-sec			using million veh-km		
	Baseline	ATMS	Percent Difference	Baseline	ATMS	Percent Difference
per morning rush hour	0.0522	0.0517		0.0418	0.0415	
Annual	11.5	11.4		9.2	9.1	
Ten years	114.9	113.7	-1.06%	91.9	91.4	-0.54%
Percentage of Total Crashes	0.407%	0.413%	1.47%	0.435%	0.440%	1.15%

Table 4-10. Fatal Crash Analysis: ATMS vs. Baseline

Overall, the number of fatal crashes (Table 4-10) drops by one every ten years in both million vehicular-seconds and million vehicular-kilometers. The percentage of crashes that are fatal increases by less than 2%.

	Veh-Sec	Veh-km	Crashes (m veh-sec)	Crashes (m veh-km)	Fatal Crashes (m veh-sec)	Fatal Crashes (m veh-km)
ATMS	99.98%	99.23%	99.94%	98.96%	98.29%	91.86%

Table 4-11. Statistical Confidence Levels for Safety Impacts: ATIS vs. Baseline

The ATMS experiment impacts on safety are statistically significant. All the tests show extremely high scores across the board.

4.3 IMS Experiment

IMS impacts are concentrated in scenarios that have major incidents or large numbers of accidents on SR99 and I-5. Eighty percent of the delay reduction from improved IMS occurs in scenarios with a combined probability of roughly 5%. The timing and location of incidents are critical in terms of IMS effectiveness. Major disruptions on the freeway when combined with heavy demand or snow show the most significant impact. Benefit is highly concentrated, even in the freeway incident cases, among users traveling particular facilities at particular times. One may characterize IMS impacts as the most highly concentrated (of the three sensitivity analyses) in terms of geography, trip timing, and scenario. At the 12.5% incident duration reduction, however, no significant impacts can be measured for overall annualized delay or other impact measures. A sensitivity analysis at the 25% blockage duration reduction level showed an annualized reduction of roughly 90 vehicle-hours of delay per AM peak period.

Energy and Emissions Impacts: Small changes in energy and emissions impacts are indicated for the IMS experiment. These changes are so small, however, that they are statistically too small to measure over the inherent randomness in the simulation.

Safety Impacts: Small system-level changes in travel speed result in safety impacts that cannot be measured over the inherent randomness in the simulation.

4.4 Arterial Data for ATIS Experiment

The provision of arterial data roughly triples the overall system impact of ATIS in the North Corridor. Vehicle hours of delay are reduced by 478, a 2.8% decrease. Vehicle throughput is also higher, with an additional 268 vehicles successfully traversing the network on average each AM peak period. Trip time reliability is marginally worsened. Total travel is slightly increased, while stops are decreased by 5.5%.

Overall, it is clear that the provision of travel time estimates on the primary alternatives to I-5 in the North Corridor allows travelers to make more efficient route choice decisions. Patterns of use are also changed – total freeway to arterial diversion decreases when the arterial data appears in ATIS. This is because unwarranted diversions away from the freeway are reduced given that travelers now have a more current accurate estimate of arterial performance.

Delay Reduction (Figure 4-9). Statistically significant reductions in delay occur in scenarios with high demand, particularly when high demand is coupled with incidents or accidents (EG1, HD1). On an annual basis, delay is reduced by 571 hours (0.17 minutes per traveler) per AM peak period. This represents an annualized system delay reduction of 3.4% compared to the Baseline case.

Throughput (Figure 4-10). The pattern of impacts in throughput mirror that of delay reduction. On an annual basis, throughput is improved by 0.1%, corresponding to roughly 203 additional vehicles able to complete trips in the peak period over the Baseline case.

Coefficient of Variation. The Baseline case coefficient of variation is 0.242. Applying this to a trip with an expected duration of one hour, a traveler would have to budget 1.40 hours (84 minutes) to arrive at his/her destination on-time 95% of the time. The value obtained in the ATIS experiment is 0.239, indicating that travel has become slightly more predictable across the system. Under the constraints of our hypothetical one-hour trip, the amount of time needed to budget to be on-time 95% of the time is 83.5 minutes, a 1.2% reduction in trip time variability.

Percentage of Vehicle-Kilometers of Travel By Speed Range (Figure 4-11). The impact on facility speeds is small but positive. Freeway speeds improve, while the arterial facilities see slightly more higher-speed travel..

Expected Number of Stops per Vehicle-Kilometer of Travel (Figure 4-12). Freeway travel is smoother under the Arterial Data for ATIS case, particularly in the reduction of travel with more than 1 stop per kilometer of travel. This improvement on the freeways is not matched on expressway or arterial facilities – here additional travel demand translates into travel with more stops per kilometer. Overall, the number of stops in the corridor drop by 66,000 per AM peak period, a 5.5% decrease.

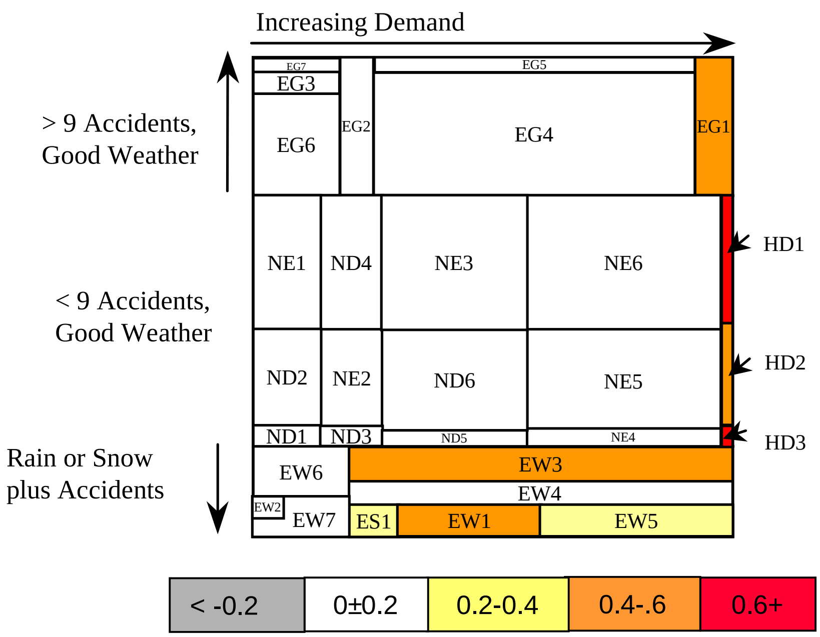

Figure 4-9. Minutes of Delay Reduction: Arterial Data for ATIS vs. Baseline

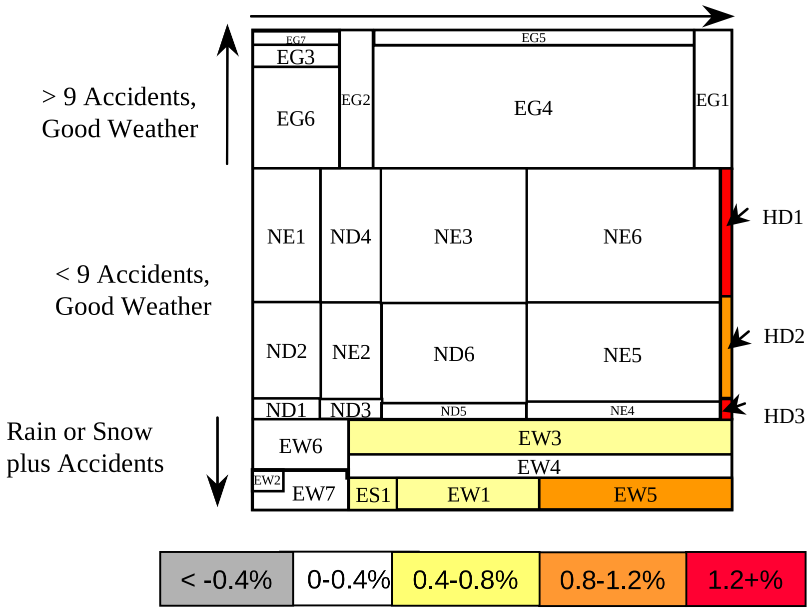

Figure 4-10. Percent Increase in Vehicle Throughput: Arterial Data for ATIS vs. Baseline

