FINAL REPORT

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Incorporating ITS into Corridor Planning: Seattle Case Study

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Parsons Brinckerhoff Quade and Douglas and CH2M Hill

FINAL REPORT

Incorporating ITS into Corridor Planning:

Seattle Case Study

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Abstract

As Intelligent Transportation Systems (ITS) technologies mature and become ready for deployment through use of regular funding sources, ITS will need to become fully integrated into the established transportation planning process. This process involves choices among competing projects within financial and other constraints. ITS components will in many cases be combined with more conventional transportation components as part of an alternative to address a specific transportation problem. This raises many questions about how to select and evaluate ITS projects as an integral element of traditional transportation construction projects. In addition, transportation planners often have less experience with ITS than with other types of transportation improvements, and hence analytical techniques that adequately address the ITS component have not been developed.

To address these issues the ITS Joint Program Office (JPO) of the United States Department of Transportation (USDOT) tasked Mitretek Systems to investigate the incorporation of ITS into the transportation planning process. To accomplish this task Mitretek initiated a multi-year, two-phase study effort. The goal of the study was to develop a methodology for public sector investment analysis. The methodology needed to be able to analyze ITS investments and to produce case-study based estimates of the relative benefits of ITS infrastructure investments versus conventional transportation investments. A goal objective of the study was to identify areas where improved methods or tools are needed for this type of analysis.

This report documents an analysis methodology, the Process for Regional Understanding and EValuation of Integrated ITS Networks (PRUEVIIN), that meets these goals. It also provides results from the application of this methodology. The study was done using the structure of a Major Investment Study (MIS) of transportation alternatives for the area north of Seattle, Washington.

KEYWORDS: ITS, simulation model, regional planning model, major investment study, alternatives analysis, corridor planning study, Benefit/Cost analysis, ITS costs, PRUEVIIN.

Foreword

This is the final report on the Seattle Case Study. It includes and replaces the earlier drafts that provided a discussion of major study elements: namely, drafts dated May 1997, June 1997, and March 1998. The main differences between this final report and the March 1998 draft are: this report includes results from the analysis of all five alternatives; a revised executive summary, abstract and acknowledgement; new section 7.9 Cost of Alternatives; and revised section 8.0 Validation. Other new sections include section 9.0 Summary of Results and section 10.0 Lessons Learned. Appendix B, Detail Alternative Cost Worksheets, has also been added.

Acknowledgments

Mitretek Systems would like to acknowledge the following persons and organizations for their guidance and support in the conduct of this study.

Paula Ewen and Mac Lister of HVH, our task managers at the Federal Highway Administration (FHWA) ITS Joint Program Office (JPO).

The internal US Department of Transportation (USDOT) advisory team of Doug Laird, Brian Gardner, and Sam Zimmerman of HEP, John Gerner of HTV, and Ron Fisher and Charlie Goodman of the Federal Transit Administration (FTA). This group provided input on the overall task scope and reviewed project progress and final results.

Karen Richter, Robert Sicko, Nick Roach, Larry Blain and their staff at the Puget Sound Regional Council (PSRC), Pete Briglia of Washington State DOT (WsDOT), and all other members of the Seattle Advisory Panel. This panel was formed early in the task to provide advice on the definition of the alternatives to be studied and to assess the applicability of the final methodologies for use by state and local governments. A complete list of organizations and contacts is provided in Appendix A of the report.

Parsons Brinckerhoff Quade & Douglas (PBQD) and CH2M Hill, our sub-contractor team in the Seattle area. Specifically, we would like to acknowledge Chris Wellander, Cathy Strombom, Youssef Dehghani, Murli Adury, Tim Bevan and Stephanie MacLachlan. This team provided the initial transportation networks for all of the alternatives; developed and executed the cost methodology; provided local coordination with transportation agencies, state and local governments; and provided significant inputs to, and review of, the drafts and the final report.

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Introduction

The goals of this study were to develop a methodology for incorporating Intelligent Transportation Systems (ITS) into the transportation planning process and apply the methodology to esitmate ITS costs and benefits for one case study. A major result from the study included the development of an analysis method for quantitatively assessing ITS impacts, called the Process for Regional Understanding and EValuation of Integrated ITS Networks (PRUEVIIN). Other significant results include the assessment of benefits from an integrated set of ITS services at the regional and corridor level, and lessons learned about incorporating ITS into the planning process. The following sections set the context for and provide a summary discussion of these findings.

Key Study Accomplishments

1. Developed an analysis methodology (PRUEVIIN). PRUEVIIN evaluates the unique aspects of ITS strategies (impacts/benefits/costs) along with more traditional corridor improvements. Traditional corridor alternatives have in the past focused on capacity and other improvements designed to relieve expected or recurrent congested conditions. The techniques have focused on average travel and conditions. However, many of transportation problems, delays, and congestion that occur in the real world are the result of non-recurrent incidents or operational inefficiencies. Traditional corridor study methods and measures of effectiveness tend to be insensitive to solutions such as ITS strategies designed to address problems arising from these non-recurrent and operational issues. ITS strategies focus primarily on improving operations and the transportation system's response to changing conditions, improving reliability of the system and letting travelers know the true condition of the transportation system.
   A goal of the study was to develop a set of integrated methods that incorporate in the analysis the types of problems and solutions that ITS strategies are attempting to remedy. This includes the system's response to varying non-recurrent conditions and the impact of information. Another important aspect of this same goal was to implement the process in an integrated framework that can analyze the net effect of the traditional and ITS elements in an overall solution to the corridor's transportation needs. This is especially important since the impacts of each element (ITS and traditional) in an overall corridor solution may interact, producing results that are not simply the sum of the individual element improvements. The PRUEVIIN methodology accomplishes this goal.

   For the study an existing commercial planning model (EMME/2) and simulation model (INTEGRATION) were used. The INTEGRATION model supports analysis of trips from each origin to each destination (similar to the regional models) but can also trace how vehicles actually move through the network. The ability to trace individual vehicles is a key feature for incorporating mode choice, route guidance, and other ITS strategies into the analysis. Key elements of the methodology are the capture of both ITS and traditional transportation improvements in both of these models; the interplay of the models to assess corridor improvements in the context of a regional network; and the development of a series of scenarios (representative travel days) to capture the conditions and effects of non-recurring congestion.

In this study the PRUEVIIN methodology was applied for an analysis year of 2020 (a typical 20 year planning time-frame), but the methodology can also be used for any time horizon, as well as for the conduct of near term "what-if" analyses by operational personnel. Since the inception of the study, PRUEVIIN has been used to support the Metropolitan Model Deployment Initiative (MMDI) evaluation program. A study in the Seattle area using the same sub-area was conducted for a horizon year of 1997-98 (*ITS Impacts Assessment for Seattle MMDI Evaluation: Modeling Methodology and Results*, Mitretek Systems, June 1999).

2. Produced Measures of Effectiveness (MOE's) for comparing alternatives. These measures reflect typical MIS issues and also capture the impacts of ITS strategies. A key phase in any MIS is the development of the MOE's that are used to evaluate the alternatives under study and reflect the issues/concerns of those in the community making the decision. Typically, measures of transportation service, costs, mobility and system performance, financial burden, and environmental/community impacts are considered. These measures, however, are usually only calculated based upon the average weekday or expected conditions. Variation in conditions (e.g. travel demand, weather, accidents) and the transportation system's response to them is not part of the analysis and consequently does not enter into the decision process. Incorporating variation in conditions is key to showing the benefits of ITS and other strategies focused on improving the operation of the system. In the study several new MOE's were analyzed that are more representative of the impacts of ITS. These new measures include reduction in travel time variability, probability of a severely delayed trip, vehicle-km traveled at various speed ranges, and number of stops per vehicle-km traveled.

3. Developed representative-day scenarios. A methodology was developed to determine the number and characteristics of the representative-day scenarios necessary to capture the variation in conditions and the effects of non-recurrent congestion. Previous studies have shown that ITS strategies can have significant impact on anomalous traffic conditions that, even though they are relatively rare, can contribute a disproportionate amount of delay and other costs. To assess the alternatives in this study that include ITS strategies, the analysis had to incorporate these anomalous traffic conditions. Since the network simulation model is capable of representing time-varying conditions, the AM peak travel conditions are characterized into a reasonable sample of scenarios that are both typical and anomalous of conditions in the study area.

Each scenario represents a combination of conditions common to the study area that may lead to the traveler experiencing very different conditions and possibly a different travel choice. The characterization of the sub-area conditions and the scenarios was obviously constrained by available data. These considerations focused attention on the following characteristics: traffic/trip volumes and their space-time patterns; weather conditions; and the effect of accidents and other incidents on traffic conditions. For the Seattle study it was determined that 30 scenarios were required to capture the yearly range of day-to-day variations in travel conditions. The probability of occurrence of each scenario during the year was also determined. For each of the 6 alternatives, the full set of scenarios was run. The resultant MOE's were then multiplied by the probability of the occurrence of the scenario. This produces an annualized value for each MOE. This annualized roll-up allows the even-playing-field examination of ITS elements alongside traditional capacity improvements.

4. Developed techniques to measure and calibrate the simulation model. This calibration approach accounted for the within-day and the day-to-day travel time variations in the transportation system. This is important because if system variability is overstated, then ITS-related 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. The techniques developed include the use of an 18-month archive of travel time estimates along the I-5 freeway in Seattle, collected at 15-minute intervals between 6:00 AM and 9:30 PM.

Observations on Methodology Development and Application

1. It is possible using a reasonable amount of resources to integrate regional travel forecasting and sub-area simulation analyses to capture the impacts of ITS and other operational strategies. The Case Study has successfully interfaced the two model systems for this purpose.

2. Simulation tools require additional levels of detail and representative coding than are typically found in regional models. If accurate simulations are to be developed then extra time must be spent in network checking and detailing to ensure that all models represent the physical features of the system at the same level of precision. Likewise, executing the integrated system (regional model + sub-area simulation + feedback) will also require additional effort, especially when representative day scenarios are used for the estimation of ITS benefits.

3. There are increased needs for data collection to support the simulation tools beyond the data collection associated with the support of travel demand models. Additional information beyond what is carried in the regional model systems will need to be obtained, geocoded, and entered into the model system. This includes data on signal operational plans, time variation in demand, and the information on weather, incidents, construction, etc. used to construct the representative day scenarios.

4. The characteristics and size limits the regional model and simulation model platforms used in the study were a significant factor in the design of the methodology. Understanding these characteristics is crucial for properly transferring data between the two platforms. One specific issue is the use of very short "dummy" links, a common practice in planning models. However, these short links are incompatible with the high-volume freeway coding requirements of the simulation model. Therefore, in applying the methodology used in this study one needs to be aware that each pairing of modeling systems will have its own set of issues that will have to be examined.

5. There are also inherent differences in operation and performance between regional and simulation tools. Each represents travel and the behavior of individuals differently. For example, regional models, especially in horizon year forecasts, often have assigned volumes on links or across screenlines which exceed coded capacity (the actual physical capacity of the facility). On the other hand, simulation models by their design cannot assign volumes to links beyond their capacity. Since these two models define capacity differently, special care must be taken. In the horizon year analyses, one should therefore always check for this over saturation condition prior to attempting a simulation run. The trips assigned over saturation can either be deferred to outside the assignment period or diverted around the sub-area. In the study a deferred trip measure of effectiveness was defined to show the level of oversaturation when it did occur. The explicit treatment of queuing in simulation and not in the regional system presents similar issues. These differences in impedance calculation led to the conclusion to only feedback the relative changes between alternatives from the simulation to the regional model. If absolute values from the simulation are fed directly back into the regional model a discontinuity between links within the simulation area and those without is created.

6. Validation is a crucial step in developing an integrated model system. The regional model system parameters and coding should be examined and modified to reflect the new services under study. For example, if ramp meters are to be examined in the analysis it is important to represent the bottlenecks in capacity due to traffic merging for all unmetered intersections in the network. This is achieved by assigning a merge bottleneck penalty to all intersections, and then for the ramp-metered intersections, the merge bottleneck on the main lanes downstream of the ramp is removed. This is a very different approach from simply increasing the capacity on the links downstream of the ramp to above the mid-link flow levels.

Background

As ITS capabilities become ready for deployment through use of regular funding sources, they will need to be integrated into the established transportation planning process. This process involves choices among competing projects within financial and other constraints. ITS components will in many cases be combined with more conventional transportation components as part of an alternative to address a specific transportation problem. This raises many questions about how to select and evaluate ITS projects as an integral element of traditional transportation construction projects.

In addition, transportation planners often have less experience with ITS compared to other types of transportation improvements, and hence analytical techniques that adequately address the ITS component have not been developed. In light of this, any approach to study these issues has to include:

- Reviewing existing procedures and developing a quantitative investment analysis methodology for state/local use in transportation planning.
- Developing case study-based estimates of relative costs and benefits of ITS versus conventional investments.
- Identifying where improved methods of project

To address these issues the ITS Joint Program Office (JPO) of the United States Department of Transportation (USDOT) tasked Mitretek Systems to investigate the incorporation of ITS into the transportation planning process. A review of current state-of-the-practice revealed that consideration of ITS is typically not an integral part of transportation planning. Rather, ITS is considered an operational detail worked out after infrastructure planning. In many cases ITS was considered too difficult to evaluate with respect to transportation planning and then relegated to operational analysis because of a lack of evaluation tools. In response to the JPO tasking, Mitretek initiated a multi-year, two phase study effort. The goal of the study was to develop a methodology for public sector investment analysis. The methodology needed to be able to analyze ITS investments and to produce case-study based estimates of the relative benefits of ITS infrastructure investments versus conventional transportation investments. A secondary goal of the study was to identify areas where improved methods or tools are needed for this type of analysis.

This study was conducted in two phases with the overall objective of both phases being to identify how best to incorporate ITS into the transportation planning process. The phase 1 analysis involved a look at the current process of prioritization of projects addressing many different transportation problems and needs across a region, such as those reflected in the Transportation Improvement Program (TIP) approval process. These results have previously been published (*Incorporating ITS into Planning: Phase 1 Final Report*, USDOT, FHWA-JPO, Washington, DC, September 1997).

The phase 2 analysis focused on the development and evaluation of alternative solutions to a given transportation problem that, depending upon evaluation results, could then be incorporated into the Transportation Plan and eventually the TIP. An example of this type of analysis is the approach taken when conducting a Major Investment Study (MIS). Although this second type of analysis is the focus of this report, methodologies utilizing cost and benefit information have been developed that are of value in both types of analyses. Phase 2 of the study started in July 1996 and selected the Seattle area to develop specific methodologies for the evaluation of project alternatives in the context of a MIS. The results of this phase are the focus of this report.

Case Study Approach

Rather than relying on a hypothetical transportation network and problem statement, Mitretek took the approach of conducting a case study. Specifically, we selected a sub-region or corridor in the Seattle area that would be suitable for analysis, i.e., where alternate solutions to a particular transportation problem can be developed, and where a variety of ITS strategies are applicable. For illustration, if the problem to be addressed is effects from congestion along an urban corridor, the list of alternative solutions might include “do-nothing”, construct a new road, add lanes to existing routes, provide HOV lanes, provide ramp metering, provide incident management systems, add bus or light rail service, as well as combinations of these listed capabilities. In this study ITS services were analyzed both separately and in combination with conventional construction options.

The alternative solutions were examined in detail, in close coordination with a local transportation consulting firm with which Mitretek contracted to support the study (specifically, the team of Parsons Brinckerhoff Quade Douglas and CH2MHill). The study team developed an analysis methodology to adapt and extend conventional transportation improvement modeling and impact analyses. The resulting methodology is designed to be more sensitive to the impacts of the selected ITS strategies and to provide for comparability across the evaluated alternatives. The analysis methodology developed and its results were reviewed with planning staff in the region at various points in the study to assess appropriateness and usefulness.

Scope

For the purposes of this study, it was assumed that a MIS type effort was needed as part of the normal transportation planning process to assess specific alternatives to solve a specific transportation problem in the Seattle area. The geographic scope of the study is a large corridor or sub-area of the transportation network. This geographic context, which parallels that called out in MIS guidance, allows for a variety of transportation alternatives to be considered and evaluated, without being so broad as to dilute the evaluation process with an intractable number of potential alternatives.

The range of transportation improvement projects considered in the study included construction of new roads or lane miles, conventional signal installations, transit improvements, Transportation Demand Management measures, Advanced Traveler Information Systems, Advanced Traffic Management Systems, and Advanced Public Transportation Systems. The study scope did not include Automated Highway Systems or Commercial Vehicle Operations.

The scope of the study does include the identification of a study area, the definition of alternatives to be considered, the development of specific analysis approaches, and the results from applying these analysis approaches. In our case we chose to evaluate several traditional transportation build alternatives in the corridor, with and without ITS components. Simulation modeling and other analytical techniques were applied to these selected cases to quantify benefits and assess the alternatives against a common set of measures of effectiveness (MOE's).

To support the decisions that must be made within the planning process, a wide variety of analytical techniques are used to provide estimates of the potential transportation impacts and costs of alternative investment strategies. Analysis techniques differ in level of detail and effort required to use them at different stages in the planning process (translating to the amount of resources required). While all of these techniques are important and are often used in combination in a conducting a planning study, this study focuses on the analysis requirements of a corridor level planning study and makes extensive use of both planning and simulation models.

Since this is a federally sponsored study providing guidance for transportation planners in metropolitan regions, the specific alternatives assessed are not tied to "actual" Seattle decisions. The study has a wider scope than the actual Seattle situation and considered alternatives beyond those that might be supported in the Seattle environment.

Study Corridor Description

The Seattle I-5 North Corridor was selected for the case study. (See Figure ES-1) The North Corridor contains the two primary continuous north-south routes into the Seattle Central Business District (CBD), I-5 and State Route (SR) 99. The dominant traffic flow direction is associated with commuting to and from the Seattle CBD and the areas immediately south. However, these two routes also carry the significant contra-flow traffic to Boeing-Everett and other points north of the Seattle CBD. These routes provide the only high capacity access of the six routes crossing the Ship Canal, the waterway that bisects Seattle west of Lake Washington. The I-5 North Corridor becomes a bottleneck to mobility for Seattle's topographically constrained regional travel. Significant highway capacity increases through construction are unlikely in the densely developed areas extending north from the CBD and across the Ship Canal. The diversity of modes and facility types in the study corridor promotes the idea of using ITS operational approaches.

In keeping with an MIS approach, a general problem statement is formulated to guide the identification of alternatives, including ITS, and the measures of effectiveness for the case study. The problem statement for the I-5 North Corridor is "Develop and evaluate alternatives to reduce congestion and improve mobility along the North Corridor extending from the Seattle CBD north to SR 526."

In all, six alternatives including a baseline were analyzed for the target year of 2020. (See Figure ES-2) The ITS Rich alternative contains significant improvements in advanced traveler information services (ATIS), advanced traffic management systems (ATMS) surveillance and signal coordination enhancements, transit priority, and incident management. Two traditional construction alternatives were also defined: major improvements to a single-occupancy vehicle (SOV) expressway and a set of high-occupancy vehicle (HOV) plus busway improvements. These were analyzed alone and in combination with the same package of ITS Rich improvements. For each alternative a

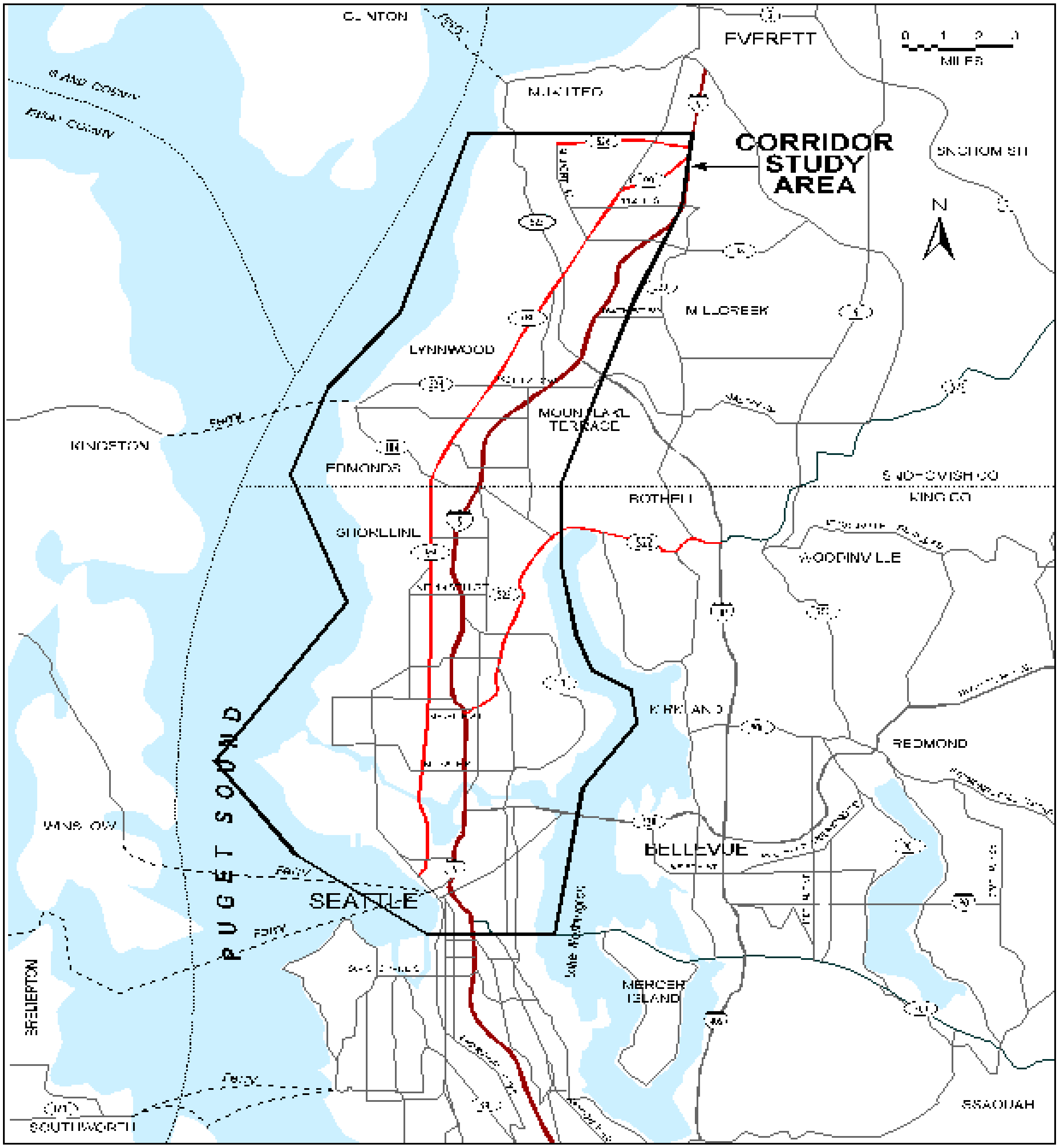

Figure ES-1. Detailed Analysis Area for the North Corridor

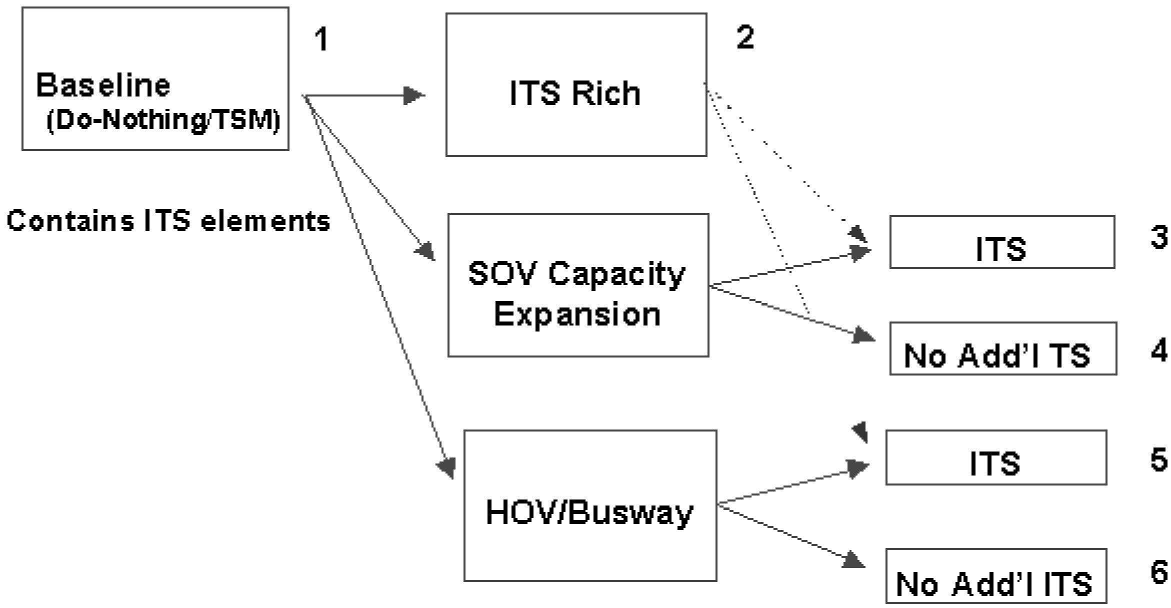

Figure ES-2. Description of Alternatives

number of measures of effectiveness were calculated. All alternatives were compared to a Baseline (Do-Nothing/TSM). The dotted line leading from the ITS Rich alternative indicates that the other ITS enhancements are derived from it, but each has been tailored to complement the specific build option.

Overview of PRUEVIIN

The Process for Regional Understanding and EValuation of Integrated ITS Networks (PRUEVIIN*)* was developed and applied as part of this study. PRUEVIIN is a two-level hierarchical modeling system for assessing the impacts of ITS at the regional and corridor scale. (See Figure ES-3) At the higher (regional) level, the analysis of overall travel patterns and the system's response to average/expected conditions is analyzed using a traditional regional planning model. Output from this analysis is then fed into a more detailed sub-area simulation model capable of modeling time-varying conditions and demands, as well as individual vehicle-level capabilities and routing decisions. At this level, the detailed traffic operations, queuing, and buildup/dispersion of demand are captured, as well as the real-time response of travelers to information. Feedback is then carried out to ensure that the impacts to expected conditions, estimated in the sub-area model, are reflected in the regional analysis. In theory, one could model the entire region using only a simulation model, but this is not yet practical for desktop PCs and current software. The EMME/2 planning model (macro scale) was used for the regional planning model, and INTEGRATION 1.5 (meso scale) for the detailed simulation model. One of

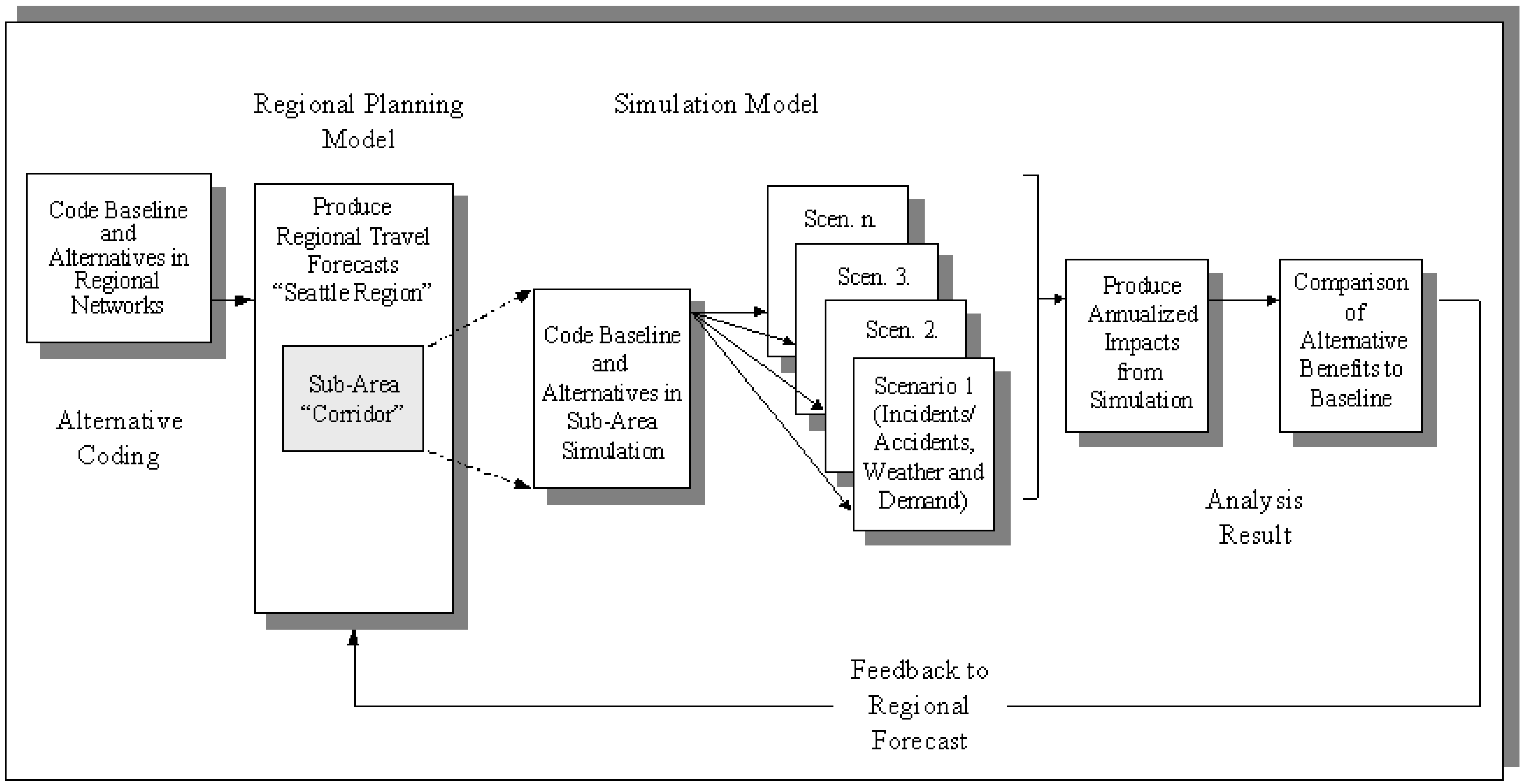

Figure ES-3. Analysis Methodology Overview

the challenges in the study was to develop expertise in mapping both the inputs and analysis results between the two modeling levels. The modeling system contains several pre- and post-processors that manage the interfaces between the models and generate results from model output data. A unique approach is taken to account for the variability in the transportation system. The weather, travel demand, and accident/incident rate variation are analyzed for the corridor over a period of time. A set of representative-day scenarios is developed that, when appropriately weighted, can be used to represent an entire year. This step requires a trade-off between adequately capturing the variability in these multiple parameters and still keeping the number of scenarios to a manageable level.

The analysis process starts by building both the planning and simulation networks. In this study the approved Puget Sound Regional Council (PSRC) 1990 travel demand modeling process was used. The simulation model for the corridor/sub-area is generated from this base network. A validation process was then conducted to validate that both models were representative of the 1990 time period. Next each alternative is defined and coded in both models for the horizon year, in this case 2020. Each alternative is first run in the planning model and the appropriate performance measures generated. From this run a demand table is generated for input to the simulation model. The simulation model is then run for each alternative with this demand and the representative-day scenarios. The appropriate performance measures are generated for each scenario and then annualized across all scenarios. Adjustments (feedback) between the two models are then made to ensure that the benefits generated in the corridor are properly reflected in the region.

Key Alternative Analysis Results

In order to understand the presentation of the results from the alternatives analysis, a further explanation of the concept of representative-day scenarios and the specific measures of effectiveness used in this study is required. Although these two concepts were initially presented in the discussion of key accomplishments, the next two sections provide a broader description, along with a few examples.

Representative-Day Scenario Example

To account for the system variability, two years of travel demand, weather, and accident/incident data in the corridor were analyzed. Using cluster analysis and other statistical techniques, 30 separate representative-day scenarios were developed to reflect these conditions. Figures ES-4 and –5 depict these scenarios. Note that each scenario constitutes a combination of weather, accidents/incidents and travel demand. The size of the box represents the frequency of occurrence of the scenario during the year. For example, using the two figures in combination indicates that scenario NE3 is a non-event (no major incident), normal weather, and normal demand scenario. Scenario EG1 contains a major incident, under good weather with demand 10% greater than average. The scenarios are arranged in such a manner that those with extreme conditions are at the edges of the figure (i.e. top, bottom and right-hand edge).

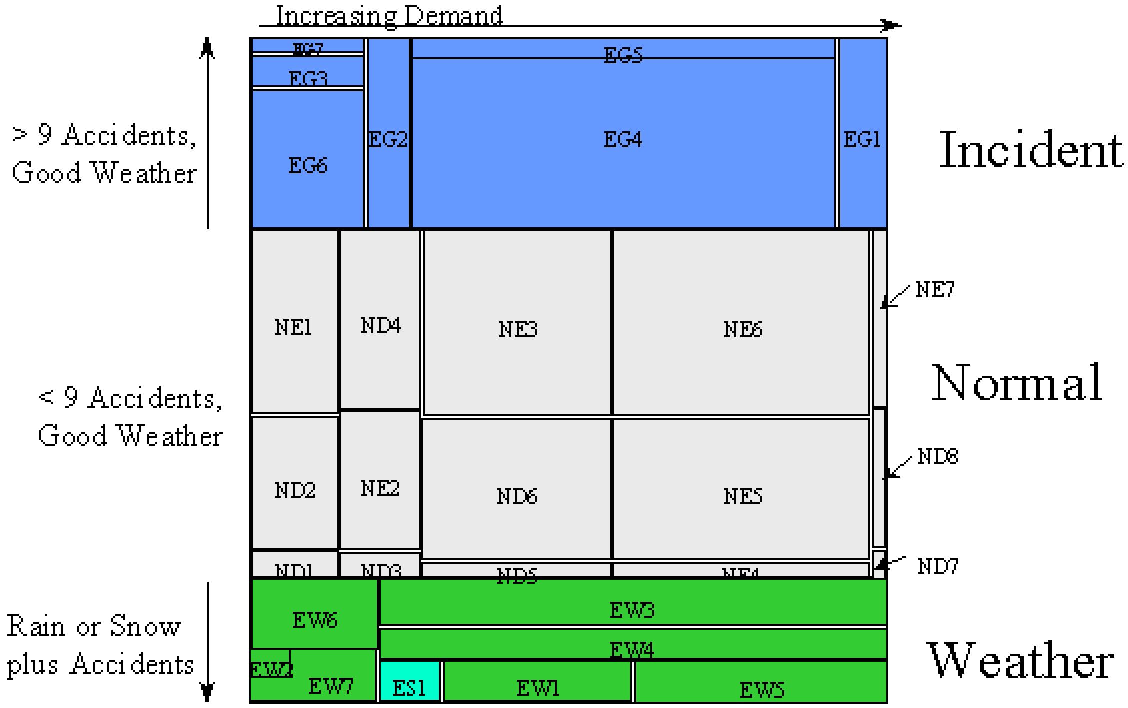

Figure ES-4. Representative-Day Scenarios Weather and Accidents View

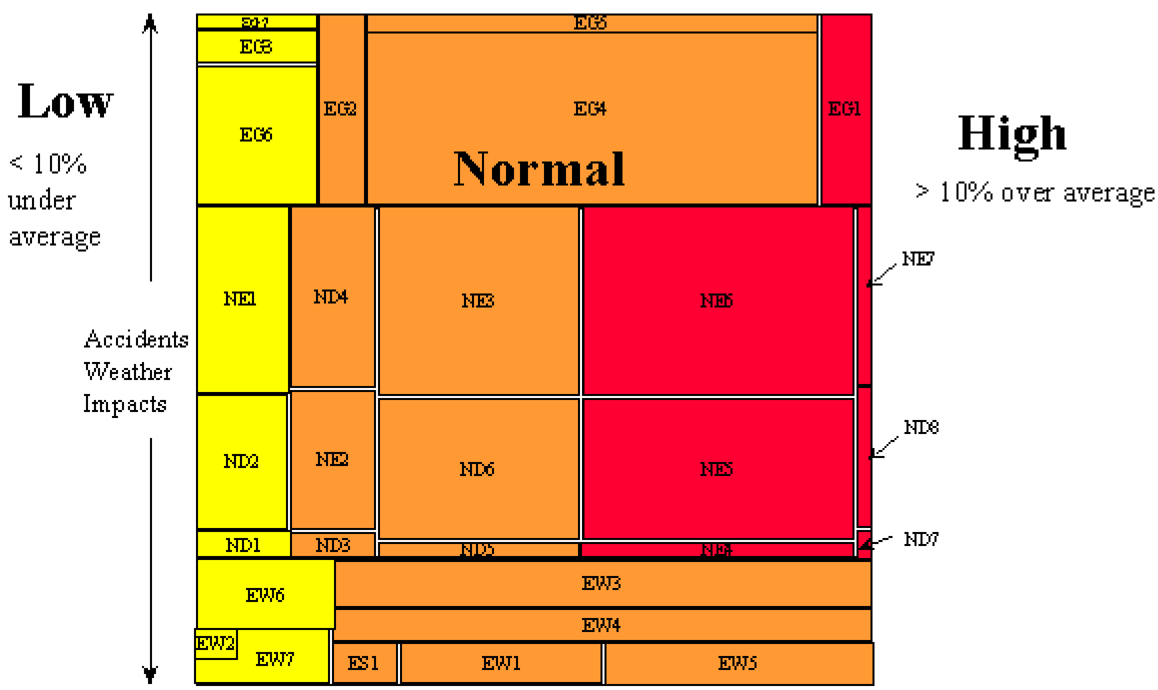

Figure ES-5. Representative-Day Scenarios Demand View

We use this arrangement of scenarios to present the measures of effectiveness results for each run of the alternative. Our results confirm the hypothesis that ITS is most beneficial when conditions deviate from the norm. (i.e. those scenarios at the edge). The highest levels of benefits occur for a number of measures of effectiveness studied in conditions of above average demand and major incidents. In these cases, the information on alternate routes, and the ability of the signal systems to respond to changing conditions provide the highest level of benefits to the most travelers. This will be further illustrated when the results are presented.

Measures of Effectiveness

During the study we discovered that additional measures of effectiveness were needed to properly represent the impact of ITS. A key phase in any MIS is the development of the measures that are used to evaluate the alternatives under study and that reflect the issues/concerns of those in the community making the decision. Typically, measures of transportation service, costs, mobility and system performance, financial burden, and environmental/community impacts are considered. These measures, however, are usually only calculated based upon the average weekday or expected conditions. Variation in conditions (e.g. travel demand, weather, accidents) and the transportation system's response to them is not part of the analysis and consequently does not enter into the decision process. However, incorporating variation in conditions is key to showing the benefits of ITS and other strategies focused on improving the operation of the system. Accordingly, in the study, several new measures were developed that are more representative of the impacts of ITS. *Delay reduction* is calculated as the difference between the travel time in each scenario and free-flow (30% of average demand, no accidents in the system, good weather) travel times. *Throughput* measures the number trips starting in the 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 trip time variation* is calculated by examining the variability of travel for similar trips in the system taken across all scenarios. This statistic is an indicator of the reliability of travel in the corridor. Speed and stops across the network are archived from each run from the whole AM peak period. 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 every 15 minutes producing an *expected number of stops per vehicle-kilometer of travel*.

Pair-wise Results

The Alternatives Evaluation section of the report contains a series of summary and detailed tables that provide a pair-wise comparison of alternatives. The summary tables provide descriptive information while the detailed tables provide the full range of both regional and sub-area MOE's. The specific set of comparisons provided in the report are indicated in Table ES-1.

Table ES-1. Alternatives Comparison Overview

Section	Pair-wise Comparison	
9.1 and 9.2	Baseline vs. Validation Network	ITS Rich vs. Baseline
9.1 and 9.3	SOV vs. Baseline	SOV vs. SOV + ITS
9.1 and 9.4	HOV vs. Baseline	HOV vs. HOV +ITS

The following paragraphs will discuss some of the results from one of these comparisons, the SOV alternative.

SR99, which parallels I-5, is both an undivided arterial and a limited access freeway. Under the SOV Capacity Enhancement alternative, a significant portion of SR99 near the Seattle CBD is converted into a limited access expressway. Table ES-2 summarizes the SOV Capacity Enhancement alternative without and with ITS improvements. These alternatives are characterized with respect to the 2020 Do-Nothing/TSM (Baseline) alternative. The SOV alternative is characterized at the regional level as providing faster travel times, particularly for trips that utilize the upgraded SR99 facility. At the sub-area level, the upgraded SR99 facility demonstrates susceptibility to congestion under weather or heavy demand cases. The result is that an expected improvement in annualized throughput and travel time is not realized. The SOV + ITS alternative mitigates to some degree the congestion conditions along SR99 under poor weather and heavy demand conditions, and provides a significant increase in annual sub-area throughput. At the regional level, the ITS improvements increase total trip length and bring additional demand into the sub-area.

The predominant trends at the regional level resulting from ITS enhancements to the sub-area, are relatively small in magnitude given that the sub-area where ITS implementation is proposed is a small subset of the region as a whole. Impacts on trips traversing the sub-area, however, are significant. Regional trends from implementing ITS, given the SOV enhancements, include a shift from auto modes to transit (0.73%), an increase in sub-area vehicle trips (0.72%), a decrease in regional vehicle trips (-0.30%), and an overall shift toward longer trips.

Some specific annualized MOE's drawn from the simulation sub-area analysis are provided in Table ES-3. Impacts of the SOV + ITS alternative are illustrated as *delay reductions* with respect to the SOV Capacity Expansion alternative. On an annualized basis, average traveler delay is reduced by 2.2 minutes per traveler per day, from 13.86 to 11.65 minutes per traveler per day. On an annualized basis, *throughput* in the SOV + ITS alternative increases to 185,565 vehicles per AM peak period (6:15 – 8:30 AM trip starts) from 168,338 vehicles. This increase of roughly 13,223 vehicles per peak period represents an increase in throughput of 10.2%. The coefficient of trip-time variation in the SOV alternative is 0.39. Applying this to a trip with an expected duration of

Table ES-2. Alternatives Comparison Summaries: SOV without ITS vs. SOV with ITS

2020 Alternative Comparison Implications SOV Capacity Expansion With ITS versus Without ITS		
Measure of Effectiveness	Impact of SOV WO ITS from NoBuild/TSM (Base)	Impact of SOV W ITS from SOV WO ITS (ITS All.)
Alternative Summary		
Regional Travel: Trips, Mode Choice, Times, and Miles Traveled		
Daily Travel		
	Overall daily person trips remain the same Shift to walk to transit trips within/from the corridor, but drop in long distance transit Park&Ride Drop in trips within study area and increase in trips to/from the subarea especially to CBD Increase in Daily V	Overall daily person trips remain the same Increase in transit person trips (slightly less than ITSRICH increase), and concomittant drop in vehicle trips Further reduction in within subarea trips and increase in trips to/from subarea. Additional increase
AM Peak Period Travel		
AM Travel	Similar patterns as found in daily travel Slight shift in overall transit results from higher walk-to-transit and drop in longer drive-to-transit Much faster travel in SR-99 corridor causes overall decrease in travel times	Similar patterns as found in daily travel Increase in transit trips but again slightly less than seen in ITSRICH Overall increase in travel conditions seen by slightly longer trips in transit and vehicle trips, and improved times, speeds
Subarea Trips	Significant increase in vehicle trips to/from/through the subarea due to diversion to SR-99 Improvements in SR-99 cause increase in subarea average speeds	Additional vehicle trips diverted to the corridor are the greatest of any alternattive Slight improvement in congested speeds due to more reliable system
Sub Area Impacts: Delay Reduction, Reliability, and Level of Service		
AM Peak Period Travel		
	Higher system demand Significant increase in travel time variability Throughput increase not concomitant with demand increase	Significant improvements in travel time variability and system throughput Changes particularly signficiant in weather or high demand scenarios
Capital & Operating Costs		
	Cost drivers are: Conversion of 14 miles of urban arterial to urban expressway Construction of nine new urban expressway interchanges Construction of nine new grade separated arterial crossings of the expressway	Capital costs to implement same elements as in ITS Rich slightly higher than for baseline due to increases in communications and traffic management costs.
Environmental Impacts		
	Likely marginally worse: increase in high-speed stops	Likely positive: many fewer high-speed stops

Table ES-3. Selected Sub-area Impacts: SOV vs. SOV + ITS

Measure per Average AM Peak Period, North Corridor Sub-area	SOV	SOV + ITS	Change	% Change
Delay Per Vehicle Trip (min)	13.86	11.65	-2.21	-15.9%
Vehicle Throughput (finished trips)	168,336	185,565	+17,227	+10.2%
Coefficient of Trip Time Variation	.39	.30	-0.10	-24.5%

60 minutes (normally distributed), a traveler would have to budget just over 99 minutes to arrive at the trip destination on-time 95% of the time. In the SOV + ITS case, the coefficient of trip-time variation is reduced to 0.30. Under the constraints of our example one-hour trip, the same traveler would have to budget 89 minutes to arrive at the trip destination on-time 95% of the time.

Figure ES-6 illustrates the conditions where the addition of ITS was most effective in terms of absolute minutes of delay saved per traveler. The largest delay reduction occurs in scenarios with incidents on SR99 (EG2) or I-5 (EG1), heavy demand scenarios (NE4, NE5, NE7, ND7, ND8), and weather/accident combination scenarios (ES1 and EW4).

The reason for ITS having a large impact in this case is that the SOV Capacity expansion alternative and the upgrade SR99 expressway facility can each be characterized as having "brittle" performance. When travel demand is close to average conditions or lighter than average and weather conditions are clear, the new SR99 expressway facility efficiently handles traffic along its length, both in terms of through movements and traffic exiting at grade-separated interchanges with the adjacent arterial grid. Travel times in these cases are improved for trips that typically use SR99. When the travel demand is high or capacity is reduced from weather impact, the upgraded SR99 facility's performance breaks down to a point that travel times actually exceed those associated with the pre-upgrade signalized arterial facility.

SR99 Expressway breakdown is a function of the narrow right-of-way accorded the new facility. The number of opportunities to exit the upgraded SR99 expressway facility and access the adjacent arterial grid are reduced since only a subset of the signalized intersections along its length have been converted to grade-separated interchanges. This results in high off-ramp utilization along SR99. Reliance on these off-ramps becomes problematic because they are relatively short and end with signals. These short ramps cannot hold many vehicles attempting to exit SR99, and if signal controllers at their terminus are set to relative long cycles, then we see periodic queue spillback into the expressway facility. The simulation model accurately reacts by severely crimping expressway carrying capacity when this condition occurs, resulting in backups in the SR99 expressway mainline. These periodic breakdown become persistent breakdown conditions when travel demand is high or under poor weather scenarios.

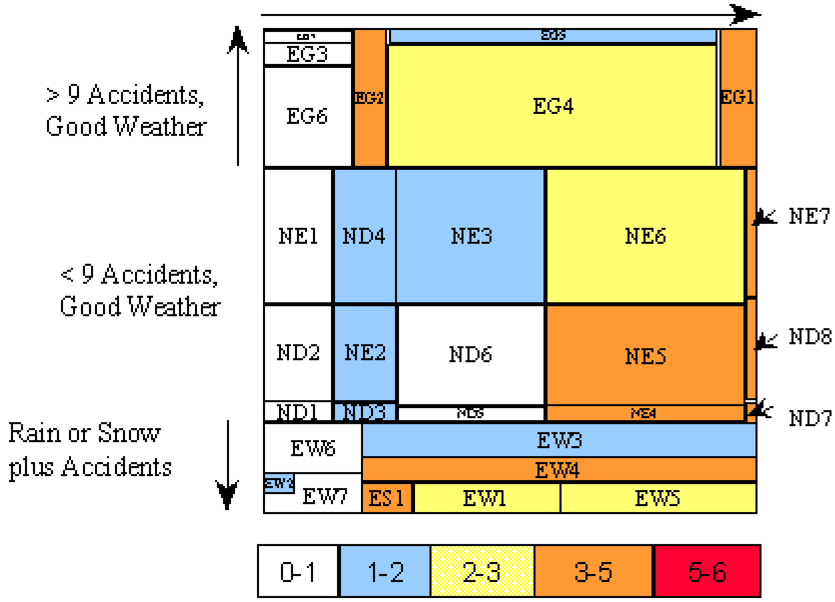

Figure ES-6. Minutes of Delay Reduction: SOV + ITS vs. SOV

ATMS control as implemented in the SOV + ITS alternative helps to mitigate the impact of SR99 breakdown. In these cases the adaptive signal control system senses the queue buildup on the off-ramp and extends the ramp's green phase to flush vehicles off of the ramp/mainline and onto the arterial grid. The minor arterials see worsened service as the green phase for the off-ramp is progressively extended, but from a system perspective, keeping the SR99 mainline from breaking down is the most critical factor in reducing overall delay.