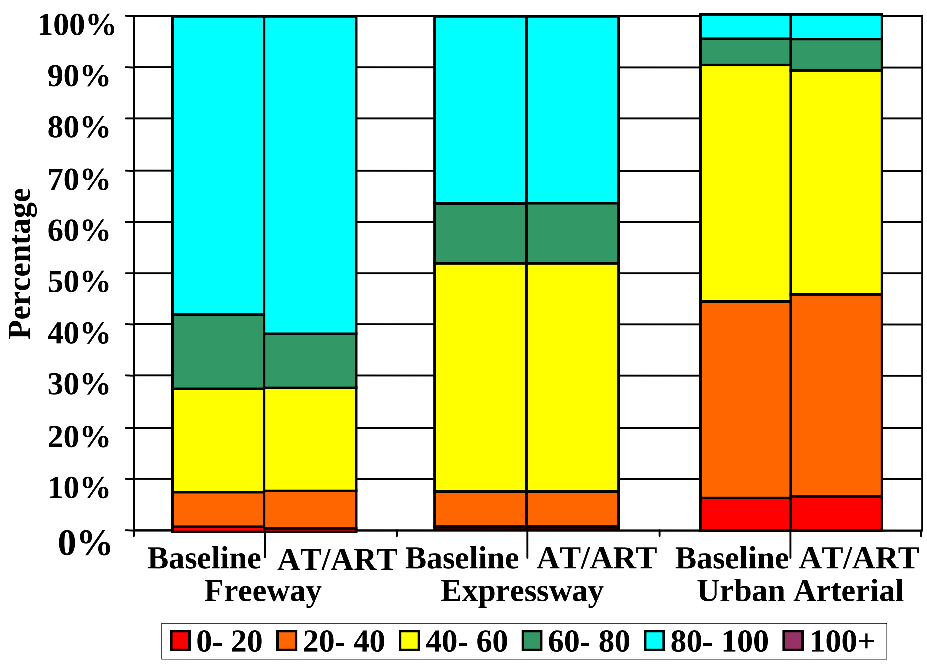

Figure 4-11. Percentage of Vehicle-Km by Speed Range (kph): Arterial Data for ATIS vs. Baseline

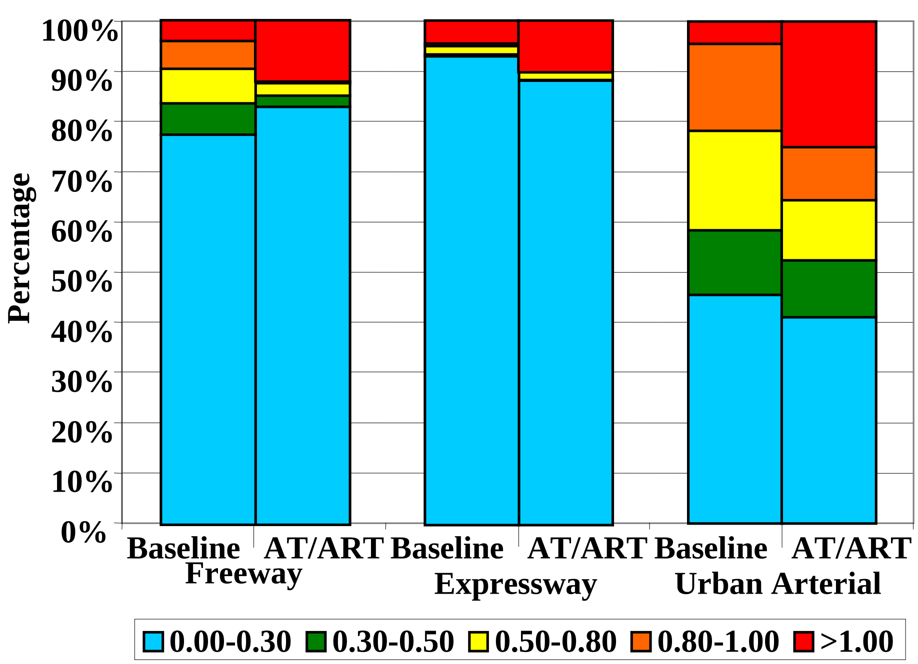

Figure 4-12. Expected Number of Stops Per Vehicle-Km: Arterial Data for ATIS vs. Baseline

Energy and Emissions Impacts:

	Number of Stops	Vehicle km of Travel	Fuel Use	Total HC	Total CO	Total NOx	Avg Fuel Use
			kL	kg	kg	kg	kmpl
Base	1,199,677.5	3,438,362.5	354.62	390.04	7043.14	846.19	9.70
Art. ATIS	1,134,168.0	3,443,492.3	351.73	382.80	6829.63	820.63	9.79
Diff.	-65,509.5	5,129.8	-2.89	-7.24	-213.51	-25.56	0.09
% Diff.	-5.46%	0.15%	-0.81%	-1.86%	-3.03%	-3.02%	0.93%
T-test	98.85%	98.22%	97.90%	98.52%	98.38%	98.48%	

Table 4-12. Energy and Emissions Impact Summary: Arterial Data for ATIS vs. Baseline

As shown Table 4-12, the Arterial Data for ATIS experiment had a significant impact on the number of stops with an approximate 5.46% decrease from the Baseline. There was also an approximate 3.0% decrease in both CO and NOx. There were also decreases of lesser magnitude in fuel consumption and HC. There was actually a slight increase in Vehicle km of Travel. According to statistical T-tests, all of the results are significant. A confidence level of 90% was used.

Facility	**Case**	**Speed (>60 km/h)**	**Stops (>0.5)**
Freeway	Arterial Data for ATIS Baseline	72.1% 72.2%	14.86% 19.22%
Expressway	Arterial Data for ATIS Baseline	48.1% 48.1%	11.72% 11.79%
		Speed (>30 km/h)	**Stops (>0.5)**
Urban Arterial	Arterial Data for ATIS Baseline	78.6% 80.3%	47.50% 47.04%
Rural Arterial	Arterial Data for ATIS Baseline	73.3% 73.5%	36.74% 39.56%

Table 4-13. Speed and Stop Range Comparison: Arterial Data for ATIS vs. Baseline

Table 4-13 supports the notion that a reduction in freeway stops is the primary driver of energy and emissions impacts in the Arterial Data for ATIS experiment. The *Freeway* in the Arterial Data for ATIS experiment had nearly the same percentage of vehicle km at higher speeds (60+ kph) but significantly less frequent stops than in the Baseline. This would support the decreases in both fuel usage and emissions. The *Expressway* had the same percentage of vehicles at higher speeds (60+ kph) as the Baseline and slightly less frequent stops. However, it had slight increases in fuel usage and emissions. The *Urban Arterial* had a smaller percentage of vehicle km at the higher speeds (30+ kph) but slightly more frequent stops than in the Baseline. Nevertheless, it had significant reductions for CO and NOx. There was also a reduction in HC, but a very slight increase in Fuel Use. The *Rural Arterial* had a slightly smaller percentage of vehicle km at higher speeds (30+ kph) but more frequent stops than in the Baseline. It had significant percent reductions in CO and NOx. There was also a reduction in HC and a slight reduction in Fuel Use.

Safety Impacts: The overall result of Arterial Data for ATIS experiment is the reduction of crashes by approximately 300 crashes over a ten year period or 0.1 per AM peak period (Table 4-14). The majority of the decrease is in the 32-40 kph range. However, there is also an increase in the higher ranges. The 100+ kph range shows a 17 percent decrease, however, it is a decrease of .01 crash per morning rush hour. This is a 1/10th of a crash saving every ten years.

	using million veh-sec			using million veh-km		
	Baseline	Arterial Data for ATIS	Percent Difference	Baseline	Arterial Data For ATIS	Percent Difference
0-32 kph	5.48	5.57	1.64%	3.15	3.24	2.86%
32-40 kph	2.05	1.86	-9.27%	1.87	1.67	-10.70%
40-60 kph	3.48	3.38	-2.87%	3.02	2.93	-2.98%
60-80 kph	1.03	1.07	3.88%	0.86	0.91	5.81%
80-100 kph	0.73	0.77	5.48%	0.65	0.69	6.15%
100+ kph	0.06	0.05	-16.67%	0.05	0.05	0.00%
per morning rush hour	**12.83**	**12.70**	**-1.01%**	**9.60**	**9.49**	**-1.15%**
Annual	**2,823**	**2,794**		**2,112**	**2,088**	
Over Ten years	**28,226**	**27,940**		**21,120**	**20,878**	

Table 4-14. Crash Analysis: Arterial Data for ATIS vs. Baseline

	using million veh-sec			using million veh-km		
	Baseline	Arterial Data for ATIS	Percent Difference	Baseline	Arterial Data for ATIS	Percent Difference
Per morning rush hour	0.0522	0.0521		0.0418	0.0417	
Annual	11.5	11.5		9.2	9.2	
Ten years	114.9	114.6	-0.28%	91.9	91.7	-0.24%
Percentage of Total Crashes	0.407%	0.410%	0.74%	0.435%	0.439%	0.92%

Table 4-15. Fatal Crash Analysis: Arterial Data for ATIS vs. Baseline

The actual number of fatal crashes decreases in this initiative. It is a very slight drop that is less than one death every ten years. This result can be seen in the statistics for both the vehicular seconds and vehicular kilometers. The percentage of fatal crashes to all crashes still rose, though, because of the decrease of non-fatal crashes in the lower speeds.

	Veh-Sec	Veh-km	Crashes (m veh-sec)	Crashes (m veh-km)	Fatalities (m veh-sec)	Fatalities (m veh-km)
Arterial Data For ATIS	98.77%	98.22%	98.98%	89.49%	89.37%	90.72%

Table 4-16. Statistical Confidence Levels for Safety Impacts: Arterial Data for ATIS vs. Baseline

The results of the t-tests for crashes and fatalities are relatively high. Crashes when calculated using million vehicular-kilometers and fatalities when calculating using million vehicular-seconds are low, but otherwise the others scored high.

4.5 Enhanced ITS Alternatives Analysis

Unlike the four preceding sensitivity analyses, the Enhanced ITS alternatives analysis reports impacts from both the regional model and the subarea simulation model. This is important for two reasons. First, as trips are diverted to/from the area, modes are shifted, and travel times and distances changed due to corridor improvements, there can be profound and potentially significant impacts outside of the simulation area. These impacts may affect overall travel patterns and the performance of the system in areas far away from the corridor. Including the regional analysis captures these impacts. Second, the regional forecasting process captures the improvements in recurrent and average "expected" conditions within the system. Long term location and travel decisions concerning trip distribution and mode choice are made based upon these expectations. The simulation model captures operational improvements, response to variation and unusual conditions, and availability of improved information. Shorter term, more flexible responses that cannot be addressed in the regional model are captured in the simulation. Both are needed to provide an overall and complete analysis. Results from the regional model are presented in Section 4.5.1. Results from the subarea simulation model are presented in Section 4.5.2.

4.5.1 Regional Impacts

The regional analysis of the Enhanced ITS alternative was carried out to capture the MMDI improvements aimed at average conditions and recurring congestion. In general these include ATMS and other strategies aimed at improving the general operations of a facility, its throughput, and travel time. The ATMS improvements assumed for the Enhanced ITS alternative are primarily along SR99 and SR522 and are described in detail in Section 3.3. Network improvements along SR99 and SR522 were coded for the alternative and the regional model executed to capture the changes in travel patterns, mode split, and route diversion (assignment). A summary of the regional measures of effectiveness (MOEs) comparing the Enhanced ITS alternative with the MMDI Baseline follows. The regional MOEs provided include: daily and AM peak period person and vehicle trips, miles and hours traveled by mode; subarea trip summaries; and average distance and travel times. Overall, the impacts of the improvements at the regional level are logical, but relatively small. A slight shift from transit to the auto modes is seen due to the improvements. Trips are longer and have improved speeds. There is also a diversion of trips to the simulation area from alternate paths.

Tables 4-17 through 4-19 summarize the daily person and vehicle travel for the region. The same overall person trips were used as inputs for both alternatives and as expected they remain the same. There is a slight drop in transit person trips and non-carpool vehicle trips. The daily vehicle miles traveled increases while the hours remain the same reflecting faster travel and longer trips. Carpools make slightly shorter trips which is reasonable since the improvements were made to general use facilities (SR99 and SR522).

Regional Travel: Daily Person and Vehicle Trips				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
Daily Trips				
Person Trips	11,573,681	11,573,680	-1	0.00%
Non-Carpool Vehicle Trips	8,679,492	8,679,234	-258	0.00%
Carpool Vehicle Trips	12,643	12,647	4	0.03%
Transit Person Trips	253,861	253,517	-343	-0.14%

Table 4-17. Daily Person and Vehicle Trip Comparison

Regional Travel: Daily Vehicle Miles and Hours Traveled				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
Daily Vehicle Miles Traveled				
Non-Carpool	70,548,712	70,653,272	104,560	0.1%
Carpool	226,241	225,511	-730	-0.32%
Transit	143,043	143,043	0	0.00%
Daily Vehicle Hours Traveled				
Non-Carpool	2,222,879	2,223,774	895	0.0%
Carpool	6,801	6,780	-21	-0.31%
Transit	8,268	8,258	-10	-0.12%

Table 4-18. Daily Vehicle Miles and Hours Traveled

Regional Travel: Daily Person Miles and Hours Traveled				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
Daily Person Miles Traveled				
Non-Carpool	100,106,160	100,230,656	124,496	0.1%
Carpool	748,612	745,846	-2,766	-0.37%
Transit	1,885,618	1,879,954	-5,664	-0.30%
Daily Person Hours Traveled				
Non-Carpool	3,084,866	3,078,922	-5,944	-0.2%
Carpool	22,131	21,818	-313	-1.42%
Transit	229,442	228,713	-729	-0.32%

Table 4-19. Daily Person Miles and Hours Traveled

Tables 4-20 through 4-22 provide similar measures for the AM peak period. Similar trends of a slight reduction in transit use and longer, faster trips are also observable. However, diversion offsets the speed improvements in the AM peak as shown by the slightly higher percentage increase in person hours traveled in LOV vehicles versus person miles traveled.