Similar results are provided in section 9.0 of the report for the comparison of the ITS Rich alternative to the Baseline, and the comparison of the HOV/Busway alternative with and without ITS to the Baseline. Also, in this section detailed results for all the MOE's are provided.

Observations on Alternatives Analysis Results

Key attributes of how an alternative might perform under expected travel conditions (such as the brittleness of the SOV alternative) could not have been predicted using only the regional model. Under normal conditions, the SOV alternative appears to have ample capacity at the SR99 interchanges. Since the regional model does not consider the periodic queue growth from traffic signals or spillback, a breakdown along SR99 does not occur. Clearly there are non-ITS solutions to the off-ramp problem: wider right of way at interchanges, revised interchange design, more interchanges, etc. However, it is likely that *these issues would not have been addressed until the engineering design phase of the alternative*. Knowing at the planning phase that the new SOV facility had this performance characteristic is a critical element to either tailoring the alternative definition or in the comparison of alternatives.

Potential Next Steps

The goal of the study was to develop and demonstrate the use of a new methodology for incorporating ITS into the transportation planning process. We feel that the methodology developed (PRUEVIIN) and the alternatives-analysis results contained in this report met this goal. The ITS cost and benefit results provided herein are a significant addition to the store of ITS knowledge. The PRUEVIIN methodology and the study results have been presented at several conferences and at the *Workshop on Methods to Model ITS Impacts* during the 78th Annual Transportation Research Board (TRB) Meeting.

There are several next steps for further use of this report and analyses using this methodology, each of which is discussed below. These include conversion of this report into more of a user-guidance document, development of a training course to teach the methodology, and the direct application of the methodology to an ongoing MIS.

This report documents a three-year analytical effort. It provides richly detailed documentation on methodology, and ITS cost and benefit results. However, it has some limitations. The document is written as a report on the results of a study effort. It is not written in the form of a users manual, providing comprehensive, ordered, guidance to a transportation planner who is interested in the implementation of this methodology to achieve similar results in his/her region. In addition this process was implemented in only one location (Seattle, Washington), and with only one planning model (EMME/2) and one simulation model (INTEGRATION 1.5). The set of ITS Rich technologies was also fixed for the study. In addition, this study was done with the knowledge of and cooperation of PSRC, the local Metropolitan Planning Organization (MPO). They participated at the front-end of the study and reviewed the results at the end of the study. However, they were not involved in the actual execution of the study or in the refinement of the alternatives as the study progressed. The study is for a "shadow MIS," not an actual MIS. We followed the MIS approach in terms of alternatives development, definition and impact measures, but were not constrained by the need for public hearings and review of alternatives.

With these facts in mind, Mitretek recommends that the best way for transportation professionals to learn this methodology would be for them to receive some hands-on training. This could be achieved by having an organization that is knowledgeable in the PRUEVIIN methodology to act as technical advisor to actually add a sub-area simulation as described in this study to an ongoing MIS. This would accomplish several objectives including: the individual staff at the transportation agency would have first-hand experience with using the process, the process would be left in-place at the agency for further studies, and the training organization would then be in a good position to write a user-guidance document for the methodology. In addition, additional knowledge would be gained by applying this process in a new environment, i.e. different problem set, alternatives, and models.

An additional approach would be for Mitretek to work with the ITS JPO to develop one or more training courses for the process. Mitretek would develop and give the course for the first several iterations. This will allow us to refine and tailor the presentation material to the transportation professionals in the various transportation agencies. Afterwards the course would be turned over to a professional training organization for wider audience presentation.

1. Introduction

1.1 Study Background

As more Intelligent Transportation Systems (ITS) capabilities become ready for deployment, they will need to be integrated into the established transportation planning process. This process involves analysis of costs, benefits, and choices among competing projects within financial and other constraints. ITS components will in many cases be combined with more conventional transportation components as part of an alternative to address a specific transportation problem. Considering ITS in the transportation planning process raises many questions about how to select and evaluate ITS projects as an integral element of traditional transportation construction projects.

In addition, the current state-of-the-practice for transportation planning does not include well-developed tools or techniques for quantitatively assessing ITS benefits, because ITS itself is new, because operational aspects are important in assessing ITS benefits but are not traditionally considered in planning studies, and because ITS planning tools and methods are still evolving. Consequently, good analytic tools for assessing ITS costs and benefits are lacking and transportation planners may have less experience with ITS compared to other types of transportation improvements. In light of these considerations, any approach to study these issues would have to include:

Reviewing existing evaluation procedures and developing a quantitative investment analysis methodology for ITS for state or local use in transportation planning.

Developing case study-based estimates of relative costs and benefits of ITS versus conventional investments.

Identifying needs for improved methods project identification and evaluation.

To address these questions the Intelligent Transportation Systems (ITS) Joint Program Office (JPO) of the United States Department of Transportation (USDOT) tasked Mitretek Systems to investigate the incorporation of ITS into the transportation planning process. To accomplish this Mitretek initiated a two-phased study effort, conducted over two years. An important goal of the ITS JPO is the consideration of ITS by transportation planners. This study develops a methodology for public sector investment analysis to analyze ITS investments, and to develop case-study based estimates of relative benefits of ITS infrastructure investments versus conventional transportation investments. The secondary study objective was to identify improvements for the analytic tools and methods.

The analysis in phase 1 studied how ITS leaders planned and deployed, exploring their methods and processes. Phase 1 reviewed the current process of prioritizing projects, examining how different regional transportation problems and needs are addressed in the Transportation Improvement Program (TIP) approval process. The analysis in phase 2 focused on the evaluation of alternative solutions to a given transportation problem. These alternatives could be incorporated, depending upon evaluation results, into the Transportation Plan and eventually the TIP. An example of this type of analysis is the approach taken when conducting a Major Investment Study (MIS). This second type of analysis is the focus of this report. Mitretek initiated phase 1 of the study in 1995 on how ITS projects were evaluated and included in a major transportation improvement program (TIP).to address ITS deployment. For this phase existing practices in two regions, Houston, TX and Seattle, WA were studied. Phase 1 focused on the prioritization process in Houston and Seattle, and identified several factors in the project evaluation process. Briefly, the conclusions reached include:

1. Planners should consider additional qualitative and quantitative factors along with traditional ones, when evaluating ITS projects, beyond those traditional factors typically found in a scoring process These additional qualitative factors include:
    a) ability to respond to and manage traffic incidents and changing traffic situations,
    b) ability to provide transportation system users with a new or improved level of service (including customer satisfaction)
    c) ability to support multiple uses for the transportation system or across different agencies, including the ability to provide planning data.
2. The additional quantitative factors that should be considered include:
    a) ability to generate cost savings (or revenue increases) to public transportation agencies.
3. ITS project funding sources should be considered, including funds allowed by federal rules and funds available from local and other sources. Planners should not artificially constrain ITS funding sources to specific, or narrow categories, such as CMAQ.

Phase 2 of the study started in July 1996, focused on the greater Seattle metropolitan region, and developed specific methodologies for the evaluation of ITS project alternatives in the context of an MIS. The results of this phase of the study are the focus of this report.

1.2 Use of Case Study Approach

Mitretek took the approach of conducting a case study rather than relying on a hypothetical transportation network. Specifically, we selected a sub-region or corridor in the Seattle area suitable for analysis. That is, a corridor where alternative solutions to a particular transportation problem could be developed, and where a variety of ITS strategies and traditional transportation improvements were applicable.

For illustration, if the problem to be addressed is congestion along an urban corridor, the list of alternative solutions might include “do-nothing”, construct a new road, add lanes to existing routes, provide HOV lanes, provide ramp metering, provide incident management systems, add bus or light rail service, as well as combinations of these listed capabilities. In this study ITS services were analyzed separately and in combination with conventional construction options.

Mitretek examined the alternative solutions for the Seattle study area, in close coordination with the transportation consulting firms Parsons Brinckerhoff Quade Douglas and CH2M Hill. The study team adapted and extended conventional transportation improvement modeling and impact analyses to be more sensitive to the impacts of ITS, and to provide for comparability of outcomes across the evaluated alternatives. The analysis methodology developed and its results were reviewed with Seattle region planning staffs during the study to assess the appropriateness and usefulness of the Mitretek approach.

1.3 Scope of This Study

This study covers: delimitation of the study area, identification of transportation problems, description of the alternatives considered, explanation of the specific analysis approaches, and examination of the results from applying these analysis approaches. We chose to evaluate several traditional transportation alternatives in the corridor, with and without ITS components. Simulation modeling and other analytical techniques were applied to these selected cases to quantify benefits and assess the alternatives against a common set of measures of effectiveness (MOEs).

The phase 2 Seattle case study assumed that an MIS was needed as part of the transportation planning process to assess specific alternatives to solve a specific transportation problem in the Seattle area. This study examines a corridor, rather than a single, traditional project. The geographic scale of the Seattle case study corridor is a sub-area of the Seattle transportation network larger than that associated with a single transportation feature (e.g., an interstate segment), but smaller than an entire urban region. This geographic scale parallels that prescribed in MIS guidance and allows for a variety of transportation alternatives to be considered and evaluated, without being so broad as to dilute the evaluation process with an intractable number of potential alternatives.

The range of transportation improvement alternatives considered in this study included construction of new roads or lane miles, conventional signal installations, transit improvements, Transportation Demand Management Systems, Advanced Traveler Information Systems, Advanced Traffic Management Systems, and Advanced Public Transportation Systems. The study did not consider Automated Highway Systems or Commercial Vehicle Operations.

The analysis tools required for ITS evaluation in the case study were compared to conventional transportation improvement planning and regional planning tools. Recommendations are made for adoption of the analysis methodologies outlined in this report in the transportation planning process and evaluation issues requiring further work are also identified. The results of specific Seattle-based simulation runs are documented in this final phase 2 report.

It is important to contrast this study with another recent work. "The Interim Handbook on ITS Within the Transportation Planning Process" (FHWA, Transcore, August 1997), a general reference, considers ITS as part of the ongoing planning, implementation, and operations activities for agencies involved in planning for and providing transportation systems and services. The Interim Handbook provides a thorough discussion on how ITS should be considered in transportation plans and improvement programs, corridor/subarea studies, and regional or statewide ITS strategic assessments. The handbook also provides reference sections on cost estimating and sketch planning techniques to evaluate ITS strategies. Except for the section on corridor/subarea studies, these topics are not the focus of this report. The work presented here goes beyond the material presented in the handbook by developing and demonstrating a structured problem identification and alternative definition process and a specific evaluation methodology for including ITS in a corridor study.

1.4 Report Organization

This report is organized into three primary parts. In the first primary part, three sections provide background information that frames the work done for the Seattle case study. Section 1 provides background information on the study. Section 2 discusses the planning context for corridor/sub-area studies and the evaluation techniques typically used in such studies. Section 3 discusses the challenges involved with including ITS alternatives in these studies.

In the second primary part of the report are the specifics of the Seattle case study. Section 4 presents the characteristics and objectives of the case study as well as an overview of the approach. Section 5 discusses the selection of the study corridor and the corresponding transportation needs and problems addressed. The set of transportation alternatives defined and evaluated in the case study are presented in Section 6. The analysis framework and approach to evaluating the alternatives is covered in Section 7. Section 8 documents the procedures and results of the process to validate the models employed in the case study. Section 9 presents the results from the analysis of the alternatives and Section 10 presents lessons learned.

2. Corridor Planning Studies

2.1 Introduction

This section presents corridor or sub-area planning studies in the context of the overall transportation planning process and discusses the evaluation methods typically used in such studies (for the remainder of this report, "corridor studies" refers to both corridor and sub-area studies). The inclusion of ITS strategies is facilitated when considered within the framework and characteristics of each different type of planning study. For any particular study, the level of detail and effort involved in defining and evaluating ITS alternatives should be consistent with that involved in defining and evaluating more traditional transportation alternatives. This section will help to frame the discussion of evaluation challenges in the next section and the specific procedures used in Seattle case study, presented in Sections 4 through 10.

"A Guide to Metropolitan Transportation Planning Under ISTEA" (U.S. DOT 1995) presents and discusses the general planning framework that ITS needs to be considered within. Corridor/sub-area planning studies, which is the focus of this report, are considered to be part the long range planning process, leading to transportation plan adoption. Where the planning process identifies a corridor or sub-area that suggests the possible need for a major investment using Federal funds, then a Major Investment Study (MIS) may be required. Figure 2-1 shows MIS within the Transportation Planning Process.

MIS and its requirements were defined as part of joint FHWA/FTA Final Rule on Statewide and Metropolitan Planning (FHWA & FTA, Federal Register, 10/28/93) to implement the concepts of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). MIS provides a common multi-modal evaluation process to follow[1] and a tool for making better more informed choices over major transportation decisions facing an urban area. The transportation planning process in general examines regional travel patterns, needs/problems, and potential solutions at a systems level usually at relatively broad detail. Where corridor major investments are contemplated, however, there is a need to provide a more focused finer analysis than possible at the regional level of analysis to fully understand the corridor's problems and tradeoffs among it's alternatives. MIS provides the focused examination of the causes of the corridor's mobility needs and related problems and the impacts/costs of solution alternatives. As such, "The MIS is an integral part of the metropolitan area's long-range

[1] Previously the FHWA and FTA both had separate requirements for a project requiring a major investment to follow. Which was relevant depended on the project's major mode (transit vs. highway) and funding source.

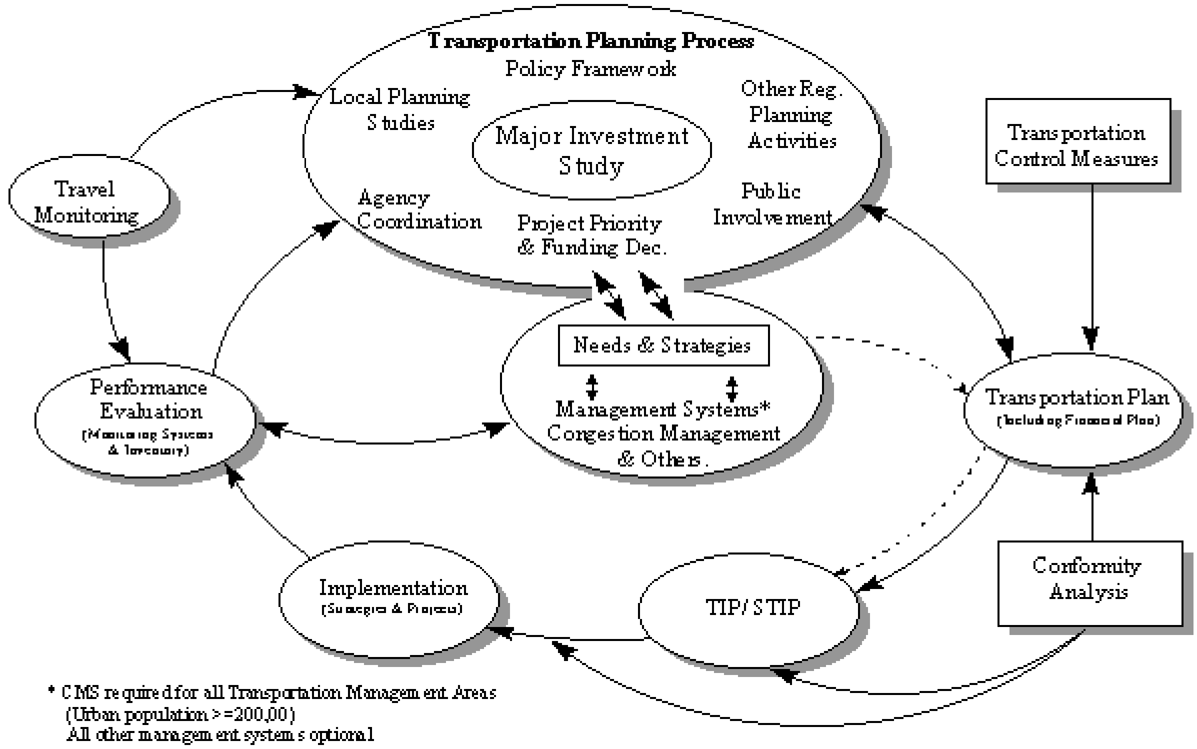

Figure 2-1. MIS and the Transportation Planning Process

planning process that is designed to provide decision makers with better and more complete information on the options available for addressing identified transportation problems before investment decisions are made." (National Transit Institute, Parsons Brinckerhoff Inc., 1996, p. 1-1).

An MIS is required any time the metropolitan planning process considers alternatives that may be characterized as:

> a high-type highway or transit improvement of substantial cost that is expected to have a significant effect on capacity, traffic flow, level of service, or mode share at the transportation corridor or sub-area scale (Statewide Planning: Metropolitan Planning: Final Rule, FHWA & FTA, Federal Register, 10/28/93), and where Federal funds are potentially involved.

Examples of a "major investment" include the construction of additional lanes, a new facility, or a new light-rail line.

2.2 Corridor Planning Study Components

As also shown in Figure 2-1 the transportation planning process is cyclical and continuous.

Each of the major components/products focuses on a different aspect, set of concerns, and level of decisions in the overall transportation planning process. Consequently, each component may require varying levels of detail, information, time horizons, or analysis turn around to meet its needs. For example, as already stated, MIS studies provide a detailed evaluation of the transportation needs and major investment options in a corridor or subarea. They look at a long range (20 year) time horizon, and may take several years to complete. How MIS relates to each of the components is briefly discussed below. While the major focus of this study was to examine ITS within the MIS process, ITS may play an important role at each point in the planning cycle. At each point the issues and concerns of incorporating ITS may also differ. Some of these issues are also highlighted below.

The Transportation plan sets the long term agenda and direction of the transportation system in a region. Since it must be financially constrained it reflects the funding priorities and tradeoffs between projects and corridors. The plan typically focuses at a regional scale examining projects of "regional significance" and the major transportation policy directions of the region. The transportation plan's inputs include local planning studies and other regional planning activities (land use, environmental, growth, etc.), and the results of special efforts such as MIS studies, and Congestion Management System (CMS) plans. Key elements in developing the transportation plan also include the policy framework and goals of the region, inter-agency coordination and public involvement to determine project priorities and funding decisions. The adopted constrained long range plan plays a critical role in MIS studies since it is used to establish the Do Nothing Alternative, especially outside the corridor under investigation. Equally important to MIS studies considering ITS is the determination of the core ITS "center systems" that serve across corridors or even the region as a whole (i.e. the ITS regional architecture/framework). Once an MIS study is carried out the transportation plan must be amended to include its preferred plan and the new plan shown to conform to the State Implementation Plan (SIP) for air quality (see conformity analysis below). Thus, the transportation plan and MIS studies are codependent, both feeding information to each other.

Congestion Management Systems (CMS) are required for all Transportation Management Areas (TMAs)[2] and are optional in smaller areas. The CMS principles are "designed to emphasize effective management of existing facilities through use of travel demand and operational management strategies", and analyze the entire transportation system's performance not the performance of any one specific mode (FHWA & FTA, 1995). CMS have two major components. The first is the definition of system performance measures, their measurement, and continued monitoring. The second is the identification and implementation of strategies that provide the most efficient and effective use of existing and future transportation facilities. Thus, CMS are operations oriented. Though they have a future component they are also typically geared towards the near term, collecting data on and evaluating today's problems and evaluating strategies implemented to solve them.

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[2] TMAs are defined as urbanized areas with population greater than 200,000.

ITS can play a major role in CMS plans, both in data collection and in management strategies. In fact, ITS technologies are one of the five key categories explicitly listed in the FHWA/FTA Management and Monitoring Systems: Final Rule[3] (FHWA & FTA, Federal Register, 12/19/96).

MIS studies and the CMS plan also have a reciprocal relationship in their support of each other and the Transportation plan (See Congestion Management Newsletter, V. 1#3, FHWA, March, 1995). CMS helps define the needs and problems in a corridor that trigger the requirement for an MIS. More important, the CMS may help understand the causes of a corridor's transportation needs and congestion and therefore help frame the MIS problem statement. MIS on the other hand, can be used to examine alternatives and provide information helpful for assessing strategies to reduce congestion in the CMS. In air quality non-attainment areas both can assist in the required analyses to justify the need for proposed Single Occupant Vehicle (SOV) capacity increases.

The shorter term **Transportation Improvement Program (TIP)** provides the project prioritization and selection for the next three years (and optionally longer). It must be updated every two years. All project elements that will be initiated (begin construction and/or operation) within the TIP time frame and receive Federal funds must be included in the TIP. Projects in the TIP must be consistent with the transportation plan and include both details and programming for the regionally significant projects specifically called out in the plan, and non-regionally significant projects. The specific projects are defined, prioritized, and programmed for project development/implementation in the TIP process. The preferred alternative from an MIS is first reflected in the transportation plan. Then as the implementation of the alternative nears and begins its specific elements (traditional and ITS) must also be prioritized and programmed in the TIP. For a discussion of issues associated with incorporating ITS elements in the TIP project prioritization and programming process please refer to "Incorporating ITS into the Transportation Planning: Phase I Final Report" (Mitretek Systems, September 1997).

Environmental analyses include the State Implementation Plan (SIP) **Conformity Analysis,** and **National Environmental Policy Act (NEPA) process.** An MIS preferred alternative must be part of SIP conforming transportation plan for final approval. This means that a conformity analysis is usually required as the plan is updated to include the MIS results. The MIS process also provides a bridge to the NEPA process and must be carried out with careful consideration of the NEPA Environmental Impact Statement requirements[4].

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[3] Growth management and congestion pricing; traffic operational improvements; public transportation improvements; ITS technologies; and where necessary, additional system capacity.

[4] Either as a pre-cursor study prior to the NEPA documentation process (Option 1), or in tandem with the NEPA process (Option 2). For more information, refer to the Desk Reference Manual for MIS (National Transit Institute, Parsons Brinckerhoff Inc., 1996).

One issue that cuts across all phases of the above transportation planning process is the requirement to include only regionally significant, and/or federally funded projects. Locally funded projects with localized impacts may, or may not be documented as part of the federally required plans and documents. Consequently, many ITS and other operational projects have often not been included historically within the planning process. These include such improvements, as traffic signal upgrades, transit vehicle and other operational improvements, information systems, etc. How these off plan ITS and other improvements can be used to enhance alternatives in MIS and the system in general must be considered in the process if the full benefits of the ITS are to be reflected in a region's transportation plans and MIS efforts (see Mitretek, September 1997).

For more information on the overall process, ITS in the planning process, and non ITS related MIS details, refer to: "A Guide to Metropolitan Transportation Planning Under ISTEA" (FHWA & FTA, 1995); the Desk Reference Manual for MIS (National Transit Institute, Parsons Brinckerhoff Inc., 1996); and "Integrating Intelligent Transportation Systems within the Planning Process: An Interim Handbook" (FHWA, TransCore , August 1997).

2.3 Supporting Analysis

As discussed above, transportation planning is a continuous process with many decision points and is intended to provide a sound environment for analyzing transportation investment and policy alternatives and allocating transportation resources in a way that best addresses the transportation needs and problems facing an area. To support the decisions that must be made within the planning process, a wide variety of analytical techniques are used to provide estimates of the potential transportation impacts and costs of alternative investment strategies. At each level of the process the appropriate analysis techniques differ in level of detail and effort required to use them (translating to the amount of resources required) depends on a variety of factors including:

- the scale and level of anticipated impacts of the decision (both geographic and costs)
- the number of alternatives
- the project time frame
- the decision time frame
- the phase in the project development cycle (concept, scoping, development, design, construction, operation).

Usually, less rigorous evaluation approaches are sufficient to support early, screening-type decisions (occurring early in the planning process) and more rigorous and detailed approaches and tools are desirable to support decisions with higher investment implications (either later in the planning process or for establishing a preferred alternative that will be considered a major investment to be folded into the transportation plan). For example, regional analyses using "planning model network tools" and representing "regionally significant" projects are usually used to support the transportation plan and its conformity analysis. Due to the long time-frame of the transportation plan these analysis techniques attempt to capture the major changes in travel patterns and location decisions, introduced by major options in a region's future transportation system. As already stated, MIS analyses perform much a much more detailed examination of the impacts of alternative decisions within a corridor or sub-area. Their goal is to distinguish between the options to solve the corridor's need and problems statement, and assist decision makers in making a preferred choice. The level of investment decision, issues to be resolved, time schedule of a typical MIS usually allow fairly complex and detailed analysis procedures to be carried out. On the other hand, TIP and CMS analyses must select from a wide variety of projects and strategies, usually with a short analysis and decision time period. Sketch techniques that can be used to evaluate a number of alternatives quickly capturing localized effects and pivoting off of current (near term) conditions often suffice for these analyses.

A thorough discussion of all possible analytical approaches is not covered here. However, it is important to keep in mind the general types of techniques that apply. Analytical techniques and tools used in planning studies generally fall into these major categories (presented in general order of increasing complexity and data requirements):

> Qualitative assessment - relies on previous experience or expert judgment. These assessments are used everyday by project managers in selecting the candidate projects for further investigation, and making quick evaluations.
>
> Sketch planning techniques - generally straight-forward, parametric, or spreadsheet analyses that provide an approximation of potential impacts (may rely on historical data). These are often used when there is a large number of options to evaluate, the impacts are localized, or the individual projects relatively small. They are also used to screen an initial set of alternatives to likely candidates for further study.
>
> Planning models - models that forecast average (steady-state) travel and transportation demand and associated impacts over a given time period (daily, peak period, etc.), typically using some variant of the four-step method (trip generation, trip distribution, mode split, and assignment) with inputs from demographic and land-use projections. These tools are used to capture long range impacts of transportation system changes at the regional level. They are also often used with refinements and additional detail for MIS and other more focused studies.
>
> Simulation models - models traffic flow and interaction with the network in more detail (e.g., signals are explicitly modeled), allows for time-variant travel demand and introduction of incidents or other non-recurring traffic events. Simulation tools may provide key inputs to a project's design and/or operation that cannot be addressed using other tools.

This study focuses on the analysis requirements of a corridor/sub-area planning study. In practice, many of these studies are likely to be Major Investment Studies (MIS). For this reason, MIS requirements and guidance provide the benchmark for the analytic approach pursued in the case study. Although the level of analytical detail varies based on the decision to be made and the ability to distinguish between options, network-based planning models are typically used to forecast the transportation demand and impacts under the different alternatives evaluated in an MIS. An MIS will often include enhancements in network coding and analysis detail, not used in the regional level transportation plan analysis. This level of detail enables some of the differences and implications of alternative investment strategies to be brought out and discussed by the decision makers, which is important when the costs and impacts of the potential investment are significant. These models usually incorporate the traditional four-step method (trip generation, trip distribution, mode split, and assignment) in the analysis framework. As will be discussed in detail in Section 7, this study adds a simulation model in order to incorporate ITS strategies into the analysis at a level of detail required to fully capture the potential benefits of ITS services and to discriminate between alternatives.

3. ITS Considerations in Corridor Planning Studies

Section 2 examined the context for corridor planning studies within the overall planning process. This section focuses on the issues associated with incorporating ITS into these studies and highlights the Major Investment Study principles used to guide the development of the Seattle area case study selected for the project. Many of the issues are discussed in more detail in the sections of the report which describe the details of the case study.

ITS strategies to date have generally not been incorporated into current MIS processes[5]. This is due both to basic differences between ITS and traditional corridor improvements and to a lack of familiarity in many areas with the potential of ITS.

Traditional solutions to transportation problems and the analyses that support them have tended to focus on long term facility/service improvements to meet capacity constraints arising during a typical day. Because they focus on the peak congestion conditions and major infrastructure investments these solutions and analyses have typically minimized or not addressed:

> The impact of operational strategies and improvements. Current operations are usually assumed.
>
> The impact of non-recurrent demands, incidents, or other unusual occurrences. Major facilities are usually not designed to accommodate unusual demands, or events. Analyses focus on meeting average conditions.
>
> Lack of information about the system, its current condition and the choices a traveler may have in making their trip. Traditional analyses assume equilibrium conditions where travelers fully know their choices, their travel times, costs, and other characteristics.

However, as has recently been reported, non-recurrent accidents and other incidents are major contributors to urban congestion. One source estimated that up to 60% of congestion can be attributed to non-recurrent delays (Lindley 1986). Not including these effects in an analysis can consequently distort the impacts of traditional alternatives and overlook the benefits of ITS.

ITS strategies on the other hand use technology, communications, and a “systems” perspective to help adjust the system to conditions as they are realized on a day-to-day basis or evolve over a longer time frame. ITS Strategies are:

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5 If they are included at all, it has usually simply been part of the Do Nothing or TSM base alternatives with little substantive analysis or refinement to support each build option.

Operations Oriented. ITS strategies such as coordinated signal systems, ramp meters, and automated toll readers directly impact the operation of the transportation system by reducing delays and adjusting the performance of the system as conditions change. They also provide the ability to manage the multi-modal components as a system instead of separate units. Traditional planning analysis efforts typically assume a steady state set of conditions over the analysis period and are consequently insensitive to changes in operations. More and more, however, it is being recognized that managing system-wide or subsystem operations may offer very cost-effective mobility improvements within a corridor comparable to traditional capacity expansion. Recognizing this, TEA-21 incorporates operational concerns into its list major planning factors that must be considered as part of a region's planning process.

Aimed at Events and Unusual Conditions. Non-recurrent incidents, special events, and weather conditions all add up to become significant factors in the delay and congestion found in our transportation systems. ITS strategies such as incident and emergency management systems, route guidance, highway advisory radio, and variable message signs, all help the system respond to these non-recurrent conditions. Yet, a typical analysis does not include incident occurrences in its validation of base conditions, and is based upon average, expected, conditions under "normal" conditions (i.e. no accidents, bad weather, or unusual conditions). It consequently cannot address the impact of incidents on the system or an alternative's ability to respond to them.

Information Oriented. ITS strategies focus on reducing the difference between a traveler's expectations of the transportation network while they are traveling (congestion, delay, and cost along each route choice) and the actual conditions they will experience when they take their trip. Traveler information systems provide more up-to-date information on accident locations, transit routes to take, cost, and other characteristics of travel options. Route guidance systems help the system operate more efficiently by routing traffic away from accidents and other occurrences of delay. As travelers and the system operators have better, more up-to-date information, significant improvements to an individual's choice can occur, especially under special circumstances. Typical analysis techniques presume that over the long run, travelers will "know" their options and make "informed" choices.

Connected Systems. ITS services are a mixture of localized elements and area-wide systems/intelligence. As communications and system intelligence/response is introduced through ITS, individual ITS elements no longer function or can be analyzed independently. Thus, the metered rate (capacity) of a ramp meter may depend upon the traffic volumes at downstream locations along a freeway, sometimes miles away.

Each of these characteristics makes ITS strategies difficult to address using traditional MIS analysis methods and measures of effectiveness and create implications throughout the MIS process. An overview of the MIS process in general and some of the issues incorporating ITS raises is provided next. This is followed by an examination of ITS in each of the major phases of the MIS process.

3.1 Overview of MIS Process

Figure 3-1 shows the major phases of a Major Investment Study (National Transit Institute, Parsons Brinckerhoff Inc., 1996). Once the need for an MIS in a corridor is identified[6] the major steps in a typical MIS process include:

Initiation, Problem Definition, and Development of Goals and Objectives (and their Measures) - the description of corridor problems and mobility needs is refined and the corridor goals and objectives that will drive the evaluation process are articulated.

Development of Initial Set of Alternatives.

Screening and Decision on Detailed Set of Alternatives.

Analysis, Refinement and Evaluation of the Alternatives - includes detailed definition of alternatives and service/operations planning, estimation of capital and operations and maintenance costs, transportation and traffic impacts analysis, land use evaluation, environmental impact analysis, and financial analysis.

Selection of a Preferred Investment Strategy.

Public and Agency Involvement - Throughout the MIS, and in particular prior to key decision points, the public is given the opportunity to comment and provide feedback on the study recommendations and the process being followed. MIS also requires close coordination between and within agencies and jurisdictions. State DOT, transit agencies, metropolitan planning organizations, and local jurisdictions all have a say in the scope of the study, range of alternatives, evaluation criteria, etc. Equally important with the introduction of ITS in the process is the need for planners and operations professionals within each agency to coordinate closely with each other where traditionally they have not. While critical to the success of the MIS process, public and agency involvement/collaboration is beyond the scope of the case study.

In order to be fully incorporated into the MIS framework, ITS strategies must be explicitly treated as an integral part of the steps and phases highlighted above. An important point that needs to be stressed up front is that ITS is an umbrella name for a suite of alternative strategies, rather than a single monolithic alternative, and includes a variety of traffic management strategies, transit applications, incident and emergency management services, and traveler information systems. The implication is that a variety of different ITS strategies

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[6] Through the CMS, local planning, or other elements in the transportation planning process. See Section 2.

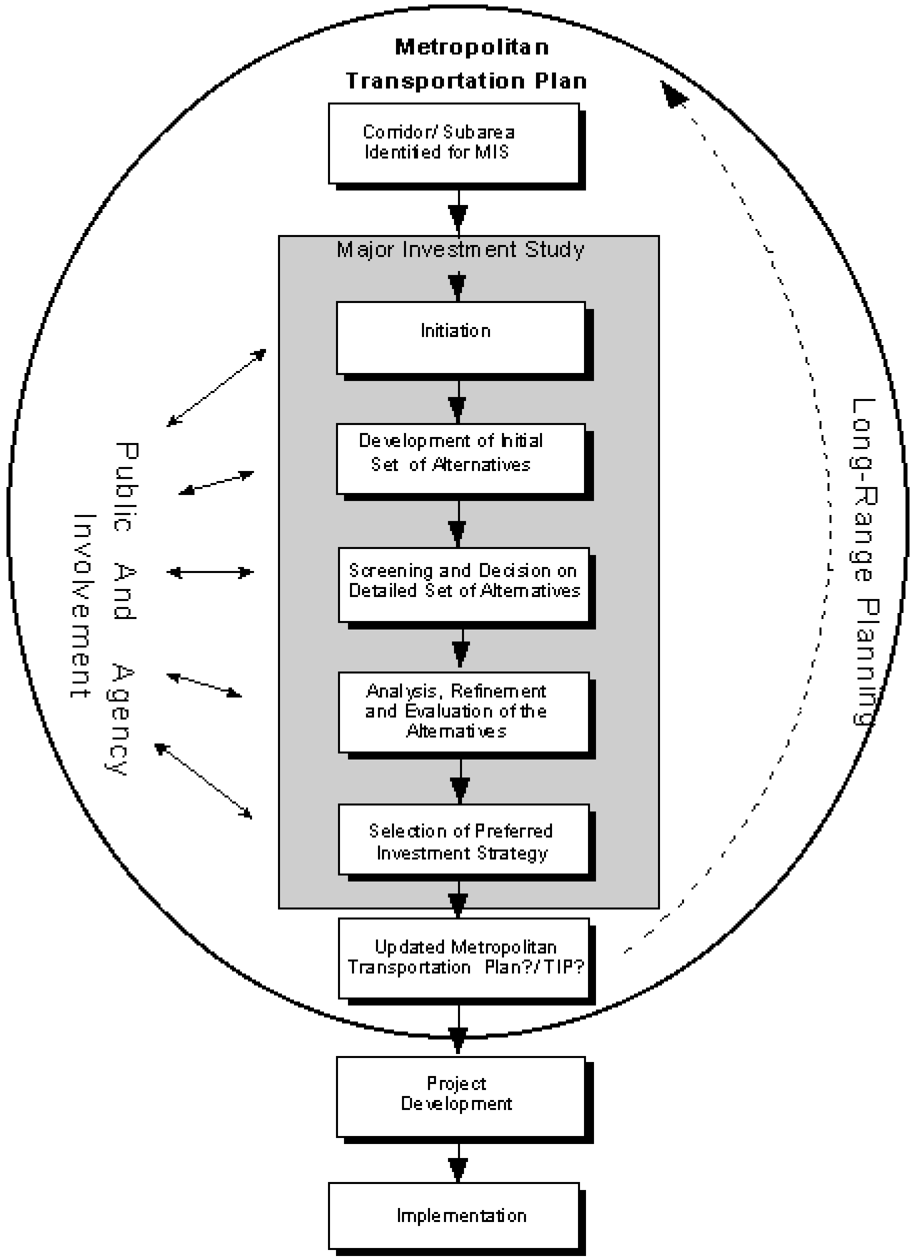

Figure 3-1. Major Phases of a Major Investment Study

can be included in a variety of ways in an MIS process. These different strategies may have very different evaluation requirements, as will be discussed later in the report.

Although the study team did not perform a thorough investigation of all previous and ongoing MIS efforts, anecdotal evidence suggests MIS studies are now just beginning to consider ITS elements in their study designs. Previous consideration of ITS in MIS alternatives has been somewhat limited ranging from none at all to inclusion of ITS in a TSM or separate enhancement package[7]. It appears that little has been done on how to how to enhance and maximize the efficiency of traditional build options. By including ITS in the baseline or in common TSM alternatives, some of the MIS efforts may be avoiding the need for thorough evaluation of ITS, since the ITS elements appear in all of the build alternatives and therefore do not become a discriminator. Further research would be needed to determine the analytical techniques used to evaluate the effects of ITS in all of these efforts.

The next three subsections discuss the challenges and implications of including ITS in three of the key steps of the MIS process: initiation and problem definition, alternative definition, and analysis.

3.2 Initiation, Problem Definition and Measures of Effectiveness

Initiation of the MIS includes the definition of problems and needs, identifying agency participants and stakeholder groups, development of the work plan, and definition of goals, objectives, and measures of effectiveness (MOE'S). Critical to incorporating ITS elements within an MIS process is developing needs and problem statements that reflect the underlying causes of the problems within the corridor and are not geared towards traditional capacity expansion alternatives. Equally important is the need to define goals, objectives, and MOE's that are sensitive to ITS and other operational improvements for the corridor or sub-area under study. Project initiation is also where it is important to identify stakeholders and key agency participants and bring them into the MIS collaborative process. Transportation planners and operations specialists need to be brought together from the beginning to help identify the corridor issues, and how ITS can be integrated into each alternative to help address them.

The problem statement and understanding of the causes of the corridor's transportation needs can be considered, in many ways, as one of the most important factors for a successful MIS process. The problem statement helps define the range of reasonable alternatives to consider, the appropriate measures of evaluation, and even the methods and level of detail required for

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7 Examples of pioneering MIS efforts that have addressed ITS in some fashion include the Capital Beltway MIS in Northern Virginia (1995) and the IH 35 MIS in Austin Texas (1996). The I 435 study of a major river crossing in Kansas City (1996, ongoing); and the I-64 MIS in Virginia from Richmond to Virginia Beach (1997, ongoing).

analysis. It is very important that the underlying causal problems of the corridor be identified, and not simply the symptoms. For example, simply stating that the corridor's problem is "Congestion" may predispose the MIS towards infra-structure and capacity expansion alternatives. On the other hand identifying the causes of congestion as high accident locations, excessive access and egress on major arterials, and/or excessive queuing and spill over at key intersections can all point to the potential benefits ITS and other operational improvements. More important, if these are the causes of the congestion then capacity expansion may not meet the corridor's needs. Problem statements that focus solely on average (peak period) needs for capacity improvements will not lend themselves as easily to ITS solutions as those that consider the impact of incidents, variability of conditions, and operational inefficiencies in the study area.

This stage of the MIS also determines the evaluation requirements for the study, since the analysis tools and techniques must be able to estimate changes in the various measures that have been identified. Also it is the combination of measures and potential alternatives that determine what methods must be developed and used to forecast travel and other impacts for each alternative. One issue is the lack of sensitivity of the MOE's used in typical corridor studies to ITS strategies and other operational improvements that impact the reliability of service, information about the system and response to non-recurrent incidents. It is very important, therefore, to provide additional measures on the variability of the system if the impacts ITS and other strategies that focus on the operation of the system are to be analyzed in a balanced way with traditional improvements. Measures such as the standard deviation of expected arrival time, recurrent delay, incident delay, and lost opportunity time (difference between the path and mode chosen, and the best choice that could be made if information was available on all options) all can be used to capture to dimensions of a corridor's problem that ITS may help solve. Further discussion of the specific measures used in the case study is provided in Section 7.

Last, while the case study focused on development of analytic methods for MIS, equally important is the collaborative nature of MIS and the participation of both operations and planning experts. The need for bringing operations into all aspects of transportation planning is becoming recognized and has been identified as a key factor in the future national transportation policies and programs. Operations brings a different perspective to a corridor's needs, problems and potential solutions that is critical if ITS is to be fully integrated into the MIS.

3.3 Alternative Definition Issues

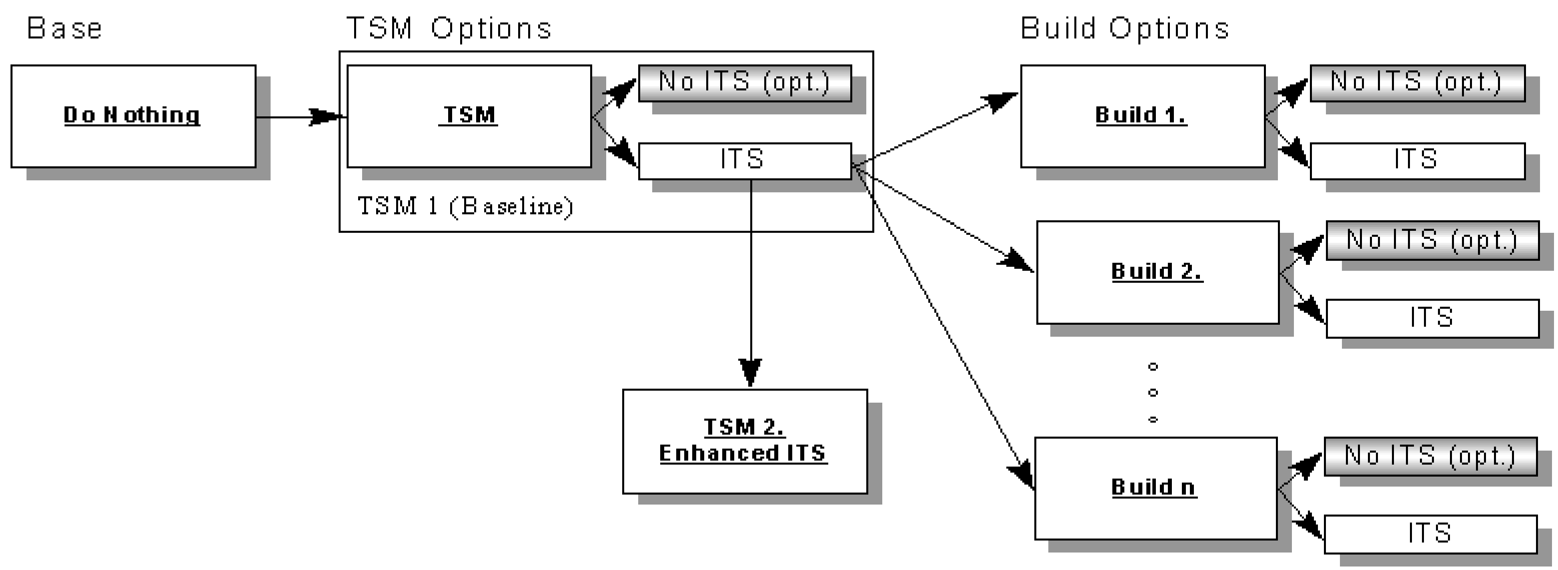
The definition of the alternatives to evaluate, and ultimately choose a preferred option from, is at the heart of the major investment study process. These include (National Transit Institute, Parsons Brinckerhoff Inc., 1996):

Do-Nothing: The Do-Nothing alternative is required by the National Environmental Policy Act (NEPA) as a baseline for estimating environmental impacts. It is defined to include those transportation facilities and services in the corridor that are likely to exist in the forecast year as well as "any improvements in other corridors that are elements of the financially constrained long range plan". All of the Do-Nothing elements must also be part of each of the other alternatives (National Transit Institute, Parsons Brinckerhoff Inc., 1996, p. 6-12). Cost effectiveness comparisons of the build alternatives with the Do-Nothing have also recently been added as part of the FTA new start criteria.

Transportation System Management: " The set of alternatives must also include a TSM alternative that represent a viable, low-cost approach to improving conditions in the corridor" (National Transit Institute, Parsons Brinckerhoff Inc., 1996, p. 6-8). The TSM alternative should represent the "best" that can realistically be done without major new physical capacity improvements. It emphasizes both small physical improvements and *operational efficiencies* such as those introduced by ITS services**.** More than one TSM alternative may be defined for a MIS analysis. All elements of the official TSM alternative, however, must also be part of the build options.

Build Options: The build options represent the reasonable major investment options for solving the MIS problem statement for the corridor which may lead to a locally preferred alternative. Each build option should be derived from the TSM alternative. "…Major new facilities are incorporated into the TSM alternative, and adjustments are made to integrate the TSM and major investment components (National Transit Institute, Parsons Brinckerhoff Inc., 1996, p. 6-15). A refined operating policy should also be developed for each build option which may include "…. ITS treatments, signalization strategies, occupancy requirements for HOV lanes, tolls, congestion pricing and reversible lanes…service frequency, integration of guideway and feeder services, fare levels, and fare structure." (National Transit Institute, Parsons Brinckerhoff Inc., 1996, p. 6-15).

ITS elements may exist in each of the above options. Where they are defined, and how, may have significant influence on the results of the analysis. As with traditional elements, ITS elements in the alternatives should develop from the Do-Nothing, to the TSM, to the build options with each level including the elements of the previous option. Figure 3-2 depicts this evolution. The systemwide characteristics of many ITS services, however, create issues on how to position ITS within a corridor study. Whether a service should be defined in the Do-Nothing, TSM, or build options also hinges on previous ITS investments and future plans in the region and the congestion management strategies found in the CMS plan (where applicable). These issues are discussed below.



ITS in Do Nothing
- Existing + Committed
- TIP
- CMS Plan

TSM 1: Base Level ITS
- Regional elements in LRP
- Expected elements in Corridor that will exist in all build options

TSM 2: Enhanced ITS
- More advanced ITS services
- High market penetration
- Private sector partnerships

ITS with Build Options
- ITS refined for each option
- Corridor ITS improvements

Figure 3-2. ITS and MIS Alternatives

One of the main characteristics of ITS services is their "system" focus and nature. The National ITS Architecture defines nine types of operation centers around which ITS services operate (Traffic Management, Transit Management, Emergency Management, etc.) These center subsystems provide management, administration, and support functions for the transportation system as a whole. The center functions are centralized and may not be limited to any corridor and their benefits dispersed. ITS services also require a communications infrastructure and system to connect the transportation network to the transportation centers. The center functions and communications system must exist, or be included in the alternatives, to implement ITS services within a corridor. There may be substantial initial and startup costs associated with implementing these center systems. Because of the initial startup costs, it is desirable to place the regional center functions (and their costs) in the Do-Nothing or Baseline TSM options.