Regional Travel: AM Peak Period Person and Vehicle Trips				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
AM Peak Period Trips				
Person Trips	2,232,811	2,232,796	-16	0.00%
Non-Carpool Vehicle Trips	1,529,112	1,529,126	14	0.00%
Carpool Vehicle Trips	9,483	9,485	3	0.03%
Transit Person Trips	72,504	72,371	-133	-0.18%

Table 4-20. AM Peak Period Person and Vehicle Trips

Regional Travel: AM Peak Period Vehicle Miles and Hours Traveled				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
AM Peak Vehicle Miles Traveled				
Non-Carpool	13,898,693	13,918,142	19,449	0.1%
Carpool	168,983	168,387	-596	-0.35%
Transit	36,581	36,581	0	0.00%
AM Peak Vehicle Hours Traveled				
Non-Carpool	485,734	486,385	650	0.1%
Carpool	5,944	5,923	-21	-0.35%
Transit	2,116	2,115	-2	-0.08%

Table 4-21. AM Peak Period Vehicle Miles and Hours Traveled

Regional Travel: AM Peak Period Person Miles and Hours Traveled				
Measure	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
AM Peak Person Miles Traveled				
Non-Carpool	20,913,894	20,929,332	15,438	0.1%
Carpool	559,213	557,020	-2,194	-0.39%
Transit	621,272	617,896	-3,376	-0.54%
AM Peak Person Hours Traveled				
Non-Carpool	717,860	719,097	1,237	0.2%
Carpool	19,565	19,581	16	0.08%
Transit	66,920	66,703	-217	-0.32%

Table 4-22. AM Peak Period Person Miles and Hours Traveled

Tables 4-23 and 4-24 illustrate the impact of the Enhanced ITS alternative improvements on throughput and trips attracted (diverted) to the simulation area. Table 4-23 provides the AM peak period trips to, from, and through the subarea that are provided to the simulation model for analysis. Here the change from 1990 to the MMDI baseline shown earlier is reversed. More trips and a higher percentage are included in the simulation as people take advantage of the reduced congestion the improvements provided and divert back to, from, or through the subarea. This diversion is also reflected in the AM peak period screen line volumes shown in Table 4-24 (Figure 4.13 provides the screen line locations). The screen line volumes show more noticeable percent changes than the overall regional travel measures as they capture more localized effects, and both mode split and diversion impacts. Screen line 43, Locust Way, shows the highest increase in travel reflecting the attraction to SR522 caused by the ATMS coordinated signal improvements. It is interesting to note that there is even a 1% increase in volumes across Lake Washington on Screen line 32 as travelers reorient how they enter the subarea. Note, that if area-wide rather than corridor improvements were made the diversion impacts shown by the screen line analysis would not be as noticeable.

Table 4-25 reveals how the trips, miles traveled, and times are interrelated and interact due to the Enhanced ITS alternative improvements. It includes both the impacts of the regional recurrent delay analysis, and the rolled up travel time impacts of the simulation representative day analysis used to capture unusual events and improved information. The table provides a breakout by origin and destination of the AM Peak Period LOV (non-carpool) vehicle trips that travel to, from, or through the simulation area. Four areas are defined: (1) the simulation area; (2) the area south of the simulation area within the North corridor influence area (including the Seattle CBD); (3) the area north of the simulation area within the North corridor influence area; and (4) the area outside of the North Corridor. These regions are mapped in Figure 4.14.

Table 4-25 captures travel time impacts at both the regional and subarea level. It also highlights the distribution of impacts and how they change for travel from or to the subarea. The table shows an increase in trips and average distance and a decrease in average travel time when the overall trips are looked at without disagregation. Again, this illustrates longer faster trips overall. It is more revealing, however, to look at some of the individual cell values. For example, trips from the south (area 2) and trips to the north (area 3) have slightly higher average travel times. These trips must travel in the reverse peak direction in order to be included in this summary which is against the improved (but fixed) signal coordination. As the peak direction travel improves the reverse direction is impacted. The highest percent improvement in travel times is for the trips from the north to and through the study area (3.99%). These trips also show an increased average distance. This is logical since these trips can take advantage of both the SR-99 and SR-522 improvements. Trips from and to outside of the corridor (area 4) increase while their average distance decreases. Again, this is the result of new relatively shorter trips being attracted to the simulation area.

Regional And Sub-Area Trips: AM Peak Period				
	Base	Alternative	Change (Alt - Base)	% Change (Change/Base)
Regional SOV	1,529,112	1,529,126	14	0.00%
SubArea SOV	256,520	257,591	1,071	0.42%
% SubArea SOV	16.78%	16.85%		
Regional HOV	9,483	9,485	2	0.02%
SubArea HOV	2,230	2,242	12	0.54%
% SubArea HOV	23.52%	23.64%		

Table 4-23. AM Peak Period Subarea Vehicle Trips.

In summary, the MMDI alternative impacts are small at the regional level. These impacts, however, are consistent and will increase as travel demand continues to grow at a faster pace than infrastructure enhancements, and as the level of ITS improvements increase.

AM Peak Period Screen Line Volumes (Vehicles)			
Screen Line	Base	Alternative	% Change
Ship Channel (35)	97,982	98,227	0.25%
Lake Washington (32)	45,243	45,723	1.06%
County Line (42)	56,598	56,988	0.69%
Locust Way (43)	44,898	45,572	1.50%
128th Street SW (46)	55,841	56,470	1.13%

Table 4-24. AM Peak Period Screen Line Volumes

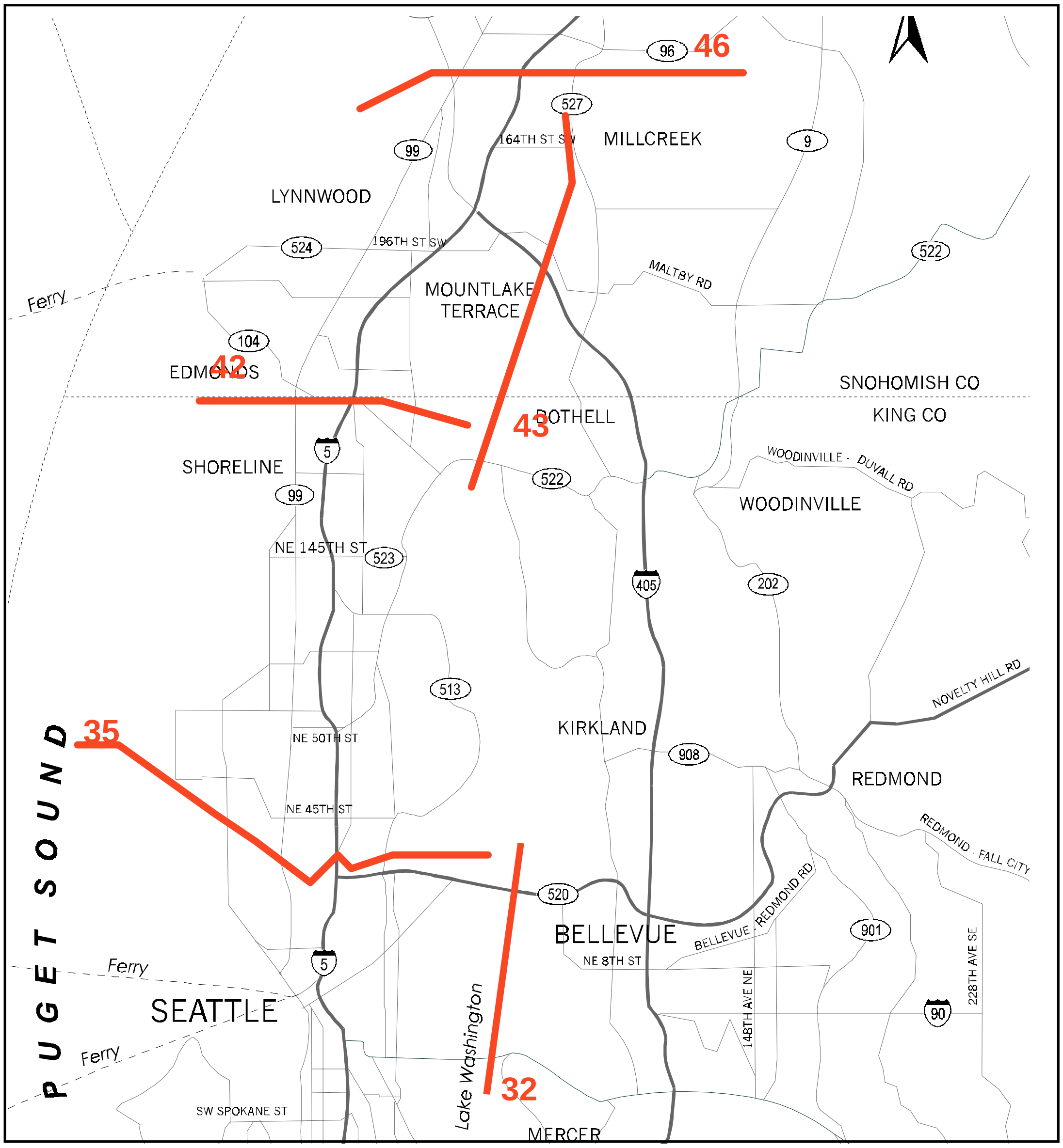

Figure 4.13: Screen Line Locations

AM Peak Period LOV Travel To, From, Through Simulation Area									
	Base			Alternative			% Change		
	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time
From:									
1 = Simulation area	173485	6.06	13.64	173667	6.08	13.58	0.10%	0.38%	-0.42%
2 = Corridor South	14192	6.92	14.89	14270	6.93	14.96	0.56%	0.24%	0.44%
3 = Corridor North	24921	11.81	25.74	25241	11.87	24.72	1.28%	0.50%	-3.99%
4 = Outside Corridor	43922	41.73	76.60	44413	41.59	75.84	1.12%	-0.33%	-0.99%
To:									
1 = Simulation area	174862	8.27	18.25	175058	8.28	18.02	0.11%	0.01%	-1.31%
2 = Corridor South	42269	11.74	24.39	42363	11.73	23.95	0.22%	-0.09%	-1.79%
3 = Corridor North	9542	19.14	38.35	9796	19.22	38.48	2.67%	0.44%	0.33%
4 = Outside Corridor	29847	38.56	66.85	30375	38.46	66.49	1.77%	-0.26%	-0.55%
Overall	256520	12.77	25.67	257591	12.82	25.49	0.42%	0.36%	-0.71%

Distances in Miles, Times in Minutes

Table 4-25. AM Peak Period Travel To, From, Through Travel Comparson (LOV Vehicle Trips)

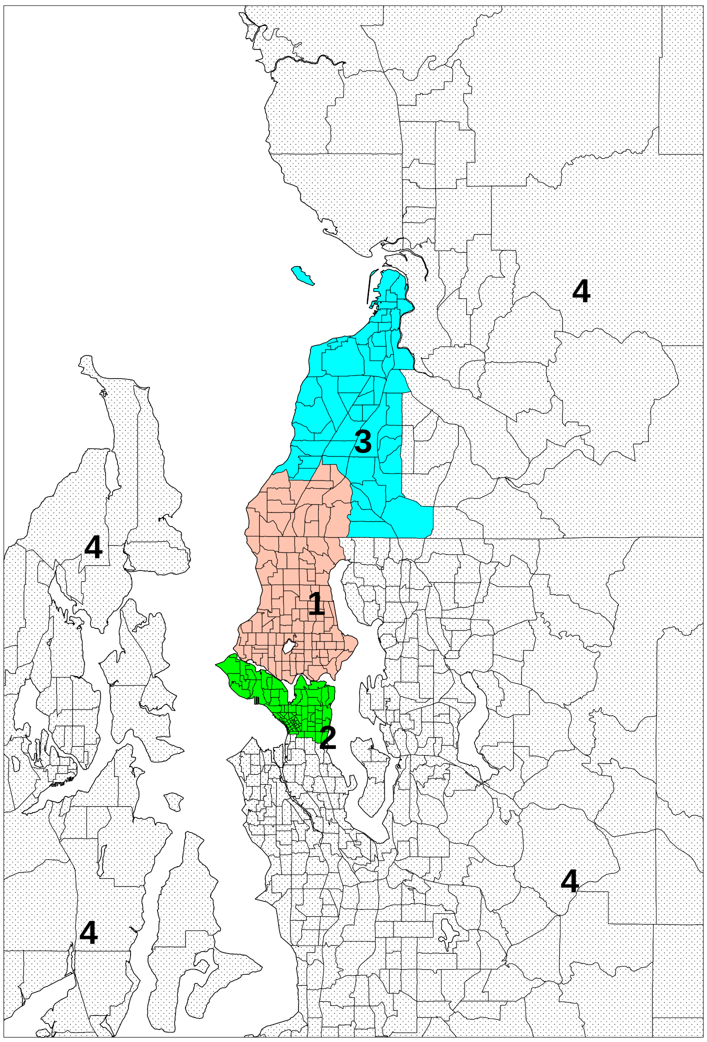

Figure 4.14: Travel Time Comparison Areas

4.5.2 Subarea Impacts

Overall, the Enhanced ITS alternative improves system performance through delay reduction and increases in throughput. Some moderate reduction in subarea stops is also indicated. The impact pattern of the Enhanced ITS alternative roughly matches the pattern seen in the ATMS experiment. Since the analysis includes additional demand drawn in from outside the corridor, overall throughput increases. One key impact of the Enhanced ITS alternative is that the corridor has improved efficiency, allowing for a simultaneous reduction in system delay as well as increased throughput. Travel time variability is reduced, and the number of stops in the network drops. Overall, this faster, smoother travel generates energy and emission estimates that compensates for the increase in overall corridor travel. Likewise, the higher overall travel speed translates into safer travel. A sensitivity analysis examining the impact of feedback to the regional model on network efficiency is also included in this subsection.

Delay Reduction (Figure 4-15). Delay reduction can be characterized as generally robust over the range of scenarios. Improvements associated with the improved signal timing plan can be observed in the scenarios with close-to-expected demand and good weather. On an annual basis, delay is reduced by 986 hours per AM peak period (0.31 minutes per traveler). This represents an annualized system delay reduction of 6.1% compared to the Baseline case, even when overall system demand has increased by roughly 0.4% from the Baseline.

Throughput (Figure 4-16). Improvements to throughput are seen under a wide range of weather or high-demand conditions, as the increase in overall travel demand is converted into corridor throughput. On an annual basis, throughput is improved by 0.64%, corresponding to roughly 1,331 additional vehicles completing trips in the peak period over the Baseline case. Of note is that the increase in throughput (0.64%) exceeds the increase in overall corridor travel demand (0.42%).

Coefficient of Variation. The Baseline case coefficient of variation is 0.242. Applying this to a trip with an expected duration of one hour, a traveler would have to budget 1.40 hours (84 minutes) to arrive at his/her destination on-time 95% of the time. The value obtained in the Enhanced ITS alternatives analysis is 0.241, indicating that travel has become slightly more predictable across the system.

Percentage of Vehicle-Kilometers of Travel By Speed Range (Figure 4-17). Small gains in travel speed can be observed on both freeways and arterials.