By themselves the individual ITS strategies and elements fall into the traditional TSM definition. They are relatively low cost with respect to most capacity and service major investments. They also, by themselves, do not typically provide additional base capacity improvements of the same scale as traditional build options. However, combining several ITS strategies into an efficient and coordinated management and information system can produce more significant benefits. ITS is also developing rapidly with many ITS services just emerging as viable options.

In addition to the mandatory TSM alternative, other TSM alternatives may be defined. As shown in Figure 3-2, two TSM options may be called for when incorporating ITS in the MIS process. The first forms the baseline TSM/ITS alternative upon which the build options are developed. It includes the ITS elements that one can be reasonably certain are feasible for implementation by the horizon year, and the regional ITS elements that may be found in the approved financially constrained long range plan. ITS elements in this alternative are also included and should make logical sense with each of the build options. ITS elements that may depend upon other forces outside the public sectors control, or those that are still in development may be inappropriate for the baseline TSM.

Often, an important role of an MIS is also to provide information on what *may* occur under more optimistic than expected conditions. The Enhanced ITS TSM option can be used to give decision makers key information on the potential of ITS services to solve the corridor's problems. In the Enhanced ITS option services can be included that depend upon emerging technologies, Information Service Provider delivery of services, and/or additional commitments by actors normally outside the MIS decision process. Therefore, this alternative can show the benefits of ITS based upon the assumptions that the less certain ITS elements come to pass.

Developing ITS for each of the build options should start with the ITS elements in the baseline TSM. Each build option should then be examined and services added to maximize its operations and the goals it is trying to achieve. Thus, an advanced traffic management and coordinated signal system may not be an appropriate addition (beyond the TSM) as part of a traditional fixed guideway transit alternative since it may reduce the level of transit ridership the alternative provides. As always, the marginal costs of any services added to a build option must also be included as part of the alternative analysis.

Two other aspects of ITS services may impact the definition of the ITS elements within the alternatives. First is the issue of estimating market penetration for ITS services that depend upon the purchase of communications devices or other equipment by the individuals using them. In a traditional MIS analysis, these purchases would be internalized by an independent market demand model relating the price of the service with its use. For example, transit ridership models incorporate the fare, or user price, into the demand estimation. Market demand models for personal information and route guidance equipment, on the other hand, are not available, or are just in their development stages. Consequently, separate levels of market penetration of these services may simply need to be assumed as part of the alternative definition. The second attribute is associated with assumptions regarding the private sector provision of ITS services such as ATIS. Alternatives defined under this premise should have documented assumptions regarding public and private sector roles and cost recovery mechanisms which will factor into the analysis of alternatives.

3.4 Analysis Issues

Traditional MIS processes have focused on facility/service improvements (as seen in the definition of major investments shown in Section 2) and on average conditions and demand. ITS strategies on the other hand aim at improving: (1) operations; (2) response to non-recurrent conditions; and (3) providing better information. ITS elements and strategies have the potential to significantly enhance the alternatives and solutions of MIS efforts. However, if they are to be properly considered on an equal basis with traditional improvements, new approaches, tools, and evaluation measures must be integrated into the MIS processes to capture their contributions to the alternatives performance.

ITS strategies such as coordinated signal systems, ramp meters, automated toll readers directly impact the operation of the transportation system by reducing delays (stops), and adjusting the performance of the system as conditions change. MIS analysis efforts typically assume a steady state set of conditions over the analysis period and are consequently insensitive to changes in operations. More and more, however, it is being recognized that managing operations can offer very cost-effective mobility improvements within a corridor. MIS studies are in fact supposed to serve for the analysis of demand reduction and operational management strategies as appropriate pursuant to the CMS requirements. (Statewide Planning: Metropolitan Planning: Final Rule, FHWA & FTA, Federal Register, 10/28/93).

Non-recurrent accidents, special events, weather conditions all add up to become significant factors in the delay and congestion found in transportation systems. ITS strategies such as incident and emergency management systems, traveler information, and dynamic route guidance can help the system respond to these non-recurrent conditions. Yet, a typical MIS does not include incident occurrences in its validation of base conditions, and since its analysis is based upon average (expected) conditions, does not address the impact of incidents on the system, or an alternatives ability to respond to them.

Last, ITS strategies focus on reducing the difference between what a traveler perceives as congestion, delay, cost, etc. of the transportation network while they are traveling and the actual conditions they will see when they take their trip. Traveler information systems provide more up-to-date information on accident locations, transit routes to take, cost, etc. Route guidance systems help the system operate more efficiently by routing traffic away from accidents and other occurrences of delay. As travelers and the system operators have better, more up-to-date information significant improvements to an individual's choice can occur, especially under special circumstances. MIS studies and analysis techniques generally presume that over the long run travelers will "know" their options and make informed choices. This presumption is appropriate for an "average day" but is not representative of knowledge under highly variable conditions.

To be able to address ITS strategies, the analysis approach used in an MIS should be sensitive to the issues discussed above. The specific analysis implications of including ITS in the areas of traffic and transportation impacts, cost analysis, financial analysis, and environmental impacts are discussed below.

3.4.1 Traffic and Transportation Impacts

The discussion above provides some insight into the data and analysis needs for capturing the transportation system performance effects of ITS strategies in a combined analysis with traditional transportation alternatives. Some of the key features that are required in the analysis framework include:

- Ability to model both traditional and ITS strategies
- Incorporation of data on incidents and other factors that induce variability in traffic conditions
- Ability to model the impact of non-recurring factors on the transportation system performance
- Ability to model the state and availability of real-time surveillance information
- Ability to model traveler response to real-time information on network conditions
- Ability to model the response of the transportation system to incidents or other changes from average, expected conditions
- Ability to model the operational efficiencies of ITS improvements under average, expected conditions
- Ability to assess the combined effects of ITS services implemented together

In order to evaluate ITS and traditional alternatives as separate or combined alternatives on the same playing field, an integrated analysis approach is required. However, the evaluation tools that are best suited for estimating ITS impacts (e.g., simulation models) may not be the same as those best suited for estimating the impacts of more traditional transportation capacity or service enhancements (e.g., regional planning models). Including more than one network model in the analysis framework then raises questions of how measures should be combined across tools and the consistency and feedback requirements between the network representations for different alternatives. Because not all ITS strategies will be amenable to network modeling, and the assumptions that drive the models often rely on them, sketch analysis techniques must also be used in the analysis framework. A range of evaluation techniques is required in order to estimate the transportation and traffic impacts of each alternative.

Additional measures beyond those of typical of MIS efforts may be required in order to highlight some of the main impacts of ITS – improved trip reliability (reduced travel time variability) and reduction in non-recurring delays. The analysis approach would then have to be capable of estimating these measures for all of the alternatives under study.

3.4.2 Cost Analysis

Agencies have less experience with implementing ITS and hence have less experience on how to estimate their capital and operations and maintenance costs. Because the operations and maintenance requirements for ITS are typically higher and more uncertain than those of traditional construction projects, funding for on-going operations and maintenance is a major concern for agencies that decide to implement ITS. Life-cycle costing should be used to compare the costs of ITS alternatives with other more traditional ones.

Because some ITS strategies (such as ATIS) involve consumer purchase of equipment or services, alternatives that depend on such decisions must address these costs somewhere in the analysis. This issue is non-trivial since assumptions must be made about the costs and number of users (or market penetration). Following general MIS guidance, these costs should be treated as a user disbenefit rather than a cost, since cost is generally defined as public agency costs. In addition, since the private sector is expected to play a big role in the delivery of ATIS services, the treatment of private sector service provider costs is another issue to be addressed. One way to handle this may be through keeping the actual costs to the private sector internal to the cost analysis system by estimating user fees as the cost transfer mechanism. This in turn is a way to address the user costs.

While not unique to ITS, allocation of costs of regional systems to the corridor/sub-area is another issue to be addressed. While always function of the no-build and TSM alternative definitions, proper cost accounting is necessary to handle the use of regional support systems or the introduction of new regional services in the corridor. The fraction of regional costs allocated to the corridor must include the full cost of support systems (e.g., management centers, hardware, software, communications equipment) that are necessary to enable the service to work in the corridor. On the other hand, the allocated costs would not include costs that are accrued outside the corridor (such as equipment costs on buses that run on routes outside the corridor).

Previous MIS efforts or alternatives analyses have studied fixed guideway transit alternatives within a corridor that require the provision of central yards, shops, and control facilities. This is similar to the notion that deployment of ITS elements within a corridor depends on the existence of a central control facility that may also serve the region as a whole. These kind of parallels provide insights on how to address the ITS issues within the MIS process.

3.4.3 Financial Analysis

The financial analysis can provide a feasibility check on the ITS assumptions in the alternatives. Building on the discussion of cost analysis issues above, it is clear that the financial analysis for an MIS with significant emphasis on ITS elements can present some interesting challenges. The fact that a market analysis might need to be done as part of the study is clearly one of the challenges. Many of the issues related to public-private partnering have implications for the financial analysis and decision-making framework for the study, since many other stakeholders and decision makers (including the private sector equipment manufacturers and/or information service providers) dictate the overall viability of the defined alternative. For example, if dynamic route guidance is in an alternative, and the assumption is that it is delivered using the private sector, the viability of the alternative requires decisions on the part of the individual consumers to purchase the equipment and service, the private sector to offer the service, and likely the public sector to share traffic conditions information with the private sector. Some financial analyses might assume that the public and private sector trade data on traffic conditions, to mutual benefit, while others might assume that the information flow is more one-sided, with a potential need to include the expected value of the information into the analysis.

The typical MIS of today would not encounter all of these concerns. However, with the advent of more flexibility in the potential privatization of toll roads federally and in certain states, even more traditional MIS efforts will need to incorporate the private sector component into the financial analysis.

3.4.4 Environmental Impacts

Because ITS strategies are comprised of communications, computer, and data processing equipment, and are not as visible to the public as traditional construction alternatives, the environmental impacts of ITS are almost certainly less than those of construction alternatives, at least with respect to right-of-way, the natural environment, visual or aesthetic conditions, historic or park land resources, and social and economic impacts related to changes in access or displacement due to physical transportation system changes. In terms of air quality, the jury is still out on how ITS strategies will stack up against traditional ones, mainly because some of the relationships are not clearly understood and the state-of-the-practice analysis tools are insensitive to some characteristics of ITS (such as smoothed traffic flow) that can affect the release of emissions from vehicles.

3.5 Summary

This section has addressed some of the considerations and challenges of fully incorporating ITS into a corridor planning study process that in the past has been more suited to traditional capacity and service alternatives. The introduction of ITS strategies was discussed as part of three important stages of the MIS (or any alternatives analysis) process: the problem definition and measures of effectiveness development stage, the alternative definition stage, and the analysis stage.

This section concludes the context setting for the Seattle case study work, which is documented in the following sections.

Because the focus is on how to include and evaluate ITS as an integral element of corridor studies, some aspects of the MIS process are not addressed in detail in the case study. These include land use, environmental impacts, financial analysis, public involvement, and selection of the preferred investment strategy. Since no actual planning decision is being supported with the study, there is no need to develop or recommend a preferred investment strategy.

4. Seattle Case Study Overview

This section provides an overview of the characteristics and primary objectives of the Seattle case study and a summary of the case study approach.

4.1 Study Objectives and Characteristics

Mitretek chose the case study approach for this analysis for a number of reasons. A case study allowed us to:

1. Develop and apply analysis and evaluation techniques to a realistic metropolitan surface transportation planning problem;
2. Address and resolve the technical issues that would occur in a typical MIS study (e.g., size of the network, ITS elements, model and network conversion, level of detail required);
3. Show how ITS elements can be incorporated in a MIS (or corridor/sub-area study);
4. Show the relative contribution of ITS to MIS alternatives and impacts.

The specific objectives of the case study included:

1. Develop tools, techniques, and methodologies for incorporating ITS in the transportation planning and public sector investment processes;
2. Show the benefits and costs of using ITS to address real needs and realistic transportation problems at the corridor level;
3. Demonstrate how ITS can enhance the effectiveness of traditional "modal" alternatives;
4. Provide guidance based on the case study results that can be easily used by transportation professionals in an MIS.

Several important characteristics differentiate this case study from the typical MIS.

Because this is a federally sponsored study providing guidance for transportation planners in metropolitan regions, the specific alternatives assessed in the case study are not tied to "actual" Seattle decisions. The study had a wider scope than the actual Seattle situation and considered alternatives beyond those that might be supported in the Seattle environment. This wider scope allowed more emphasis unconstrained by any specific considerations that would affect an actual Seattle MIS for the same corridor. Consequently, the case study's methodology and lessons learned are more useful and valid than the actual quantitative results. The case study should not be read as an attempt to develop, recommend, or justify an actual investment strategy for the Seattle region.

We selected a geographic study area that provided a realistic set of conventional transportation build alternatives for the case study into which ITS elements could be integrated. The addition of ITS options affords the opportunity to assess the costs and benefits of various transportation build alternatives, with and without ITS. We chose the MIS to provide structure and context for defining and evaluating alternatives. Because the analysis is not tied to the actual planning process in Seattle, the case study can be considered a “shadow” MIS, which reflects the analysis and methodologies of an MIS without the administrative, public participation, and detailed engineering aspects of a “real” MIS process.

4.2 Study Approach

The approach is shown in Figure 4-1. A summary of each major step or task is given below. The steps are shown in sequence but, in fact, were carried out roughly in parallel.

1) **Select Region** - Both Houston and Seattle were studied in phase 1 of this project and both indicated a willingness to continue coordination with the study team. However, only one area could be chosen for phase 2 due to resource considerations. Seattle was selected as the case study area for a number of reasons:

    - the existence of a number of transportation planning model networks,
    - ability of the Seattle-area subcontractor to access Seattle-area project plans and historical data,
    - subcontractor familiarity with the Seattle-area transportation network and planning environment, and
    - the existence of good historical data on Seattle-area traffic volumes and other network statistics. These statistics are routinely collected by Washington State Department of Transportation (WSDOT) as part of its ongoing Traffic Management System efforts, and provided a good source of data for validating the models developed.

2) **Form Project Advisory Team** - Following a Federal review of the study team formation, we established a local project advisory team to provide advice to the study team. The local advisory team consists of Seattle region transportation professionals from those agencies and organizations involved in planning and operating the transportation systems in Seattle (particularly in the study corridor). The local advisory team provided their perspective on the reasonableness of the case study baseline and the definition of alternatives; as well as the evaluation approach and proposed measures of effectiveness. They also monitored the progress of the study, and reviewed the study findings and recommendations.

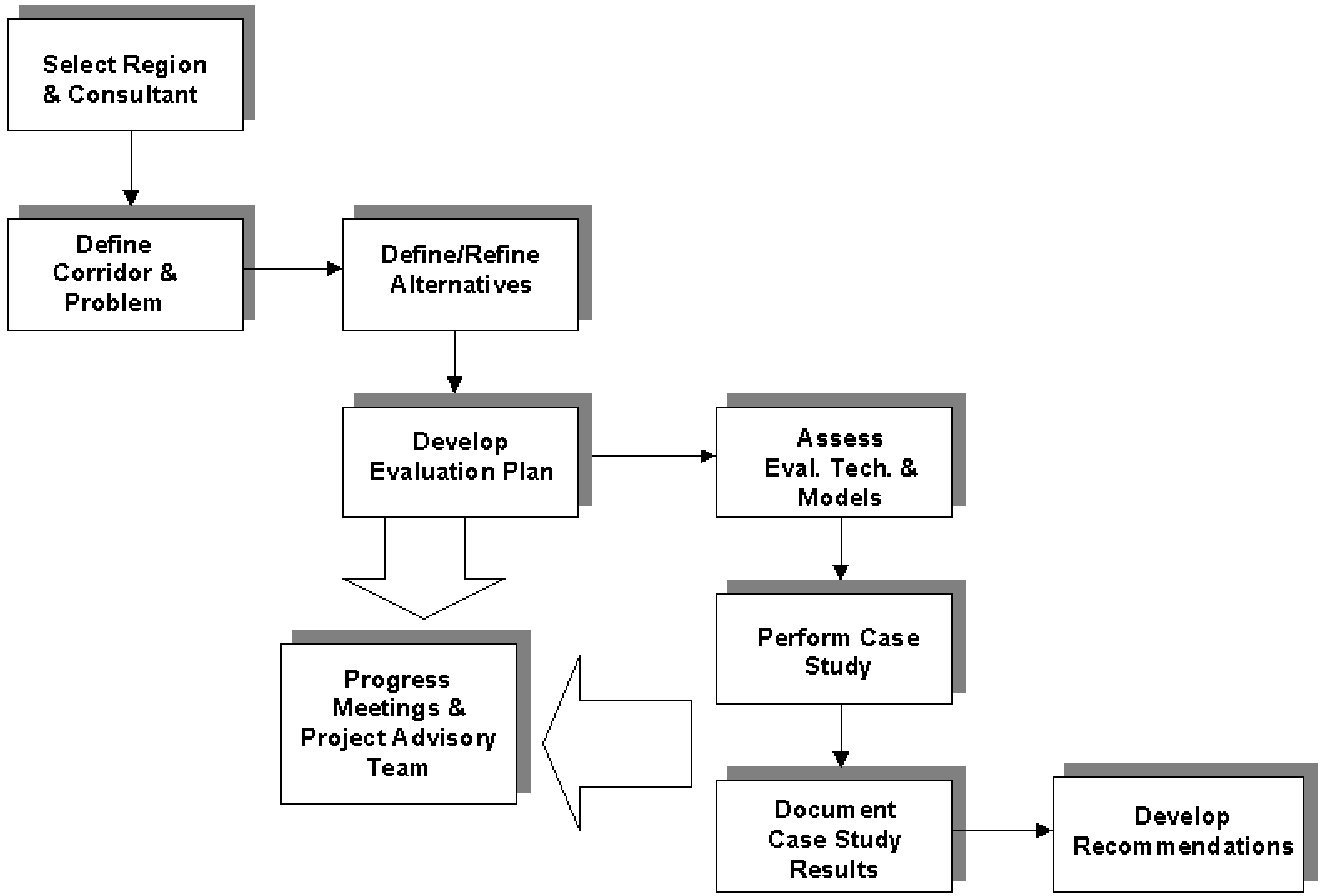


Figure 4-1. Phase 2 ITS Case Study Approach

3) The Puget Sound Regional Council (PSRC), Seattle's regional Metropolitan Planning Organization (MPO), helped to facilitate and host our meetings. Other organizations represented on the local advisory team were:

- WSDOT
- Regional Transit Authority (RTA)
- King County Metro
- King County Transportation Planning
- Community Transit
- University of Washington
- Washington State Transportation Center (TRAC)
- Local divisional offices of FHWA and FTA provided local advisory team representatives. Appendix A contains a list of the names of the individuals who served on the advisory team.

4) **Define Corridor and Problem** - Given the goals and objectives of this study, we had to select a suitable corridor with known or projected transportation needs or problems. The next section of the report (Section 5) addresses this task.

5) **Define/Refine Alternatives** - In accordance with MIS guidance, a set of distinct transportation alternatives (considered to be "build options" from the baseline network) were developed and refined as potential solutions to the transportation needs and problems in the study corridor. These alternatives represent different investment strategies and different modal orientations toward addressing the corridor transportation problems. The study objectives dictate that the alternatives specifically address the inclusion of ITS elements by themselves and in combination with more traditional build alternatives. Section 6 addresses the principles used to develop alternatives and provides a description of the baseline and the alternatives evaluated in the case study.

6) **Develop Evaluation Approach** - In this study, "analysis" refers to processes that develop information on the costs, benefits, and impacts of alternative transportation projects. Transportation models, for example, might provide such information on impacts, while financial analyses might provide information on costs. Analysis makes no normative judgments, i.e., makes no attempt to place values on the information. In contrast, "evaluation" refers to processes that use such information to make comparisons, such as to make clear the advantages and disadvantages of the alternatives in addressing transportation needs and problems. For example, use of measures of effectiveness require judgments about the values of what is effective and how to measure it. Evaluation puts the

analysis-generated information into a framework that facilitates decisions among the transportation alternatives. By "evaluation approach," we mean the combination of both analysis and evaluation processes. An analysis approach was developed and used to estimate the costs and transportation impacts of each alternative. In order to achieve the study objectives, the evaluation approach included analysis methods and evaluation tools which had to capture the impacts of ITS alternatives as well as of the traditional transportation alternatives. The analysis methods and evaluation measures are discussed in Section 7. The evaluation of the alternatives is covered in Section 9.

7) **Assess Analysis Methods** - Part of the development of the analysis methods involved research on the available analysis techniques and transportation models that were both well-documented and could meet the study objectives. We reviewed a variety of analysis methods, i.e., networks, simulations, and sketch planning techniques that could address ITS strategies. This task resulted in the final set of transportation models and evaluation methods for the case study that are documented in section 7.

8) **Perform case study** - This step involves the actual execution of the evaluation approach to analysis of possible transportation alternatives for the Seattle metropolitan corridor.

9) **Document Case Study Results** - The results of the model validation process are reported in Section 8. The results of the alternatives evaluation can be found in Section 9.

10) **Develop Recommendations** - Based on the results and their implications and the experiences/ lessons learned during the case study, the project team made several recommendations regarding analytical issues and next steps. These recommendations are captured in Section 10.

5. Selection of Study Corridor

5.1 Selection of Study Corridor

After selecting the Seattle region for the case study, the study team developed a list of factors to select a corridor of study in the Seattle area. Overall stipulations for selection of a candidate corridor included:

- have "generalizable" transportation attributes,
- allow realistic application of a variety of ITS strategies, and
- have transportation data readily available to expedite the case study.

The corridor candidates were evaluated on the following selection factors:

1. Geographical extent
2. Transportation planning and operating jurisdictions
3. Traffic volumes
4. Type and condition of major transportation facilities
5. Service levels
6. Origin-destination (OD) patterns and land use
7. Topography
8. Potential changes in transportation facilities
9. Current or future transportation problems
10. Existence of a freeway with alternative routes (for traffic diversions)
11. Existing and potential multi-modal options
12. Data availability

The Seattle metropolitan region is topographically confined, with Puget Sound to the West and Lake Washington to the East of the Seattle central business district (CBD). South of the Seattle CBD, the region includes multiple activity concentrations, including the city of Tacoma, the Fort Lewis Military Reservation, the Seattle Tacoma International Airport, and the Port of Seattle. To the East of the Seattle CBD and Lake Washington are the Bellevue area and Redmond (home of software giant Microsoft), and to the North is the city of Everett (home of the Boeing aircraft assembly plant). Since all of these areas are on a relatively narrow north-south axis, the initial candidate corridors could be grouped easily into three categories:

1. Segments of Interstate Route 5 (I-5), the main North-South freeway through the Seattle CBD;

2. Interstate Route 405 (I-405), a hemi-beltway through Bellevue and the Seattle environs on the East side of Lake Washington, intersecting I-5 North and South of the Seattle CBD; and

3. The East-West State Route 520 (SR 520) and Interstate Route 90 (I-90), which bridge Lake Washington, connecting the Seattle CBD with Bellevue to the East.

The I-90 corridor extending East from Seattle across Lake Washington and Mercer Island to Bellevue was considered, but eliminated since it did not have alternative routings for diversions of traffic off the freeway, except for the routes named above, and it would not be a candidate for multi-modal operations.

Considering the three main interstate routes in the region, five corridors, two with subparts, were defined:

1. The North Corridor - centered on I-5 Northward from the Seattle CBD to about Everett
2. The Tacoma CBD - centered on I-5
3. The South Corridor -
    a) Centered on I-5 Southward from the Seattle CBD
    b) Centered on SR 509.
4. The Bridge Crossing
    a) Centered on I-90.
    b) Centered on SR 520.
5. The Eastern Circumferential - centered on the I-405 hemi-beltway.

All five corridors include limited access routes, as well as less controlled routes providing diversions from the primary limited access route. The subparts of corridor 3 allow a focus on a freeway or on an arterial facility. The subparts of corridor 4 are both limited access and alternatives for the other. The attributes of the subparts of corridors 3 and 4 are sufficiently different to deserve separate listings. The resulting seven corridors were used initially to develop detailed attributes, according to the twelve selection factors, for further discussion with the local advisory team. Table 5-1 shows an initial assessment of the twelve selection factors against the seven potential corridors.

Table 5-1. Corridor Selection Characteristics (multiple pages)

	CORR. 1	CORR. 2	CORRIDOR 3		CORRIDOR 4		CORR. 5
	I-5 North	I-5: Tacoma	I-5 South	SR 509	I-90	SR 520	I-405
Geographical Extent	Seattle CBD to 164th St, Sno Co.	SR 512 to Pierce /King Co. Line	Pierce/King Co. Line to Seattle CBD	188th St to 1st Ave S Bridge	Issaquah to Seattle CBD	Redmond to I-5	I-5 (Tukwila) to I-5 (Sno Co)
Jurisdictions	WSDOT; PSRC; King Co. (incl. Metro); Snohomish Co.; Cities: Seattle, Lynnwood, Mountlake Terrace; Comm. Transit	WSDOT, PSRC, Pierce Co., City of Tacoma, Pierce Transit, Port of Tacoma	WSDOT; PSRC; King Co.(incl. Metro); Cities: Seattle, Federal Way; Pierce Transit	WSDOT; PSRC; King Co.(incl. Metro); Cities: Seattle, Burien, SeaTac	WSDOT; PSRC; King Co.(incl. Metro); Cities: Seattle, Issaquah, Bellevue, Mercer Island	WSDOT; PSRC; King Co.(incl. Metro); Cities: Seattle, Redmond, Bellevue, Kirkland	WSDOT; PSRC; King Co.(incl. Metro); Snohomish Co.; Cities: Bellevue, Tukwila, Renton, Kirkland, Bothell, Lynnwood; Comm. Transit
Selected Volumes							
ADT	114200	91500	94400	22700	65000	54000	81000
AM Pk Hr	7900	6600	8700	2500	6300	3800	6400
PM Pk Hr	8300	5700	9000	3000	5600	3800	6000
Express (SB/NB)	5520/5375						
Type/Condition	3-5 lane freeway with 2-4 lane reversible roadway, directional split toward Seattle CBD, relatively high transit service. HOV lanes in most of corridor	3-5 lane freeway, low directional split, low to moderate transit service. HOV lanes planned throughout corridor	3-5 lane freeway, significant directional split toward Seattle CBD, relatively high transit service. HOV lanes built/committed throughout corridor	3-4 lane freeway, moderate dir. split toward Seattle, low transit service. HOV lanes planned for 1st Ave S. Bridge. HOV bypass NB onto bridge.	3-5 lane fwy. with 2-lane reversible roadway across Mercer Is. & bridges, dir. split toward Seattle CBD, relatively high transit service. HOV lanes in most of corridor	2-3 lane fwy., dir. split toward Seattle CBD, very high transit service over bridge. HOV planned on part of corridor (politically sensitive corridor)	2-4 lane circumferential fwy., low dir. split, minimal transit service. Outside HOV lanes built/committed in most of corridor (inside HOV through Tukwila)

Table 5-1. Corridor Selection Characteristics (multiple pages)

	CORR. 1	CORR. 2	CORRIDOR 3		CORRIDOR 4		CORR. 5
	I-5 North	I-5: Tacoma	I-5 South	SR 509	I-90	SR 520	I-405
Service Levels	Heavy peak period congestion. Significantly exacerbated by incidents	Existing congestion primarily due to incidents. Future regular peak period congestion forecasted	Heavy peak period congestion. Significantly exacerbated by incidents	Peak period congestion limited to 1st Ave S bridge, which is currently being expanded.	Low congestion east of I-405 (spillover to I-405). Moderate peak period congestion West of I-405. Significantly exacerbated by incidents	Heavy peak period congestion. Significantly exacerbated by incidents	Heavy peak period congestion. Significantly exacerbated by incidents
OD Patterns/Land Use	Suburban to urban freeway. Heavy commute trip orientation to/from Seattle CBD. Land use built out along much of corridor.	Urban Freeway. Multiple intra-, inter-, and through corridor trips, Room for land use growth at south end of corridor.	Suburban to urban freeway. Heavy commute trip orientation to/from Seattle CBD. Limited land use growth potential.	Suburban freeway. Links airport, suburbs, industrial areas w/Seattle. Minimal growth potential as-is (unless later linked with I-5).	Suburban to urban freeway. Heavy commute trip orientation to/from Seattle CBD. Experiencing more growth than other corridors-heavy recreational demand.	Suburban to urban freeway. Heavy commute trip orientation to/from Seattle CBD. Potential for growth at east end of corridor.	Suburban circumferential freeway. Widely dispersed trip patterns. Land use relatively low density.
Topography	Level to moderate terrain	Level to moderate terrain	Level to moderate terrain		Level to moderate terrain		Level to moderate terrain
Potential Changes	Light rail parallel to portion of corridor	Commuter rail parallel to corridor	Commuter rail parallel to corridor		Light rail parallel to portion of corridor	HOV lanes up to bridge	HOV lanes to move to the inside

Table 5-1. Corridor Selection Characteristics (multiple pages)

	CORR. 1	CORR. 2	CORRIDOR 3		CORRIDOR 4		CORR. 5
	I-5 North	I-5: Tacoma	I-5 South	SR 509	I-90	SR 520	I-405
Current or Future Problems	Significant existing congestion and safety problems	Significant existing safety problems. Flow near capacity. Future congestion.	Significant existing congestion and safety problems	Congestion on 1st Avenue South Bridge. Connection to I-5 will increase congestion.	Moderate existing congestion and safety problems.	Significant existing congestion and safety problems west of I-405.	Significant existing congestion and safety problems
Limited Access plus Alternative Routes?	Yes	Yes	Yes	Yes	Yes	Yes	Limited alt. routes
Existing or Potential Multi-Modal Options?	Currently significant bus transit and car/vanpool usage. Future rail potential.	Currently heavily SOV. Potential for commuter rail, increased bus and carpool.	Currently significant bus transit and car/vanpool usage. Future rail potential.		Currently significant bus transit and car/vanpool usage. Future rail potential in part of corridor.	Heaviest bus transit in region. Moderate car/vanpool use. (Avg. veh. occ. is 1.77 in AM peak.)	Heavily SOV with limited transit/carpooling. Some potential for increased bus transit.
Data Availability	Real time surveillance, volume & speed from loops, CCTV. Existing volumes, vehicle occupancies, accident data, transit data, signal system, land use and network model data.	Existing volumes, vehicle occupancies, accident data, transit data, signal system, land use and network model data.	Limited real time surveillance, existing volumes, vehicle occupancies, accident data, transit data, signal system, land use and network model data.		Real time surveillance, existing volumes, vehicle occupancies, accident data, transit data, signal system, land use and network model data.	Real time surveillance, existing volumes, vehicle occupancies, accident data, transit data, signal system, land use and network model data.	Limited real time surveillance, existing volumes, vehicle occupancies, accident data, transit data, signal system, land use and network model data.

In addition to the twelve corridor selection characteristics, several other analysis considerations were used to differentiate potential corridors. These considerations included the availability and status of network models, previous or ongoing planning studies, and the applicability of prior case study work to these locations.

For the final selection of a corridor, the seven corridors were recombined into five candidates. Examining the attributes of the five, just four factors strongly differentiated the choices. These are:

1. Model Readiness: availability of subarea network models.
2. Data Availability (Baseline and Validation): especially good historical traffic flow data from permanent loop detectors and other surveillance systems.
3. Range of Alternatives (including alternate routes): existence of a mix of conditions and modes providing wide latitude for applying ITS technologies.
4. Transferability: the degree to which the corridor resembles other metropolitan areas.

Each corridor was given a rating of favorable, neutral or less favorable on this reduced set of selection factors. These results are shown in Table 5-2.

As shown, the candidate corridors varied little on the model readiness factor. There were scattered subarea models for all the candidate corridors. The corridor with the most favorable ratings was Corridor 1, the North Corridor (centered on I-5 north). The telling factor for this corridor was the operation of the North Seattle Traffic Management Center. This represented an intensive and historical database of permanent loop detector information, as well an ongoing surveillance and control capability. In terms of alternative routes, SR 99 parallels I-5 in this area up to Everett, and SR 99 itself provided interesting options for arterial treatments.

The corridor also contained light rail and commuter rail proposals from the Regional Transit Authority (RTA) referendum, that passed a few months after our corridor selection. The North section of I-5 contains an express section and HOV lanes, with extensive ramp metering. All factors considered, Corridor 1 was the dominant choice for our case study purposes.

5.1.1 The Study Corridor

Evaluating these key factors, the North Corridor was selected for our case study analysis. This corridor is described further in Subsection 5.1.2. Figure 5-1 shows the North Corridor's relation to the other corridors in the Seattle region. Figure 5-2 depicts the North Corridor geography in more detail.

Table 5-2. Corridor Evaluation Matrix

Selection Criteria	CORRIDOR North Corridor	CORRIDOR Tacoma CBD	CORRIDOR South Corridor	CORRIDOR Bridge Crossing	CORRIDOR Eastern Circ. I-405
1. Model Readiness	**O**	**O**	**O**	**O**	**O**
2. Data Availability (Baseline and Validation)	+	**O**	**O**	**O**	**O**
3. Alternatives Applicability(incl. Alt. Routes)	+	+	+		
4. Transferability	+	**O**	+		

KEY

\+ = Favorable **o** = Neutral = Unfavorable

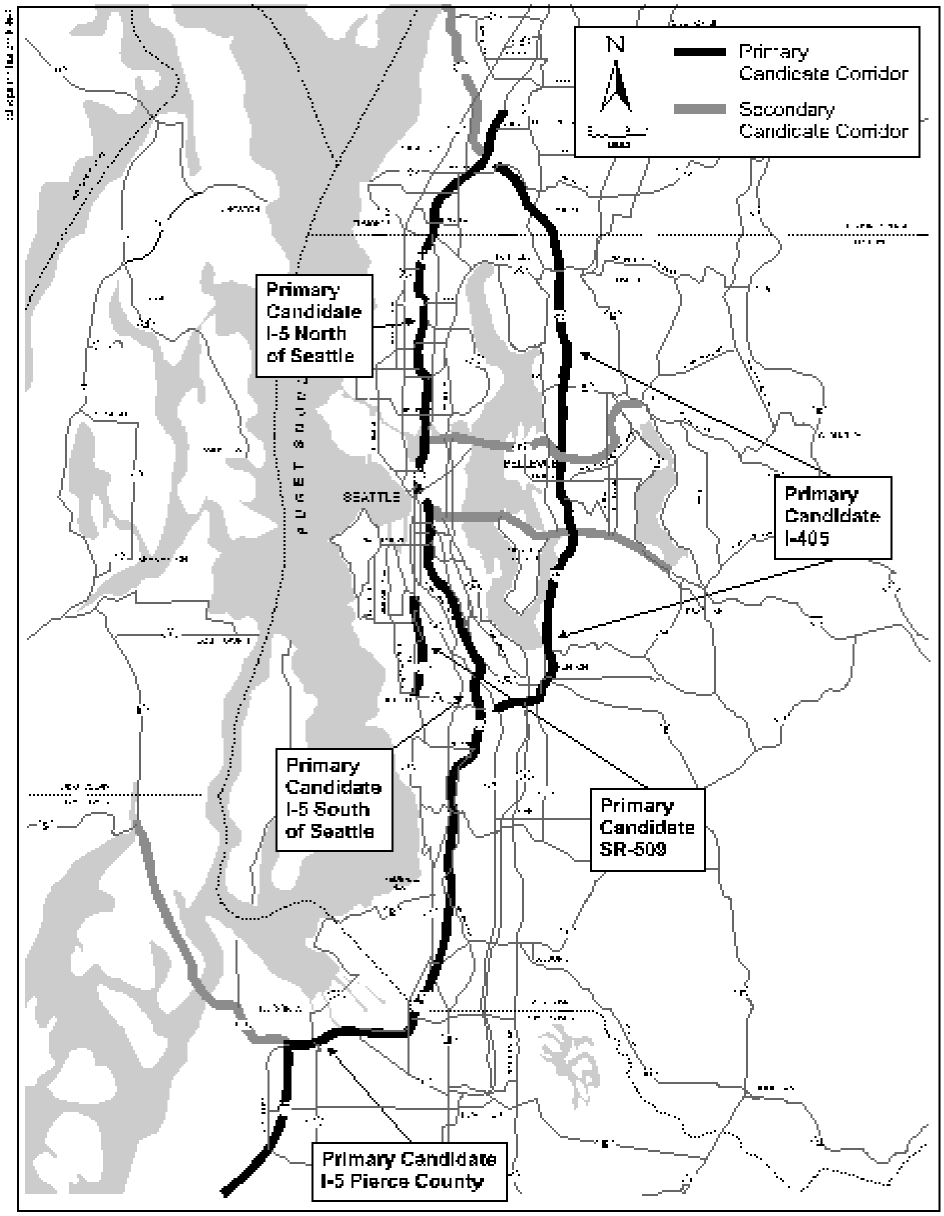


Figure 5-1. The North Corridor in Regional Context

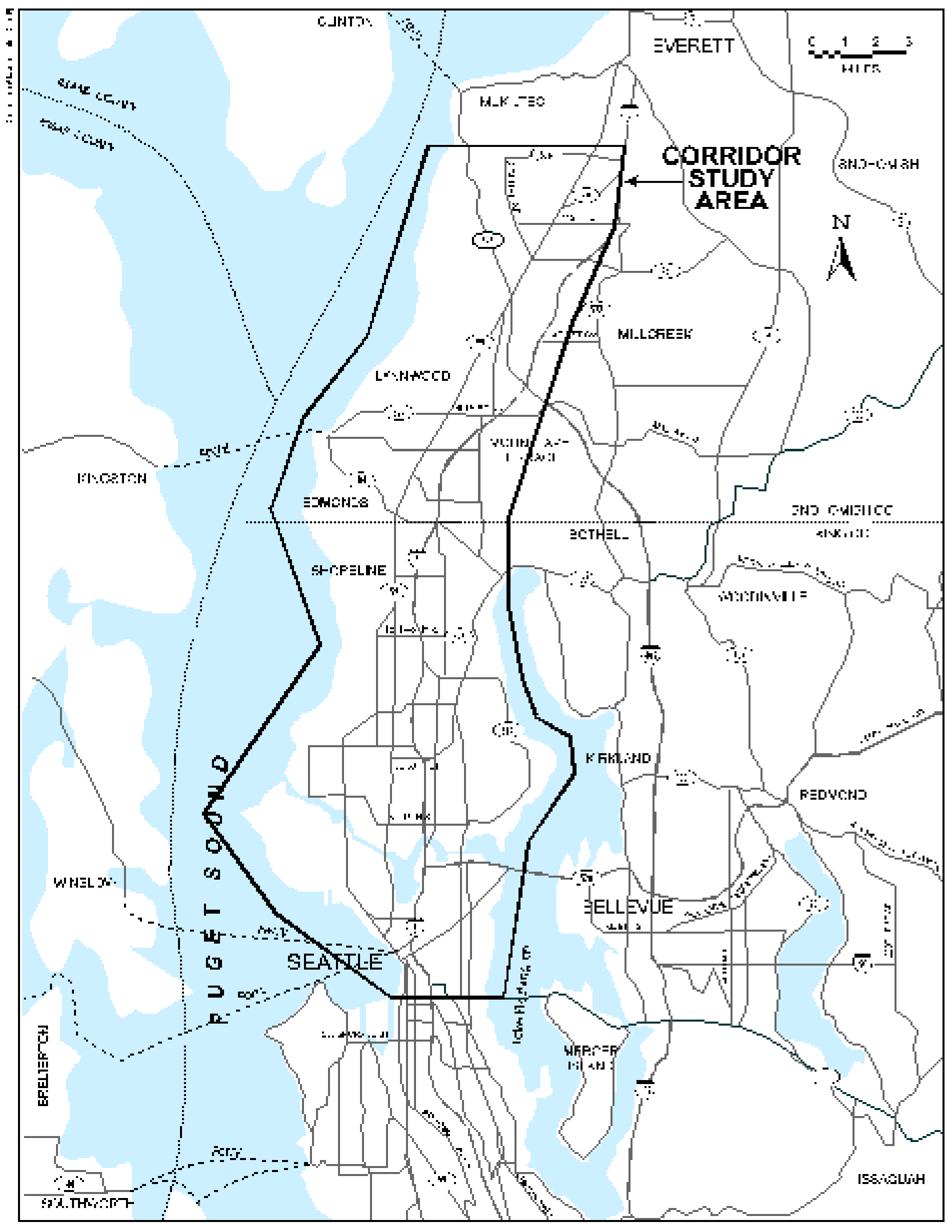


Figure 5-2. The Detailed Analysis Area for the North Corridor

5.1.2 Description

The North Corridor contains the two primary continuous north-south routes into the Seattle CBD---I-5 and SR 99. The dominant traffic flow direction is associated with commuting to and from the Seattle CBD and the areas immediately south, however, these two routes also carry the significant contra-flow traffic to Boeing-Everett and other points north of the Seattle CBD. These routes provide the only two limited access highways of the six routes crossing the Ship Canal, the waterway that bisects Seattle west of Lake Washington. The Seattle CBD can also be approached from the northeast via SR 522 (Lake City Way) around the top of Lake Washington. Some of this traffic filters down through the University district, but most of this northeast flow will also join I-5 at the junction (Exchange 171) that tends to be the AM peak choke point, north of the Ship Canal crossing. The east-west crossing on SR 520 across Lake Washington feeds primarily into I-5 (Exchange 168). Traffic on I-405 going around the CBD through Bellevue and Redmond to the east of Lake Washington largely joins I-5 (at Exchanges 182 in the north and 154 in the south).

The Ship Canal connects Lake Washington to Puget Sound and cuts off northern Seattle from the CBD. The I-5 bridge and the SR 99 (Aurora) bridge are the two major crossings, along with four local crossings. SR 99 is a limited access facility through the CBD and across the Aurora Bridge. I-5 operates separate, and reversible, express lanes from the CBD, across the Ship Canal which re-merge north of the bridge. The traffic patterns, in particular during the morning commute, tend to show that the I-5 bridge crossing is not the major bottleneck, but that the significant flow constraint is the interaction of express lane, HOV crossovers and ramp traffic near Northgate (Exchange 173), just to the north of the I-5 bridge.

After selecting the North Corridor, we left open the issue of the corridor termini. For emulation of an MIS, a part of the corridor close to the CBD, with both transit and highway segments, would suffice. As discussed in Section 7, the analysis was conducted on both a subarea and on a regional scale. We used a regional planning-scale model for the northern part of the region, and a more detailed traffic simulation model for a subarea closer to the CBD. Constraints of the traffic simulation model confined the corridor to the subarea from North of the CBD to the junction of I-5 and I-405. The case study corridor was analyzed at the two scale levels, generally along I-5 from the CBD toward Everett, and extending east to the planned North-South line of the light rail transit system.Seattle voters approved a Regional Transit Authority (RTA) plan for light rail service from the CBD and across the Ship Canal through the University District. In addition, express bus service will extend around the top of Lake Washington, along I-5 and SR 99. Commuter rail will extend near the shore of Puget Sound, north to Everett. Along with existing bus transit service and HOV facilities on I-5, the selected case study corridor is multi-modal.

The entire signalized street network in the corridor, along with the freeways already under TMC control, will be coordinated jointly between WSDOT and the local jurisdictions through the TMC. This coordination will extend to more of the corridor the surveillance and control capabilities that are now limited to the freeways under WSDOT control. The coordination also will provide greater latitude for operational solutions to traffic congestion, especially due to incidents, or to other unusual conditions in the corridor.

5.2 Problem Statement

The I-5 North Corridor becomes a bottleneck to mobility for Seattle's topographically constrained regional travel. Significant highway capacity increases through construction are unlikely in the densely developed areas extending north from the CBD and across the Ship Canal. The diversity of modes and facility types in the study corridor promotes the idea of using ITS operational approaches.

In keeping with an MIS approach, a general problem statement is formulated to guide the identification of alternatives, including ITS, and the measures of effectiveness for the case study. The problem statement for the I-5 North Corridor is:

"Develop and evaluate alternatives to reduce congestion and improve mobility along the North Corridor extending from the Seattle CBD north to SR 526."

6. Alternatives Considered

Given the selected corridor and the transportation problem statement discussed in the previous section, the next task was to identify a number of different alternative transportation solutions or strategies (referred to as alternatives) that could address the problem. This section provides insight into the alternative development and screening process (Sections 6.1 and 6.2) and then defines the alternatives studied in the case study (Section 6.3). Each of the prescribed alternatives is then evaluated according to the analysis approach (or analysis plan) described in Section 7. Thus, the development of alternatives is crucial to the overall study process and is the first major window for demonstrating how to include ITS elements.

6.1 Principles for Alternative Development

The study team generally followed MIS guidance (National Transit Institute, Parsons Brinckerhoff Inc., 1996) for development of the transportation alternatives to be evaluated. The guiding principles for alternative development used in the case study can be summarized as follows:

- Include Do-Nothing (No Build) as an explicitly considered alternative (including existing infrastructure/services and committed projects)
- Consider a wide range of transportation options/ solutions (different modes, ITS, etc.)
- Consider only "reasonable" alternatives that have the potential to address the transportation needs and problems
- Ensure that each alternative is distinct from the others
- Refine each alternative to optimize its capabilities
- Keep the number of alternatives manageable
- Ensure that the alternatives address the study goals and objectives (that is, that they demonstrate ITS-only options, traditional "build" improvements, and alternatives that are combinations of traditional and ITS elements)
- Keep the ITS elements relatively consistent in the build alternatives with ITS, while tailoring the ITS strategies to the specific characteristics of the build, in order to obtain some comparison of the relative performance of a common ITS "investment package" across different alternatives

The last two bullets in the above list of guiding principles are quite specific to this study and are not necessarily meant to be turned into guidance on how ITS should be included in these types of studies. For example, keeping a consistent set of ITS elements across any alternative with ITS is somewhat constraining and may be at cross purposes with the particular policy objectives of a given build alternative. A more flexible approach would be to change the ITS strategies or elements in a way that would be consistent with the emphasis of a particular alternative (for example, if the alternative emphasizes transit relative to SOV capacity, then the ITS elements to be combined with that particular alternative would be only those that are consistent with the transit emphasis). For the purposes of this study, the experimental design advantages of keeping a relatively consistent package of ITS elements outweighed the advantages of highlighting the more flexible approach. Although not highlighted in the study, one of the experimental design advantages is that a common package of ITS elements could actually be thought of as a separate (very aggressive) TSM alternative, upon which the conventional build alternatives are added.

In order to investigate important technical issues and to simplify the analysis, some MIS guidelines were not rigidly followed. For example, in order to demonstrate the analysis approach for Transit Signal Priority and to provide a cleaner comparison, it was not assumed to be in the Baseline Alternative, even though Seattle has committed to using this ITS strategy along a few bus routes in or near the study corridor. Another simplification that was made early in the study was to combine the Do-Nothing conceptual alternative with the traditional “lower cost” Transportation System Management (TSM) or Travel Demand Management (TDM) alternatives. This simplification did not compromise the objectives or applicability of the study and allowed more time and resources to be spent on development of the build alternatives and analysis approach.

The level of detail that the alternatives had to be taken to corresponds to the level needed for performing cost estimation and modeling/evaluation of transportation impacts. The level of specification needed to do programming level cost estimation was usually the driving force in the final level of detail prescribed. The alternatives design concept, scope, basic configuration parameters, and high-level equipment requirements were generally specified. Preliminary engineering-type design options such as exact alignment options or the use of standards are not addressed by the study alternatives, since the intent was to stay at the level needed for evaluation of transportation impacts[8].

6.2 Development and Initial Screening of Alternatives

A wide variety of alternatives were initially considered by the study team, resulting in the following set of conceptual alternatives, which will be elaborated upon in the remainder of this section:

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8 More detailed engineering, financial and environmental assessments would be carried out in a typical MIS to support detailed design and detailed design and environmental analysis

1. **Do-Nothing/TSM** - a baseline case (the baseline is characterized by traditional transportation facilities and services as well as programmed ITS elements). All other alternatives are constructed from this baseline.
2. **ITS Rich** - an alternative comprised only of ITS strategies added to the Do-Nothing/TSM
3. **SOV Capacity Expansion** - a traditional type of alternative emphasizing roadway upgrades and increased general purpose capacity
4. **SOV Capacity Expansion Plus ITS** - an alternative that combines ITS strategies with the third alternative
5. **HOV/Busway** - another traditional type of alternative emphasizing HOV and transit options for addressing the North Corridor's transportation needs
6. **HOV/Busway Plus ITS** - an alternative that combines ITS strategies with the fifth alternative
7. **Toll Facility/ Pricing** - an alternative that would introduce toll collection on the I-5 reversible express lanes as a way of working the demand side of the problem
8. **Toll Facility/ Pricing Plus ITS** - an alternative that combines ITS strategies with the seventh alternative
9. **Fixed Guideway Transit** - an alternative that focuses on fixed guideway rail service to serve the transportation needs of the North Corridor
10. **Fixed Guideway Transit Plus ITS** - an alternative that combines ITS strategies with the ninth alternative

6.2.1 Overview of Conceptual Alternatives

An overview description of each conceptual build alternative (except for the combined traditional plus ITS alternatives) is provided below to better illustrate the nature of the preliminary set of alternatives (the ITS elements will be discussed in more detail later in Section 6.3):

6.2.1.1 ITS Rich Alternative

The ITS Rich Alternative is intended to show how far the addition of ITS strategies (beyond Baseline) without any traditional build components could go towards improving the transportation conditions in the North Corridor. An aggressive implementation of ITS strategies in the North Corridor is assumed, composed of traffic management and surveillance, incident and emergency management strategies, ITS services for transit, and traveler information improvements.

6.2.1.2 SOV Capacity Expansion Alternative

Currently, SR 99 parallels I-5 and is both an undivided arterial and a limited access freeway. From SR 599 to SR 509 in the south, SR 99 is a limited access freeway. It then becomes an arterial to just before Spokane Street where it then reverts back to a limited access freeway as it passes through downtown Seattle. At N 50th Street near the Woodland Park Zoo, it becomes an arterial once again and continues as such until it connects with I-5 near Mukilteo.

Under this alternative, the portion of SR 99 north of N 50th Street would be turned into an expressway. This would involve limiting access to and from SR 99 by placing median barriers to eliminate turns onto and off of SR 99. This limited access highway could extend to the King/Snohomish County Line or as far north as traffic volumes warrant it. Some suggested access points are: N 85th Street, Northgate Way, N 130th Avenue, N 145th Street, 175th Street, and 196th Street SW.

In addition, SR 525 (in the northern portion of the study corridor) would be widened between SR 99 and I-5.

6.2.1.3 Busway/HOV Alternative

Under this alternative, the I-5 freeway would have continuous, barrier-separated, high occupancy vehicle (HOV) lanes from downtown Seattle to SR 526 in South Everett by the year 2020. To achieve this, a movable barrier-separated southbound contraflow HOV lane would be added on the express lanes during the PM peak from Ravenna Boulevard to Stewart Street as proposed in the Puget Sound HOV Pre-Design Studies. A series of additional HOV improvements would be implemented such as putting HOV lanes on SR 526 (Airport Rd to I-5) and SR 99 (Winona Ave. N. to CBD), implementing arterial HOV on SR 99 (Winona Ave. N to Everett Mall Way), and construction of various freeway to freeway HOV connectors and direct access ramps.

Transit improvements for this alternative would include completion of a transit lane on SR 522, addition of several new regional express bus routes with frequent service, and construction of several park-and-ride lots.

6.2.1.4 Toll Facility/Pricing Alternative

Under this alternative, the reversible express lanes that extend from downtown Seattle to Northgate would become a toll road. Transit and HOVs would be allowed to use these lanes at either no cost or a reduced cost. This would allow non-SOV vehicles to benefit by using an uncongested highway that would provide adequate speed and reliability. If there is enough capacity, SOVs could pay a toll and be allowed to use these lanes. By allowing SOVs to buy into this roadway, funds could be generated to ensure the maintenance of the facility; however, the tolls for SOVs would have to be set such that a significantly higher level of service is maintained on the toll road relative to the I-5 mainline. Tolls could be based on the amount of congestion as well as by time of the day.

Tolls on other roads in the I-5/North Corridor could be considered as part of this alternative; however, a significant amount of construction would be required in order to provide the control needed to implement them.

6.2.1.5 Fixed Guideway Transit Alternative

This alternative would be based on the Regional Transit Authority's proposal which was voted in during the November 1996 election. The light rail plan includes twenty-five miles of a starter system with twenty-six stations within walking distance of major destinations as well as connections to local and regional bus service. The line would run from the SeaTac Airport to the University District connecting Rainier Valley, downtown Seattle, First Hill, and Capitol Hill. If additional funding can be secured, the line would be extended to Northgate through Roosevelt. In downtown Seattle, the existing bus tunnel would be turned share both bus and light-rail use. The northern portion of the light-rail system from downtown Seattle to the University District would have nine stations. The segment between downtown Seattle and the University District would be via a tunnel.

In addition to the light rail, commuter rail service would be in place offering two-way, rush-hour train service using existing railroad tracks between Everett, Seattle, Tacoma and Lakewood. The eighty-one mile commuter rail system would include fourteen stations. In the North Corridor, service between Seattle and Everett would have five stations in Seattle, Edmonds, Mukilteo, Bond Street Station in Everett, and Everett Station. (Stations may also be added at Richmond Beach and Ballard if added funding is secured; however, they will not be assumed for this analysis.)

Implementation of commuter rail would require making track and signal improvements, improving the capacity of those lines for other passenger and freight trains as well. Park-and-ride lots, transit centers and stations would also be constructed to support the commuter rail system.

6.2.2 Alternative Screening Process

Due the nature of the study, a formal evaluation and screening process was not followed in narrowing down the list of alternatives to further develop and analyze. The study team decided to drop four of the nine "build" alternatives due to schedule and resource limitations. In coordination with the Seattle Project Advisory Team, the decision was made to drop alternatives 7-10 in the above list (Toll Facility/Pricing, Toll Facility/Pricing Plus ITS, Fixed Guideway Transit, and Fixed Guideway Transit Plus ITS). Several factors led to the decision regarding the particular alternatives that were dropped. Once the decision was made to drop a conventional build alternative, eliminating the same alternative with additional ITS elements was a foregone conclusion.

The Toll/Facility Pricing alternative was considered to be less generalizable than the other traditional alternatives and also less likely to be viable given the history and geometric characteristics of the I-5 Expressway. Another consideration was that an example policy analysis on the topic of transportation pricing was recently completed for the Seattle area (ECO Northwest and Deakin Harvey Skabardonis, 1994). One important finding of the pricing investigation was that substantial public opposition is likely to be encountered with the introduction of many of the potential pricing strategies described in the alternative overview. The previous effort provides a base of information on pricing options and their analysis, and it was felt further investigation was not warranted. Lastly, because of the empirical evidence already documented (Mitretek Systems, October 1997), there did not appear to be much interest in developing techniques to evaluate the effectiveness of ITS strategies such as electronic toll collection systems (which are quite complementary to this particular alternative). Some of the congestion-based aspects of the alternative would have been difficult to implement without the use of electronic toll collection. Indeed, almost every new toll system implemented across the U.S. within the last few years uses some type of electronic toll collection method.

The Fixed Guideway Transit alternative was dropped for a variety of reasons, but mostly due to resource and schedule considerations given that significant network model coding work would be required in order to evaluate it. Another important reason why the alternative was not taken any further is that the HOV/Busway Plus ITS alternative covers nearly all of the potential ITS strategies that can be combined with the Fixed Guideway Transit alternative; thus, the potential gain in methodology development experience for incorporating ITS elements would have been relatively small.

The remaining five alternatives were further developed and evaluated. Figure 6-1 illustrates the alternatives development philosophy used in the case study. The shaded boxes (above the horizontal dashed line) indicate the final set of alternatives taken into the development, refinement, and evaluation stages. The dashed lines originating from the ITS Rich box indicate the commonality of the ITS elements across all build alternatives with ITS. The next subsection provides more details on the final set of alternatives for the case study, including more discussion of how ITS was included with the alternatives.

6.3 Description of Final Alternatives

The final set of alternatives for the case study are detailed and depicted in this subsection. In the interest of highlighting the incorporation of ITS strategies in the alternatives, more detail is provided on the specifics of the ITS strategies. The Horizon Year for the alternatives analysis is 2020. Because of its importance in setting the stage for the analysis, the baseline alternative is described first, with particular attention to the ITS elements assumed to be present.

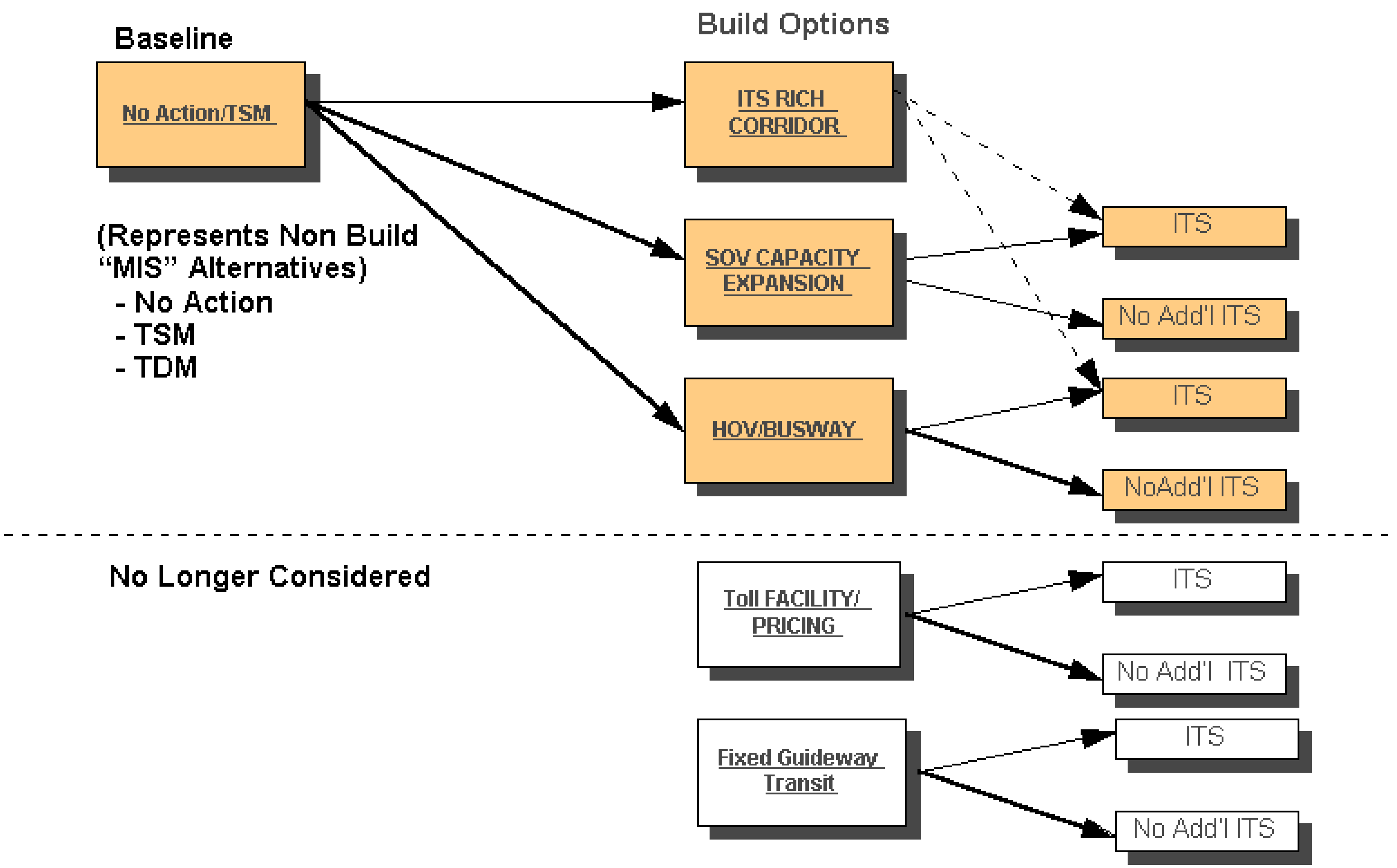


Figure 6-1. Alternatives Development Approach for Seattle ITS Case Study

6.3.1 Do-Nothing/TSM Baseline

Following MIS Guidance, the Do-Nothing/TSM Baseline (often referred to as the Baseline) alternative represents the current transportation systems, infrastructure, and services and the projects that have been committed to (financially and otherwise) in the current TIP. In this case study, the 1996-1998 TIP of the PSRC was used to define the region's committed projects, which corresponds to the PSRC 2020 No-Build Network. The North Corridor characteristics were covered in Section 5 and will not be repeated here. Instead, the major traditional committed projects and TSM elements beyond the existing infrastructure and the ITS elements assumed to be represented in the Baseline alternative are described.

The PSRC 2020 No-Build Network, which was used as the basis for this alternative, includes all committed projects within the regional modeling area (inside and outside of the North Corridor). A separate TSM alternative was not constructed; however, these type of strategies are assumed to be represented in the 2020 No-Build Network. The following bullets are indicative of traditional projects that are currently committed or being built in the North Corridor study area:

- HOV lanes added between 128th St. SE and SR 526
- 196th St. SW interchange upgrade
- Various arterial street improvements (also reflects TSM)

TSM elements assumed to be in the Baseline include the following examples (some of which are contained in the 1995 MTP for the Seattle region):

- Intersection modifications and management (channelization, widening, exclusive turn lanes)
- TDM measures such as ridesharing, and flexible/alternate work schedules (these are not explicitly addressed in this case study)
- Various transit service improvements throughout the region

Table 6-1 defines the ITS infrastructure and services assumed to be in the Baseline for this study. The major ITS categories included in the table are Traffic Management/ Surveillance, Incident and Emergency Management Systems, Advanced Public Transportation Systems (APTS), and Advanced Traveler Information Systems (ATIS). The table provides a short description of each ITS element in the Baseline and an indication of the level of deployment assumed in the study corridor. In some cases, assumptions that are crucial to the cost estimation of the other (build) alternatives are documented in the last column. While the ITS elements in the table largely represent the actual Seattle situation and near term committed plans (including plans based on the Model Deployment Initiative Program), no attempt was made to exactly represent the current and committed projects, and some liberties were taken

Table 6-1. Do-Nothing/TSM Baseline ITS Elements (multiple pages)

ITS Elements	*Description*	*Assumed Level of Deployment*	*Cost Considerations*
Traffic Management/ Surveillance Baseline (e.g., ATMS)			
Signal Systems	Existing time-of-day signal system with traffic responsive elements (minimal ramp metering and arterial control coordination) --system supports emergency signal priority at some	Arterials/ streets throughout the North Corridor	.
Traffic Management System	WSDOT surveillance (FLOW) system with communications system, vehicle detectors, cameras, ramp meters, (VMS and HAR installations covered in ATIS)	Existing/Committed North Corridor Coverage mainly on I-5 from below CBD to just north of SR 525. Regional coverage includes I-405, I-90, SR 520.	Build off existing TMS system
.	.	Ramp meters at various locations on I-5 throughout North Corridor	.
.	.	Good surveillance (1/2 mile spacing) coverage on freeways only - spotty coverage elsewhere	.
Transportation Management Centers (TMCs)	Existing/committed TMCs and operations/control centers (WSDOT TSMC, King County Metro operations/dispatch center, local signal system operations	Good coverage of North Corridor	Assume that no brand new physical plants/ facilities are necessary to implement ITS strategies in build alternatives
Communications Systems/ Infrastructure	North Seattle ATMS Project assumed to be completed providing infrastructure/ techniques for traffic data sharing and coordination of operations for traffic management systems of 15 jurisdictions in North	Full North Corridor coverage	Assume that this comm. system supports most ITS needs (infrastructure side)

Table 6-1. Do-Nothing/TSM Baseline ITS Elements (multiple pages)

ITS Elements	*Description*	*Assumed Level of Deployment*	*Cost Considerations*
Incident and Emergency Management Baseline			
Incident Management Sytems	All current/committed programs	Region-wide coverage (10 incident response vehicles)	
Emergency Traffic Signal Priority	Allows emergency/fire/medical vehicle to gain priority at selected signals throughout the network for quicker response	Region-wide coverage	
APTS (Transit) Baseline			
Transit Management System	Sign-post based transit vehicle tracking (AVL), GIS and CAD system with 2-way communications for schedule adherence monitoring, coordination, and security purposes	King County Metro Transit - region/fleet wide	
Regional Rideshare Program	Links employees with carpools, vanpools, and customized bus services	Serves customers in 8-county region	
Electronic Fare Payment System	Regionally integrated fare card (smartcard) system for customer convenience and operator cost savings + enables flexible pricing	Regional (Metro Transit, Community Transit, Pierce Transit, and Washington State Ferries (WSF))	
Trip planning/ customer assistance	All programs designed to support customers needs for schedule and route information (automated and manual) e.g., Interactive Voice Response phone system, BUS-TIME, BusView, Regional Automated Trip	Regional - Metro Transit assumed to have most advanced system	
Support systems	Scheduling, operator assignment, passenger counting system, electronic fare boxes,	Regional	

Table 6-1. Do-Nothing/TSM Baseline ITS Elements (multiple pages)

ITS Elements	*Description*	*Assumed Level of Deployment*	*Cost Considerations*
ATIS Baseline			
Advisory-based Traveler Information			
	Public display devices		
	VMS signs	Coverage on freeways/ along baseline TMS at strategic locations	
	Information kiosks/disp	A few at strategic transit center locations in the North Corridor	
	Broadcast systems		
	Radio traffic reports	Area wide	
	FM Subcarrier Systems (SWIFT, MDI)	Area wide	
	HAR sites	At strategic locations-run by WSDOT as part of TMS	
	Other - cellular phone information system, etc.	Area wide	
Multimodal Pre-Trip Planning			
	Public Access Internet (Similar to current FLOW map), telephone information, Cable TV distribution, etc.	5% market penetration of travelers - area wide coverage (baseline surveillance system)	Assume that the customers use equipment bought for other purposes (e.g., PCs, TVs, phones)
			No service charge for the traffic information (free)

with the assumptions (as discussed in Section 6.1). For more information, the Seattle Application for Participation in the ITS Model Deployment Initiative Program (1996) provides additional details on actual existing and planned ITS infrastructure and services in the area.

The Advanced Traffic Management infrastructure included in the Baseline includes WSDOT Traffic Management System elements along I-5 and other major freeways such as ramp meters, surveillance (cameras and vehicle detectors), communications system. As denoted, good coverage (e.g., 1/2 mile spacing of loops) exists mainly on the freeways. Several transportation management or operations centers already exist to serve the North Corridor; the study team assumed that these centers would be capable of implementing the ITS strategies in the build alternatives (eliminating the need for construction of brand new centers). The signal system in the Baseline can be described as a time-of-day system with traffic responsive elements such as actuation in some areas. The North Seattle ATMS Project is assumed to be completed providing the communications infrastructure and techniques for sharing of traffic-related data and coordination of operations for traffic management systems of 15 jurisdictions in North Corridor. This project is important to the Baseline since it provides full North Corridor coverage and connects the transportation management systems in nine cities, two counties, three transit agencies, and WSDOT together with a communications infrastructure which can be leveraged in the build alternatives.

The Incident and Emergency Management Systems assumed in the Baseline basically consists of existing and committed programs. In the Seattle area, WSDOT has ten incident response vehicles that are in radio contact with WSDOT and Washington State Police. Information on the incidents is relayed to FLOW system operators for distribution to the media and the public. Emergency vehicles can gain priority at selected traffic signals in the region.

Several ITS-related elements relevant to the study are included in the Baseline under the APTS category, including transit management systems, rideshare programs, electronic fare payment, trip planning/customer assistance, and other supporting systems. These types of transit applications have already been implemented in Seattle. Many of them are being upgraded as part of the Model Deployment Initiative Program in Seattle (which can be considered to be committed for the purposes of this study). As stated earlier, no transit priority system is assumed to be in the Baseline alternative.

For ATIS, the Baseline assumptions roughly correspond to actual conditions. Advisory-based traveler information (based largely on reports of incidents, severe congestion, and major transit service disruptions) is considered to be widespread and includes (1) public display devices such as Variable Message Signs (VMS) and information kiosks, (2) broadcast systems such as radio traffic reports, FM subcarrier systems such as being tested with a small number of users in Seattle, and Highway Advisory Radio (HAR), and (3) other systems such as the cellular phone traffic information service. Free, publicly available multi-modal pre-trip planning information is assumed to be available via the Internet (similar to the current FLOW map), telephone information, and cable TV distribution. Approximately 5% of travelers are assumed (for analysis purposes) to use this information to help plan their travel. Travelers are assumed to use equipment bought for other purposes to gain access to this pre-trip information (such as a computer or telephone).

It should be reiterated that all other build alternatives consist of changes or additions to the Baseline alternative. This applies to ITS elements as well as the traditional transportation elements.

6.3.2 ITS Rich Alternative

The ITS Rich Alternative is intended to show how far the addition of ITS strategies (beyond Baseline) without any traditional build components could go towards improving the transportation conditions in the North Corridor. An aggressive implementation of ITS strategies in the North Corridor is assumed, for two primary reasons. First, this assumption allows an assessment of how the costs and impacts of this alternative measure up against the more traditional alternatives. Second, it provides the study team the opportunity to demonstrate the evaluation methods that can be applied to a variety of ITS strategies. Figures 6-2, 6-3, and 6-4 depict the key ATMS and APTS strategies included in the ITS Rich Alternative. Table 6-2 provides a description of each element in the ITS Rich alternative and an indication of the level of deployment assumed in the study corridor. Assumptions that are crucial to the cost estimation are documented in the last two columns.

The ATMS improvements in the ITS Rich alternative include a signal system upgrade throughout the key arterial routes in the North Corridor. This advanced coordinated/ adaptive signal system is assumed to be based on the use of traffic responsive elements, cross-jurisdictional coordination, integrated ramp metering and arterial control, use of emerging signal control algorithms in the research community, and use of standards for compatibility. Figure 6-2 shows the primary and secondary corridors of the advanced signal system that assumed to be used for the AM peak period (which is the period of time being modeled, as discussed in Section 7). The primary corridors, which are assumed to be favored over secondary corridors for receiving green-wave priority in the signal optimization, correspond to the key north-south routes providing significant capacity during the AM peak. Because of the variety of travel patterns south of 130th Street and north of the ship channel, a network control grid operation is assumed to be in place at the intersections in this area (which includes the University District). More about these assumptions and their implications for the analysis is discussed in Section 7.

Also included as an ATMS improvement is an expansion of the traffic management system surveillance and communications infrastructure along the major freeways and state routes in the northern part of the study corridor. Figure 6-3 portrays these extensions to the Baseline along I-5, SR 526, and SR 525. These extensions will allow better freeway management and improved incident management detection, verification, and response capabilities. In addition, the quality and quantity of real-time traffic data for ATIS is improved.

Incident and Emergency Management Systems tend to be regional in nature and are hard to confine to the North Corridor. The associated improvements assumed in the ITS Rich Alternative are:

(1) A fleet tracking and management system, with Dynamic Route Guidance capabilities added to the 10 (Baseline) incident response vehicles, to enable faster response to incidents

(2) Mayday Support Systems that allow GPS-based information on incident location and other critical information to be transmitted to and received by the incident response dispatch center

The assumption for the Mayday Support Systems is that the public sector costs only include the communications equipment and software needed to capture this type of information.

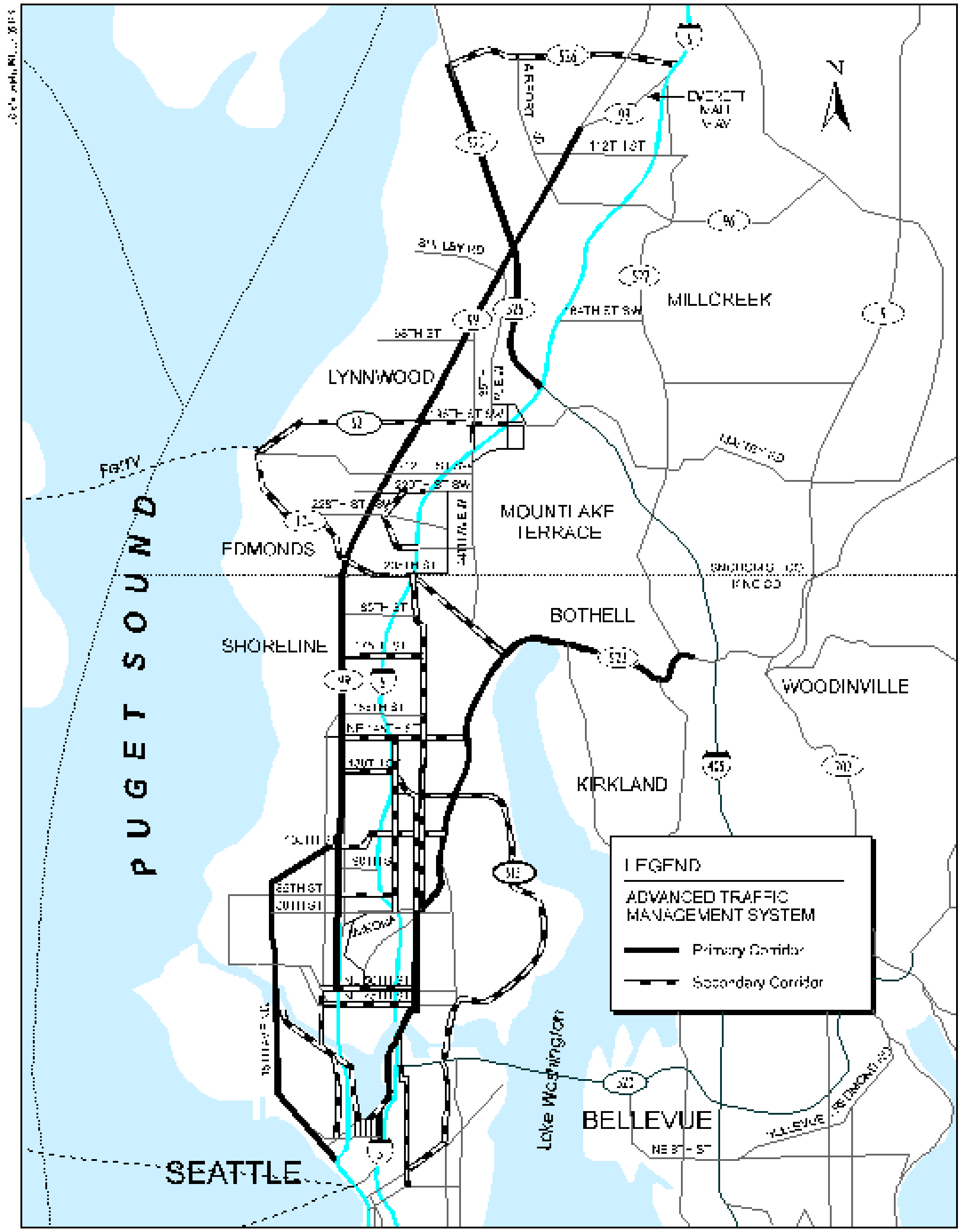


Figure 6-2. ITS Rich Alternative ATMS Plan (Part A)

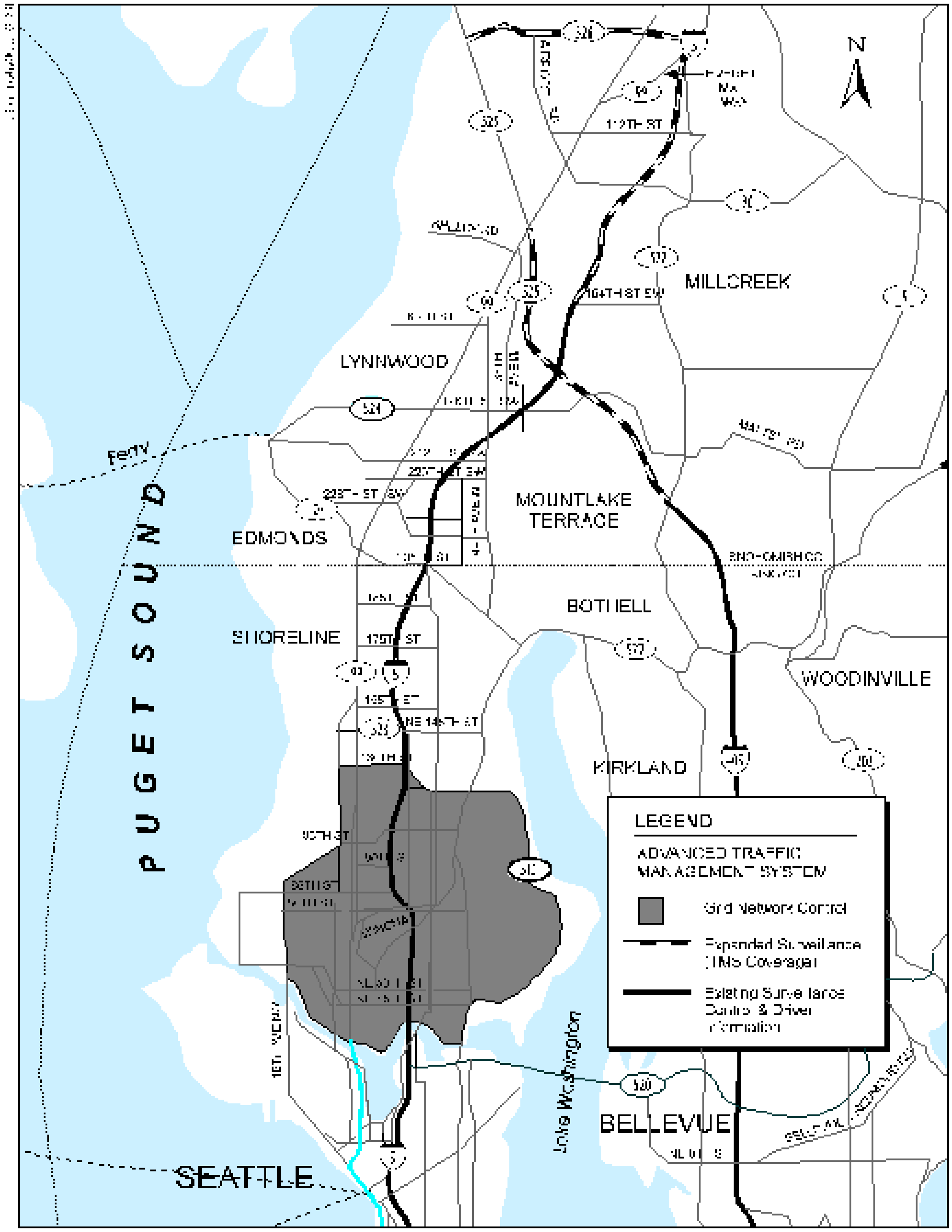


Figure 6-3. ITS Rich Alternative ATMS Plan (Part B)

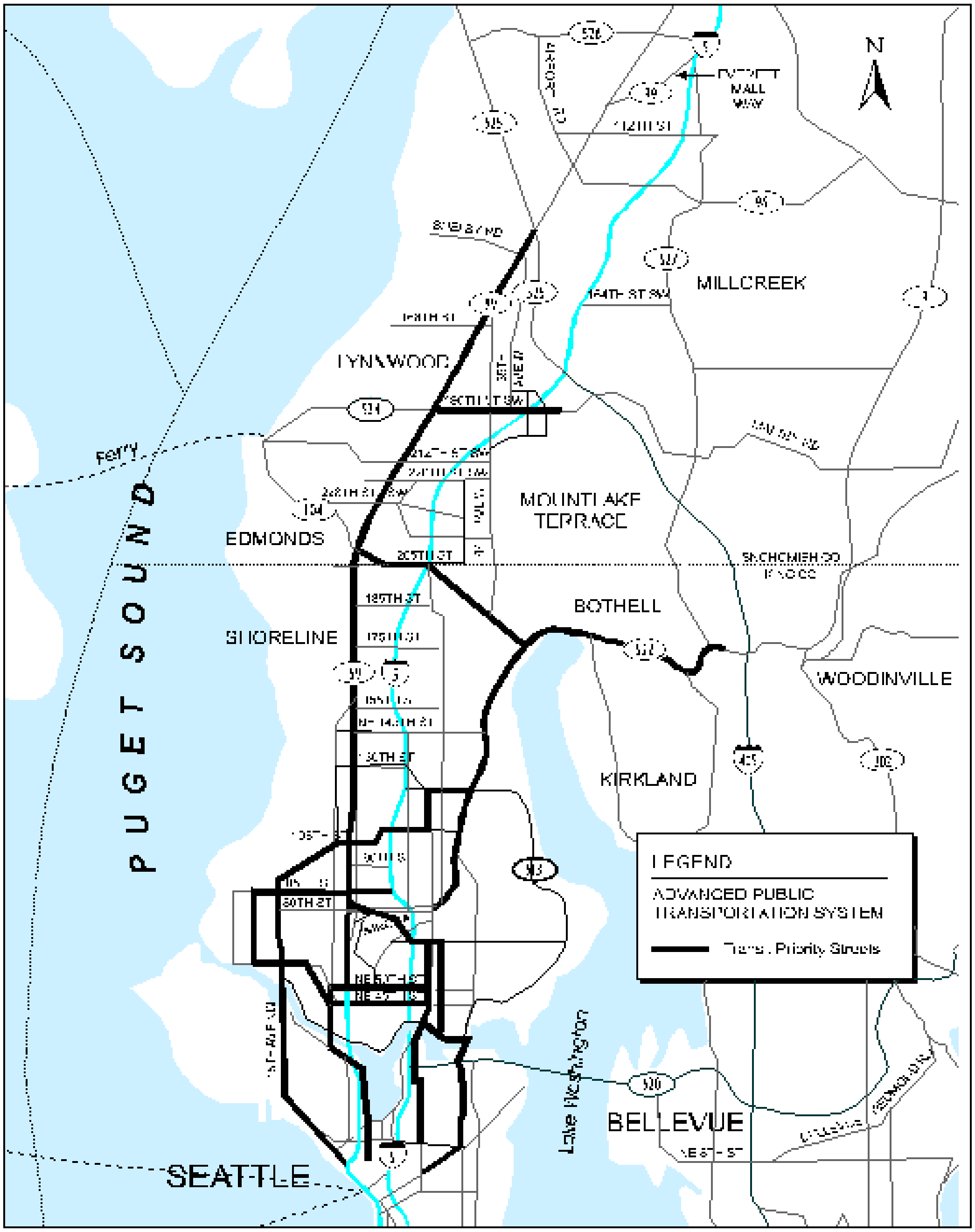


Figure 6-4. ITS Rich Alternative Transit Priority Plan

Table 6-2. ITS Rich Alternative Improvements (multiple pages)

ITS Elements	*Description*	*Assumed Level of Deployment*	*Capital Cost Assumptions and Elements*	*O&M cost considerations*
Traffic Management/ Surveillance Improvements (e.g., ATMS)				
Coordinated/Adaptive Signal System	Replace signal system along major routes in the corridor with advanced traffic responsive system with good ramp metering and arterial control coordination --system also supports the transit/EMS priority system plan	See ATMS Plan for Primary Corridor, Secondary Corridor, and Grid Control Areas	Cost to upgrade system at central locations and at the intersections corresponding to ATMS Plan with some additional local surveillance to drive responsive control algorithms - same unit cost applies to all upgraded	includes change in communications, operations, maintenance costs associated with the new system
Expanded Traffic Management System	WSDOT surveillance system with communications system, vehicle detectors, cameras, ramp meters, (VMS and HAR installations covered in ATIS)	Expanded Coverage on I-5, SR 526, SR 525, SR 104 (See ATMS Plan for limits) Corresponds to Future TMS Expansion Plan	Use typical configuration, loop detectors every 1/2 mile, CCTV cameras at major interchanges, one new ramp metering installation(s) at SR 526	consider operator costs (labor), maintenance, etc. (includes VMS/ HAR O&M)
			Communications System to handle expanded TMS	
			TSMC upgrade cost for computers, software, communications, data processing, and physical facility	

Table 6-2. ITS Rich Alternative Improvements (multiple pages)

ITS Elements	*Description*	*Assumed Level of Deployment*	*Capital Cost Assumptions and Elements*	*O&M cost considerations*
Incident and Emergency Management Improvements				
Incident Response Team Fleet tracking, management and Dynamic Route Guidance System	Use tracking system and route guidance to provide faster response to incidents	Region-wide implementation (all vehicles in baseline fleet - currently 10) – scale to North Corridor estimate	For baseline vehicles in fleet, include same in-vehicle equipment as Dynamic Route Guidance (GPS, map database, communications transceiver, processor, GUI/display) + some central costs for tracking system /	includes communications costs plus other O&M
Mayday Support	Allows GPS information on incident locations and type/severity of situation to be received by the dispatch center. This information could be sent from private Mayday service provider or Route Guidance ISP based on their customers assistance requests.	Region-wide (scale to North Corridor estimate)	Communications/ software / GIS integration costs at the dispatch center	

ITS Elements	Description	Assumed Level of Deployment	Capital Cost Assumptions and Elements	O&M cost considerations
APTS Improvements				
Transit Priority System	AVI (transponder)-based communications between transit vehicle and roadside (signal) controller allows green phase adjustments (primarily extensions) to enhance transit service	See transit priority plan - several routes within the North Corridor	Transit vehicles must be equipped with transponder units; wireless readers at priority intersections (assume signals upgraded by ATMS plan are capable of handling this system); central computing/ software for transit probe data analysis	communications system costs are mostly maintenance (no usage fee)
Enhanced/Expanded Transit Management System	GPS-based transit vehicle tracking, GIS, and CAD system with 2-way communications for schedule adherence monitoring, feeder coordination, and security purposes	Region-wide (scale to North Corridor estimate)	Transit vehicle equipment costs include GPS, comm. transceiver, GUI/data terminal, and display; central costs include software upgrade - assume same wireless communications system is used as baseline	for central and vehicle systems

Table 6-2. ITS Rich Alternative Improvements (multiple pages)

Table 6-2. ITS Rich Alternative Improvements (multiple pages)

ITS Elements	*Description*	*Assumed Level of Deployment*	*Capital Cost Assumptions and Elements*	*O&M cost considerations*
ATIS Improvements				
Advisory-based Traveler Information				
Information is primarily exception-based. Coverage includes freeways, major state routes, and transit service disruptio				
	Public display devices			
	VMS signs	Coverage on freeways/ major state routes in primary corridor plan at strategic locations prior to diversion points	Add 15 VMS signs beyond baseline to coincide w/ expanded TMS coverage (surveillance) in ATMS plan and a few along ATMS primary corridor routes (e.g., SR 99, SR	Communications infrasducture O&M is covered by TMS and /or Baseline
	Information kiosks/disp	At strategic transit centers/ Park & Ride locations in the corridor	Add 10 Information kiosks/displays at Transit centers/ key Park & Ride lots in corridor	
	Broadcast systems			
	Radio traffic reports	area wide	none beyond baseline	none beyond baseline
	HAR sites	At strategic locations - run by WSDOT as part of TMS	Add one HAR site near I-5/ SR 99/ SR 526	Incremental costs negligible compared to overall TMS O&M costs
	Public Access Internet	Coverage on freeways/ major state routes area wide	none beyond baseline	none beyond baseline
			No special traveler/vehicle equipment is needed beyond radio or computer (no cost beyond baseline)	No traveler O&M costs

ITS Elements	*Description*	*Assumed Level of Deployment*	*Capital Cost Assumptions and Elements*	*O&M cost considerations*
Multimodal Personalized Pre-Trip Planning				
Information is personalized, based on knowledge of network conditions, with rich coverage on both transit and roadv				
	Advanced, interactive fixed-end (home, office based) trip planning service (provided by private Information Service Provider - ISP)	10% market penetration of travelers	None beyond baseline – assume that the customers use equipment bought for other purposes(e.g., PCs,	$10/month service fee for customers assumed to handle total cost transfer
Dynamic Route Guidance				
Information is based on knowledge of network (roadway only) conditions, drivers assumed to provide real-time probe				
	Drivers in vehicles equipped with this service are provided real-time route updates during their trip through the network based on current traffic conditions	10% market penetration of SOV and HOV (carpool) travelers	In-vehicle equipment costs include GPS, map database, communications transceiver, processor, GUI, and display	$10/month service fee for customers assumed to handle cost transfer for ISP
	Real-time updates provided by private ISP			$5 monthly marginal fee for all communications

Table 6-2. ITS Rich Alternative Improvements (multiple pages)

The private sector is assumed to be providing the Mayday service, and those costs (including in-vehicle costs) are not included in the ITS Rich Alternative.

APTS improvements under this alternative include an aggressive transit priority system implementation and an enhanced transit management system. Figure 6-4 depicts the transit priority routes for the ITS Rich Alternative. All of the streets outfitted with transit priority equipment are also upgraded signals under the ATMS plan (many of them fall along the primary corridors such as SR 522, SR 99, and 15th Ave. NW. The transit vehicles are equipped with a transponder tag (identification tag) in order to be detected as they approach the equipped intersections. Depending on the traffic conditions and state of the signal, a decision can then be made to extend the green phase (or provide an early green phase) in order to allow the bus to clear the intersection. There are a variety of operational strategies that can be employed, some of which would only be activated if the bus is behind schedule. However, an important point to remember is that no traditional infrastructure improvements such as transit-only or HOV lanes, widened lanes, bus turnout bays, special transit bypasses, or other similar improvements beyond the Baseline are assumed to be provided in the ITS Rich Alternative. This may limit the effectiveness of the transit priority system, since the bus traffic typically shares lanes with other vehicles and may not be able to get to the front of the intersection queue in order to obtain the benefits of the priority scheme.

The other APTS improvement assumed for the ITS Rich Alternative is an enhanced/ expanded transit tracking and management system. A GPS-based system with two-way data and voice communications between buses and the dispatch/operations center provides the ability to track and communicate with the buses at any location and any time within the coverage area, and is useful for security reasons as well as operational reasons. The system is assumed to provide a wealth of information on schedule delays and estimated arrival times for ATIS users. Because a two-way communications system exists for the King County Metro fleet in the Baseline, it is assumed to carry over to this alternative.

Many of the ITS applications relevant to transit are regional in nature. Transit priority, which is highlighted in this analysis, is the obvious exception. Because many transit-related ITS applications are already included in the Baseline alternative, there was no need to include them under ITS Rich.

The ATIS services assumed in the ITS Rich Alternative include enhanced advisory-based traveler information, multimodal personalized pre-trip planning, and dynamic route guidance. The level of deployment and market penetration, assumptions on the information availability, and cost assumptions and elements are discussed in Table 6-2. The deployment assumptions made are that the private sector offers the advanced ATIS user services to consumers, and a certain level of market penetration is exogenously assumed (the assumption is that the services have been offered for a while and the market penetration corresponds to a steady-state value). Though the method of data sharing is not critical to our analysis, the public and private sectors are assumed to share traffic data, so that full set of information on network conditions and transit services are available to the multimodal personalized pre-trip planning and dynamic route guidance customers (but not the advisory-based traveler information users).

For the advisory-based traveler information, additional variable message signs, kiosks, and highway advisory radio sites are assumed to be put in place under this alternative. Public access internet is still assumed to be provided, but given its characteristics relative to the advanced ATIS services, it is characterized more along the lines of the basic traveler information. Given the improved surveillance capabilities that are assumed in the ITS Rich Alternative, it is more likely that a higher percentage of travelers will believe the information provided to be credible and will respond to it than in the Baseline.

The multimodal personalized pre-trip planning service is assumed to be a new service that combines detailed knowledge of network conditions and planned events such as construction activities with knowledge about transit conditions in order to provide customers with comparative information on the outcomes of using different travel modes and routes for their trip (before they depart). It is assumed to be personalized with traveler preferences on travel modes, normal destinations, etc. The travelers are assumed to be able to choose a mode based on the service, and, if the mode chosen is automobile, then the currently fastest route (at the departure time) is assumed to be provided to them. No real-time updates are provided after they depart (although they can still receive advisory-based information). Ten percent of travelers in the study corridor are assumed to use this service. Although no unique capital requirements are levied, since the customers use equipment bought for other purposes to receive the service, a monthly fee of $10 is assumed to handle the total cost transfer requirements to the private sector information service provider.

Dynamic route guidance is another new service assumed under the ITS Rich Alternative. In addition to receiving regular route updates based on current traffic conditions, the vehicles are assumed to be capable of reporting their travel times on certain links as they traverse the network (providing probe reports). Ten percent of SOV and HOV travelers in the study corridor are assumed to use this service. The capital requirements include in-vehicle equipment costs of vehicle location system, map database, and communications equipment, processing hardware and software, and a graphical user interface/display and/or speaker system. A monthly fee of $10 is assumed to handle the total cost transfer requirements for the real-time updating to the private sector information service provider. Another monthly fee of $5/month is assumed to handle the marginal charges for data communications.

The ATIS services discussed above highlight some challenges mentioned in Section 3 regarding incorporating ITS into corridor-level planning studies. These include making assumptions about the private consumer marketplace and associated resource requirements, public-private partnerships, and the decision-making context. These issues will be discussed further in the last section on analysis and implications of the case study (Section 10).

6.3.3 SOV Capacity Expansion Alternative

Currently, SR 99 parallels I-5 and is both an undivided arterial and a limited access expressway. From SR 599 to SR 509 in the south, SR 99 is a limited access freeway. It then becomes an arterial to just before Spokane Street where it then reverts back to a limited access freeway as it passes through downtown Seattle. North of downtown to Winona Avenue N (just past the Woodland Park Zoo), it operates as a divided arterial expressway. Other than at interchanges through this section, access is by right turn on and off only. North of Winona, it becomes an arterial once again and continues as such until it connects with I-5 near Mukilteo.

Two potential options to upgrading SR 99 were initially studied:

(a) *Arterial expressway option*: the portion of SR 99 north of Winona Avenue N would be improved to operate as an arterial expressway

(b) *Elevated expressway option*: a viaduct structure providing two lanes in each direction would be built above the existing SR 99 roadway from Everett Mall Way in south Snohomish County to just south of Winona Avenue N.

Option (a) was selected and further developed as the most promising and realistic of the two alternatives. Both options would have environmental issues (particularly related to ROW and aesthetics) to overcome, but the arterial expressway option is generalizable in terms of alternative types and methodology development. It should be emphasized that this option is not supported locally, and while generically feasible at the planning level may have detailed engineering issues to overcome at specific locations (again, detailed engineering was not carried out as part of this analysis method case study).

Figure 6-5 depicts the alternative configuration and limits. Under this alternative, the portion of SR 99 north of Winona Avenue N would be improved to operate as an arterial expressway, similar to how it currently operates between downtown and Winona Avenue. This would involve limiting access to and from SR 99 by placing median barriers to eliminate left turns onto and off of SR 99. This limited access highway could extend to the King/Snohomish County Line or as far north as Everett Mall Way in south Snohomish County if traffic volumes warrant it. Interchanges would be built at ten critical intersections, and grade separated crossings at nine others (see Figure 6-5 for locations). Most of the interchanges are assumed to be tight, full diamond interchanges with bi-directional ramps. Due to its characteristics, a pair of half-diamond interchanges is assumed for N 80th Street/Green Lake Drive/N 85th Street. Another component of the SOV Capacity Expansion Alternative is that SR 525 (in the northern portion of the study corridor) would be widened from 2 to 4 total lanes between SR 99 and I-5. Several King County Metro and Community Transit routes are affected by this alternative.