Expected Number of Stops per Vehicle-Kilometer of Travel (Figure 4-18). A moderate improvement in stops can be observed for both freeway and arterials. Of note is the reduction in highly-congested arterial travel (1.00 stops per km or above).

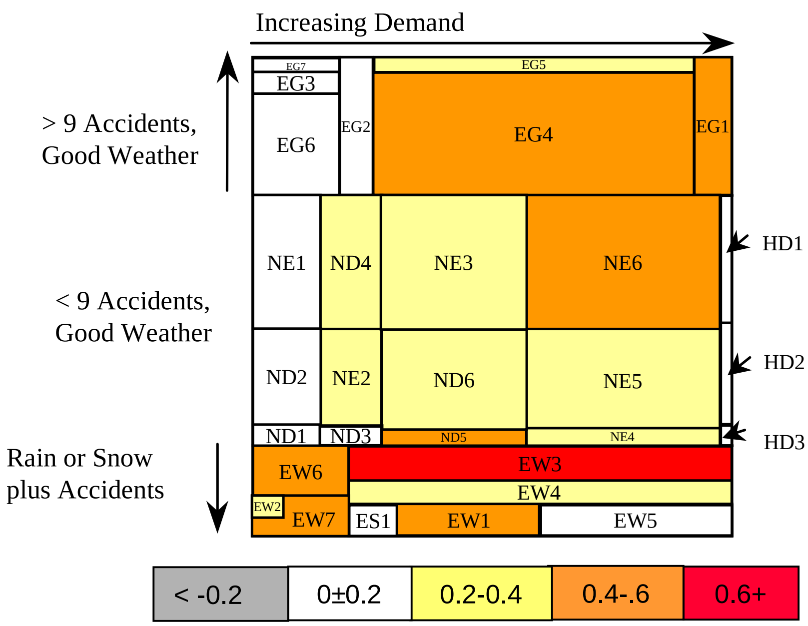

Figure 4-15. Minutes of Delay Reduction: Enhanced ITS Alernative vs. Baseline

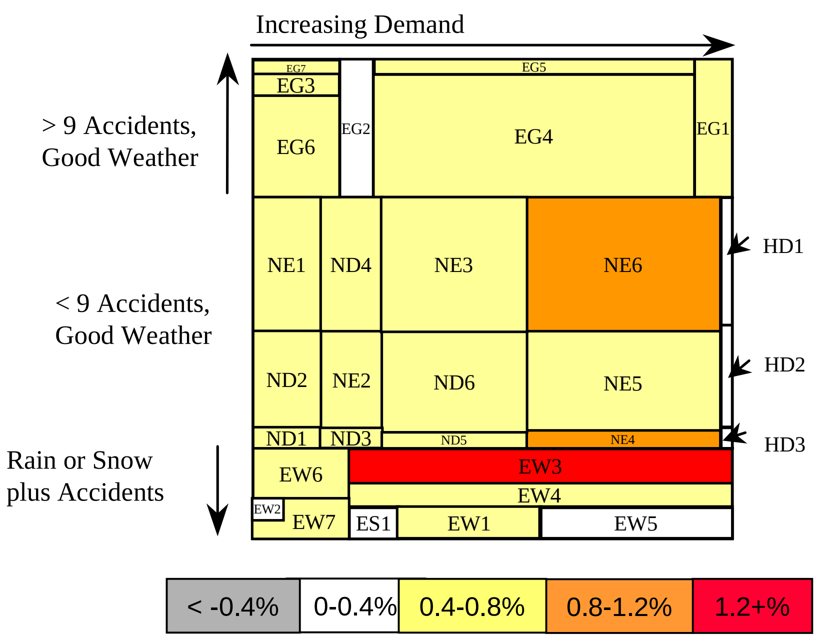

Figure 4-16. Percent Increase in Vehicle Throughput: Enhanced ITS Alernative vs. Baseline

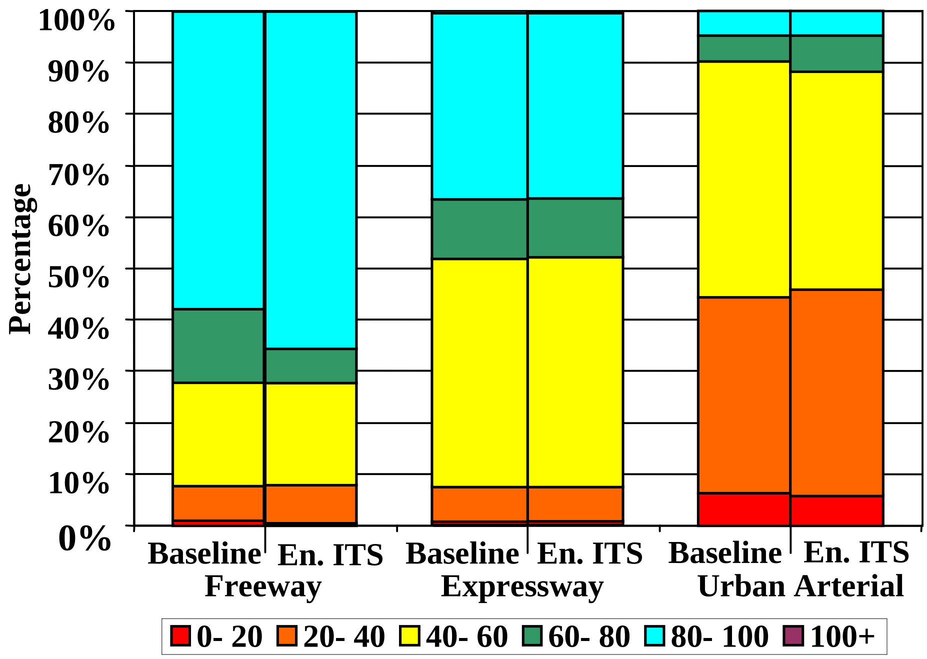

Figure 4-17. Percentage of Vehicle-Km by Speed Range (kph): Enhanced ITS Alernative vs. Baseline

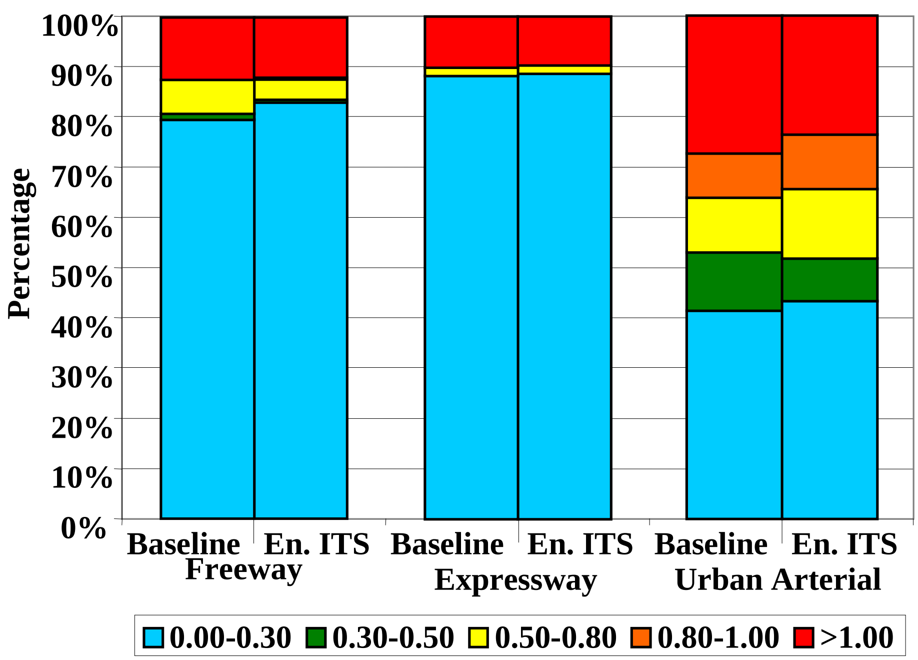

Figure 4-18. Expected Number of Stops Per Vehicle-Km: Enhanced ITS Alernative vs. Baseline

Effect of Additional Travel Demand (Feedback). A summary of network efficiency impacts associated with the Enhanced ITS alternative with feedback to the regional model is presented in Table 4-26. The integrated deployment reduces overall subarea delay by 6.1% while carrying additional 1,300 vehicles in the AM peak period. Subarea travel increases by 0.9% although total number of stops drops by 4.7%.