6.3.4 SOV Capacity Expansion Plus ITS Alternative

This alternative combines the traditional improvements of the SOV Capacity Expansion Alternative with the ITS strategies in the ITS Rich Alternative. The traditional improvements remain exactly as specified in Section 6.3.3. The only changes to the ITS strategies from the ITS Rich specification are attributed to the characteristics of the SOV Capacity Expansion alternative. These changes are mainly oriented to the SR 99 Expressway:

- The signal coordination system around the upgraded expressway needs to be changed. SR 99 mainline won't have signals within the study area, because of the introduction of the expressway with interchanges and grade separated crossings. However, the intersection of the ramps and the cross streets for the new interchanges will be part of the overall coordinated/adaptive signal system.

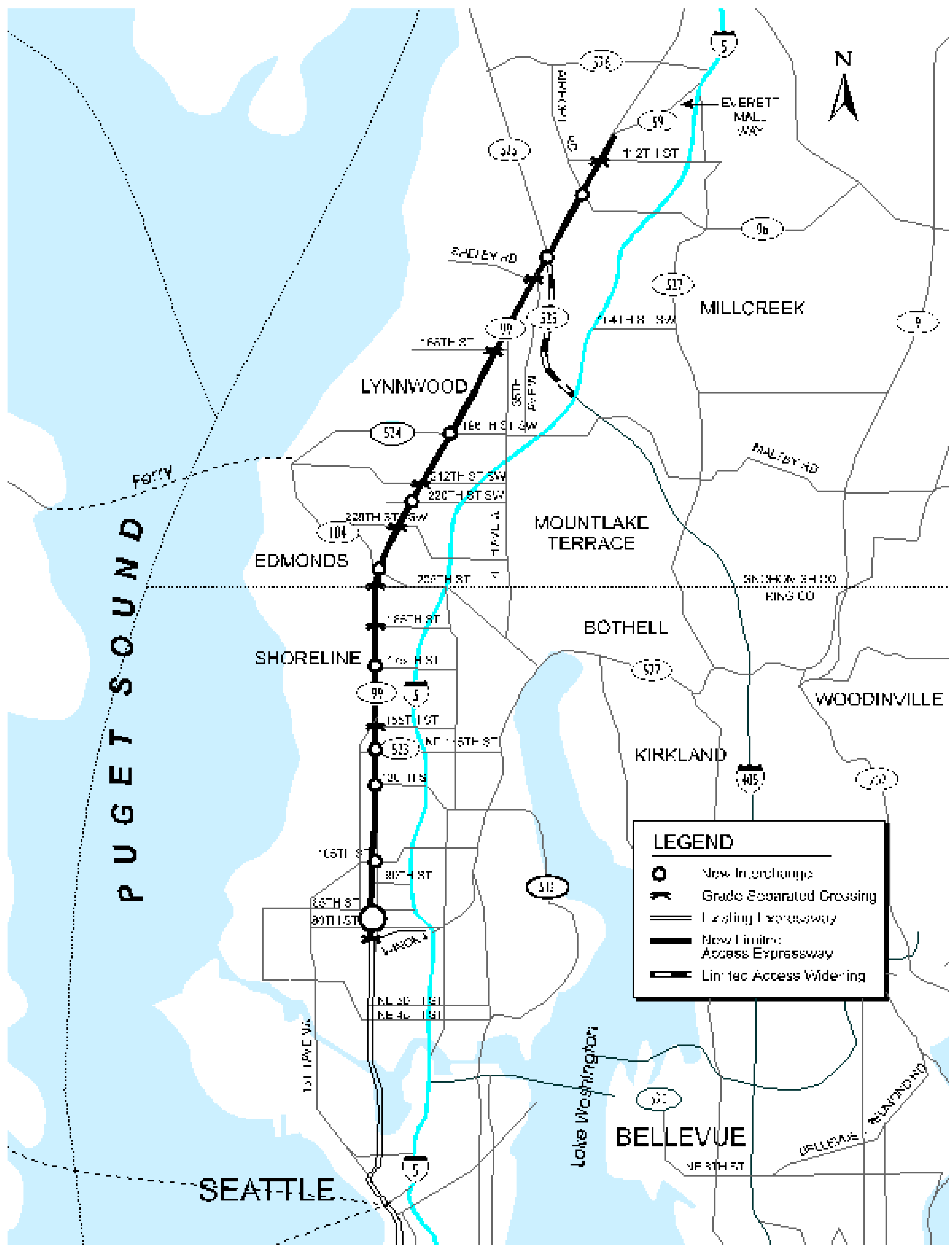


Figure 6-5. SOV Capacity Expansion Alternative

- The SR 99 expressway is included as a part of the TMS (surveillance) expansion plan in the corridor, because of its character as a limited access, higher volume expressway. This segment, which is an addition to the ITS Rich expansion plan, would extend along the length of the upgraded expressway and also south of Winona down across the bridge over the ship channel.

- A ramp meter installation is proposed for the ramp from SR 99 to SR 525 SB, in order to provide the opportunity to meter the flows being fed into I-405 and I-5.

Figure 6-6 shows these changes in context with the SOV Capacity Expansion components.

6.3.5 HOV/Busway Alternative

Figure 6-7 depicts the roadway improvements and other physical enhancements of the HOV/Busway Alternative. Under this alternative, the I-5 freeway would have continuous, barrier-separated, high occupancy vehicle (HOV) lanes from downtown Seattle to SR 526 in South Everett. To achieve this, it would require adding a movable barrier-separated southbound contraflow HOV lane on the express lanes during the PM peak from Ravenna Boulevard to Stewart Street as proposed in the Puget Sound HOV Pre-Design Studies. This would require adding a new lane through the University District and lane conversion between the north end of the Ship Canal Bridge and Stewart Street. A ramp at NE 42nd Street would provide bus access to the southbound contraflow lane.

The HOV lanes in the I-5/North Corridor would become an "HOV Expressway" by adding new direct access ramps to/from park-and-ride lots and bus flyer stops and barrier separating the HOV lanes from the general purpose lanes. HOV access would be provided to I-5 near the International District Station in downtown Seattle. A new freeway to freeway HOV connection would be provided by constructing a reversible HOV ramp between SR 520 and the I-5 express lanes. At the I-5 express lanes and NE 50th Street, a new HOV ramp would provide direct access to and from the North while at I-5/NE 145th, direct access ramps would be added to and from the south.

In Snohomish County, direct access/freeway-to-freeway HOV improvements would include:

- Direct access to/from the south and the north at the Lynnwood Park and Ride
- HOV-only interchange to/from south at 164th/SR 525
- Direct access to/from south at I-5/SW 128th Street
- Direct access to/from south at 164th/Ashway Park & Ride Lot/I-5
- SR 526 to I-5 HOV connection to and from the south
- I-5/I-405/SR 525 HOV connections

Other physical improvements which comprise the Busway/HOV Alternative are those included in the long-range plan for the region, including completion of HOV lanes on SR 99

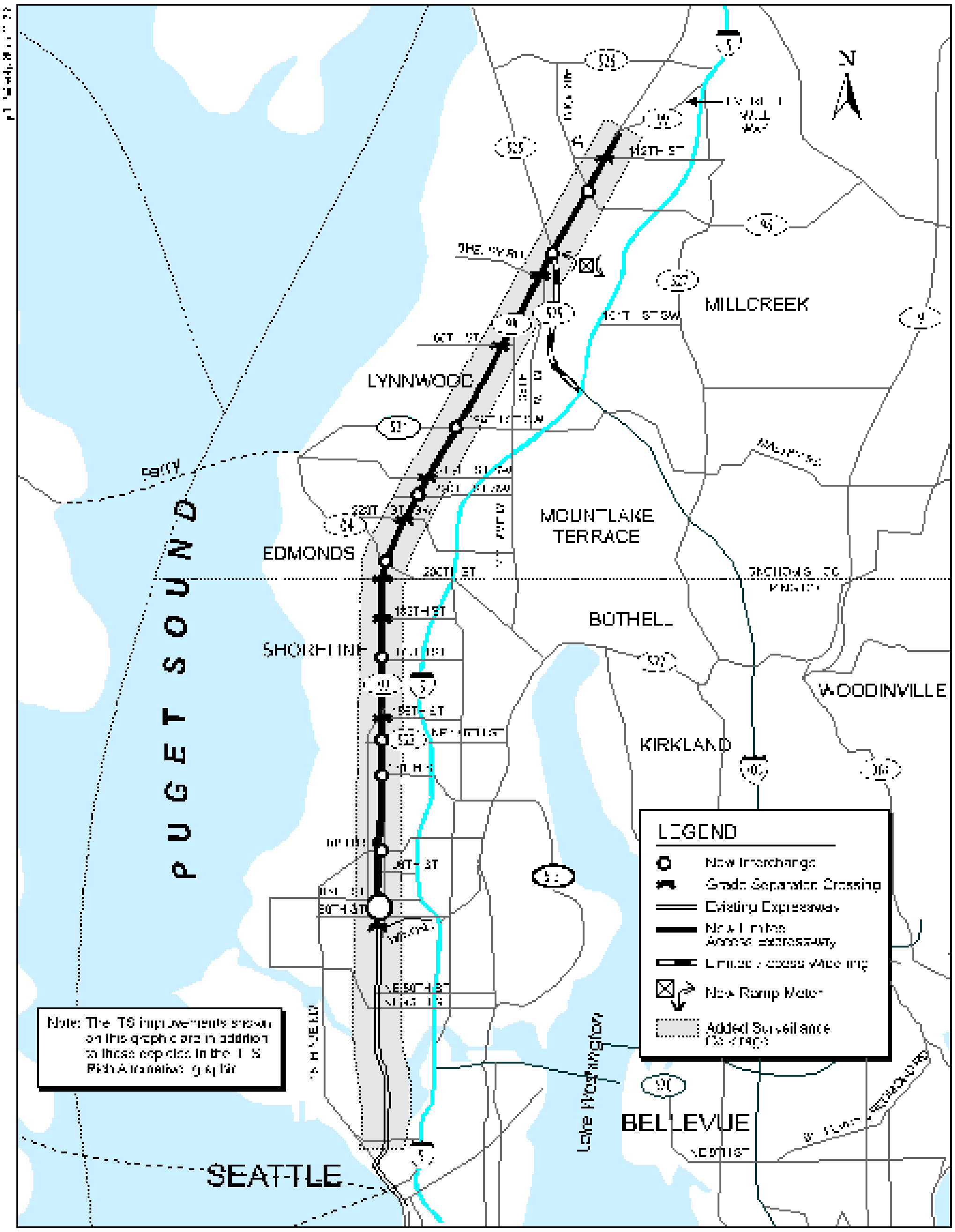


Figure 6-6. SOV Capacity Expansion Plus ITS Alternative

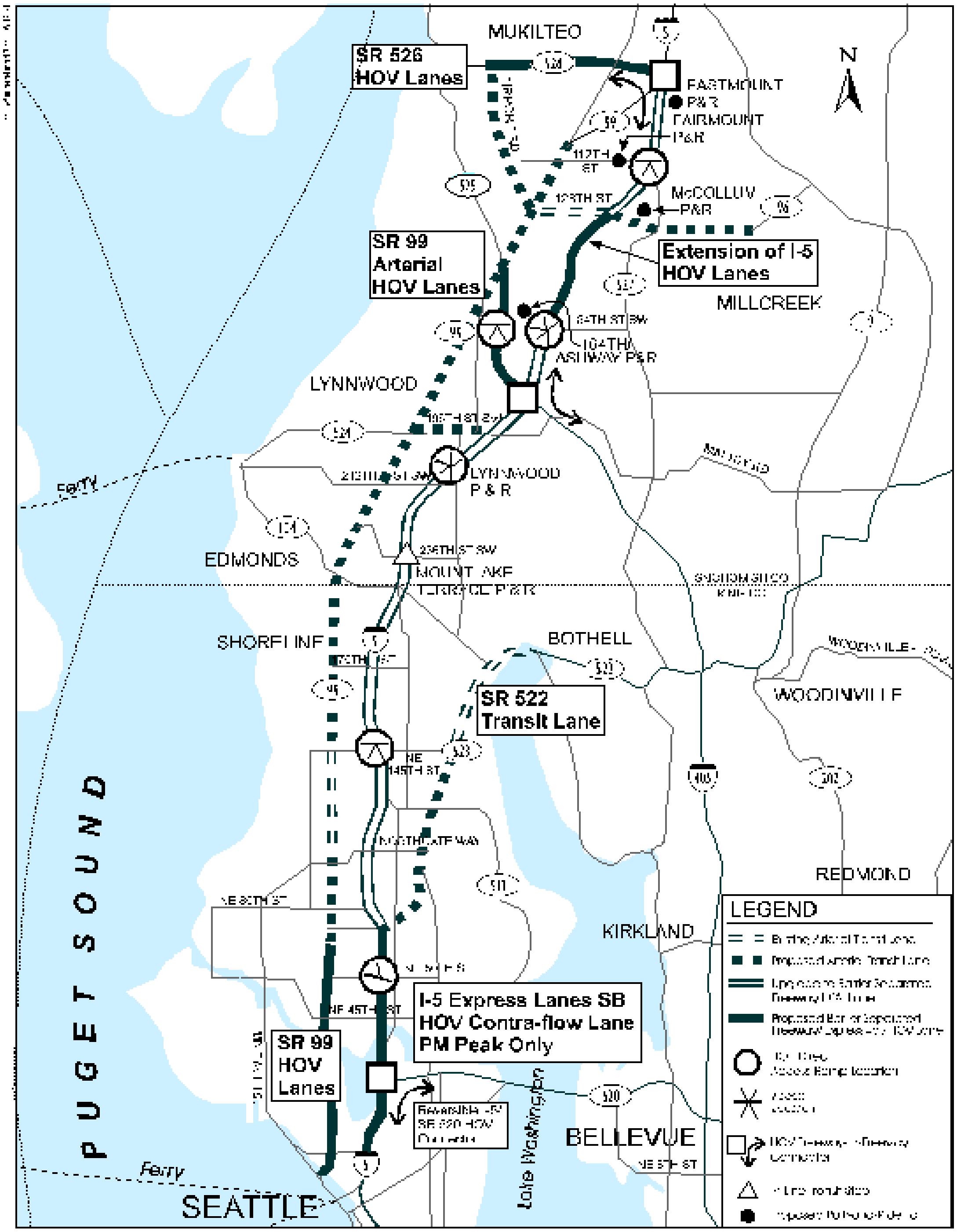


Figure 6-7. HOV/Busway Alternative: Roadway Improvements/HOV Direct Access

Other physical improvements which comprise the Busway/HOV Alternative are those included in the long-range plan for the region, including completion of HOV lanes on SR 99 and SR 526 and a transit lane on SR 522.

Figure 6-8 depicts the transit service improvements of the HOV/Busway Alternative. In keeping with the proposed RTA plan (Regional Transit Authority, 1996), nine new regional express bus routes would be added to provide access to Seattle and North King County centers. The routes would provide fast and frequent service (most would have 15 minute peak and 30 minute off-peak headways) throughout the day, connecting communities such as Lake Forest Park, Northgate, Shoreline and West Seattle to the region. The Everett to Seattle via I-5 route is considered to run with 10 minute peak and 20 minute off-peak headway. The express bus routes are bi-directional (i.e., serve both directions with layovers) and travel non-stop along expressway and major arterial stretches (the stops are indicated on Figure 6-8). Four new regional express bus routes would connect Snohomish County to such destinations such as Everett Community College, Alderwood Mall, Everett mall, Southeast Everett/Boeing, the Technology Corridor (Canyon Park), the University of Washington and Microsoft. The new regional express routes include:

- Everett to Seattle via I-5
- Everett to Seattle via SR 99
- SW Everett to Bellevue via SR 527
- Lynnwood to Bellevue via I-405
- Woodinville to Northgate via SR 522
- Northgate to Issaquah via I-5, SR 520, and I-90
- University District to Redmond via SR 520
- Seattle to Bellevue via I-90

6.3.6 HOV/Busway Plus ITS Alternative

This alternative combines the elements of the HOV/Busway Alternative with the elements of the ITS Rich Alternative in order to see their effectiveness when combined. The traditional improvements remain exactly as specified in Section 6.3.5. There are only very minor changes to the configuration of ITS strategies from the ITS Rich specification; these are attributable to the changes introduced by the construction and service characteristics of the HOV/Busway alternative. These changes are discussed below:

- The signal coordination/ramp metering system may need some very minor tailoring (changes in signal locations, operations plan adjustments, etc.) to account for new HOV direct access ramps. Boulevard to Stewart Street as proposed in the Puget Sound HOV Pre-Design Studies. This would require adding a new lane through the University District and lane conversion between the north end of the

Ship Canal Bridge and Stewart Street. A ramp at NE 42nd Street would provide bus access to the southbound contraflow lane.

The HOV lanes in the I-5/North Corridor would become an "HOV Expressway" by adding new direct access ramps to/from park-and-ride lots and bus flyer stops and barrier separating the HOV lanes from the general purpose lanes. HOV access would be provided to I-5 near the International District Station in downtown Seattle. A new freeway to freeway HOV connection would be provided by constructing a reversible HOV ramp between SR 520 and the I-5 express lanes. At the I-5 express lanes and NE 50th Street, a new HOV ramp would provide direct access to and from the North while at I-5/NE 145th, direct access ramps would be added to and from the south.

In Snohomish County, direct access/freeway-to-freeway HOV improvements would include:

- Direct access to/from the south and the north at the Lynnwood Park and Ride
- HOV-only interchange to/from south at 164th/SR 525
- Direct access to/from south at I-5/SW 128th Street
- Direct access to/from south at 164th/Ashway Park & Ride Lot/I-5
- SR 526 to I-5 HOV connection to and from the south
- I-5/I-405/SR 525 HOV connections

Other physical improvements which comprise the Busway/HOV Alternative are those included in the long-range plan for the region, including completion of HOV lanes on SR 99 and SR 526 and a transit lane on SR 522.

Figure 6-8 depicts the transit service improvements of the HOV/Busway Alternative. In keeping with the proposed RTA plan (Regional Transit Authority, 1996), nine new regional express bus routes would be added to provide access to Seattle and North King County centers. The routes would provide fast and frequent service (most would have 15 minute peak and 30 minute off-peak headways) throughout the day, connecting communities such as Lake Forest Park, Northgate, Shoreline and West Seattle to the region. The Everett to Seattle via I-5 route is considered to run with 10 minute peak and 20 minute off-peak headway. The express bus routes are bi-directional (i.e., serve both directions with layovers) and travel non-stop along expressway and major arterial stretches (the stops are indicated on Figure 6-8). Four new regional express bus routes would connect Snohomish County to such destinations such as Everett Community College, Alderwood Mall, Everett mall, Southeast Everett/Boeing, the Technology Corridor (Canyon Park), the University of Washington and Microsoft. The new regional express routes include:

- The introduction of arterial transit lanes will have an impact on the operation of the Transit Priority system along SR 99 and SR 522 and 196th Street, SW. Because transit vehicles now have their own lane, queue spill-back is likely to be less of a problem. The overall ability of the Transit Priority system to facilitate bus movement (according o the operations policies established) will be enhanced along these streets.

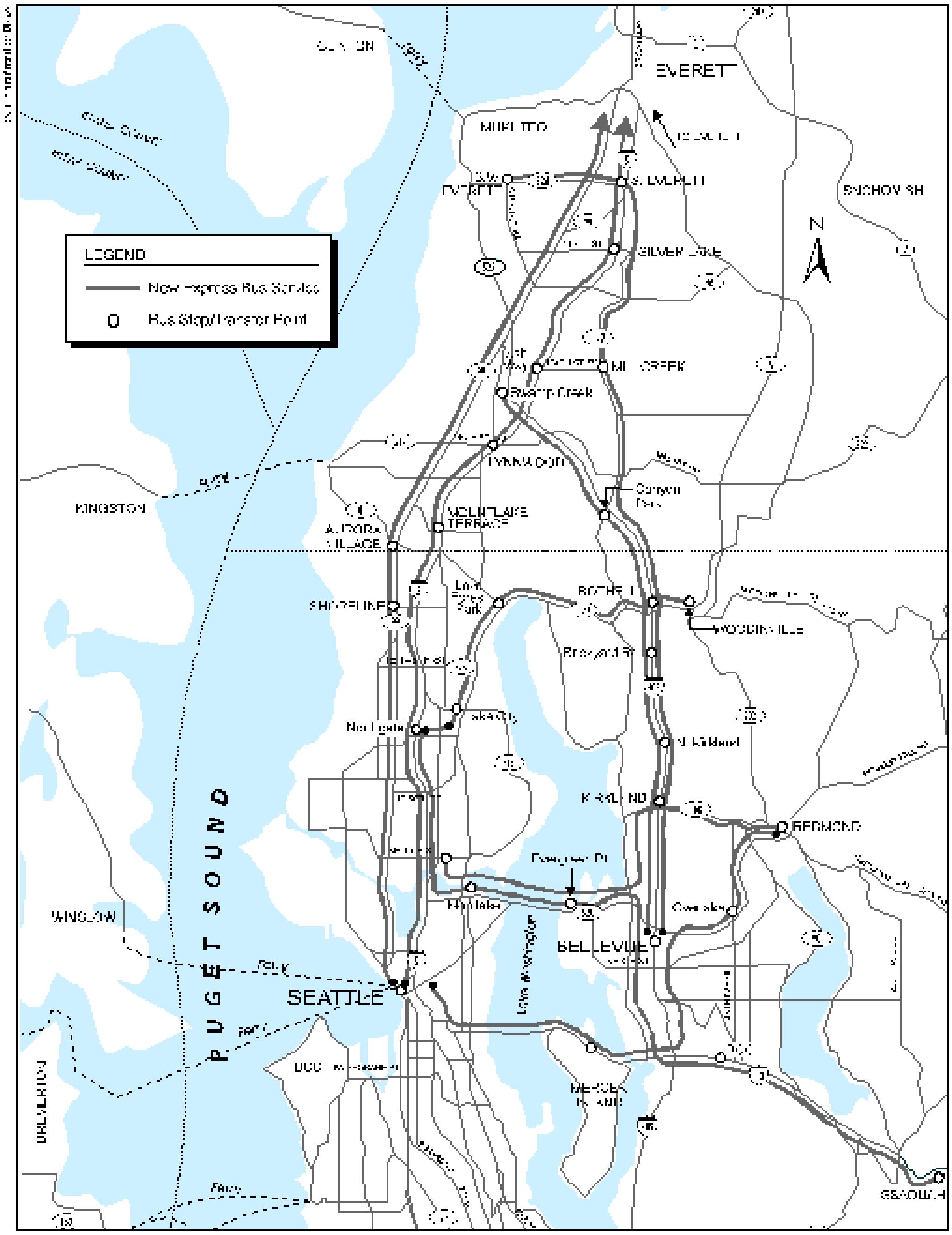


Figure 6-8. HOV/Busway Alternative: Regional Express Bus Service

7. Analysis Approach

The following section discusses the analysis approach developed to perform the shadow MIS study. Section 7.1 describes project goals and objectives including some rationale for the technical analysis approach and process carried out for the Seattle area case study. Section 7.2 outlines the steps of the process used in the case study. An overview of the regional process and the enhancements made for the study is provided in Section 7.3. An overview of subarea simulation is provided in Section 7.4 and details of how it is used to model ITS elements are described in Section 7.7. Section 7.5 describes the interface between the regional process and the subarea simulation. The development of representative day scenarios is discussed in Section 7.6. Section 7.8 presents the cost approach and assumptions.

7.1 Goals and Overview

The goals and objectives for the case study are:

1. **Develop an integrated model system that evaluates the unique aspects of ITS strategies (impacts/benefits/costs) along with more traditional corridor improvements.** Traditional corridor alternatives have in the past focused on capacity and other improvements designed to relieve expected or recurrent congested conditions. The analytic techniques, methods, and measures of effectiveness have as a consequence also focused on capturing the impacts on average travel and conditions. However, many of transportation problems, delays, and congestion that occur in the real world are the result of non-recurrent incidents, inclement weather, or operational inefficiencies. Traditional corridor study methods and measures of effectiveness tend to be insensitive to solutions such as ITS strategies designed to address problems arising from these non-recurrent and operational issues. ITS strategies focus primarily on improving operations and the transportation system response to changing conditions, improving reliability of the system, and letting travelers know the true condition of the transportation system (reducing knowledge gap between perceived and actual conditions).

   One central goal for the technical process was to develop a set of integrated methods that incorporate in the analysis the types of problems that ITS strategies are attempting to remedy and potential solutions. This includes the system's reaction to varying non-recurrent conditions and the impact of information. Another important aspect of this same goal was to implement the process in an integrated framework that can analyze the net effect of the traditional and ITS elements in an overall solution to the corridor's transportation needs. This is especially important since the impacts of each element in an overall corridor solution may interact producing results that are not simply the sum of the individual element improvements.

2. **Build upon existing models and techniques to show what can be done today.** The study also focused on building and testing evaluation methods that are based upon, but extend, the methods and techniques that exist today. A number of techniques are

available to practitioners today to incorporate ITS into ongoing corridor studies and MIS analyses. Regional Forecasting processes based upon the traditional four step travel demand process, which are typically used as the framework for MIS technical analyses, focus on the expected or average conditions. On the other hand simulation models such as those used by Mitretek to evaluate the National ITS Architecture explicitly address the variation in conditions, traffic operations, and availability of information within the system. These simulation models were also extended to address assignment and mode choice as part of the overall travel forecasting process (traditionally only assignment is carried out in simulation tools). They also tradeoff more precision and detail in the subarea with the size of the problem they can address. The challenge was how to combine and extend both of these modeling approaches into an integrated framework to study both traditional alternative and ITS strategies at the same time.

3. **Conduct a "shadow MIS" by analyzing a problem of similar size, scope, and complexity as might be found in actual MIS effort**. Often research is carried out on small test problems to develop prototype methods that may prove difficult to implement in actual studies. The size of real world problems is often larger than research test cases, or the alternatives much more complicated and "messy". An important aspect of the technical analysis was thus to base it on a "realistic" area, using base networks and models that might be found in actual MIS efforts. The study approach afforded the opportunity to experience and address problems and technical difficulties that practitioners might actually encounter. The study and alternatives chosen for analysis have been previously described in Sections 5 and 6.

4. **Produce Measures of Effectiveness and comparisons between the Study Alternatives that reflect typical MIS issues and capture the impacts of ITS strategies**. A key phase in any MIS is the development of the measures of effectiveness that are used to evaluated the alternatives under study and reflect the issues/concerns of those in the community making the decision. Typically, measures of transportation service, costs, mobility and system performance, financial burden, and environmental/community impacts are considered. These measures, however, are usually only calculated based upon the average weekday or expected conditions. Variation in conditions and the transportation system response to it is not part of the analysis and consequently does not enter into the decision process. Incorporating measures of variation is key to showing the benefits of ITS and other strategies focused on improving the operation of the system.

5. **Develop a methodology to define the representative day scenario data necessary to capture the conditions and effects of non-recurring congestion.** Previous studies have shown that ITS strategies can have significant impact on anomalous traffic conditions that, even though they are relatively rare, can contribute a disproportionate amount of delay and other costs. How to define a set of scenarios that capture these anomalous conditions and assess the transportation system's response to the problems they create (both with and without ITS) was a major part of the study effort.

6. **Identify areas where improved methods and/or tools are needed for this type of analysis and further research may be warranted**. Incorporating ITS strategies into the planning process and into corridor studies specifically is still in the early stages. This effort was never intended to provide the final answer on how to incorporate every possible ITS strategy under all potential MIS efforts. Rather, it provided an opportunity to understand what can be done with existing techniques, where the problems lie, and where to direct future development efforts.

7.2 Analysis Framework

A goal of the case study was to follow the analytic steps of a typical MIS study and use/develop methods applicable to an actual MIS effort. Issues and concerns that might actually arise in real world settings could then be experienced and addressed. Consequently, the steps followed in carrying out the case study were:

1. Definition of the MOE's to reflect important goals/objectives and reflect the impacts of the potential alternatives under study.

2. Development and testing of the travel forecasting process.

3. Development of database /network for defining the transportation alternatives and preparing data for the base year system validation.

4. Validation of both the regional and subarea simulation travel forecasting processes and their interface using base year data.

After validation, the development of the methods, techniques, and model parameters is complete. The resultant "analysis process" was then applied to the horizon year as follows:

5. Definition and refinement of alternatives.

6. Coding and representation of alternatives within the forecasting system

7. Production of the travel forecasts

8. Production of travel and cost related measures of effectiveness.

9. Calculation of environmental and other impact measures using post processing.

10. Evaluation analysis and comparison of alternatives.

These steps are discussed below highlighting the issues and concerns important to the evaluation of ITS strategies.

1. **Define Measures of Effectiveness**. The issues and concepts associated with defining the MOE's in a MIS to account for ITS have already been discussed in Section 3. Again, defining the Measures of Effectiveness to be used in the evaluation analysis is a critical

first step in any corridor study because it is the combination of measures and potential alternatives that determine what methods must be developed and used to forecast travel and other impacts for each alternative. If ITS impacts are to be captured in the analysis the calculation of the traditional MIS measures (change in travel time and cost, vehicle miles traveled, mode share) must be sensitive to the operation of the system and the variance of conditions. Additional measures should also be included to reflect the system's response to variation in conditions and changes in information.

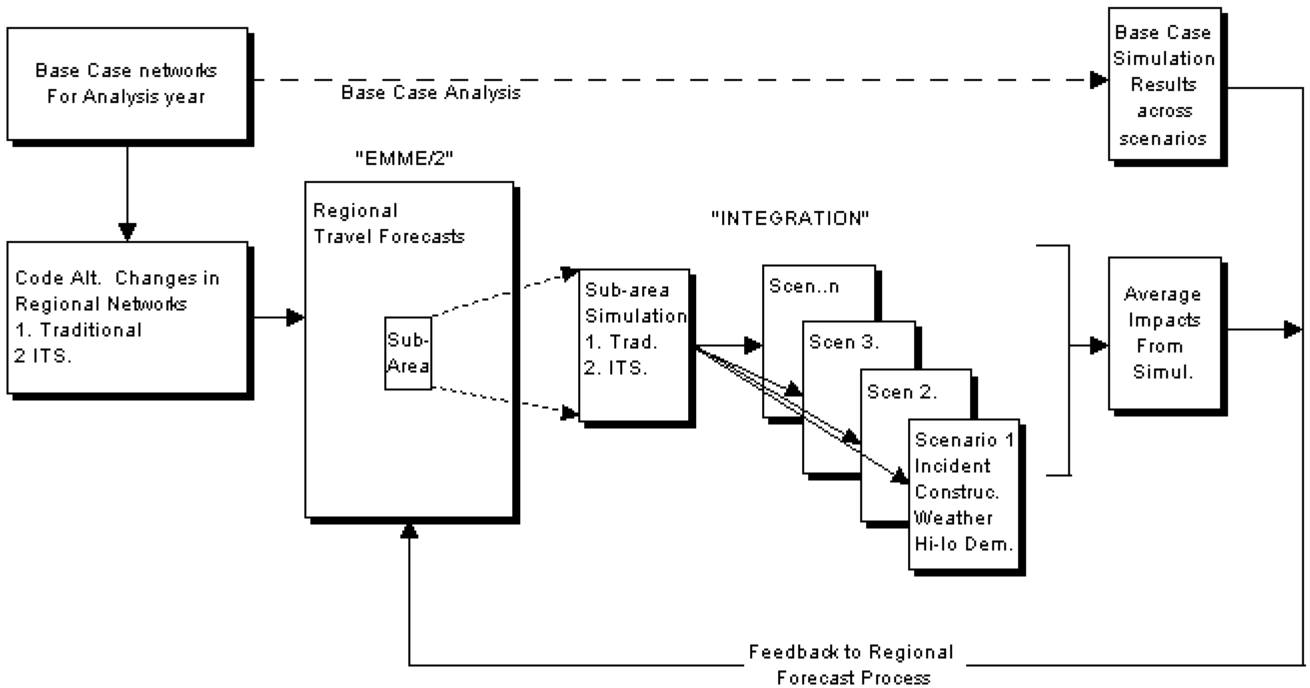
Consequently, early in the study substantial effort was spent in defining the desired set of measures and how they might be produced. Table 7-1 provides a list of candidate measures and those selected for incorporation in the study. The case study focused on the travel and cost related MOE's directly derived from the alternative definition and travel forecasting process. These included the traditional measures such as changes in travel time by mode, throughput, mode choice, vehicle miles traveled, and costs. Additional measures that would capture the operations and impacts of ITS were examined including deferred trips, incident delay reduction, standard deviation of travel times, and number of vehicle stops within the system. As discussed later in this section other equally important impact measures, such as changes in air quality, were not focused on as part of the study. While ITS alternatives are expected to yield different numerical results, the calculation is not explicitly a function of ITS and no methodological development would be included.

2. **Develop Travel Forecasting Process and MOE Production Macros**. Once the candidate MOE's are defined the travel forecasting process can be developed. The travel forecasting process is the overall set of analytic methods used to capture the changes in travel caused by each future transportation alternative. It provides the foundation for the measures of effectiveness calculation and alternative evaluation. In traditional MIS studies a regional network based travel forecasting process is borrowed or developed as the basic travel forecasting tool. Operational strategies or variations in conditions are not generally considered. In contrast, Figure 7-1 shows the travel forecasting process and analysis flow developed for the study. It includes:

Table 7-1. Impact Measures for Alternative Evaluation

Primary outputs/ measures	
	Travel time by mode (HOV,SOV,Transit)
	Throughput (person, vehicle)
	Mode choice , Trips by mode
	VMT by mode (HOV, SOV, Transit)
	PMT by mode (HOV,SOV,Transit)
	Peak Period Vehicle stops/starts
	Deferred Trips
	Capital costs
	O&M costs
Derived measures	
	Value of time savings
	Delay reduction (recurrent and incident)
	Mode shift from SOV
	Congestion index
	LOS by link
	Reliabilitiy and Variance reduction (Standard dev. of arrival times, travel times)
	Mobility Index
Alternate Measures Considered	
	Accidents
	Fatalities
	Air emissions
	Usefulness of information
	Energy consumed
	Equity
	Utilization of services (average vehicle occupancy, transit load factor)
	Number of person trips with error in route/mode choice. due to poor information
	Travel time/Best Information travel time
	Accessibility

- A regional forecasting process to predict the regional travel patterns and perceived/expected conditions.
- A subarea travel simulation to capture the operational characteristics of the subarea and the variation within the analysis period.
- Representative day scenario analysis to represent non-recurrent conditions
- Feedback to ensure that the impacts to expected conditions estimated in the subarea travel simulation are also reflected in the regional analysis.



Code Alernative in Regional Networks Based upon Detailed Definition

Regional forecast Process. Captures average "perceived" conditions for analysis period (type of day, time of day, ex. average weekday AM Peak 3 hour Period.) Regional travel patterns Regional Diversions

Initial Sub-area Traffic Simulation Captures re-current conditions, time variation within simulation period, traffic operations.

Scenario Analysis To Capture non-recurrent conditions, traveler information

Calculation of change in perceived conditions, statistics across scenarios

Feedback to regional models Based upon change from Base.

Figure 7-1. Analysis Flow Overview

In order to mirror a set of methods/processes used in actual MIS studies, it was decided to adopt the Puget Sound Regional Council's currently approved regional forecasting process as a starting point for the study's regional process. This travel forecasting application is implemented in the EMME/2 travel forecasting platform developed by INRO Consultants. The regional forecasting process provides the regional travel patterns, trips, mode shares, and average trip measures for each alternative.

Outputs from the regional analysis must then be interfaced with the more detailed analysis provided by the subarea travel simulation process. This level captures the time-variant and operational details of the transportation system. At this level the detailed traffic operations, queuing, and buildup/dispersion of demand is captured and the accuracy of the traveler's information on the system can also be represented. The subarea travel simulation was developed using the INTEGRATION 1.5x simulation package due to its ability to represent Advanced Traveler Information Systems (ATIS) and other key features (Van Aerde & Hellinga, 1995). INTEGRATION focuses its analysis around trips from each origin to each destination (similar to the regional models), but can also trace how vehicles actually move through the network. This is an important factor for incorporating mode choice, route guidance, and other ITS strategies in the analysis.

Figure 7-1 depicts the use of representative day scenarios for capturing the non-recurrent variation in demand due to incidents, weather, construction, and other events. Expanding the analysis to include the variation in conditions when incorporating ITS elements into the analysis is critical to capturing their true impacts. Each scenario is selected to capture a type of incident/occurrence representing a typical day that may lead to the traveler experiencing very different conditions and possibly a different travel choice. Figure 7-2 shows some of the issues that determine how/why the scenarios are selected.

An important consideration is the randomness of the event and its area of influence. The system response to a local predictable event such as construction may be very different to a global unpredictable event such as a snow storm.

Last, the interface between the regional forecasting process and the subarea travel simulation and feedback between the two are important components of the overall travel forecasting process. Because where people are coming from and going to is very important when providing and representing information in the analysis, the interface should not simply "cut" the simulation network from the regional system. Rather, a focusing approach is needed which preserves the ultimate origin and destination of each trip, the characteristics at each trip end, and the travel time/cost that occurs in reaching/leaving the simulation subarea.. Likewise, it is crucial to use a simulation system which maintains the origin, destination, and route of the trips in order to provide route choice and diversion information to them. As explained in Subsection 7.5 macros and procedures were developed to capture the trips traveling through the subarea and convert them to the subarea simulation zone structure.

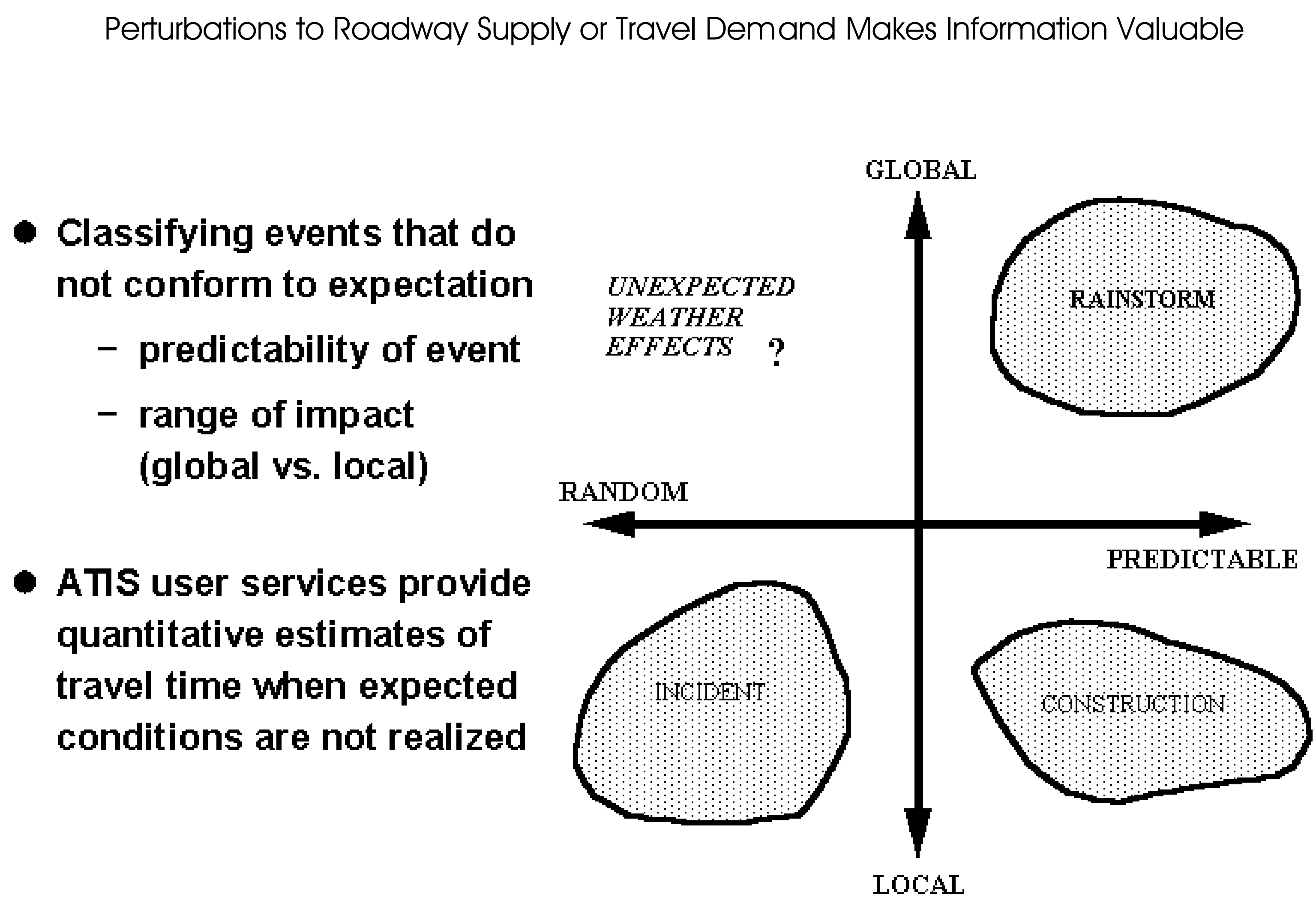


Figure 7-2. Importance of Scenario Definition

Procedures were also developed to produce focused networks converted to the INTEGRATION simulation software format.

Within the interface feedback between the two levels of analysis is important to capture how ITS services may impact expected, or average conditions. As shown in Figure 7-3, the improvements in reliability and/or variation may also have an impact on the perceived/expected conditions represented in the regional model system that can in turn influence the day-to-day travel decisions individuals make. If the chance that they will be an hour late when they take transit (due to missed transfers, unreliable service, or other factors) can be eliminated, the average travel time is improved and the likelihood that they will take transit increases. The results from the representative day simulations are therefore combined to estimate the change in expected, or perceived, conditions and fed back to the regional travel forecasting process.

3. **Develop Database/Network**. Initial network representation and data base collection/ development are also very important steps in establishing the analysis framework for an MIS. During this process the additional data and level of effort required to support ITS and other system operation evaluations will be significant. Networks used to support regional forecasting are typically coded to represent major facilities and travel movements under average conditions. Additional network detail is usually required for subarea simulation to capture turning bays and movements, interchange configurations, and traffic operations. Adding this detail requires additional data collection on signal location, signal timing, intersection design, turning restrictions, and other operational details.

   All travel and network performance information must also be broken out and collected for small time increments within the analysis period (every 5,10,15 minutes). Typically, regional models are validated to daily or peak period totals and more detailed information is not maintained within the regional data systems. To capture ITS benefits, information is also needed on non-recurrent events within the system and their impacts. This includes location and time of day of accidents, duration of accident related lane blockage, occurrences of significantly high or low demand, special events, severe weather, and construction. Collecting and merging this information into a consistent database can be a major effort.

   Checks should also be made to ensure that the data collected and network coding properly reflect the base conditions without the reductions in variability and operational improvements offered by ITS and other operational improvements. Often, regional model coding conventions presume the system is reliable and represent cases where there are no incidents or non-recurrent bottlenecks within the system. Examples include the absence of reduced capacities due to merge areas

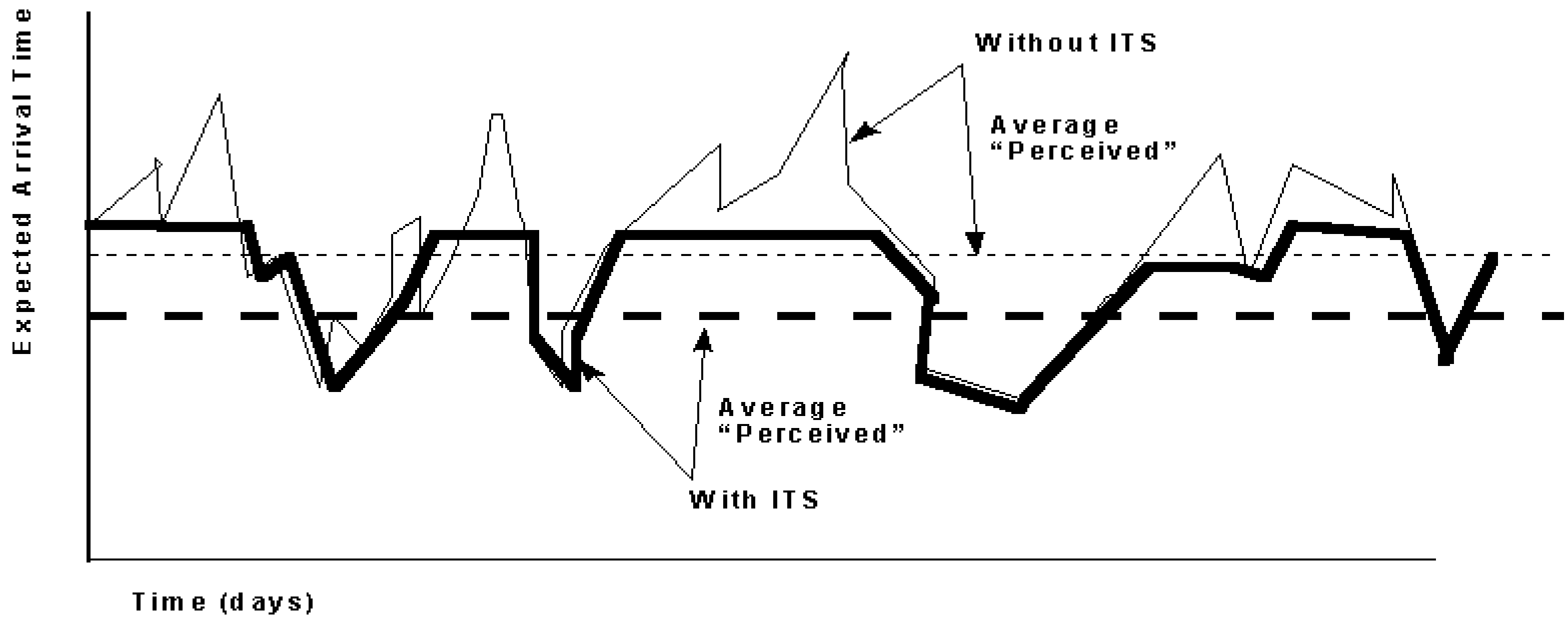


Figure 7-3. Importance of Scenario Definition

downstream of major entry points on freeways, the assumption of reliable transit service in coding expected transfer times, the friction (and lower speeds) on diamond HOV lanes due to parallel congested general purpose lanes, and the presumption in the coding of the general highway system that there are no incidents. If the initial coding already presumes that the system is performing reliably and without incident, then it is difficult to reflect the operational improvements provided by ITS strategies. If operational improvements are to be captured then the initial coding should be modified and the models re-validated to reflect the actual operating conditions within the system.

4. **Validate Travel Forecasting Process.** A key step in any MIS study is validation of the travel forecasting process. In the case study both the regional forecasting process and the more detailed subarea travel simulation were validated to 1990 conditions. The regional forecast process was validated to replicate the 1990 conditions originally observed in data obtained from PSRC. Checks were made to ensure that the enhanced process produced results similar to the PSRC 1990 validated model. The subarea travel simulation was also validated to capture the variation in volumes by time across the subarea borders and to reflect the percent of trips using each type of facility (I-5, SR 99, other arterials). The validation is explained more fully in Section 8.

5,6,&7. **Produce Horizon Year Alternative Forecasts**. Once the system is validated the horizon year forecasts by alternative can proceed. This includes the detailed definition of each alternative, it's representation and coding within both the regional forecast system and the subarea simulation, and the execution of the travel forecasting process. The same methods, coding conventions, and processes that were used in the validation must also be used in conducting the horizon year alternative forecasts. It is likely that many of the ITS elements being considered in the alternatives did not exist or were not implemented in the base (1990) validation year. In these used by the travel forecasting process should be estimated and input.

In traditional MIS studies, the alternatives are defined primarily by infrastructure and other physical improvements overlaid on the TSM network. In these efforts coding conventions developed in the validation can be applied to the alternative representation in a fairly straightforward manner. An issue associated specifically with the alternative definition and coding is the need for specifying an operations plan for each alternative. This may include signal phasing, priority schemes, ramp metering strategies, HOV restrictions, and other operational strategies. Since operations plans are a function of demand it is likely that base year (1990) operations will perform poorly in the future year. The operations plan in the subarea travel simulation may therefore need to be tailored to each alternative in an iterative fashion as part of the alternative refinement. Also some ITS elements may impact both the system response to changing conditions, and the average, expected, need capabilities of a particular network segment. One example is adaptive signal and coordinated signals along a road segment. When part of an alternative these systems need to be represented in both the subarea simulation (response to conditions and specific phasing principles), and in the regional forecasting networks (expected speeds and capacities).

8. **Produce Travel and Cost related MOE**. The measures of effectiveness can be separated into two categories. The first are travel and cost related that are the direct result of the alternative definition and the changes in travel behavior that implementing the alternative would produce. The second are the environmental and other social impacts of the alternative and its travel.

   The travel and cost related measures are the primary outputs of the travel forecasting process and include such measures as capital and operating costs, changes in trips between origins and destinations, mode share, travel times, and volumes (person and/or vehicle) on parts of the system. In an MIS all of the measures are calculated relative to the horizon year base alternative for evaluation (usually the TSM). Again, for the case study this was defined as the Do-Nothing/TSM alternative.

   The calculation of capital and operating costs raises a number of issues when comparing ITS strategies with traditional alternatives. In the study, the traditional alternative costs have been estimated using procedures and values derived from the Seattle area and previous WSDOT studies. All costs have been calculated as differences from the Do-Nothing/TSM Alternative and special care is being made to properly capture the fixed (capital) and operating and maintenance costs of the ITS strategies.

   With two model systems being used in the analysis to represent the same area, an issue arises as to which should produce the summary MOE's. For the case study all measures concerning average travel or expected conditions are obtained from the EMME/2 regional system. Conversely, all measures describing the variation in conditions and use of information by travelers in making their travel choices are obtained from the INTEGRATION simulation. Where conditions and measures are affected by both, the subarea simulation information is normalized to the regional forecast results for comparability.

   All of the MOE's are calculated over the full horizon year for each alternative. This includes both combining the regional travel forecast and subarea simulation results for an average weekday and expanding the average weekday values to annual statistics. Annual MOE's are estimated for an alternative as follows:

1. 3AM peak period subarea travel simulation impacts for an average weekday are obtained by combining the results of the representative day scenarios travel simulations[9].

2. The subarea travel simulation and regional travel forecasts for the AM peak period are merged to obtain system-wide impacts.

3. These results are expanded to average weekday values using the ratios obtained from the PSRC regional forecasting process.

4. The average weekday values are expanded to annual estimates based upon the relationships between average weekday and average daily values. Average daily values include weekends and holidays. Again, the relationships found in the PSRC regional process were used.

9. Calculate Environmental and Other Impacts. Other environmental and social impacts are typically calculated in an MIS study through post-processing of the travel forecasting, costs, and facility design/Right Of Way analyses. These include measures of accidents, air quality, noise pollution, water pollution, and equity. While the importance of these measures is recognized, it was decided to focus the study effort on capturing the primary outputs and measures estimated directly from the models. This is where the issues associated with capturing ITS in MIS analyses are and where the methods development was needed. The techniques required for the determining the environmental and other impacts should be similar weather ITS is or is not part of an alternative, and no new methods, or procedures were being developed to directly estimate these derived impacts. While these impacts are important and would be calculated in an actual MIS they were not addressed in this effort.

10. Alternative Evaluation and Comparison. The last step in the overall analysis process is the evaluation and comparison of the alternatives across all of the MOE's. In an actual MIS this would lead to the selection of a preferred alternative for incorporation into the region's transportation plan. It would also entail close inter-agency collaboration, and an active public involvement program in order to help the decision makers make their decision. As stated previously the case study focused on the development of the analysis methods and tools for comparison, was not part of an actual decision process, and therefore did not include these important interactions. It did, however, compare and evaluate the alternatives, especially the differences between the with and without ITS options.

7.3 Regional Travel Forecasts

The previous section described the analysis framework and the sequence of steps required for the MIS evaluation. This section and the next expand on the two major components within this

[9] The "average" weekday thus accounts for the variation in conditions and is not limited to recurrent conditions as in a typical MIS.

framework, namely the regional travel forecasting process, and the subarea travel simulation process. Figure 7-4 provides an overview of the interplay of these two processes.

Throughout the analysis the regional travel forecasting process leads the subarea travel simulation process. The regional travel forecasting networks are first established for each alternative (both in the validation year 1990 and the horizon year) and interfaced with the subarea travel simulation models. The regional process is then executed and the results fed to the subarea simulation process. Both processes require the definition and development of their respective transportation networks, specification of demand files, and definition of the appropriate analysis parameters for the year under analysis. The MOE's are derived from both processes, averaged across scenarios, and then compared as part of the alternative evaluation.

As indicated above the regional travel forecasting process provides the basic forecasts of travel and transportation services that are used as inputs into the subarea travel simulation, and also to assess shifts in overall travel patterns and impacts between MIS alternatives. The regional forecasts provide the most likely travel patterns/facility use based upon the average, or perceived, conditions of the transportation system for a given time-of-day period. They reflect the conditions the travelers expects to see based upon their experience and their resultant travel choices.

As stated, one of the objectives of the study was to carry out an "MIS like" study following processes that may be applied in actual MIS efforts. Consequently, the Puget Sound Regional Council's (PSRC) Regional Travel Modeling Process were adopted as the initial starting point for the regional travel forecasting system used in this study. EMME/2 travel forecasting package macros and programs, base transportation networks, and demographic files were obtained from PSRC in October 1996.

The PSRC forecasting process is described in detail elsewhere (Technical Report MTP-12, PSRC, September 1994; Travel Demand Modeling Workshop, PSRC, June 1994) This subsection provides an overview of the PSRC regional travel forecasting process and describes the enhancements that were developed to address the ITS services for the study.

The PSRC Regional Travel Forecasting process provides forecasts of zone-to-zone travel by mode (non-carpool vehicle, carpool vehicle, transit), purpose (Home Based Work, Home Based College, Home Based School, Non-Home Based, and Commercial Vehicle), and time-of-day (Total daily, AM 3 hour peak, PM 3 hour peak, and Off peak) for the four county PSRC region. As shown in Figure 7-5 the modeling area encompasses King County, the City of Seattle, Pierce County including Tacoma, Kitsap County, and Snohomish County. This area is represented using 832 internal traffic analysis zones and 18 external stations. The transportation system modeled within this area is shown in Figure 7-6 and includes approximately 550 miles of freeways and expressways, 675 miles of urban arterials, and 2650 miles of rural arterials. Local roads are represented by centroid connectors and there are approximately 1,050 miles of centroid connectors represented in the highway network.

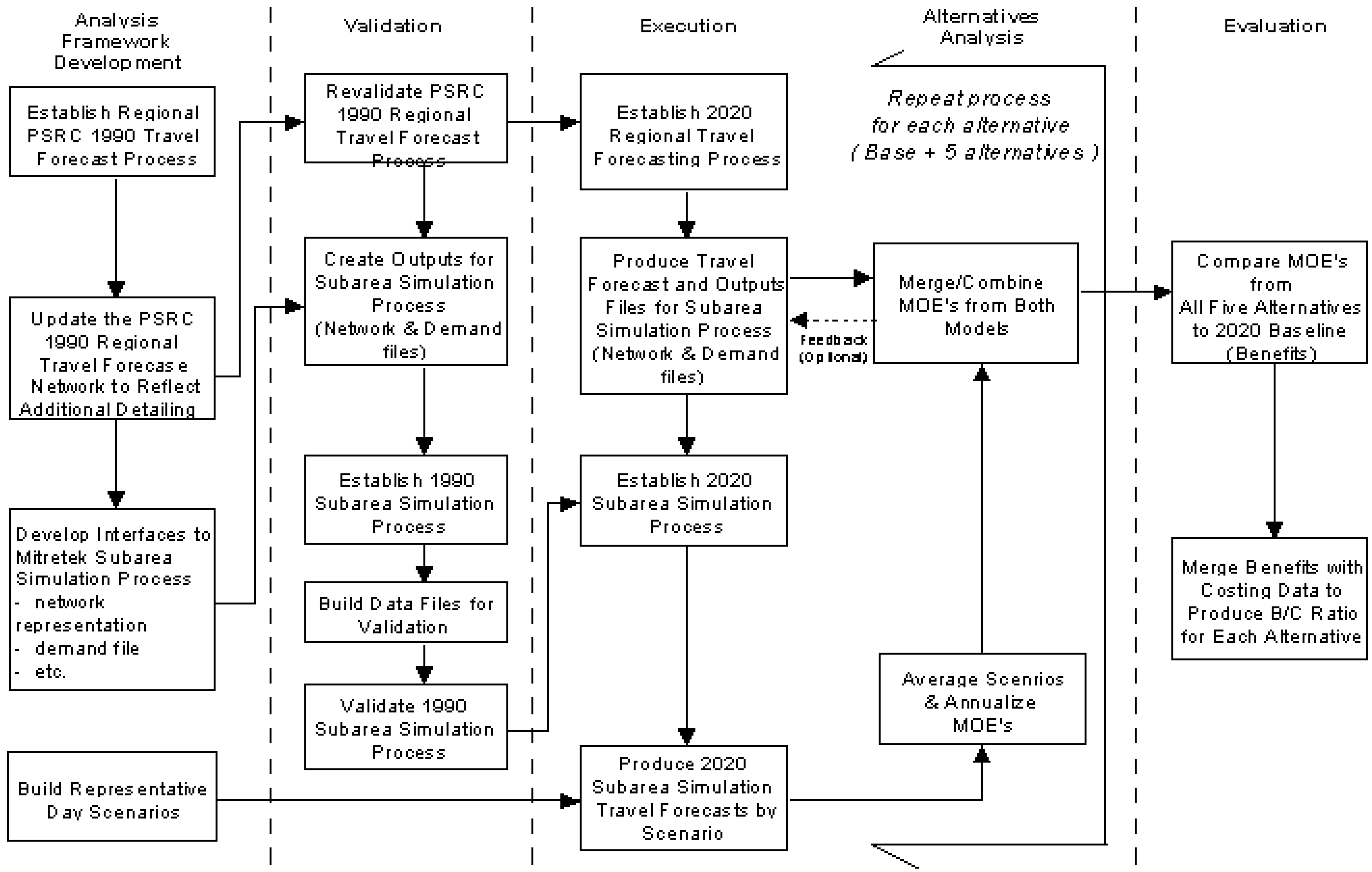


Figure 7-4. Travel Forecasting Process Development

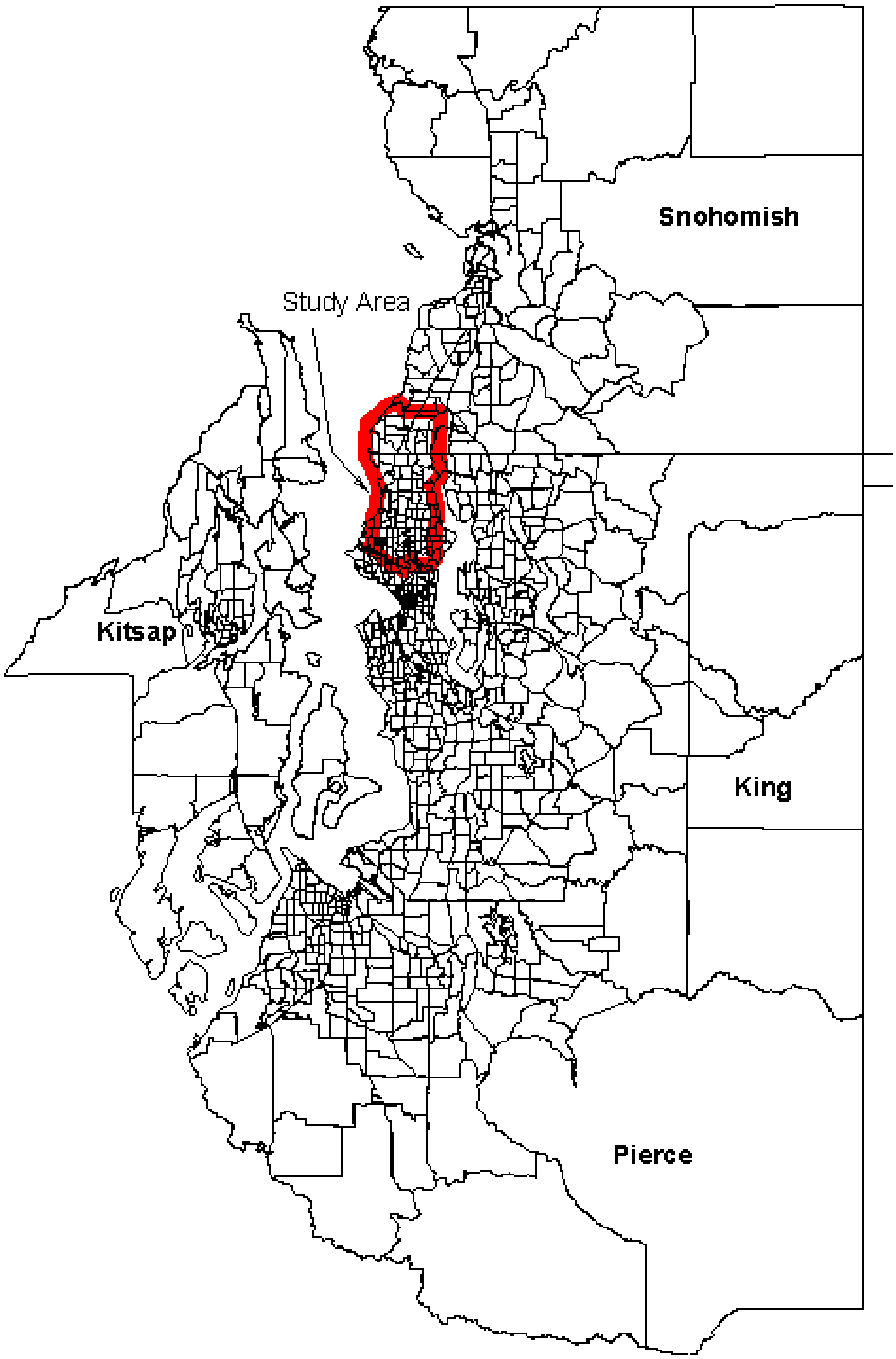


Figure 7-5. Regional Travel Forecast Area And Traffic Analysis Zones

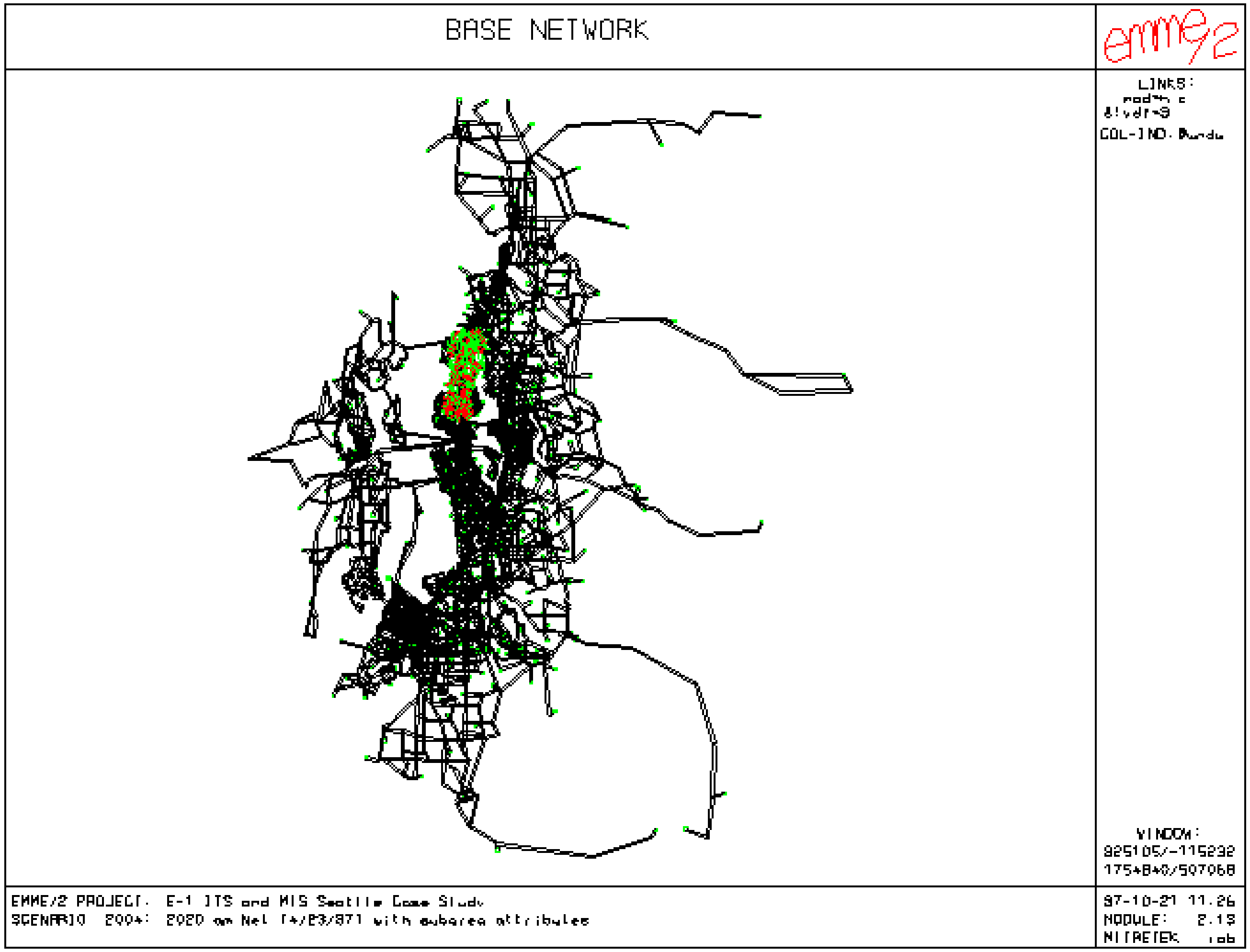


Figure 7-6. Regional Forecast Network

The PSRC Regional Travel Demand Process for the Seattle Region is a "traditional four step" travel forecasting process (i.e. 0. Land Use Forecasting and Data Preparation, 1. Trip Generation, 2. Trip Distribution, 3. Mode Split, and 4. Assignment). The process has been continually updated since it was first developed in the 1970s utilizing the Urban Transportation Planning System (UTPS) software platform. In 1989 the PSRC process was converted from the UTPS software platform (no longer supported) to the microcomputer based EMME/2 travel forecasting platform developed by INRO Consultants Inc. This provides additional capabilities including true simultaneous multi-class highway assignment, and multi-path transit assignment.

As part of the ongoing update and review cycle the complete PSRC process has also been undergoing a detailed review and enhancement during 1996 and 1997. Some of this work including the "Interim" trip generation model is discussed below. Additional enhancements including incorporating non-vehicle trips throughout the process, and enhanced trip distribution, and mode choice models are expected to become operational in the next year. The steps in the PSRC process are shown in Figures 7-7 and 7-8. Figure 7-8 includes a change in producing the initial trip tables and transferring the regional model output to the subarea simulation. Notable are the inter-connections between land use and transportation: PSRC's pioneering panel survey, the use of composite impedance's in land use analysis to account for the accessibility provided by all travel modes, and the numerous feedback loops from one step to another.

Land use forecasting is carried out approximately once every three years using the Long Range Plan transportation elements and national/regional econometric forecasts as inputs. It includes a detailed local review and approval of the small area estimates of land use and employment. The interrelationships between the land use and travel demand forecasting are shown in Figure 7-7.

The study's regional travel forecasting follows the process laid out in Figure 7-8. Once the land use forecasts are adopted subarea studies evaluate transportation options based upon them. The land use and trip generation data are the same as used in the 1995 Vision 2020 Update and Metropolitan Transportation Plan (MTP) approved by the PSRC General Assembly in May 1995. The Do-Nothing/TSM (Base) and Build Alternative networks are all based upon the PSRC 2020 NoBuild alternative (E220NB) which reflects the PSRC 1998 Transportation Improvement Program.

As shown in Figure 7-8, to produce an alternative's regional forecast, the alternative is coded, then 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). One slight modification to the PSRC model setups has been made for consistency across the alternatives. As reflected in Figure 7-8 the study process starts with the same "seed trip tables" for each alternative.

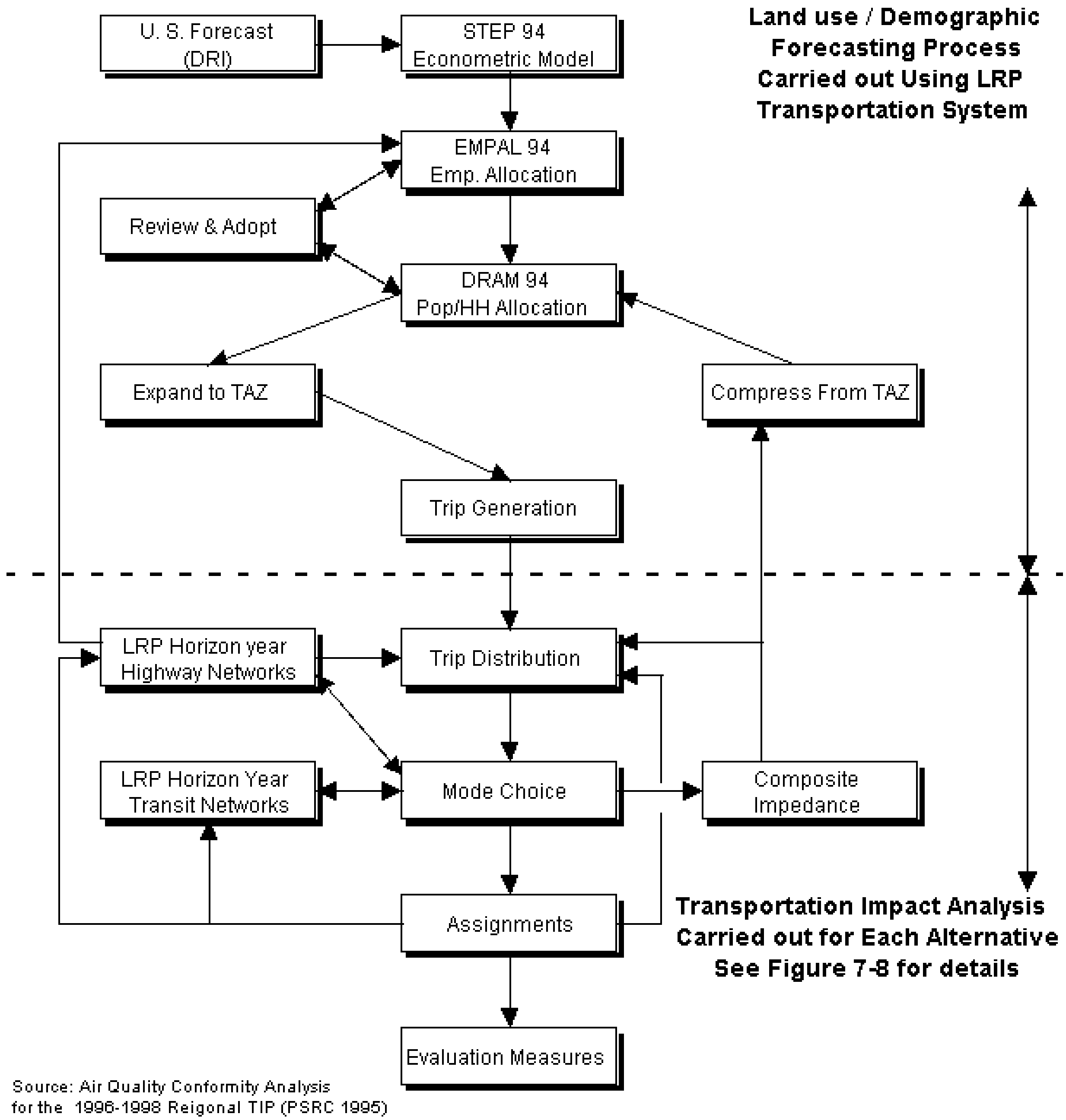


Figure 7-7. Overview of PSRC Regional Land Use/Transportation Forecasting Process

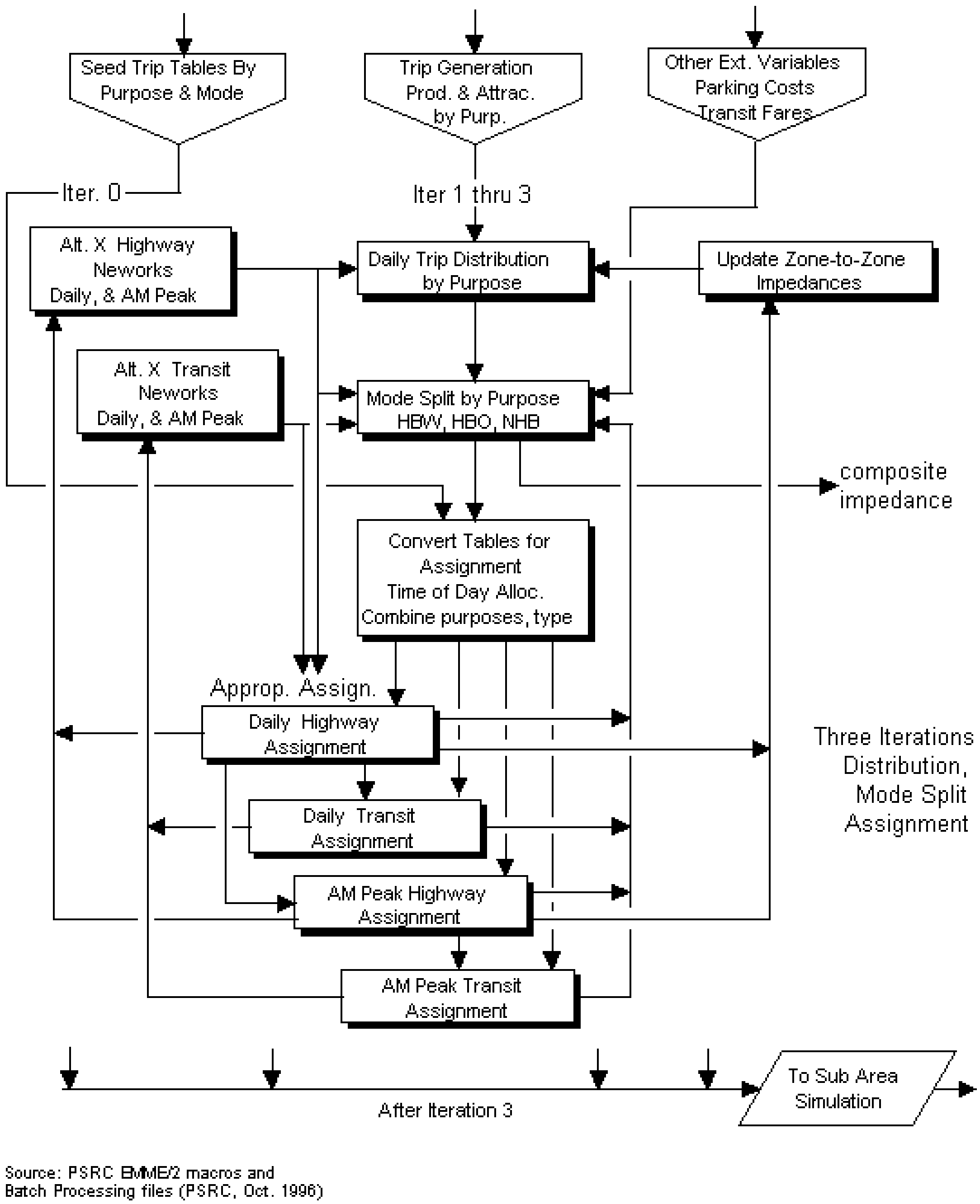


Figure 7-8. Regional Travel Forecasting Process for Case Study

This insures that the only differences in results are those due to the changes in transportation service and not variations in the starting conditions. Within the study corridor the PSRC networks and process have also been "enhanced" in several other ways to incorporate ITS strategies. These enhancements include making the geographic network link structure consistent with the subarea travel simulation (INTEGRATION) requirements; expanding the facility type, capacities, and speed codes for different types of ramps, HOV, and express facilities; and providing additional volume delay functions for ramp meters. The rest of this section provides a brief summary of the steps in the process[10] and more detail on the enhancements incorporated for the case study analysis.

7.3.1 Zonal Land Use And Socioeconomic Data

As shown in Figure 7-5 the land use and other socioeconomic data used in the PSRC forecasts are derived from the DRI national economic forecasts. The DRI national economic series provide inputs to the STEP94 econometric model which links the Seattle area's economic growth to the nation's and produces aggregate four-county jobs and personal income for 30 industrial sectors within the region. STEP94 also produces regional control totals for populations, households, labor force and unemployment.

The regional council then uses the DRAM/EMPAL land use/transportation analysis models to allocate the regional population and employment totals to 219 forecast analysis zones and ultimately the 832 internal traffic analysis zones (TAZs). These models feed back the estimated travel time for EMPAL's employment allocation and the composite time for DRAM's population/household allocation to capture the transportation and land use interaction. While not exercised for this study, the models could be employed to capture the long term changes in induced demand and land use produced by ITS strategies as a part of a regional plan update.

The PSRC also collects data to support its model development activities. It has completed a four-year household diary survey and plans are underway for another wave of the Puget Sound Transportation Panel Survey (six waves of the panel survey have been conducted). Other inputs supplied by PSRC include screen line counts, parking costs, and transit fares.

7.3.2 Trip Generation

Based upon the employment, households, and other socioeconomic data, trip generation provides the daily trips produced and attracted to each zone by purpose. PSRC has recently completed a major update of its trip generation model based upon the 1985 - 1988 cross sectional travel survey and two waves of the Puget Sound Transportation Panel longitudinal survey (DKS & Associates, Trip Generation Update, June 1994). The "Interim" trip generation models forecast "motorized trips for the current PSRC process." An additional set

10 The following is summarized from the MTP-12 technical report (PSRC, September 1994); and the 1994 Travel Demand Modeling Workshop Notes (PSRC, June 1994).

of rates including non-motorized trips (bike and walk) were also estimated for ongoing model development work.

The trip generation models for zonal trip productions and attractions both use cross classification and provide trip rates for each cell in the cross classification matrix. The trip production models produce daily person trip productions for Home Based Work (HBW), Home Based College (HBCOLL), Home Based Shop (HBS), Home Based Other (HBO), Home Based School (HBSCH), Non Home Based trips (NHB). Commercial vehicle trips (COM) are also produced. All of the home based trip purposes use a cross classification of Size of Household (1,2,3,4+) and Household workers (0,1,2,3+) to determine trip rates. The Non Home Based trip productions must use nonresidential variables in their estimation and are thus set equal to the NHB attractions.

The trip attraction models produce the daily trips attracted to each zone for the same trip purposes as in the production models. The attraction models are also cross classification models based upon number of employees by type of employment and three activity density categories. A comprehensive comparison of trip attraction models around the country was made as part of the trip generation model update. The rates were adjusted to reflect this comparison and to match the regional totals from the recent households surveys. This resulted in an increase of NHB trips from 2.15 trips per household in the previous model to 2.64 trips per household. The attraction rates for households in general were lowered.

Special generator trips are also estimated for the Sea-Tac Airport, Fort Lewis/McChord, the Seattle Center, the Kingdome, and the Tacoma Dome. In the PSRC process the special generator trips are added after trip distribution and are allocated proportional to the HBW trips to/from the zones where the special generators exist.

As stated, the trip productions and attractions were provided by PSRC as part of the land use/demographic data for the analysis years (1990 and 2020). They, consequently, remained fixed across the traditional and ITS alternatives.

7.3.3 Transportation Service Representation

The transportation system and the service that it provides for each alternative is represented for the regional travel forecast within the EMME/2 travel forecasting platform. EMME/2 is a network transportation analysis package that simulates an alternative using the following basic elements: (1) Nodes and Traffic Analysis Zones (TAZs); (2) Links; (3) Turns; (4) Modes; (5) Transit Vehicles; and (6)Transit Lines. Nodes represent point locations within the transportation network such as intersections, transit stops, or park and ride lots. Traffic Analysis Zones and their centroids are special nodes within the system that represent an area where travel demand is generated or attracted. Any network forecasting system simulates the travel between TAZs. Travel within each TAZ such as a local neighborhood is not represented and considered “off network”. Links connect two nodes and represent road segments, transit facilities, or access/to from a TAZ. Each basic element has a number of attributes such as x and y coordinates, length, lanes, and capacity, which are used to describe a service or facility of the alternative being modeled.

A transportation option is represented by four sub-networks within an alternative's EMME/2 databank: (1) a daily highway network, (2) a daily transit network, (3) an AM Peak Period highway network, and (4) an AM peak period transit network. Midday and PM highway networks are also maintained for time-of-day assignments, but are not required to carry out the basic alternative forecasts. Details of how PSRC codes and represents different system elements within for each of these sub-networks within EMME/2 can be found in the PSRC documentation and EMME/2 manual.

There is no universally correct set of coding rules that are appropriate for all purposes. Rather, the principles used and network detail represented depend upon the intent and use of the forecasts being made and the alternatives/alternatives under investigation. The PSRC network representations have been developed for regional analysis associated with long range plan and policy analysis and air quality conformity determination. This subsection focuses on the enhancements made to the PSRC basic coding procedures for the case study in order to:

Capture the subarea and network detail. Regional coding conventions are developed at the level of regional options and may be insensitive to many proposed changes within a corridor analysis such as interchange design, inclusion of ramp meters, and HOV design. Consequently additional network detail and coding conventions were added.

Represent the elements of both the traditional and ITS alternatives under study. Many of the options and tradeoffs under investigation may not be defined in the regional coding conventions. Additional features may also need to be added to represent the system sensitivity to elements of the alternatives under study. Thus, coding conventions were made to represent facilities such as barrier separated HOV lanes and diamond versus cloverleaf interchanges. Extra attributes were also added to facilitate the identification and representation of traditional elements and ITS strategies such as Advanced Traffic Management Systems (ATMS) and Priority Bus corridors.

Be consistent with the coding requirements of the subarea travel simulation model and its interface to the regional travel model. One of the major functions of the regional process in the study is to provide information and networks to the subarea travel simulation. As discussed elsewhere the regional process and subarea travel simulation represent travel through their networks very differently. In order to minimize differences and distortions between the two systems it was decided to represent an alternative's network as consistently as possible within the two systems. Thus, network detail was added to the regional (EMME/2) model system as required by the subarea travel simulations (INTEGRATION) coding conventions.

Based upon the above the following enhancements to the basic network representation were made: (1) addition of new facility types to represent ramps, local access, and special facilities; (2) addition of new volume delay functions (VDFs) and other functions to represent the new facility types; (3) addition of EMME/2 Extra Attributes on nodes, links, and transit lines to identify the corridor subarea and to facilitate modifications for ITS strategies; and

(4) detailed coding of interchanges and other divided separated facilities for consistency with INTEGRATION and to better represent details within the corridor.

Tables 7-2 through 7-4 provide the basic link characteristics used by the PSRC process and the additional facility types, VDFs numbers, and extra attributes. Table 7-2 describes the additional link types defined for the study networks which include High Level of Service (LOS) Ramps, Low LOS Ramps, Ramp Meters, Local Access Links, HOV Bypass Ramps, Freeway HOV Diamond Lanes, Freeway Barrier Separated HOV, Arterial HOV, and Ferry. As explained below, the additional ramp definitions were added to allow detailed coding of the interchanges and divided facilities within the study corridor. The HOV definitions are used in the HOV/Busway alternative. The Ferry and Freeway HOV Diamond Lanes and Express links currently exist in the PSRC networks and their facility type code simply acts as an identifier in the evaluation of the alternatives and in the simulation analysis.

The standard and extra attributes coded for links in the network are also shown in Tables 7-3 and 7-4. Additional attributes are coded to allow special processing of specified links within the system. The three types of identifier serve unique purposes: identify links to allow for special pre-processing of the link attributes, identify links and nodes as part of all facilities within the simulation area, and identify links that are used to facilitate the representation of the ITS services within the study corridor. The special preprocessing identifier @nramp, for example, is used to modify the capacity of the main lanes on freeways which are downstream of ramps without ramp meters. The capacity of these lanes was lowered by 5% from the line haul freeway to account for capacity reduction due to weaving. (See Van Aerde & Baker, 1996).

By far the most significant effort in enhancing the networks for the study was spent in detailing all interchanges throughout the corridor and in fully expanding both I-5 and SR 99 throughout the subarea. The coding conventions used are shown in Figure 7-9. This effort was carried out to provide a one-to-one link correspondence between the regional EMME/2 networks within the subarea and the corresponding INTEGRATION simulation network and to provide geometric consistency between the two systems. Because of the regional level of analysis and the large area and amount of road system covered, many regional forecast processes such as PSRC's simplify interchange representation to a single node. Subarea travel simulations, because they address operational detail require network coding that is more representative of the actual physical layout and geometry of the system . For example, regional network models typically require lanes with different vehicle restrictions on the same roadway to be coded as separate parallel links (general purpose, HOV, express).

Dummy links with 0 or very short distances and times are used to allow movements between the parallel links. Dummy links may also be coded to trace specific movements such as turns through an intersection. These dummy links can be problematic in simulation systems since simulations track a vehicle through space and time and must "store" the vehicle within the network at all times. The dummy links create an artificial bottlenecks and queue buildups. It

Table 7-2. Additional Facility Types for Case Study

	Name	Description	Facility Types	Allowable modes*	Capacity per lane	Initial Speed	Other Notes
1	High LOS Ramp	Ramp connection with free merge at entry and exit	7	hbc	1200	**35**,45,55	Initial speed depends upon level of to and from facilities
2	LowLOS Ramp	Ramp connection with control at exit	8	hbc	900	**25**,30	Initial speed depends upon level of to and from facilities
3	Ramp Meter	Link with Ramp Meter at exit	9	hbc	900	25	
4	Local Access Link	Neighborhood diversion for access to expressway where direct ramp does no exist (SR-99)	10	hbc	900 * 5 lanes	20	assume several access points thus lanes set to 5
5	HOV Bypass Ramp	Ramp/lane for HOV bypass around Ramp Meter	7,8	hb	1200	**35**,45,55	Initial speed depends upon level of to and from facilities
6	Freeway Diamond HOV	Freeway HOV in diamond lane (painted stripe) configuration	11	hb	1500	52	Base PSRC coding
7	Freeway Barrier Sep. HOV	Barrier separated HOV with controlled access/egress	11	hb	1500	65	removes friction from parallel GP lanes
8	Arterial HOV	HOV lane (striped) along Arterial	11	hb	= par. GP lanes	= par. GP lanes	Will have some delay due to lights and rt.turns
9	Arterial Transit Only	Transit only lane (striped) along Arterial	11	b	= par. GP lanes	= par. GP lanes	Allows buses to bypass queue's at intersections
10	Express	Express Lanes	12	hbc	1800	55	Same as PSRC but with identifier
11	Ferry	Represent ferrys crossing the Puget Sound	13	hbc	Veh/boat	Actual	Facility type added for network checking
	*Modes	h = HOV b = Bus c = Passenger car					

Table 7-3. Link Attributes

EMME/2 Batchin/Batchout Link Record (See additional variable record for other link variables)
Modified PSRC Auto Network

Field	Variable	Unit	Start-End	Format
1	CARD		1	1
2	ANODE		2-8	I7
3	BNODE		9-15	I7
4	LENGTH	Miles	16-22	F7.2
5	MODES ALLOWED		23-34	13A1
6	LINK TYPE		35-38	I4
7	LANES		39-42	I4
8	VDF (VOL. DELAY FUNCTION)		43-46	I4
9	UL1 (LOS E CAPACITY)	vehicles/hour/lane	47-54	I8
10	UL2 (INITIAL TIME)	Minutes	55-62	F8.2
11	UL3 (FACILITY TYPE)		63-70	I8
12,13,14 . . .	EXTRA ATTRIBUTES		71 . . .	

Notes

CARD = EMME/2 card type: a = add, d = delete, m = modify, t = initialize, c = comment.

ANODE = "From" Node #. All EMME/2 links are coded as one way.
Check Available Node List if you are adding new node.
1 - 850 = PSRC Traffic Analysis Zone
851 - 1000 = PSRC Network Node
1000 - 9999 = PSRC Network Node
10,000 - 99,999 = Node added for Interchange Expansion

BNODE = "To" Node #. See ANODE Description.

LENGTH = Measured Distance in miles
Be sure to use Decimal point!
Do not use distance calculated from X and Y Coordinates

MODES = Modes allowed on Link:
h = carpool, c = general use (car)
b = bus, r = rail, f = ferry
w = walk to transit, a = drive to transit

LINK TYPE = EMME/2 Link type
90 = Normal
Other = Screenline #

LANES = Number of DIRECTIONAL Lanes available during time period
Number of boats per hour for Ferry Links

VDF = Volume Delay Function number to use for link

PSRC

DY	MD	PM	AM	
9	9	9	9	Auto Access
10	47	49	50	Auto
20	31	30	30	Ferry
40	40	40	40	Transit Only

NEW

DY	MD	PM	AM	
12	22	32	42	High LOS Ramp
13	23	33	43	Low LOS Ramp
14	24	34	44	Ramp Meter
15	25	35	45	Local Access

UL1 LOS E CAPACITY = EMME/2 average through capacity at LOS E in vehicles per hour per lane for roadway links in vehicles per boat for ferry links

UL2 INITIAL TIME = Initial time on Link used in first pass of assignment. free flow or posted speed in Daily Network. Daily Assigned Speed in Am, Pm,... Networks

UL3 PSRC FACILITY TYPE = Facility Type used by PSRC expanded for ramps, etc.

PSRC
1 Freeway
2 Expressway
3 Urban Arterial
4 One Way
5 Centroid Connector
6 Rural Arterial

New Ramps
7 High LOS Ramp
8 Low LOS Ramp
9 Ramp Meter
10 Local Access

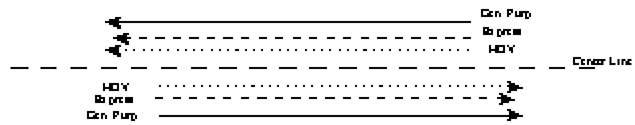
Other
11 HOV Lane
12 Express Lane
13 Ferry

EXTRA ATTRIBUTES
See Extra Attribute Page.

Table 7-4. Summary of Extra Link Attributes

Name	Type	Description
@nramp	Link	Link is downstream of Normal (no ramp meter) ramp
@hovtp	Link	Type of HOV facility (freeway diamond, freeway barrier separated, arterial HOV, Arterial transit only
@suba	node	Subarea identifier for nodes
@wndw	Link	Subarea identifier for links
@cape	Link	Copy of link capacity in baseline (no ITS) networks
@time0	Link	Copy of initial travel times in baseline (no ITS) networks
@itscr	Link	Type of advanced traffic control
@trnpr	Link	Transit priority Link
@cross	Link	Link upstream of transit priority link
US1	Trn Seg.	Travel time savings per mile along segment due to transit priority

1. Expand interchanges and separated facilities to represent simulation model coding conventions. Use right hand rule with HOV lanes, express lanes, and General purpose lanes always coded from in to out..



2. Expand Interchanges in the corridor to reflect potential movements. Examples are provided below.

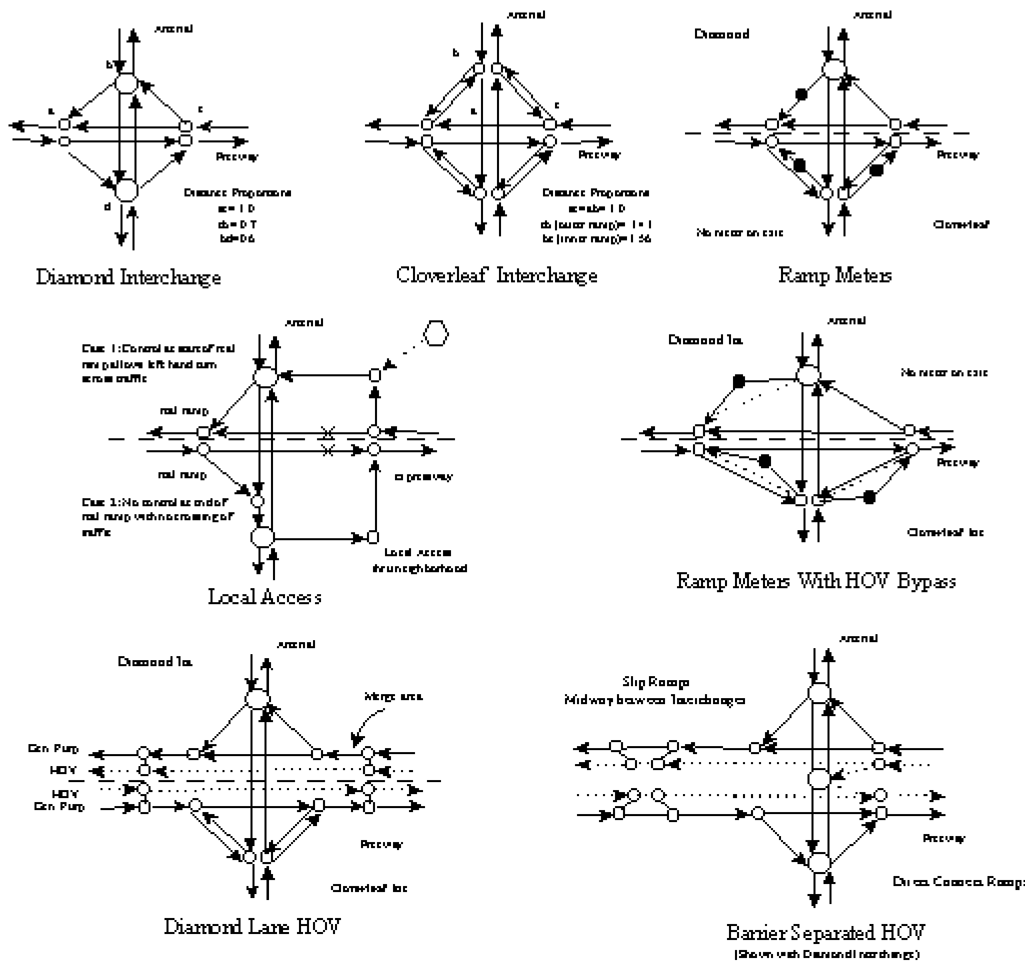


Figure 7-9. Detailed Network Coding Geometry

is also very important when feeding information back between the two systems to minimize differences in assigned flows, paths, and other results that may be caused simply from differences in coding detail.

As shown, the major enhancements to the base coding methods/processes took place within the highway networks. The transit networks were also updated to account for the additional network detail and then theenhanced 1990 validation system was compared/validated against the 1990 PSRC model results as well as real world data to ensure that no major distortions to the forecasting process were introduced due to the enhancements.

Last, a number of other enhancements were made to enable the representation of ITS services including such elements as ramp meters, coordinated signal systems, bus priority and advanced transit management.

7.3.4 Trip Distribution

Trip distribution allocates the trips produced in each zone to the trips attracted to each zone across the region and the travel "friction" or impedance between each zone pair. The PSRC process currently uses EMME/2's two dimensional balancing module to implement a doubly constrained gravity model. This model requires that for each trip purpose both the total productions leaving a zone and the total attractions coming to a zone are preserved in the process.

The congested AM Peak Period travel times are used as impedances for HBW and HBCOLL trips while the average daily congested impedances are used for the other trip purposes. The factors reflecting the relative desire to travel for a given travel time to reach a destination (friction factors) have also been adjusted to account for the new trip generation models, the Census Transportation Planning Package, and Puget Sound Transportation Panel surveys. The process also uses "K factors" to adjust to/from specific areas.