Measure per Average AM Peak Period, North Corridor Subarea	Baseline	Enh. ITS (with feedback)	Change	% Change
Vehicle-Hours of Delay	17,879	16,893	-986	-6.1%
Vehicle Throughput	209,372	210,704	+1,331	+0.7%
Coefficient of Trip Time Variation	.242	.241	-.001	-0.4%
Vehicle-Km of Travel	3,438,000	3,487,000	+49,000	+1.4%
Total Number of Stops	1,200,000	1,149,000	-51,000	-4.3%

Table 4-26. System Efficiency Impacts, Enhanced ITS Experiment (with feedback to regional model)

Measure per Average AM Peak Period, North Corridor Subarea	Baseline	Enh. ITS (no feedback)	Change	% Change
Vehicle-Hours of Delay	17,879	16,534	-1,345	-7.8%
Vehicle Throughput	209,372	210,007	+635	+0.3%
Coefficient of Trip Time Variation	.242	.233	-.008	-3.3%
Vehicle-Km of Travel	3,438,000	3,453,000	+15,000	+0.4%
Total Number of Stops	1,200,000	1,144,000	-55,000	-4.6%

Table 4-27. System Efficiency Impacts, Enhanced ITS Experiment (no feedback to regional model)

The impact of regional feedback can be seen by comparing these results against the Enhanced ITS analysis performed under baseline travel demand in Table 4-27. In this case, higher delay reduction is seen (7.8%) as well as a reduction in trip time variability (3.3%), while the increase in throughput is lower (0.3%). This result stems from the fact that under feedback to the regional model, the improvements in the subarea attract new demand to the improved facilities. The new demand raises the overall level of congestion in the network, resulting in increased throughput but lower delay reduction and higher trip time variability.

Energy and Emissions Impacts:

	Number of Stops	Vehicle km of Travel	Fuel Use	Total HC	Total CO	Total NOx	Avg Fuel Use
			kL	kg	kg	kg	kmpl
Base	1,199,677.5	3,438,362.5	354.62	390.04	7043.14	846.19	9.70
En. ITS	1,148,521.5	3,486,915.5	355.13	387.77	6955.23	835.65	9.82
Diff.	-51,156.0	48,553.0	0.51	-2.27	-87.91	-10.54	0.12
% Diff.	-4.26%	1.41%	0.14%	-0.58%	-1.25%	-1.25%	1.24%
T-test	96.16%	99.99%	89.33%	78.50%	85.08%	90.84%	

Table 4-28. Summary of Energy and Emissions Impacts: Enhanced ITS vs. Baseline

As shown in Table 4-28, the Enhanced ITS experiment had a significant impact on the number of stops with an approximate 4.26% decrease from the Baseline. However, the reductions to emissions were less significant and there were actually increases in VKT and fuel usage. According to statistical T-tests, Fuel Use, HC, and CO were considered to have insignificant results, while the reduction in NOx was significant. A confidence level of 90% was used.

Facility	**Case**	**Speed (>60 km/h)**	**Stops (>0.5)**
Freeway	Enhanced ITS Baseline	72.1% 72.2%	16.36% 19.22%
Expressway	AFT Baseline	47.8% 48.1%	11.35% 11.79%
		Speed (>30 km/h)	**Stops (>0.5)**
Urban Arterial	AFT Baseline	80.5% 80.3%	48.29% 47.04%
Rural Arterial	AFT Baseline	76.2% 73.5%	36.52% 39.56%

Table 4-29. Speed and Stop Range Comparison: Enhanced ITS vs. Baseline

The *Freeway* in the Enhanced ITS alternative had nearly the same vehicle km at higher speeds (60+ kph) but significantly less frequent stops than in the Baseline (Figure 4-29). However, the decreases in CO and NOx are very slight, and there is almost no change in Fuel Use and HC. The *Expressway* had a slightly lower percentage of vehicles at higher speeds (60+ kph) and less frequent stops than in the Baseline. However, it had small increases in fuel usage and emissions. The *Urban Arterial* had nearly the same percentage of vehicle km at the higher speeds (30+ kph) but slightly more frequent stops than in the Baseline. Nevertheless, it had significant reductions for both CO and NOx. There is also a reduction in HC, but a very slight increase in Fuel Use. The *Rural Arterial* had a higher percentage of vehicle km at higher speeds (30+ kph) but fewer frequent stops than in the Baseline. It had significant percent reductions in CO and NOx. There was also a reduction in HC and a slight reduction in Fuel Use.

Safety Impacts: The following is a breakdown of the MOE's for the Enhanced ITS Alternative experiment. The cells highlighted in gray are those that have extreme values within the table.

	Using million veh-sec			Using million veh-km		
	Baseline	Enhanced ITS	Percent Difference	Baseline	Enhanced ITS	Percent Difference
0-32 kph	5.48	5.43	-0.91%	3.15	3.23	2.54%
32-40 kph	2.05	1.66	-19.02%	1.87	1.49	-20.32%
40-60 kph	3.48	3.59	3.16%	3.02	3.12	3.31%
60-80 kph	1.03	1.06	2.91%	0.86	0.90	4.65%
80-100 kph	0.73	0.80	9.59%	0.65	0.70	7.69%
100+ kph	0.06	0.05	-16.67%	0.05	0.05	0.00%
Per morning rush hour	**12.83**	**12.59**	**-1.87%**	**9.60**	**9.49**	**-1.15%**
Annual	**2,823**	**2,770**		**2,112**	**2,088**	
Over Ten years	**28,226**	**27,698**		**21,120**	**20,878**	

Table 4-30. Crash Analysis: Enhanced ITS vs. Baseline

The Enhanced ITS Alternative had a number of significant reductions, especially in the 32-40 kph speed range. This was followed by a moderate increase in the 80-100 kph range. Approximately 500 fewer crashes are predicted over a ten-year period under the Enhanced ITS alternative.

	using million veh-sec			using million veh-km		
	Baseline	Enhanced ITS	Percent Difference	Baseline	Enhanced ITS	Percent Difference
Per morning rush hour	0.052	0.053		0.042	0.042	
Annual	11.5	11.6		9.2	9.3	
Ten years	114.9	115.8	0.78%	91.9	93.1	1.35%
Percentage of Total Crashes	0.407%	0.418%	2.70%	0.435%	0.446%	2.53%

Table 4-31. Fatal Crash Analysis: Enhanced ITS vs. Baseline

The total number of fatal crashes (Table 4-31) increased, but only by one fatality every ten years. The number of fatal crashes as a percentage of all crashes went up because of the dramatic decrease in crashes in the lower speed ranges. Higher speed ranges historically have higher fatalities. Fatal crash rate, however, declines 0.6%.