While very few changes were made to the trip distribution models during the study validation process, the resultant distribution of trips does change due to the study alternatives and ITS strategies. As shown in Figure 7-8 three iterations of feedback between the assignment models and trip distribution are carried out to allow the results of each alternative to reach equilibrium. The changes in capacity, delay, and congestion resulting from each alternative are thus fed back and reflected in the final travel patterns.

7.3.5 Mode Choice

PSRC's mode choice model(s) allocates the motorized person trips among available transit and auto modes and sub-modes. Because of the different trip characteristics (time, cost, potential for use) transit is divided into two sub-modes: (1) Walk access, or those transit trips within walking distance of the initial boarding stop; and (2) Auto access, or park and ride trips where the transit riders must drive to their initial boarding location. Likewise, the auto vehicle trips are divided into sub-modes by auto occupancy (Drive alone, 2, 3, 4+). The Home Based Work Trips may either use or not use the HOV facilities based upon their auto occupancy and the modeled HOV restrictions (currently set at 3+ for the 2020 forecasts) and the mode choice model accordingly outputs carpool and non-carpool vehicle trip tables separately for assignment. The PSRC process also uses separate mode choice formulations based upon trip purpose. Separate models are used for : the Home Based Work and College trips; Home Based Other; and Non-Home Based trips.

The PSRC mode choice models are multinomial logit models in structure, which allocate the trips for each origin and destination to available modes based upon:

the characteristics of the travelers (as represented by the origin and destination zone demographic and economic data)

the characteristics of the trip (purpose, time, cost, available modes, number of transfers)

the characteristics of the modes available for the trip (time and costs for each mode).

These are reflected within the utility calculations for each mode within the logit formulation and the probability of choosing each mode is then estimated as:

$$P_{ijm} = \frac{e^{-Utility_{ijm}}}{\sum_{m} e^{-Utility_{ijm}}}$$

Where:

P_{ijm} = Probability of mode m for trip from i to j

$Utility_{ijm}$ = Relative "Value" of using mode m from i to j

Function of travel times and cost for mode m

The parameters used to calculate the utilities for each mode choice model (HBW, HBO, NHB) are shown in Table 7-5.

The regional mode choice models are used to estimate the mode shares and vehicle trips that occur under average weekday conditions, based upon the traveler’s past experiences and perceptions of tradeoffs between modes. In this study how these mode choices vary in response to traveler information, incidents, weather conditions, and other varying conditions is explored as part of the subarea simulation analysis by the HOVSHIFT extension to the INTEGRATION simulation system. The regional mode shift model formulations as shown in the logit equation and Table 7-5 provide the basic form for the HOVSHIFT implementation.

Table 7-5. Mode Choice Utility Coefficients

Utility=mode specific constant + Coefficient(1)*Variable(1)+Coefficient(2)*Variable(2)...

Home Based Work	Auto								Transit							
Mode	Mode Specific Constant				Hwy Excess	Hwy Run	Hwy Cost	Park Cost	Walk Acc. Time	Wait One	Wait Two	Trn Run	Auto Acc Time	Trn Fare	TXFR	Auto Acc Penalty
Auto	Inc1	Inc2	Inc3	Inc4	By Auto Occ.	0.028	0.008	0.115								
1	1.9145	-0.149	-0.783	-1.9402	-0.08	"	"	"								
2	2.2816	0.5857	0.3182	-0.4718	0.283	"	"	"								
3	2.5986	1.2197	1.008	0.7962	0.357	"	"	"								
4+	2.8026	1.5277	1.622	1.7062	0.507	"	"	"								
Transit									0.06	0.06	0.06	0.028	By Acc.	0.008	0	By Inc.
Walk Acc.									"	"	"	"	0	"	"	0
Drive Acc (Inc 1)									"	"	"	"	0.19	"	"	0.944
Drive Acc (Inc 2)									"	"	"	"	0.19	"	"	-0.111
Drive Acc (Inc 3)									"	"	"	"	0.19	"	"	-0.243
Drive Acc (Inc 4)									"	"	"	"	0.19	"	"	-0.109

Home Based Other	Auto									Transit							
Mode	Mode Specific Constant				Hwy Excess	Hwy Run	Hwy Cost	Park Cost	Hwy Dist.	Walk Acc. Time	Wait One	Wait Two	Trn Run	Auto Acc Time	Trn Fare	TXFR	Auto Acc Penalty
Auto	Inc1	Inc2	Inc3	Inc4	by Auto Occ.	0.02	0.008	0.03	by Auto Occ.								
1	-0.244	-1.1798	-1.6601	-2.5076	0.133	"	"	"	0								
2	0.7783	-0.1194	-0.5383	-1.408	0.133	"	"	"	0								
3	0.9024	-0.0817	-0.6768	-1.3376	0.429	"	"	"	0.039								
4	1.7975	0.9491	0.623	-0.2439	0.429	"	"	"	0.039								
5+	1.8303	0.981	0.5519	-0.2128	0.429	"	"	"	0.039								
Transit										0.06	0.07	0.08	0.02	By Acc	0.008	0	By Inc.
Walk Acc.										"	"	"	"	0	"	"	0
Drive Acc (Inc 1)										"	"	"	"	0.2	"	"	1.9557
Drive Acc (Inc 2)										"	"	"	"	0.2	"	"	1.6492
Drive Acc (Inc 3)										"	"	"	"	0.2	"	"	1.7559
Drive Acc (Inc 4)										"	"	"	"	0.2	"	"	1.5538

Non Home Based	Auto					Transit							
Mode	Bias Constant	Hwy Excess	Hwy Run	Hwy Cost	Park Cost	Walk Acc. Time	Wait One	Wait Two	Trn Run	Auto Acc Time	Trn Fare	TXFR	Auto Acc Penalty
Auto	by Auto Occ.	by Auto Occ.	0.02	0.008	0.02								
1	-3.5067	0.144	"	"	"								
2	-2.3751	0.197	"	"	"								
3	-1.3312	0.373	"	"	"								
4	-0.9128	0.482	"	"	"								
5+	-1.5653	0.876	"	"	"								
Transit						0.04	0.04	0.04	0.02	0.1977	0.008	0	By Acc.
Walk Acc.						"	"	"	"	"	"	"	0
Drive Acc.						"	"	"	"	"	"	"	2.1971

The time and cost coefficients are used in the simulation's logit formulation. The other zonal and interchange information on parking costs, income, destination, auto ownership and other factors is then combined to produce a matrix containing the portion of the utility for each mode that does not vary with the travel times and costs. These matrices are input into the simulation's mode choice analysis and remain constant during the simulation period. The regional mode shares are also used to validate the simulation mode choice analysis for average day conditions. This is explained in more detail in subsequent sections.

Assignment

The assignment phase of the regional process assigns both the auto vehicle and transit trips to the highway and transit networks respectively. As shown in Figures 7-7 and 7-8, four sets of assignments are made for each alternative forecast (initial and three iterations for feedback). Assignments are carried out both on a daily basis and by time period. Prior to the assignments the trips must first be converted from production and attraction format to origin destination format and also separated by time period. Trip productions are associated with the home (or base end) of the trip, while trip attractions are associated with the activity for which the trip is made. The daily commute to and from work, for example, is thus represented as two productions in the residential zone and two attractions in the zone of work. These must be converted to an AM trip with origin in the home zone and destination at the work zone, and a PM trip with the origin and destination reversed. Table 7-6 shows the factors applied to the initial and return trips (transposed matrix) by purpose.

Prior to the auto assignment adjustments must also be made to convert from the assigned period to hourly volumes. In the PSRC process the assigned volumes are adjusted within the Volume Delay Function (see below) in order to estimate an hourly volume/capacity ratio and update the congested impedance for each link. The period to hourly factors used are shown in

Table 7-6. Time-of-Day Conversion Factors

	Production to Attraction Factor				Attraction to Production Factor				Origin to Destination	
Assignment Table	HBW	HBO	NHB	Commercial	HBW	HBO	NHB	Commercial	Local School	Through Trips
Daily Non Carpool	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.04	1
Daily Carpool	0.5	n.a.	n.a.	n.a.	0.5	n.a.	n.a.	n.a.	n.a.	n.a.
Am Peak Non Carpool	0.3625	0.1475	0.0795	0.035	0.023	0.018	0.006	0.035	0.04	0.08
Am Peak Carpool[1]	0.6	n.a.	n.a.	n.a.	0.15	n.a.	n.a.	n.a.	n.a.	n.a.
Daily Transit	0.5	0.5	0.5	n.a.	0.5	0.5	0.5	n.a.	n.a.	n.a
AM Peak Transit	0.3625	0.1475	0.0795	n.a.	0.023	0.018	0.006	n.a.	n.a.	n.a

1. AM peak Carpool factor greater than .5 reflects adjustments to account for addition non-work HOV trips

Table 7-7. Assignment Period to Hourly Adjustment Factors

Assignment Period to Hourly Volume Adjustment Factors								
	Daily		AM Peak		PM Peak		Off Peak	
	No. of Hours	Hourly Factor	No. of Hours	Hourly Factor	No. of Hours	Hourly Factor	No. of Hours	Hourly Factor
Auto	24	0.08	3	0.4	3	0.375	18	0.125
Ferry	24	0.08	3	0.34	3	0.34	18	0.125

Assignments are carried out using the EMME/2 system (EMME/2 User Manual, Version 8.0, INRO Consultants, 1996). Auto assignments use a multiclass equilibrium assignment process and assign two vehicle trip tables during each pass: Carpool vehicles (3+ auto occ.), which can use all auto facilities, and Non-Carpool, which are not allowed to use the HOV system. A central element in the equilibrium assignment process is the Volume Delay Function (VDF), which updates a link's impedance (travel time) based upon its capacity and assigned volume. The basic VDF function used by the PSRC process is:

$$IMP_{new} = IMP_0 * (1 + .15 * (PtoH * Vol / CAP) ** 4)$$

Where:

IMP_{new} = Updated link impedance, or travel time

IMP_0 = Initial impedance, or free flow time

PtoH = Period to Hourly conversion factor

Vol = Assigned volume for the period

CAP = Level of Service E Hourly Capacity for Link

As discussed in the previous sub-section on network representation (7.3.3) the within the corridor VDFs for facilities such as ramp meters have also been modified to reflect queues and other ITS related conditions. Other modifications to capacities and free flow speeds are also introduced to reflect the impact of traffic management systems and bus priority.

Transit Assignments are carried out after each highway assignment. The transit assignments are also carried out within the EMME/2 system. They update the transit travel times based upon the congested highway times and perform a transit multipath assignment for both the auto access (park and ride) and walk access trips leaving each zone. The transit assignments provide the number of transit riders on each segment of the transit system and the boardings, alightings, and transfers at each transit stop. They also provide walk and park and ride access information.

After the final iteration and assignments the regional model results are converted and linked to the subarea travel simulation. As explained earlier the regional travel forecasts provide information on the average, or expected, conditions and assume stable (static) state throughout the analysis period (whether daily, AM peak period, peak hour, PM peak period, or some other time period). The subarea travel simulation accounts for traffic operations, queue formation and congestion build up, and other variations in conditions throughout the analysis period and more directly models many of the problems that ITS strategies are designed to solve.

7.4 Subarea Travel Simulation

The Subarea Travel Simulation directly addresses many of the issues/problems that ITS strategies are designed to solve, and are not readily captured by the regional "expected condition" travel demand system. Simulations (as opposed to the regional four step travel forecasting) explicitly represent small time increments throughout the analysis period and track how travelers move through the transportation system at each small time slot. Thus, they capture the variation in conditions over the analysis period, and how/where congestion builds up and disperses. They also analyze how the transportation system responds to non-recurrent situations and conditions throughout the day due to accidents, other incidents, weather, or construction. They include the explicit representation of signals and traffic operations to capture the creation of queues and upstream/downstream bottlenecks on the system. They also have the ability to represent how much assistance in response to the actual conditions of the network that a traveler may have from reports, ranging from information about accident locations to detailed route guidance.

The travel simulation platform employed in the case study subarea simulation process is INTEGRATION Ver. 1.5x5. INTEGRATION is a product of MVA and Associates in Blacksburg, Virginia. Mitretek Systems has also contributed an array of support modules to assist in its use. The variant used is an augmented version of the simulation used in the National ITS Architecture development effort (Mitretek Systems, June 1996), the TravTek field operational test evaluation (Van Aerde, et al 1995), and in modeling efforts for the estimation of ITS benefits (Mitretek Systems, June 1997). The strength of this particular version of INTEGRATION is in its representation of a wide range of ATIS user services, although ATMS and other ITS elements may also be reflected.

This version of INTEGRATION is a meso-scale traffic simulation. At this modeling scale, each vehicle is tracked individually and is identified by a range of attributes such as trip origin and destination, ATIS-capability class, and whether or not the vehicle acts as a travel time probe in the network. Vehicle interactions, however, are modeled in a simpler fashion than micro-scale simulations such as TRAF-NETSIM or THOREAU. Lane assignments within a link are not made, nor are car-following rules used to capture congestion effects. Instead, time-variant macro-scale impedance functions are employed with a simple queuing representation to model congestion effects. This lower level of detail in modeling vehicle interaction allows for a computationally more efficient approach.

INTEGRATION Ver. 1.5x5 is differentiated from the current MVA commercial product, Ver. 2.0, which models car following. Testing at Mitretek indicates that Ver. 1.5x5 simulates networks of the size of the North Corridor model at 15-25 times faster than Ver. 2.0.

The information that INTEGRATION requires is similar to that developed for the regional networks, but with more detail on the physical and operating characteristics and the time of travel. INTEGRATION uses five separate input files to input its basic information: (1) Nodes, (2) Links, (3) Signal Plans, (4) Demands (travel), and (5) Incidents. As in the regional networks the node and link data describe the geometric characteristics of the road network. However, since queuing and storage of vehicles on the link during red phases of signals is an important aspect of simulation, properly capturing the correct physical length of the segment is much more critical in the simulation networks. The travel demand for the simulation period is also similar and is obtained directly from the regional model system. In the simulation, however, for each origin and destination, the trips by purpose are combined. The resultant overall travel demand for each origin and destination is then subdivided based upon the probability of trips starting in each time segment.

The signal plan and control information must also be developed and input for the simulation process. Typically, this information must be developed and input from a source other than the regional networks. For the Seattle networks the infomation on the location of the signals, phasing, and types of controls and coordination was obtained from the Washington State DOT, the North Seattle Traffic Management Center, and local agencies. One issue that must be addressed when developing future signal and phasing inputs for future alternatives is what overall plans to use for the base alternative since the future phasing cannot be observed. The recommended approach is to collect information on the current existing phasing in the field and develop a simulation using these values, then develop a second simulation using the routines in the simulation package that optimize the signal phasing and note the differences in performance. This difference is assumed to represent inherent decay that occurs in any static phasing plan due to day to day variations, changing conditions, or changing policies. In the base for the future year the system is first optimized and the same degradation is then applied to the base phasing plan to represent the base conditions. This produces more realistic results than assuming optimized phasing at all times for future operations and allows the benefits of different advanced traffic management schemes to be reflected in the analysis.

The incident files allow incidents to be described and their impact examined within the simulation system. When the incident occurs, the number of lanes, facilities it impacts, and its duration are input for each desired test case.

The case study subarea network modeled in INTEGRATION is large-scale for a traffic simulation. The network contains 2,250 links and over 1,000 nodes. During the 2020 morning peak period, roughly 350,000 vehicles are tracked traversing the network. Depending on the scenario modeled, there may be as many as 75,000 vehicles concurrently on the network. In addition, over 150 signals are modeled at the intersections of major facilities in the corridor. The 150 signals capture only a fraction of the complete number of signals in the corridor, but signalization is coded where signals are known to exist at intersections within the EMME/2 regional network representation. On a 200-mHz Pentium-based PC, the subarea traffic simulation requires around 90 minutes to execute a complete AM peak period, depending on overall vehicle load.

Parameters on link characteristics are derived primarily from the EMME/2 regional model. For example, link capacities are consistent between the two models. For the links in the network where signalization is added to the simulation network, link capacities in INTEGRATION are adjusted so that the resulting average link capacities remain consistent between the two models. In this respect, the similarity in link characterization between the two models is a significant factor in representing the network in a consistent manner at both modeling scales. This feature is also exploited in the representation of ITS elements.

An important element of the study was the development of a time variant HOV-Mode Shift module for the subarea simulation, HOVSHIFT. This module estimates the HOV mode shares by time segment to account for the build up and dispersal of congestion within the AM peak period. Conditions may be almost at free flow at the start of the peak period, building to breakdown conditions, and then falling off later in the morning. These different conditions by time segment may have particular impact on carpooling and mode choice tradeoffs. While the regional model assumes a single expected time for the analysis period (AM peak), the HOVSHIFT component captures the variation in conditions by time segment within the analysis period.

HOVSHIFT uses as inputs the subarea simulation travel times by time segment for paths using HOV facilities and paths that are barred from using HOV facilities , and the zone-to-zone peak period person trips that are eligible for carpool formation. Vehicle trips ineligible for carpool formulation are also obtained from the PSRC regional process for background assignment. HOVSHIFT then determines the carpool and non-carpool share of trips for each origin, destination, and time segment using the following LOGIT formula:

$$MS_{HOV,i,j,s} = \frac{e^{(\alpha t_{HOV,i,j,s} + K_{i,j})}}{e^{(\alpha t_{HOV,i,j,s} + K_{i,j})} + e^{(\alpha t_{SOV,i,j,s} + K_{i,j})}}$$

where:

$MS_{HOV,i,j,s}$ = Carpool Share for i, j, s

$K_{i,j}$ = Non travel time utility component

$\alpha t_{mode,i,j,s}$ = Travel time coefficient * Travel time for mode i, j, s

i, j, s = origin i, destination j, time segment s

The travel time coefficient is obtained from the regional mode choice models. The utility coefficients represent all of the origin and destination specific non-travel time variables that impact mode share such as income, parking cost, employment type, and car ownership. They are determined by matching the HOVSHIFT results summed across all time segments for each origin-destination pair to the regional mode choice model outputs. For each MIS alternative, the subarea simulation components are run iteratively to convergence as shown in

Figure 7-10 below. Again, the resultant HOV mode choice for the simulation period is constrained to match the regional value for each origin-destination pair, but now varies for each time segment based upon the shifts in travel times and costs throughout the peak period[1].

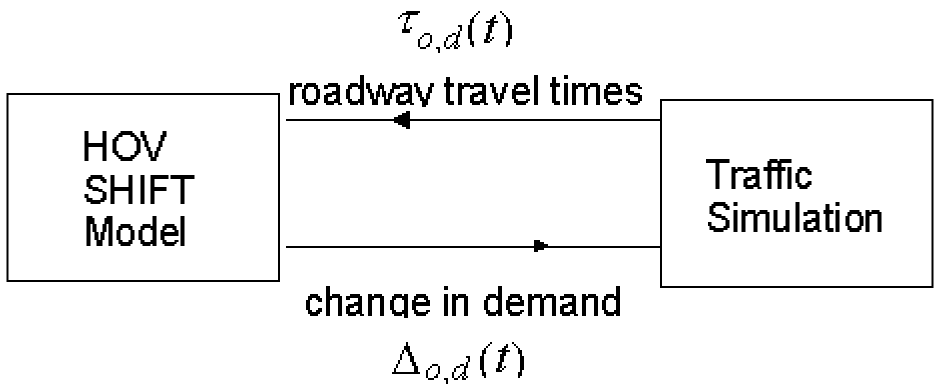


Figure 7-10. Iterative Approach in the HOVSHIFT Framework

The true benefits of including this module and time sensitivity in the simulation include estimating the impacts of information on carpool choice, as well as the impacts of operational changes throughout the peak period. While a separate rail transit vs auto time variant mode choice module has been developed (Mitretek Systems, June 1996) future work will extend the real time analysis to full multi-modal mode choice.

7.5 Regional Model to Subarea Travel Simulation Interface

The regional travel forecasting system provides link data , analysis period demand files, and information on the expected, or average conditions (flows, speeds, trips in the period) to the INTEGRATION subarea travel simulation. This subsection provides an overview of the regional travel forecasting system to subarea simulation interface process developed for the study. It also highlights some of the experiences and issues encountered while developing the interface.

There are several important features that an interface between the two scales of modeling systems must have or address when carrying out a multi-modal analysis required for an MIS.

First, the simulation system must handle the size of the network (nodes, links, signals) and number of vehicles represented in the subarea. In most cases the complete regional system will not be able to be input into the simulation software and a subarea network must be extracted for the simulation analysis. For example, in our study the vehicle trips forecast for

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11 New utility coefficients are estimated each time a change in an alternative or socio-economic characteristics causes a shift in the non-travel time variables influencing mode shift.

the Seattle region in 2020 are approximately 2.1 Million during an average weekday AM Peak period. The INTEGRATION's (v.1.5x) maximum vehicles during an assignment period used for the study is, however, 375,000. It is important when developing the subarea that the **horizon** year (2020 for the case study) network and demand be used to size the network and to determine the external connections. Peak levels of demand represented by different scenarios should also be accommodated. The subarea network should also be large enough to capture important alternate routes where traffic may divert to/from due to changes in the subarea system, incidents, and congestion. It took several iterations in developing the simulation boundaries and networks as part of the study to strike a balance between the software limits and the need to capture the potential route diversions and other factors.

Second, since an important aspect of the study is the analysis of mode choice shifts due to ITS and other factors, information on the complete trip had to be preserved for trips traveling to, from or through the subarea. This was especially important since it was impossible to include the Seattle central business district (a major destination for corridor trips) in the subarea analysis due to the number of trips and network size maximums of the simulation. This required that a "focused" network and zone system be developed for the simulation rather than the typical network "window" being cut from the regional system. Focused networks aggregate the areas outside the subarea into super districts, termed sectors, and retain origin-destination information about the trips through the subarea. Another advantage of focused networks is that where trips enter or leave the subarea can shift based upon the congestion and/or improvements within the corridor. A windowed network simply cuts the regional system from the subarea, creates "external" stations at the border crossings, and fixes the trips crossing at those points to those locations.

Third, congestion and other system effects that occur outside the subarea but are substantially influenced by the subarea trips should be accounted for in the interfaced system. In the North Corridor case study the Seattle CBD is south of the subarea under study and congestion on the road network leaving the subarea along with several route choices for trips to/from the CBD into the subarea could profoundly shift how people traveled through the corridor. A sketch network to the south of the subarea representing the major facilities to/from the CBD was therefore developed, including I-5, SR 99, SR 520, Freemont, and Broadway.

The simulation system's zones and networks are shown in Figures 7-11 through 7-13. Figure 7-11 shows both the traffic analysis zones within the subarea and the aggregated districts used to capture travel to/from the subarea throughout the region. Figure 7-12 shows the regional context of the simulation network and displays the subarea network, the sketch network extension to the CBD, and the external district connectors. Last Figure 7-13 provides a plot of the detailed simulation network within the subarea.

An overview of the interface between the regional system and the subarea simulation developed with the above considerations in mind is shown in Figure 7-14. There are three steps to interfacing the two systems: (1) Prepare Regional Networks; (2) Prepare Demand Files; and (3) Prepare Subarea Simulation Networks. Each is briefly explained below.

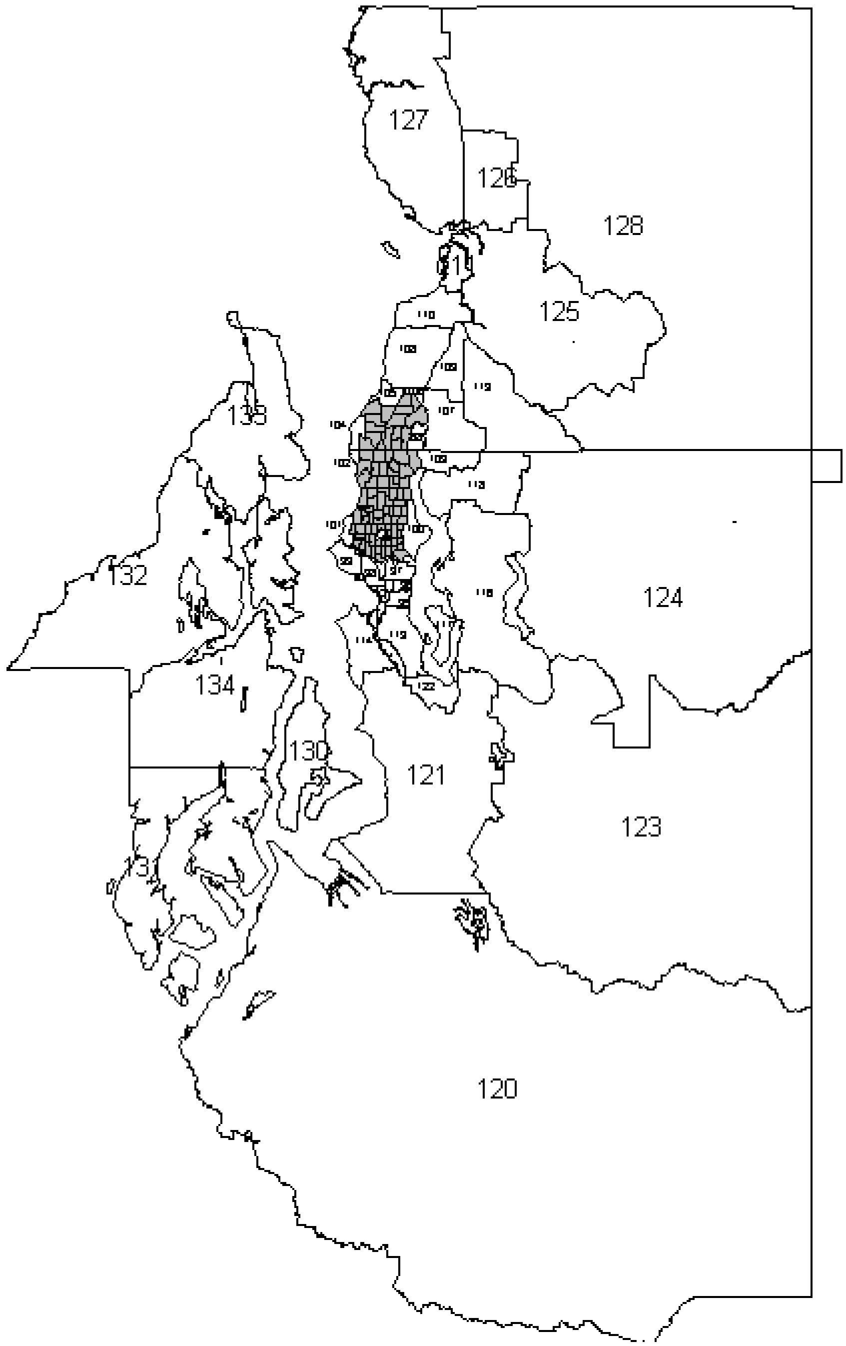

Figure 7-11. Subarea Simulation Traffic Analysis Zones and External Districts

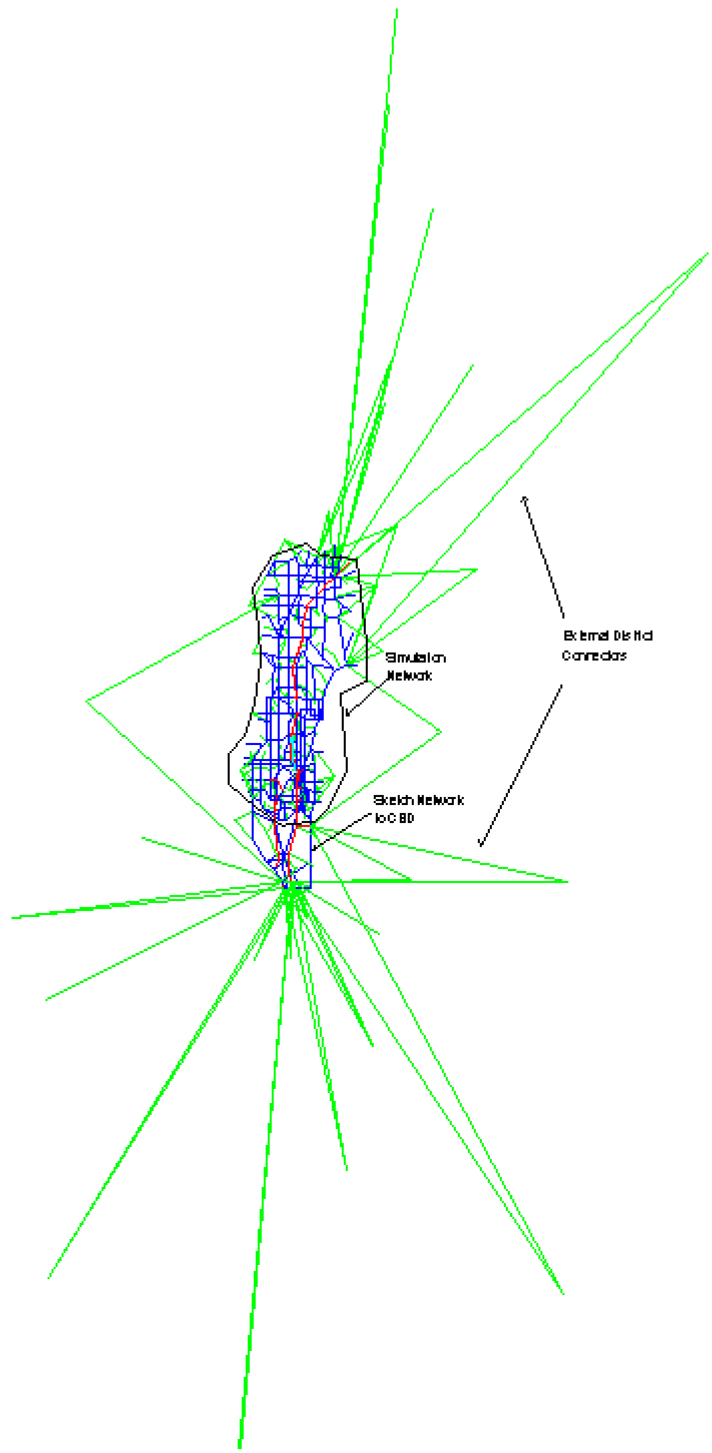

Figure 7-12. Simulation Network

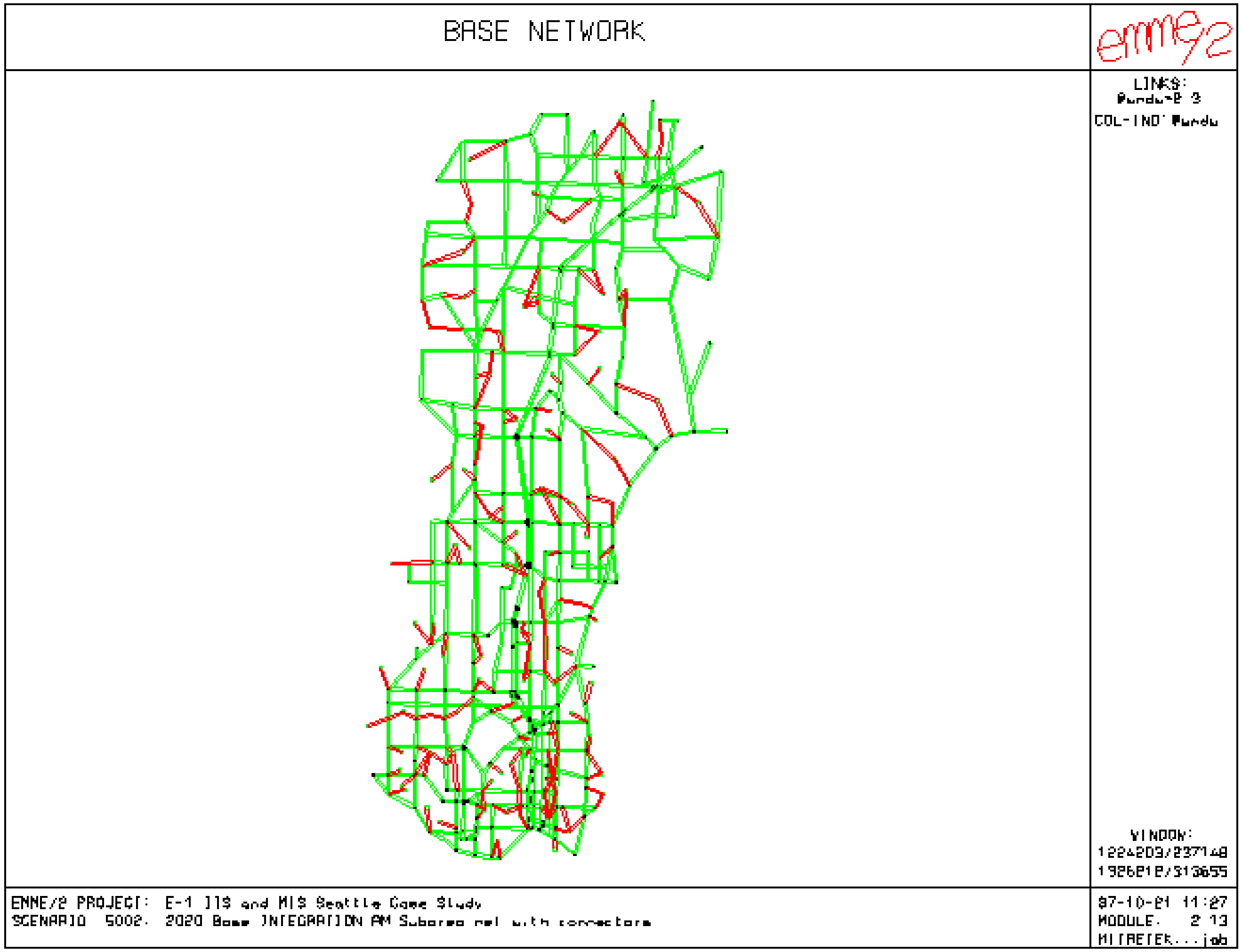

Figure 7-13. Subarea Simulation Network

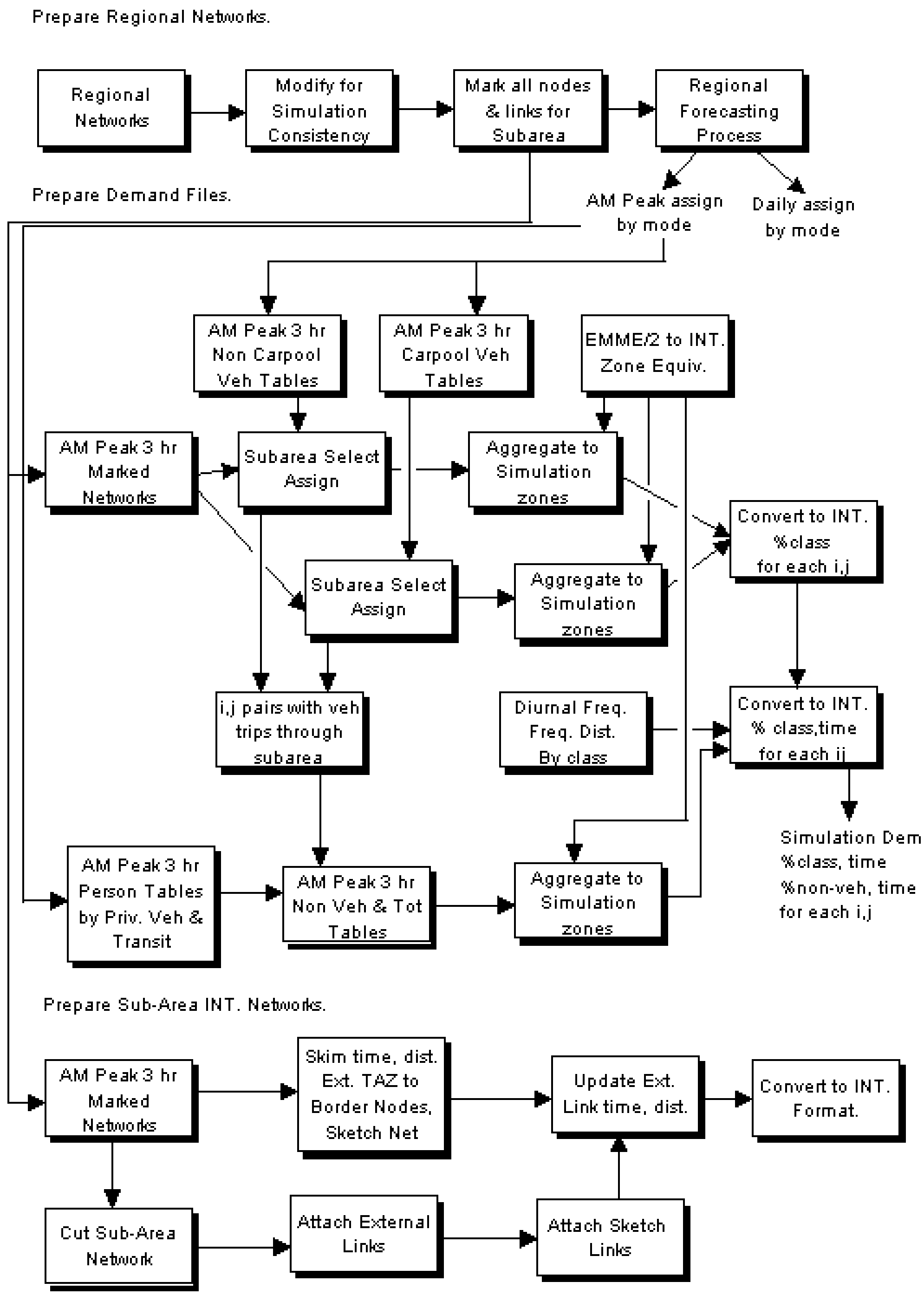

Figure 7-14. Regional Travel to Subarea Simulation Interface Overview

First, the regional networks within the EMME/2 system are pre-processed to prepare them for both the regional forecasts and the development of data for the subarea simulation. As already discussed the most important aspect of this step is modifying the regional networks so that they are consistent with the simulation system requirements within the simulation area (network detail, geometry). Once this is complete all of the links, nodes, and zones within the simulation area are then marked. This allows them to be selected for the simulation networks after the regional forecasts are carried out. The regional forecast process is then executed.

The next step after the regional forecasts are made is to prepare the resultant demand files for input into the subarea simulation process. In the study this was carried out for the AM Peak 3 hour period. The regional forecasting process produces trip tables by purpose, mode, and time period, while the subarea simulation only requires the information for the simulation period by mode. The first step in the process is then to aggregate the regional trip tables by purpose for assignment. The next step is to extract all of the trips that use any link within the subarea in separate trip tables. This is done for the carpool (3+ vehicles) and non-carpool vehicle trips using separate subarea select assignments. In both all vehicle trips are assigned in order to reflect overall congestion. Since a multi-modal analysis is being carried out the total person trips and trips made by transit for all origins and destinations with vehicle trips going through the subarea are also selected at this time. Each of these tables are then aggregated to the simulation zone system. The last step in the demand preparation process is to allocate the resultant trips for each class of traveler (carpool, non-carpool, transit) by time increment within the simulation period. The diurnal frequency distributions for this step come from the validation process and survey data. The resultant demand files by traveler type, origin, destination, and starting time are then ready for the simulation. The final step is the preparation of the subarea focused networks for simulation. There are three parts of these networks. The first is the detailed simulation network within the simulation subarea.

Figure 7-13 provides a plot of the detailed simulation network within the subarea. This is simply selected from the regional networks. The second is the sketch network to/from the CBD. This is developed by marking the nodes along the major facilities and routes to/from the subarea at significant diversion points or entry/exits. The initial travel time and distance between these points are then skimmed from the regional networks, and sketch links are created connecting the points using the skimmed values. Last the link characteristics (lanes, capacities, time) found on the regional network path links between the points are transferred to the sketch links. The external district connectors make up the third link type within the simulation network. These are created in the same fashion as the sketch links. The major entry and exit points to the corridor system are determined for each external district based upon the regional assignments. The times and distances between these points and the external district are then skimmed and the external district connectors created network extension to the CBD, and the external district connectors. Once the simulation network representation is created within EMME/2 it is then sent through a number of conversion routines developed by Mitretek to convert the data to INTEGRATION format and to add additional data required by INTEGRATION for queuing representation and other factors. These additional values (jam density is an example) are entered based upon facility type. Additional information such as the signal and incident files are then added and the simulation network is ready for testing and execution.

In developing the interface between these two systems a number of technical and mechanical problems were encountered and overcome that will not be detailed here. However, there are several important considerations that deserve note,including differences in network detail and modeling conventions; time variation of external data; and implementation of feedback. How each is addressed depends upon the specific characteristics of the software packages used and the area under study.

Network details and modeling conventions: Each modeling system uses different conventions and relationships to represent travel through a network and its impacts on time, cost, and other parameters. One of the common complaints made about regional systems when examined on a detailed link-by-link basis is that they produce inaccurate assignments and turning movements. Another is their lack of consideration of traffic operations. As more network detail is added and more realistic interchange and other coding is added to the regional systems, many of these apparent deficiencies can be and are overcome within the regional frameworks. Recent applications are now in fact incorporating intersection and signalization factors directly into the regional modeling process (Kurth & At van den Hout, 1996; Partridge & Krajcsar, 1996; Horowitz, 1997). A goal of the overall travel forecasting process is consistency in the results between the two levels of modeling. It is therefore very important to attempt to make the network representations for each as consistent as possible. At a minimum the network configurations, geometry, and initial speeds should be made consistent. Then, the differences in representation that remain are only due to the nature and inherent assumptions found in the model systems and not the coded representation of the alternatives that each sees.

Even with consistent coding there are fundamental differences in how regional "static" and simulation "dynamic" models represent transportation networks and travel throughout the day. Regional models assume steady state conditions over the assignment period and base their analysis on the average conditions that result when equilibrium is met. Simulations start with free flow conditions and track how the traffic builds up and diminishes over the analysis period. Differences in volume delay functions, system capacity definition, and queuing treatment all lead to potential differences in results. Careful examination should be made of the operations and assumptions of each of the model systems to ensure that unwanted effects are not taking place once the systems are combined. For example, it was found that very short (0.01 miles) dummy links found in the PSRC regional networks cause phantom bottlenecks to occur in the simulation system and coding had to be revised to account for how the simulation treats these short links.

Time variation of external links: Another issue related to how each model system functions is the treatment of time variation in demand and conditions on the external links outside the subarea. Tracking where the trips are coming from as they enter the simulation area and where they are going to as they leave is required for multi-modal analysis. While they are necessary, incorporating these external links into the simulation introduces other issues in the process. For example, the simulation model begins introducing trips from all origins and destinations at initial conditions at the start of the time period. If the external links are long it may take substantial time (30, 45, 60 minutes) for their demand to reach the subarea border. The simulation period may have to be increased and the external trips started early, or special pre- and post processing of the trip times on these links may have to be carried out. To account for this situation in the study the coded distances and speeds on these external links were artificially shortened at the beginning of the simulation assignment so trips would enter the subarea at the right time. The links were then re-adjusted after the assignment in order to estimate the correct MOE values.

Another factor associated with the time variation of conditions on these external links is the influence of vehicles and travel that do not enter the simulation area. Within the simulation the build up and release of demand and delay is purely a function of the travel on the simulation system. The congestion caused by other traffic on the external links in the real world can influence the time that it would take the traffic to reach the study area by different routes. Using average or congested values on the external links is inadequate since it causes the initial routes chosen in the “free flow” uncongested conditions to be incorrect. For example, if the congested times along a freeway are used to reach the study area, the initial shortest path in the early morning assignment avoids the external connector tied to the freeway and takes an alternate route. The freeway does not therefore receive the appropriate traffic in the early morning time periods. To overcome this issue the external district connectors are coded with their free flow initial speeds as described earlier in this subsection. In the validation process factors are introduced on the external links to adjust the assignment and match observed volumes entering the subarea during each time segment. These factors represent the difference in the impedance and travel captured in the simulation and that caused by the traffic/influences outside the system. The sketch network to the CBD also addresses this issue since it was designed to extend the simulation’s representation of the network outside the detailed area. In the sketch network the majority of the traffic using the facilities is coming to/from the subarea even though it is outside of the subarea’s physical footprint. On other external connectors this may not be the case and the time variation in conditions may not be predominated by the travel captured in the demand files.

Feedback and oversaturation: Last, feedback between the two levels of analysis is important to capture how ITS services may impact conditions travelers expect to experience and base their travel decisions upon. The regional model system represents the average conditions that most travelers experience in their day-to-day travel and consequently expect to see when making their trip. As shown in Figure 7-2, the improvements in reliability and/or variation may impact the conditions travelers experience and shift the their perception of expected conditions. This, in turn, can influence the day-to-day travel decisions individuals make. If the chance that a person will be an hour late when they take transit (due to missed transfers, or unreliable service) can be eliminated, the average travel time is improved and the likelihood that they will take transit increases. The results from the representative day simulations are therefore combined to estimate the change in expected, or perceived, conditions and fed back to the regional travel forecasting process.

It is important to exercise care when providing feedback between the two analysis levels. Each model system represents travel and delay very differently. The same transportation alternative in both systems may by the very nature of the volume delay calculations and difference in the static and dynamic aspects of their approaches produce different outputs in terms of delay and speed. If the simulation link times and delays are directly transferred to the regional network during feedback, a discontinuity will be created as the subarea boundary is crossed. Times and speeds for similar facilities will be different depending simply on whether they are within or outside of the simulation area. This distorts trip distribution and other accessibility dependent travel impacts (generation, land use).

Because of the differences in perspective and calculation between the two systems it was decided that the percent differences caused by incorporating ITS into an alternative would be fed back to the regional analysis. This approach takes advantage of the fact that an MIS focuses on the differences between alternatives. It also assumes that the regional process has been validated to capture the regional impacts of traditional options. The feedback loop therefore calculates the percent change between the without ITS and ITS options in the simulation analysis (for example, NoBuild vs. ITS Rich), and then applies this percent change to the regional values. The changes in free flow speed and capacity caused by an alternative were also input into regional system as a starting point for the process. It was felt that this captures the relative difference between the alternatives for the MIS analysis though additional research on feedback issues may be warranted for regional, long range analyses.

Another feedback issue is created by the differences in how regional models and simulation models address oversaturated conditions. Large increases and travel coupled with modest baseline capacity improvements often cause oversaturated conditions in regional forecasts where the forecast demand exceeds the network capacity especially in the peak periods of the day. Typically, regional models allow these oversaturated conditions to occur, since one of their functions is to determine the location and severity of deficiencies in the system.

On the other hand, subarea travel simulations represent traffic operations and queues explicitly. In these systems when demand exceeds capacity for the overall simulation period queues grow until the system breaks down, often halting the simulation. For the study a deferred trip measure representing trips that could not be assigned within the peak period was added to the MOE's to resolve the potential problems caused by over-saturation in travel simulation models. The deferred trips represent trips that will either be made during a different time period or deferred entirely as the result the severe system congestion. Other approaches to this issue could entail developing demand sensitive time-of-departure models, peak spreading methods, and/or "trip not taken" adjustments. These all entail substantive revisions to the regional process and were therefore not pursued. In any case, it is important to check for oversaturated conditions whenever regional models are interfaced with travel simulations to make sure that the trips the regional model is providing can/are actually being served within the simulation analysis.