	Veh-Sec	Veh-km	Crashes (m veh-sec)	Crashes (m veh-km)	Fatalities (m veh-sec)	Fatalities (m veh-km)
Enhanced ITS	92.6%	99.9%	98.3%	81.9%	99.4%	98.9%

Table 4-32. Statistical Confidence Levels for Safety Impacts: Enhanced ITS vs. Baseline

SECTION 5: CONCLUSIONS

This section presents summary of key findings. A brief outline of potential extensions to this effort is presented in Section 5.2.

5.1 Key Findings

A key feature of the MMDI evaluation effort is in the identification of benefits associated with the deployment of integrated ITS, rather than stove-pipe functional or jurisdictional systems. The Seattle MMDI deployment has examples of both functional (utilization of arterial congestion data for both traffic signal control and ATIS) and jurisdictional cooperation (traffic signal coordination along major arterial corridors). Based on the full range of assessments conducted in this study, some key observations can be made on the impact of integrated ITS systems.

The *benefit of jurisdictional cooperation for signal control* is illustrated in the impacts associated with the ATMS experiment. The combination of better data on arterial queue length in the AM peak and the coordination of signals at variable progression speeds (both major and minor) is projected to reduce system-wide delay by 7%. The subarea model available for this effort and the experiments performed are not detailed enough to produce a traffic signal timing plan that can be directly implemented in the field. However, for traffic engineers in Seattle, Lynnwood and other jurisdictions in the North Corridor, the 7% delay reduction provides a quantitative estimate of potential benefit that can be used in prioritizing the development of a detailed plan for SR99 or SR522. Further, the delay reduction figure demonstrates to local jurisdictions that cooperation on timing plans has a quantifiable potential benefit, bolstering an argument that was heretofore conjecture.

Another useful observation concerning jurisdictional cooperation for signal control is that although well-timed plans are generally beneficial, the range of conditions (particularly the combination of weather and travel demand variations) seen in the North Corridor cannot always be satisfied with a single fixed plan. A case can be made, therefore, that *even more benefit could reasonably be expected if alternative plans could be implemented* for particular observed conditions. For example, a coordinated plan with shorter cycle lengths and faster progression speeds could be developed for light demand conditions. This signal control strategy would require cooperation between jurisdictions on a day-to-day basis to select the appropriate coordinated plan from a list of approved alternatives.

ATIS has largest impact during conditions associated with the worst congestion: heavy demand, major accidents or extreme weather. Eighty percent of the total delay reduction from ATIS is accounted for a set of scenarios with a combined probability of 28%. This set is composed of scenarios with either heavy demand, a major accident, extreme weather, or a combination of these factors. ATIS effectiveness under these conditions is reflected in its impact on travel time variability. In the ATIS experiment an average of 260 hours of vehicle delay is eliminated each AM peak, compared with 1,218 hours in the ATMS experiment. However, the ATIS impact on annual travel time variability (-2.5%) is larger than the ATMS experiment (-2.1%).

Integrating arterial congestion data with freeway-based ATIS clearly improves the effective utilization of ATIS services by the travelers modeled in the North Corridor. The delay reduction associated with a 6% usage rate in the AM peak more than doubles from 1.5% to 3.4% when congestion data on parallel arterial facilities (SR99 and SR522) is made available to ATIS. User delay reduction is similarly enhanced. This larger impact should be interpreted understanding the focus of the evaluation network on corridor-specific travel. Travelers planning for long trips from the extreme north to south within the Puget Sound region, e.g. Everett to Tacoma, have freeway-to-freeway alternatives (I-5 vs. I-405) that are not represented by the current North Corridor model. The range of choices is limited to the corridor level (SR99 vs. I-5), so we expect some underestimation of benefit for these types of trips. Providing arterial congestion data is likely more useful for the inter-corridor, moderate length trip maker (e.g., Edmonds to the University of Washington campus) than for the long regional trip maker.

Another goal for MMDI evaluation is to *quantify the overall system impacts of integrated ITS compared with isolated deployments of ITS functional components*. An examination of the conditions where benefit can be expected from each functional component is illustrative of how these functional components may be interacting. For example, IMS and ATIS have highest impact in many of the same situations, primarily corresponding to freeway incident cases and extreme weather cases. Traffic signal control impacts are insensitive to incidents and have highest impact where the ratio of travel demand to roadway capacity is close to expectation. In scenarios where impact by functional component overlaps, impacts from adding in a new functional component is diluted by the simple fact that there is less delay to eliminated.

At the corridor level, projected energy and emission impacts associated with MMDI-related ITS enhancements are small and indeterminate. Overall energy consumption in the corridor is projected to increase as additional travel demand is drawn into the more efficiently operating corridor roadway system. However, fuel economy (on a miles-per-gallon basis) within the corridor is slightly improved because of reduced stop-and-go traffic conditions. Overall emissions of pollutants (HC, CO, and NOx) are generally slightly lower, but in many cases these reductions are too small to be statistically significant.

Projected corridor-level safety impacts are small but positive. Using an analysis of travel speed and crash rates, the MMDI-related ITS enhancements generally produce slightly higher travel speeds and hence less frequent crashes. Although the proportion of all crashes that involve at least one fatality increases with travel speed, the overall number of fatal crashes typically remains steady because of the overall reduction in total crashes.

Another observation that can be made is that the impacts associated with the Enhanced ITS alternative are relatively small when compared with the impacts projected for fully integrated end-state ITS deployments like the one tested in the Seattle 2020 analysis. The difference in impact is reflective of the significant difference in how much ITS is deployed in each case. For example, the 2020 ITS Rich alternative features comprehensive adaptive ATMS arterial control, integrated freeway/arterial surveillance supplemented by probe vehicles for ATIS, and higher usage rates for advanced pre-trip and en-route traveler information services. The Enhanced ITS alternative is best viewed as an evolutionary step towards such a fully integrated ITS deployment.

5.2 Potential Extensions

A number of extensions to the experimental plan reported in this document may be considered for future analysis.

- Explicitly treat time-shifting and trip postponement in the traveler behavior model. To date in our analysis, only route choice has been considered for traveler decision-making with ATIS. Mitretek began work in implementing model routines within PRUEVIIN to address this issue in October 1998 based on feedback from our Seattle site visit in September 1998. The technique for MMDI evaluation is based on a earlier method developed at Mitretek [31]. Implementation of that module was not completed in time for this analysis effort.

- Examine impacts of ATIS using non-uniform market penetration. The observation from these experiments that ATIS benefits are non-uniform based on trip patterns and trip timing brings into question the accuracy of our current uniform market penetration assumption. Previous work by Mitretek on a small, hypothetical network [21] indicates that ATIS benefits may be underestimated if a uniform market penetration assumption is made, both for user benefits and for system impacts. This analysis technique can be adapted for use with PRUEVIIN and the North Corridor network. MMDI evaluation team members conducting ATIS surveys in Seattle, in conjunction with Mitretek, have designed survey questions to test for empirical evidence that users tend to be geographically clustered. Based on responses to this survey, one might consider a plan to adapt the current analysis technique, implement and repeat the ATIS experimental plan.

- Examine impact of changes in overall traveler information usage (radio + TV + web).

- Examine impact of higher levels of jurisdictional cooperation for real-time traffic signal control.

- Consider a PM peak analysis. New data being made available from other MMDI team members indicate that ATIS usage may be significantly higher in the PM peak period than in the AM peak period. Mitretek could revise the North Corridor data sets to identify the potentially larger benefits that accrue in the PM peak and compare them with the AM peak analysis. Similarly, an off-peak or weekend analysis may prove useful to complete a 24-hour, 7-day a week analysis of ITS benefits.

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