7.6 Representative Day Scenario Development

The subarea simulation is carried out for a number of representative day scenarios to capture the performance of the alternatives under varying conditions throughout the year (e.g. weather, incidents, special events). Typically, MIS forecasting processes are executed for expected, or average, conditions for the horizon year and consequently represent recurrent conditions and congestion. The representative day scenarios (hereafter simply scenarios) expand the analysis to account for non-recurrent situations where the transportation system may perform very differently, leading to shifts in traveler's desired travel choices and in the impacts of the alternatives. This is especially important if ITS and other operational strategies that help the transportation system and traveler respond to varying situations are part of the MIS options under study. The problem of scenario definition is how to select a small set of representative scenarios (10 - 25) that will both reflect the varying conditions and differences in each alternative's responses throughout the year and keep the computing, storage, and staff effort required to carry out the simulations reasonable. The scenarios should be defined to represent the expected conditions over the average year (or other evaluation period). They must be also be mutually exclusive and collectively exhaustive so that their probabilities of occurrence sum to one. The annual impacts, or MOE's, for an alternative are thus derived by running the subarea simulation process for each scenario and aggregating as follows:

$$Annual\_MOE_i = \sum_s MOE_{is} * Weight_s$$

where:

$Annual\_MOE_i$ = MOE i annualized to capture the alternative's performance under varying conditions

MOE_{is} = MOE i for scenario s

$Weight_s$ = Weight, or probability, of scenario s, $\sum_s Weights_s = 1$

s = Scenario s

The dimensions used to define the scenarios depend upon the region where the MIS is being performed and the specific conditions found in the corridor contributing to its problems. Data availability is also an important factor. For the case study the following dimensions were used:

- Traffic/trip volumes and their space-time patterns
- Weather
- Major incidents along the interstates and state routes
- Minor accidents throughout the system

Statistical analysis on Seattle area peak period data (both AM and PM) from 1994 and 1995 was used to define the scenarios. The above dimensions were first divided into "event" and "non-event" categories. An event was considered to be a condition extreme enough to cause either a noticeable change in the transportation system's performance, a change in traveler behavior, or both; and rare enough to be considered abnormal (i.e. non-recurrent). In the case study an "event" peak period has at least one of the following characteristics:

- Poor weather conditions (visibility, rain, wet surface, freezing rain, frozen ground, and snow cover)

- Lane minutes of delay greater than 30 minutes in the WSDOT incident information
- Number of accidents greater than 6 in the Seattle area accidents information.

Non-events are those that cause minor fluctuations in the system's performance and are more common. Non-events are likely to be incorporated into the traveler's expectations of average conditions upon which they make their habitual travel choices (route, mode, time-of-departure). In the case study peak periods with good weather, no incidents, and less than six minor accidents throughout the study area were classified as non-event.

Travel demand varies from day-to-day as well due to random fluctuations and special activities such as festivals or sporting events. Consequently, demand variation was included in both the event and non-event scenarios. Thirty scenarios were defined for the case study: Twenty two of these were identified for subarea simulation: fifteen event scenarios; and seven non-event scenarios[2]. The scenarios are presented in a tree structure in Figure 7-15 with the conditional probabilities at each level shown (probabilities at each branch always sum to 1). For non-event days some of the impacts at the end of the tree branches were interpolated based upon controlled variation of the number of minor accidents and demand variation.

The remainder of this section describes how the scenarios for the case study were defined and incorporated into the subarea simulations. The steps for scenario definition include:

- Data source identification and collection.
- Initial data reduction and analysis of each dimension (weather, incidents, accidents, travel demand) to specify observed probabilities of variation and classify event and non-event periods.
- Scenario Definition and Likelihood Estimation based on the combined analysis of the dimensions (including cross tabulation, correlation, and cluster analyses).
- Development of inputs for subarea simulation.

Separate subsections are provided for each of these steps below. First, however, a brief overview of the scenario definition approach is given.

7.6.1 Scenario Definition Approach

The travel forecasting process (including both the regional forecasts and subarea simulation) must be validated to represent the network geometry, capacity, control and traffic characteristics of the study area (see Section 8). These processes are usually developed and

2 The simulated non event scenarios were used to understand the affects of variations in travel demand and number of minor accidents on these "normal" days. This information was used to interpolate the impacts of the remaining 8 non event scenarios that were not simulated.

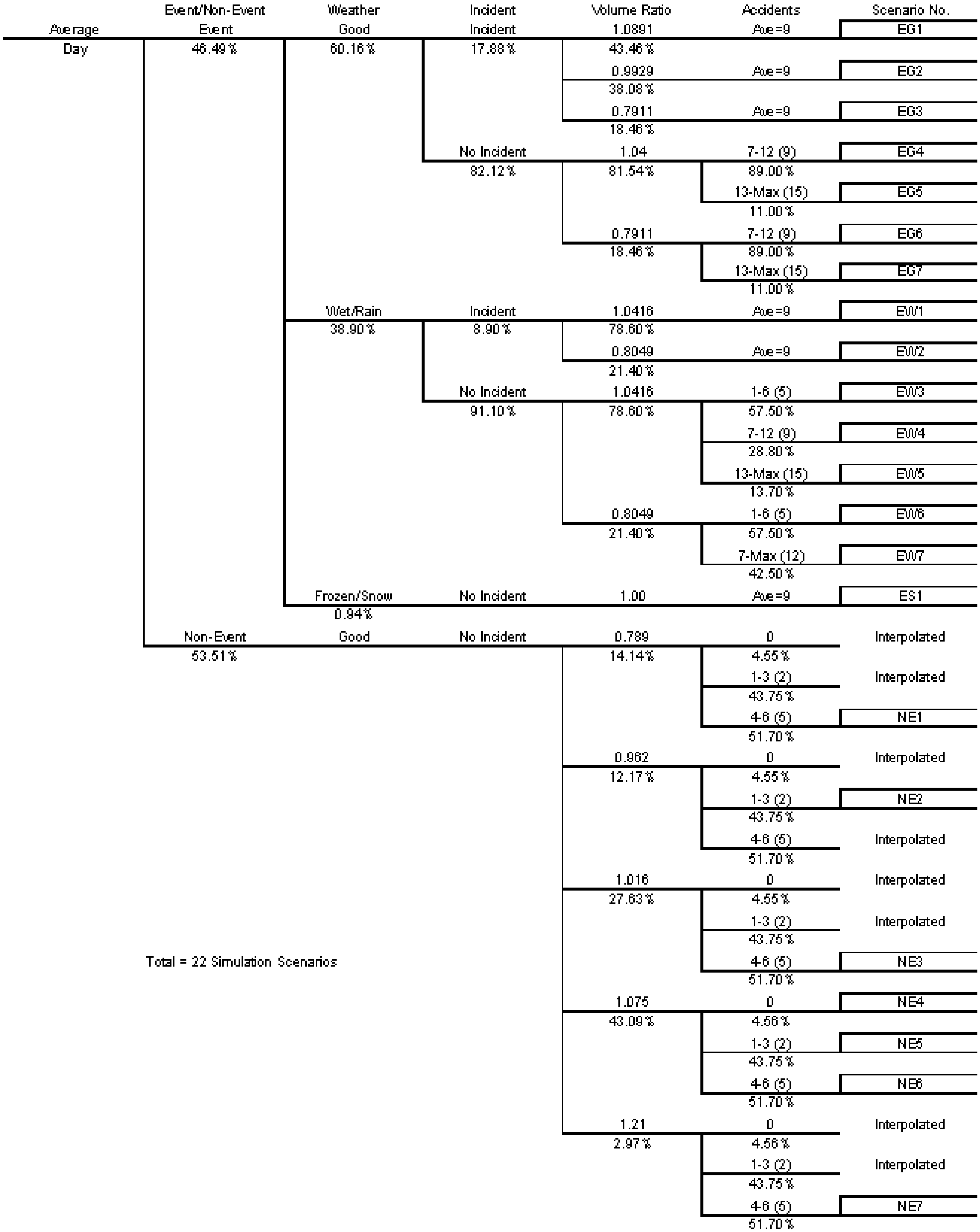

Figure 7-15. Seattle Area Case Study Representative Day Scenario

validated to represent expected conditions on a typical day by time interval (e.g., an average weekday daily, AM peak period, or PM peak period travel). Normally, all atypical conditions (accidents, construction, severe weather, special events) are removed from both the validation data and forecasting process. When applied, typical forecast processes are also usually only run to represent one set of average conditions (usually the average weekday). Expansion factors are then used to convert the average forecasts to annual values[3].

Implicit in the typical analysis is the assumption that the relationship between the average "modeled" conditions and the annual values remains constant. In other words, the instances with conditions better than the average or worse than the average is assumed to remain the same both over time and under different alternatives. This is not likely to be the case when ITS and other operational strategies are incorporated into the MIS analysis since they cause the system to react to the varying conditions. The goal of defining the set of representative day scenarios is to explicitly represent the conditions where the alternatives may respond differently and include the differences in the analysis.

It is fairly easy to define a small set of scenarios like "accident blocking three lanes on southbound I-5" that would cause major disruptions to the system and show significant benefits for ITS services such as incident response or route guidance.

However, there are very many links of I-5, or any other highway, that this could include. Of course, what is specified and where it is located can make a large difference in the results. Also, the subarea simulations require large amounts of computer time and resources to execute. For example, in the case study to simulate a scenario for an alternative required 12 hours of computing time using a Pentium 200 Mhz PC and 176.5 MB of disk storage[4]. The major issue in defining the scenarios therefore becomes how to select the smallest representative set that will both reflect the varying conditions and differences in each alternative's response to them and keep the computing, storage and staff effort reasonable.

Figure 7-16 provides a schematic of the principles of scenario definition. The figure shows how the delineation of scenarios varies across the scenario definition dimensions. For illustration only three of the many possible scenario dimensions are shown: Traffic Demand; Weather Severity; and Incident Severity. Each scenario represents a range of potential values along each of the dimensions as shown by the boxes in Figure 7-16. The scenarios are selected based upon the likely change in potential impacts caused by the ITS services and other characteristics of each alternative. Where the impact is likely to be low, a relatively large range of values for each of the scenario dimensions can be represented by a single scenario. Variations in mild weather conditions, low-to-average traffic, and minor accidents have little to no impact on expected travel conditions and can thus be represented by a single non-event scenario (the large box in the lower left corner of Figure 7-16). As conditions

3 Typically, the expansion factor is simply based upon the frequency of days as well, which also implies that the conditions are uniform. For example, there are 255 weekdays in a year and an expansion factor of 255 is often used to convert the forecast average weekday totals to average annual weekday totals.

4 This includes separate simulations using 4 random seeds per scenario. As explained later in this subsection 22 scenarios were defined for the case study. This equates to 264 hours of computing time and 3883 MB of storage for each alternative.

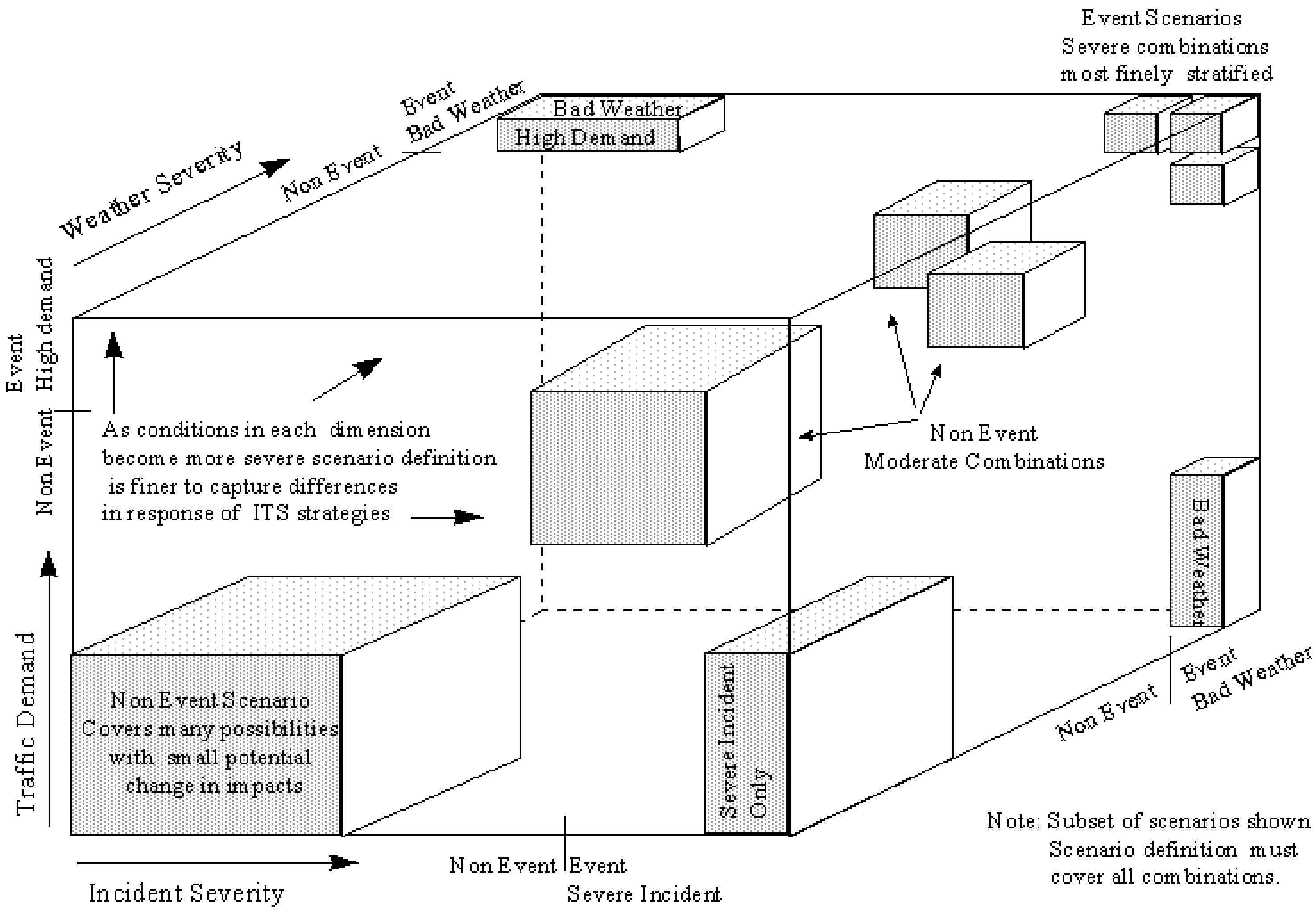

Figure 7-16. Conceptual Representative Day Scenario Definition

along each dimension become more severe the scenario definition becomes finer since both the difference in actual and average conditions and the impacts of each alternative will be greater. Rain and snow affect private automobiles and transit very differently. ATIS may provide different benefits for incidents and bad weather versus an incident in good weather. A finer delineation is needed to capture these variations. Combinations of severe conditions for several dimensions may have the greatest variation in impacts and thus need the finest stratification.

Each scenario is defined for subarea simulation by assigning a value for each dimension from the range of possibilities the scenario represents (a point within the box). For example, the least stringent non-event scenario in Figure 7-16 may be defined by three mild accidents in the system, travel demand at 0.95 times average weekday conditions, and cloudy 40 degree fall weather with no rain. Parameters representing these conditions are coded for simulation. The likelihood that the each scenario will occur is then determined and used to weight the results of the simulations. Data from 1994 and 1995 were used for the Seattle area case study and the probabilities determined statistically.

Again, all potential combinations of the scenario dimensions must be captured within defined scenarios, and the scenarios cannot overlap. This ensures that the probabilities sum to one.

Sources

The first step in scenario definition was identifying data sources and obtaining the data bases for analysis. In the Seattle region, the following data sources are available:

- Freeway traffic volumes and speeds. Fixed loop (vehicle counts) and loop pairs (speed) exist for the freeways and ramps under North Seattle TMC management. This includes historical records for volumes from 1978-present in 5-minute interval. Recently some speed data at locations have also been collected. Interventions (ramp settings) are recorded for recent years and manually recorded prior to that.
- Incident and accident data. Two sources of information are available. Detailed data on "incidents" are from the WSDOT Incident Management Center. Beginning in 1991, this information includes manual records on WSDOT response to "significant" incidents (generally those lasting over an hour). Recent years have automated database records. Many attributes of the incident and response are included, such as lanes blocked and remediation time. WSDOT also maintains information on all reported accidents from the State Patrol. The State Patrol archives accident records back 6 years. Compared to WSDOT records, this information has much more detail on the cause of the accident, vehicles involved, and severity and less on the impacts of the accident to traffic such as its the duration of blockage, number of lanes blocked, or exact location.

- Traffic volumes and speeds off freeways. This includes pneumatic counter data for continuous, periodic and irregular samples at various sites. There are only a few permanent count sites run by WSDOT other than the TMC loops on the expressways. Raw data are kept in 15 minute intervals, with annual ADT estimates published for state routes. Data collection and archiving includes data from both WSDOT and local jurisdictions.
- Weather data. The National Climatic Data Center maintains archives of hourly surface weather observations. These include all weather attributes of possible interest, although they are collected only at the SeaTac airport for the Seattle region.
- Transit data. Historical signpost-AVL and APC data exist for established checkpoints, and quarterly samples are given by route. The data are insufficient for link-based operating speed analysis.
- Speed profiles. Scattered historical data exist. The study team collected a few GPS-based profiles for I-5 and SR 99.

The TMC loop counts of expressway traffic volumes were obtained for 1990 to give baseline validation to the mesoscale network model. Given the availability of incident data, it was decided to start scenario definition by using the 1994-95 period. The TMC, weather and incident data were obtained for this period.

Significant volumes of data are involved. There are hundreds of WSDOT-response incidents, tens of thousands of accidents, 17,520 hours of weather observations, and approximately 1400 individual loops in the TMC data reporting every 5 minutes. Altogether, there are about 3 gigabytes of data for the 1994-95 period, most of it in the traffic loops data. Even so, a major deficiency continues to be the lack of fine resolution traffic data from roads other than the expressways. Under the circumstances, traffic impacts of incidents or weather can be only partially estimated from the data since inevitably they will involve off-freeway and off-state route diversions and congestion.

7.6.3 Initial Data Analysis of Scenario Dimensions.

After obtaining the data, data input routines were developed and initial analysis carried out. One of the first tasks was that of reducing the information into indicators that could be used for subsequent analysis and event/non-event classification. Initially, the analysis focused on the AM peak period since this is the period used in the subarea travel simulations. The scenario definition was expanded to include both the AM and PM peak periods to better capture variability of non-recurrent events when it was discovered that their conditions were somewhat different[5]. The AM peak periods were significantly more likely to have severe weather conditions, while the PM peak periods had higher likelihood of accidents and

[5] This is justified since, as in many studies, relative symmetry is assumed between the AM and PM periods

incidents. Findings relevant to the weather, incident and accident analysis, travel demand variation, and their implications for the scenario development process are discussed below.

Weather Information

The National Climatic Data Center information from the SeaTac airport for 1994 and 1995 was obtained and used to analyze variations in weather conditions[6]. This information included hourly observations on 47 data items for each day of the year, 24 hours per day. The 47 data items provide detailed meteorological and environmental information such as ceiling height; sky condition; total sky cover; amount, type, and height of up to four cloud layers; fine gradations of types of precipitation or visibility factors (e.g., snow, snow pellets, ice crystals, snow showers, and snow grains; or fog, ice fog, ground fog, blowing dust, blowing sand, smoke and/or haze, and dust); wind speed and direction, temperatures, barometric pressures; and other data. These data (with the exception of visibility and wind) do not directly give surface conditions and are difficult to relate to the transportation system and travel impacts. Therefore, these data were combined and reduced into a few indicators deemed relevant to surface transportation. In order to capture the variability in the data a scale was devised for each indicator. The indicators and their scales are:

- Visibility factor (derived from: precipitation and obscuration detail - see above examples-; ceiling height; and cloud covers, types and heights), scale 0-10
- Visibility (miles as reported), observed values vary from 0 to 100 miles
- Wind speed (knots as reported), observed values vary from 0 to 32 knots
- Rain (based on the non frozen precipitation detail for the current hour), scale 0-10
- Wet Ground (likelihood of ground wetness derived from the precipitation, frozen precipitation, temperature, humidity, dew point, degree of overcast, and darkness over the last four hours), scale 0-10
- Frozen Precipitation (based on the frozen precipitation detail for the current hour), scale 0-10
- Frozen Ground (likelihood of surface freezing derived from the precipitation, frozen precipitation, temperature, humidity, dew point, degree of overcast, and darkness over the last four hours), scale 0-10
- Snow Cover (likelihood of snow cover based on cumulative frozen precipitation), scale 0-10

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6 1994 and 1995 were chosen to be consistent with the other data sources on accidents and traffic conditions.

The original precipitation and obscuration details are generally coded to a three level scale such as: light rain, moderate rain, heavy rain; or light drizzle, moderate drizzle heavy drizzle. This was expanded for most of the indicators to merge the underlying elements and reflect the influence of previous hours on current conditions. In general, an indicator value of 0 represents good weather or zero probability of inclement conditions. The highest value (5 or 10) represents severe weather or 100 % probability of inclement conditions.

Table 7-8 shows the percentage hours with each of the weather indicator values for 1994 and 1995 for both the AM and PM peak periods. The table shows that AM conditions are generally worse than those in the PM, with higher probabilities of poor visibility, precipitation, poor ground conditions, and snow cover. PM conditions on the other hand are generally more windy. However, in both the AM and PM peak periods good weather generally prevails, with poor visibility, wet ground, and rain being the most likely inclement conditions (e.g., the AM peak hours had probabilities of 35.6% for wet ground, 23.8% for rain to some degree, and 29.3% for poor visibility). Frozen precipitation and snow cover, while rare, does occur regionally and did occur heavily during the winter of 1996-97.

The weather data were analyzed to determine what could be considered an unusual weather, or event, day. An attempt was made to use a single combined weather indicator which was a weighted sum of the hourly weather indicators. This proved to be ineffective since a severe score on any one indicator such as visibility could be significant, yet was masked if the other indicators had low scores. Consequently, a maximum non-event level was set for each weather indicator. If the average indicator score for a peak period exceeded the maximum, it was considered as to be an event period due to weather. The indicator criteria are shown in Table 7-9. Using these criteria, 25% of the peak AM periods being classified as weather events and 15% of the peak PM periods.

It was also found that the weather indicators associated with wet/poor visibility (rain, wetness, and visibility factor) were highly correlated ($R^2 >= 0.80$). The indicators associated with frozen conditions (frozen precipitation, frozen ground, and snow cover) were highly correlated as well ($R^2 >= 0.82$). These were therefore collapsed into "wet" and "snow" events for the scenario development.

<u>Incidents and Accidents</u>

The next factors to be considered are incidents and accidents. Incidents will be used to refer to the cases reported in the WSDOT incident response database and generally are defined as accidents or other events causing some highway condition on a state route that requires about an hour or more of WSDOT activity to deal with. Accidents include all reported (by the State Patrol) highway accidents.

As with the traffic volume data, there is a demarcation between incidents and accidents on state routes that are dealt with in WSDOT databases and all reported accidents as recorded in State Patrol files. Because of confidentiality, the detailed State Patrol files could not be obtained. Accordingly, the WSDOT files are relied on, covering both the state routes outside the City of Seattle and data for all Seattle city streets. All accidents reported are available as county level annual tabulations.

Table 7-8. Distribution of Peak Periods by Weather Indicator (1994 - 1995)

	Percent AM Peak Hours with Indicator Score (1994 - 1995)												
Weather Indicators	0	1	2	3	4	5	6	7	8	9	10	> 10	Total
Visibility Factor	71.7%	3.0%	10.2%	10.5%	0.0%	4.6%	--	--	--	--	--	--	100.0%
Visibility (Miles)[1]	3.6%	0.8%	2.0%	1.1%	1.4%	2.7%	3.1%	6.8%	0.4%	0.1%	12.6%	65.4%	100.0%
Wind Speed (knots)[2]	1.4%	0.0%	0.0%	5.4%	10.2%	18.9%	14.1%	13.5%	11.7%	7.2%	4.6%	13.0%	100.0%
Rain	76.2%	0.0%	0.0%	23.7%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	--	100.0%
Wet Ground	64.4%	1.5%	2.2%	5.5%	1.3%	1.7%	4.5%	0.7%	0.8%	5.6%	11.8%	--	100.0%
Frozen Precipitation	99.5%	0.0%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	--	100.0%
Frozen Ground	96.3%	1.6%	0.4%	0.8%	0.1%	0.2%	0.2%	0.0%	0.1%	0.1%	0.2%	--	100.0%
Snow Cover	97.8%	1.3%	0.6%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	--	100.0%

	Percent PM Peak Hours with Indicator Score (1994 - 1995)												
Weather Indicators	0	1	2	3	4	5	6	7	8	9	10	> 10	Total
Visibility Factor	80.0%	1.2%	11.3%	6.9%	0.0%	0.6%	--	--	--	--	--	--	100.0%
Visibility (Miles)[1]	0.5%	0.6%	0.7%	1.0%	1.1%	2.3%	2.3%	7.5%	0.0%	0.1%	17.7%	66.2%	100.0%
Wind Speed (knots)[2]	0.7%	0.0%	0.0%	2.2%	5.3%	8.8%	9.4%	10.5%	17.7%	8.1%	11.0%	26.3%	100.0%
Rain	81.9%	0.0%	0.0%	17.7%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	--	100.0%
Wet Ground	72.9%	1.8%	1.7%	5.2%	1.3%	2.1%	2.9%	0.8%	0.7%	2.8%	7.8%	--	100.0%
Frozen Precipitation	99.7%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	--	100.0%
Frozen Ground	99.5%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	--	100.0%
Snow Cover	99.6%	0.2%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	--	100.0%

1. Visibility is in miles as reported. The > 10 miles column includes values from 10.1 to 100 miles
2. Wind Speed is in knots as reported. The > 10 knots column inlcudes values from 10.1 to 32 knots

Table 7-9. Weather Even/Non-event Criteria by Weather Indicator

Weather Indicator	Range	Minimum "Event" Criteria
Visibility Factor	0-5	3
Rain	0-10	3
Wetness	0-10	5
Frozen Precipitation	0-10	1
Frozen Ground	0-10	5
Snow Cover	0-10	1
Peak AM Periods with Weather Events	25%	
Peak PM Periods with Weather Events	15%	

Incident data are available for all of the WSDOT Northwest District, inclusive of all of King and Snohomish counties. To date, only King County accident data have been obtained. Table 7-10 below indicates the numbers of accidents and incidents being analyzed. These data indicate that there is a substantial filtering of the records down to the most significant in the study area.

The incidents can be fully characterized by location, environmental conditions, impact on the highway, and duration. For purposes of defining the scenarios, an expanded study area is used. This expanded area includes 237 incidents in 1994-95 out of 428 for the entire two county area. The expanded area is defined as the simulation subarea plus:

- All of I-5 in King and Snohomish counties
- All of I-405
- I-90 from Seattle to about twelve (12) miles east
- SR 520 to about 8 miles east
- All of SR 99 in King and Snohomish counties

Table 7-10. **Accident and Incident Statistics for Seattle Area**

Total reported accidents, King County 1994-95	94,273
Fatal	218
Injury	39,370
Property Damage	54,685
Total reported accidents, Seattle 1994-95	39,079
Total reported accidents, King County State Routes, outside Seattle 1994-95	12,694
Total King and Snohomish incidents, 1994-95	428
Incidents in expanded study area	237
Incidents in expanded study area, AM peak	23
Incidents in expanded study area, PM peak	18
Incidents in expanded study area, I-5	158
Incidents in expanded study area, I-90	12
Incidents in expanded study area, SR 99	6
Incidents in expanded study area, I-405	36
Incidents in expanded study area, other state route	25

The reason for using the expanded area is that ITS strategies applied within the simulation area will be effective for diversions around incidents outside the area. The expanded area was used to analyze the incidents for event/non-event classification, and to determine the probabilities of incident location when defining the scenarios.

Even with the expanded area, the incident sample is relatively small. Most are on I-5 and I-405. This indicates more about WSDOT incident response strategies than accident distribution. However, these are also the routes with best traffic loop instrumentation.

The incident files were combined with the volume and other peak period information to determine the likelihood and potential severity of an incident for the scenario definitions. AM or PM peak periods with any incident at all are rare. Only 6.8% of the AM peak periods and 6% of the PM peak periods for weekdays have incidents recorded in the incident file. However, it was decided to define peak periods with lane minutes of delay due to incidents at greater than or equal to 30 minutes as incident event periods. This provides a clear distinctionbetween incidents and minor accidents in the accident file. As shown in Table 7-11, this changes the percentage of peak periods with "event" incidents only slightly from the values found using any incident to define an event.

Table 7-11. Event/Non-Event Incident Criteria

Peak Period	% Periods No Incidents	% Periods Lane Minutes Delay >=30
Peak AM Period	6.8%	6.0%
Peak PM Period	6.0%	5.2%

The accidents reported in the State Patrol accident files were also analyzed to examine the likelihood of minor accidents throughout the system that may not be reported by the WSDOT Incident Management Center. These are assumed to cause less than 30 minutes of lane delay. An accident is nearly always occurring somewhere in the system. While each accident may be small, their cumulative impact may be noticeable in the system. Therefore, peak periods with a small or average number of accidents are considered a non-event occurrence. On the other hand if an unusually large number of accidents occurs in a period, it is classified as an event. Table 7-12 shows the distribution of the number of accidents during peak AM and peak PM weekday periods on major arterials and interstates.

Table 7-12 highlights the much larger likelihood of accidents occurring in the peak PM periods. This made it somewhat difficult to select a common criteria for defining accident event periods. Number of accidents in a peak period greater than six was chosen as a balance between AM and PM conditions. It was also reasoned that this number of accidents in any peak period may have noticeable impacts on the system and that ITS and other operational strategies can help reduce those impacts.

Travel Demand Variation

Travel demand can also vary from day to day due to special events, weather conditions, or seemingly random combinations of other factors (e.g. sickness, vacations, shopping trips). Variation in travel demand can also have a significant impact on the performance of the transportation system, especially if it is operating close to capacity. Variation in travel demand was analyzed based on traffic volume data from the WSDOT Traffic Management Center and FLOW program for 1994 and 1995. Analyzing this data set proved to be one of the major efforts of the scenario development due to its size, reliability, and organization.

Significant effort was spent in developing software to extract the volumes and organize them by both date and location. Due to the unreliability of loop detectors routines also were required for checking the volume information for bad loops, and adjusting the data accordingly.

A set of eleven strategic count locations were selected to represent the variation in overall travel demand in the Seattle area that may impact the study area. These included locations on I-5, SR 99, I-405, I-90, and SR 520. The average weekday two-way, 24-hour volumes

Table 7-12. Event/Non-Event Minor Accident Analysis

Number of Peak Period Minor Accidents	Cumulative % Weekday Peak AM Periods	Cumulative % Weekday Peak PM Periods
0	5.8%	1%
1	17.2%	3.8%
2	33.7%	7.0%
3	52.7%	16.0%
4	68.3%	26.3%
5	78.6%	37.7%
6	84.8%	51.1%
7	89.0%	61.5%
8	92.4%	71.3%
9	95.8%	80.4%
10	97.6%	85.2%
11 or greater	100%	100 %
Maximum number reported	20	27
Percent Event Periods Number of accidents > 6	15.2%	48.9%

observed from these locations for 1994 and 1995 are shown in Figure 7-17. As shown, information from January 1994 was excluded from the analysis, since it was verified by WSDOT that bad detector data were corrupting the information. Holidays and weekends were also excluded. Figure 7-17 shows that the demand variation can be significant with representative average volumes ranging from approximately 91,000 to 170,000. While holidays themselves were excluded, data exploration showed that many of the extreme cases fell within one or two days of a major holiday. The cause of other major variations could not easily be identified.

The regional forecasting process provides the average annual weekday travel demand for the horizon year. Consequently, the analysis needed to represent the variation within a year from the year's average weekday demand. Average demand increased from 1994 to 1995 by 6%. A "Volume Ratio" (average weekday demand = 1) was defined by dividing each day's average volume by the annual average for the year it occurred in (133,218 for 1994, and 141,824) for 1995. This new ratio was used to remove the growth trend from the data and was used subsequently to define the volume levels for each scenario.

7.6.4 Scenario Definition and Likelihood Estimation

Once the data were prepared and initial analysis was performed with respect to non-event/ event criteria for each scenario dimension the next step was to define the actual scenarios and

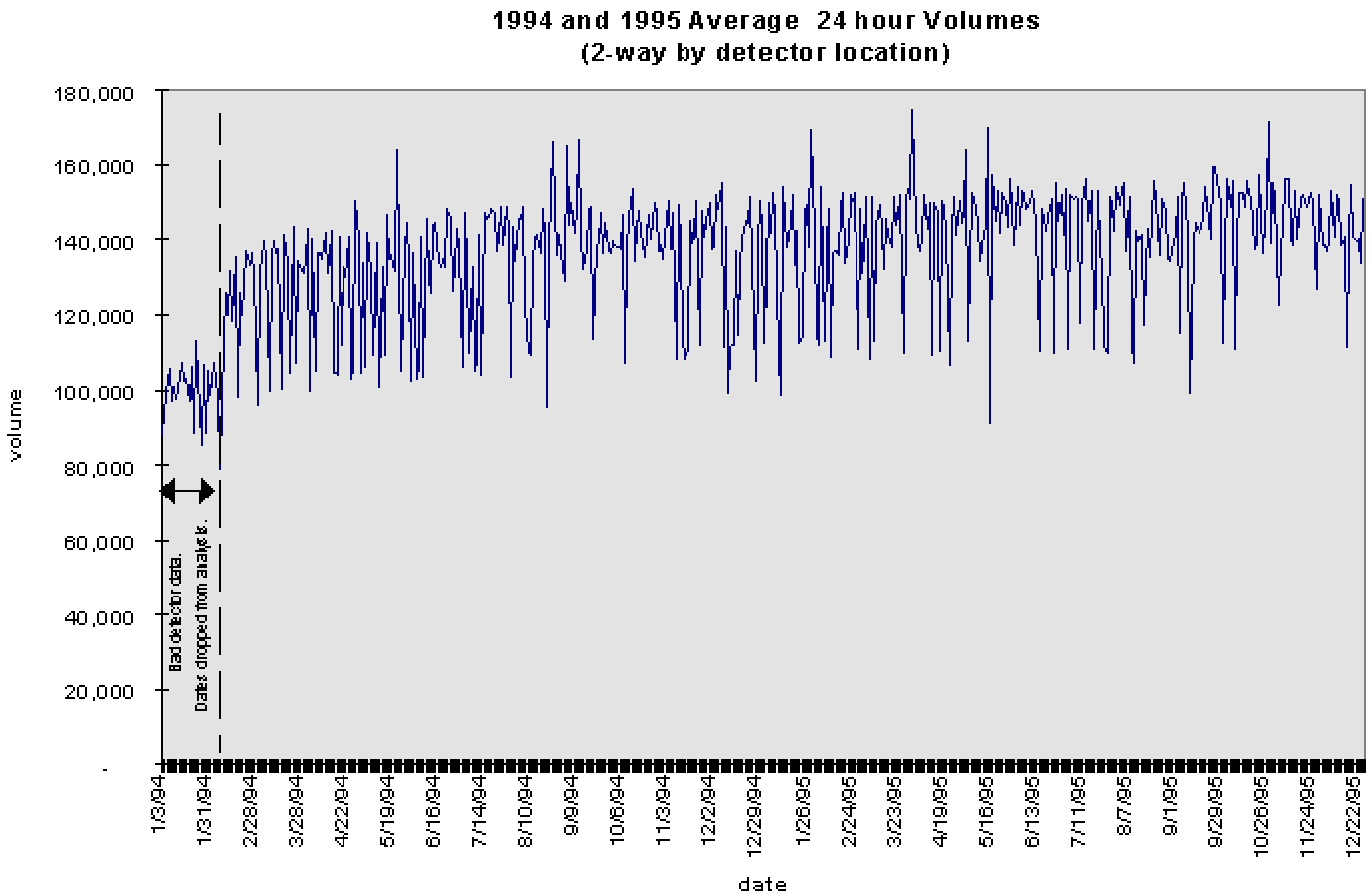

Figure 7-17. 1994 and 1995 Average Weekday 24 Hour Volumes

calculate their likelihood. Initial correlation analysis on daily and peak period aggregations of the data showed virtually no correlation between the major scenario dimensions[1] (weather, incidents, accidents, and volumes). The scenario definition and likelihood estimation, therefore, became a relatively simple process of sequential segmentation and analysis of the 1994 - 1995 data for each dimension of the scenario tree (see Figure 7-15). At each level branching criteria were determined, the data subdivided, and cross tabulation and frequency analysis carried out to determine the relative probabilities of each subdivision. The sequential order of analysis was: (1) Non-Event/Event; (2) Weather; (3) Incident/No Incident; (4) Travel demand variation; and (5) Accidents. This divide and conquer strategy of sequential subdivision following each branch of the scenario tree ensures that the final set of scenarios will be mutually exclusive and cover all possibilities. Care must be exercised, however, since it can also generate a very large number of scenarios, which would be difficult to process reasonably in subarea simulation.

Determining the sequential order of analysis for the scenarios was a somewhat subjective decision. The branching criteria for event vs. non-event, type of weather, and incident vs. no incident were predetermined based upon the initial data analyses and were therefore broken out first. When the segmentation progressed to examining the travel demand variation and minor accidents, additional cluster analysis and frequency distributions were performed to determine how the branching should most effectively be carried out.

The potential impacts of ITS strategies and differences between alternatives are likely to be most significant within the event scenarios. Therefore, the first step in the scenario definition was to segment the AM and PM peak periods by the event and non-event criteria defined in the last section. If a peak period met the criteria for an event on any dimension it was classified as an event period. The independent probabilities of an event for each dimension from the previous section and the probability of an event occurring in any of the dimensions are shown in Table 7-13. The combined analysis resulted in a 46.5% probability of an AM or PM peak period being classified as an event period and a 53.5% chance of a peak period being classified as non-event.

Once the likelihood of a period being an event or non-event period was determined the next step was to analyze each independently. The non-event days are considered average days but still have variations in demand and minor accidents. The event days have one or more occurrences of severe weather, an incident, or more than six accidents as well as variations in demand. Event periods were further segmented into event periods with good weather (60.16%), wet/rain (38.9%), and snow/frozen (.94%). Each of these was divided based on an

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17 All correlations of the peak period data between the major dimensions were found to be between -0.15 and +0.15. Hourly and location specific analysis may be required to truly examine relationships between weather and accidents or volumes. For example, a very clear relationship was found between the number of accidents by hour and location and the onset of a major storm on the day with the highest reported number of accidents (60 accidents occurred in the system on November 10, 1995) in the data base. This relationship was hidden at the daily and regional levels.

Table 7-13. Event Probabilities Across Dimensions

Scenario Dimension	AM Peak Period Event Probability	PM Peak Period Event Probability	Combined Peak period Event Probability
Weather (See Table7-9)	25%	15%	20%
Incidents (See Table 7-11)	6.0%	5.2%	5.6%
Accidents (See Table 7-12)	15.2%	48.9%	32.1%
Combined	37.3%	55.7%	46.5%

incident occurring or not occurring. Separate frequency distributions were carried out for the frequency of minor accidents for non-event periods and event periods. A low, median, and high frequency level were then typically chosen for the scenario branching.

Since no natural categorization exists, a separate analysis was also performed on the travel demand variation at each branch of the scenario tree (non-event/event, weather, incidents) to determine its segmentation. Cluster analysis, which groups observations into a specified number of most similar groups according to some criteria, was used for this analysis. The Ward's cluster method, which minimizes the variance between observations within each cluster, was chosen as the specific method. Clustering was carried out on the volume ratios (observed volume/average annual volume) on the peak periods within each segment. For each scenario branch several different levels of clustering were also explored and the volume ratios and probabilities from the lowest number of clusters which still captured the demand variation. For example, under the non event scenarios five clusters were chosen with the following volume ratios and probabilities:

1. Volume ratio of 0.789 with 14% probability
2. Volume ratio of 0.962 with 12% probability
3. Volume ratio of 1.016 with 27% probability
4. Volume ratio of 1.075 with 43% probability
5. Volume ratio of 1.21 with 3% probability

The five levels were needed to capture the likelihood of very low or high demand under otherwise normal conditions. The specific volume ratios chosen for each of the scenarios are shown in Figure 7-15.

7.6.5 Scenario Representation Within Subarea Simulation.

To analyze an alternative a subarea simulation analysis must be carried out for each of the defined scenarios. This process includes developing the inputs to represent the scenario and carrying out simulations for four separate random seeds. The four random seed simulation runs are averaged to produce the scenario results. Twenty-two of the thirty simulation scenarios were identified for subarea simulation. These included all of the event scenarios. A subset of the non-event scenarios that captured the impacts on normal days of demand variation and number of minor accidents were simulated. These were then used to determine the impacts of the remaining eight non-event scenarios through interpolation. An alternative's results are obtained from the weighted average of the scenarios using the scenario probabilities as weights. Each alternative, therefore, required 88 individual subarea simulation runs (22*4 random seeds) to obtain its overall results.

To develop the simulation inputs for a scenario, values must be specified for the weather impacts, incident and accident locations, and travel demand volume. How these values were determined and input for the case study is described below.

Weather Impacts

Severe weather such as rain, wet conditions, ice, and snow causes a network-wide reduction in capacity as drivers maintain wider spacing, take longer to clear intersections, and operate at lower speeds than under dry pavement conditions. A study in Houston found a reduction in freeway capacity volumes of 14 to 19 % due to rain. A similar effort in Minneapolis reported that even trace amounts of precipitation reduces capacity by 8 % and the reduction increases by 0.6% for every 0.01 in./hr increase in rainfall. Snow caused an additional 2.8% reduction (Highway Capacity Manual, TRB, 1994). Other research has also established concomitant shifts in the free flow speed, and shape of the volume speed functions under adverse weather conditions (Hall and Barrow,1988, Ibrahim and Hall, 1994 ,Hanbali and Kuemmel, 1993, Gillam & Withill, 1992).

The above impacts of weather are input to the INTEGRATION subarea simulation by adjusting three network-wide parameters that factor coded link capacities, free flow speeds, and speeds at capacity. The adjustment factors are used are shown in Table 7-14.

Table 7-14. Subarea Simulation Adjustment Factors due to Weather

Condition	Capacity Percent Change	Speed at Capacity Percent Change	Free Flow Speed Percent Change
Wet/Rain	- 12 %	- 20 %	- 10 %
Frozen/Snow	- 20 %	- 35 %	- 20 %

Incident and Accident Assumptions

The location, start time, duration, and severity of the incidents and accidents assumed for each scenario can have significant impact on the relative benefits of each alternative and its

ITS services. For the scenario definition incidents are major accidents which cause more than 30 lane-minutes of delay, and accidents are minor accidents that occur throughout the transportation network.

To represent the incidents and accidents in the INTEGRATION subarea simulation, a separate "Incident" file is prepared for each scenario. The incident file has the location (link number), start time, time to clear or duration, and lanes blocked coded for each accident or incident. As discussed previously very good information on each of these parameters was provided in the WSDOT incident files. Much more limited information was available for the minor accidents. Locational analysis was performed on both to determine the likelihood of an incident or accident occurring on each facility in the network. This information was then used to guide the subjective placement of the incidents and accidents for each scenario to obtain representative impacts. The incident and accident inputs for each scenario are shown in Table 7-15. Geographic location of the incidents and accidents are shown in Figure 7-18. To reduce the impact of using the same accident locations for each analysis, several subsets of accidents were defined and used in different scenarios.

Travel Demand Level

The average weekday travel demand for the horizon year for the subarea simulation is obtained from the regional travel forecasting process in the form of person and vehicle trip tables. To represent the travel demand for each of the twenty-two scenarios, these trip tables are simply factored by the scenario's specified volume ratio shown in Figure 7-15. For example, the volume ratio for the NE1 (non-event, low demand, high accident scenario) is 0.789.

7.7 ITS Service Representation

This section describes how the ITS elements and strategies were incorporated into the study. When forecasting each alternative's travel an attempt was made to simulate the net impacts of all the traditional build and ITS elements identified as part of the alternative. This captures the combined effects of the overall system and addresses the tradeoffs (both positive and negative) that may occur when two competing services may be part of the same overall package.

As discussed previously, the regional forecasting process provides the overall travel patterns and forecasts the impacts of changes in the average or perceived service a traveler sees in making their choices. The simulation model captures how the system responds to changing conditions, traffic operational improvements and updates in information. An integrated process has been provided that interfaces both systems and provides the framework for analyzing each ITS element in an overall alternative. The initial representation of each ITS element depends on the problems/issues within the overall transportation system that it is designed to address. Table 7-16 provides a summary of the ITS elements and their initial representation. As shown, the ATIS elements that provide updated information and system

Table 7-15. Subarea Simulation Scenario Incident and Accident Definitions

							Scenarios (See Figure 7-15)																					
						Name	NE1	NE2	NE3	NE4	NE5	NE6	NE7	EG1	EG2	EG3	EG4	EG5	EG6	EG7	EW1	EW2	EW3	EW4	EW5	EW6	EW7	ES1
			Incident																									
	Facility	Dir.	From-To	AM Start	Duration	Lanes																						
1	I-5	S	50th NE - 45th NE	6:45	90	1.5								X		X					X							
2	SR 99	S	40th NW - 38th NW	7:00	60	1.5									X							X						
			Accident			# of Acc.	5	2	5	0	2	5	5	9	9	9	9	15	9	15	9	9	5	9	15	5	12	9
	Facility	Dir.	From-To	AM Start	Duration	Lanes																						
1	SR 523	E	SR99-Ashford	6:30	15	1								X		X	X	X		X	X			X	X		X	X
2	I-5	S	130th - Northgage Way	7:00	20	0.5									X			X	X	X		X			X	X	X	
3	I-5	S	Northgate Way - 92nd	7:15	10	1		X			X																	
4	I-5	N	50th NE - 66 NE	8:30	20	1								X			X			X	X						X	
5	I-5	N	Westlake - 36th Ne	8:15	10	1	X		X			X	X															
6	I-5	S	south of 44 Ave W	6:15	10	1									X	X		X	X	X		X		X	X	X	X	X
7	I-5	S	175th - SR 523	7:30	30	0.5								X			X	X			X		X		X			
8	I-5	S	NE 205th - 175th	7:00	20	0.5	X		X			X	X															
9	I-5 EXPRESS	S	N. of Bridge	8:00	10	1								X	X		X		X	X	X	X					X	
10	SR99	S	65th NW - N. 50th	8:30	10	0.5		X			X																	
11	SR99	S	76th Ave W -230th	8:00	10	1	X		X			X	X															
12	SR 99	N	SR 523 - 175th	8:15	20	1												X							X	X		
13	SR 99	S	Holman - Greenlake	6:45	20	0.5								X		X	X	X		X	X		X	X	X		X	X
14	SR 99	S	On Channel Bridge	7:45	15	1									X	X		X	X	X		X		X	X			X
15	SR 99	S	SR 104 - Richmond	8:00	10	1										X		X		X				X	X		X	X
16	SR 522	S	south of SR 104	6:30	15	1								X	X		X	X	X	X	X	X			X			
17	SR 522	N	110th - 130th	7:00	25	1									X	X			X	X		X	X	X		X	X	X
18	SR 522	S	Ballinger Way - 145th	8:30	15	1	X		X			X	X															
19	SR 523	S	64th - Pacific	7:15	15	0.5									X			X	X			X			X		X	
20	SR 104	E	76th Ave W - I5	8:00	15	1								X			X	X		X	X				X			
21	RAVENIA	W	25th NE - 12th	7:30	10	1								X			X	X			X		X		X		X	
22	15th Ave N.W.	S	N.W. Market - 65th N.W.	6:45	15	1	X		X			X	X															
23	44TH	S	66th - SR 104	8:15	30	1								X		X	X			X	X			X				X
24	ROOSEVELT WAY	S	Northgate - 85th	7:45	10	1												X							X			
25	130TH	W	I5 - SR99	6:30	20	1									X			X	X	X		X					X	
26	SR 524	E	88th -76th SW	8:45	10	1										X		X		X			X	X	X	X		X
27	HOLMAN	N	100th - Greenwood	7:30	15	1									X	X			X	X		X		X				X

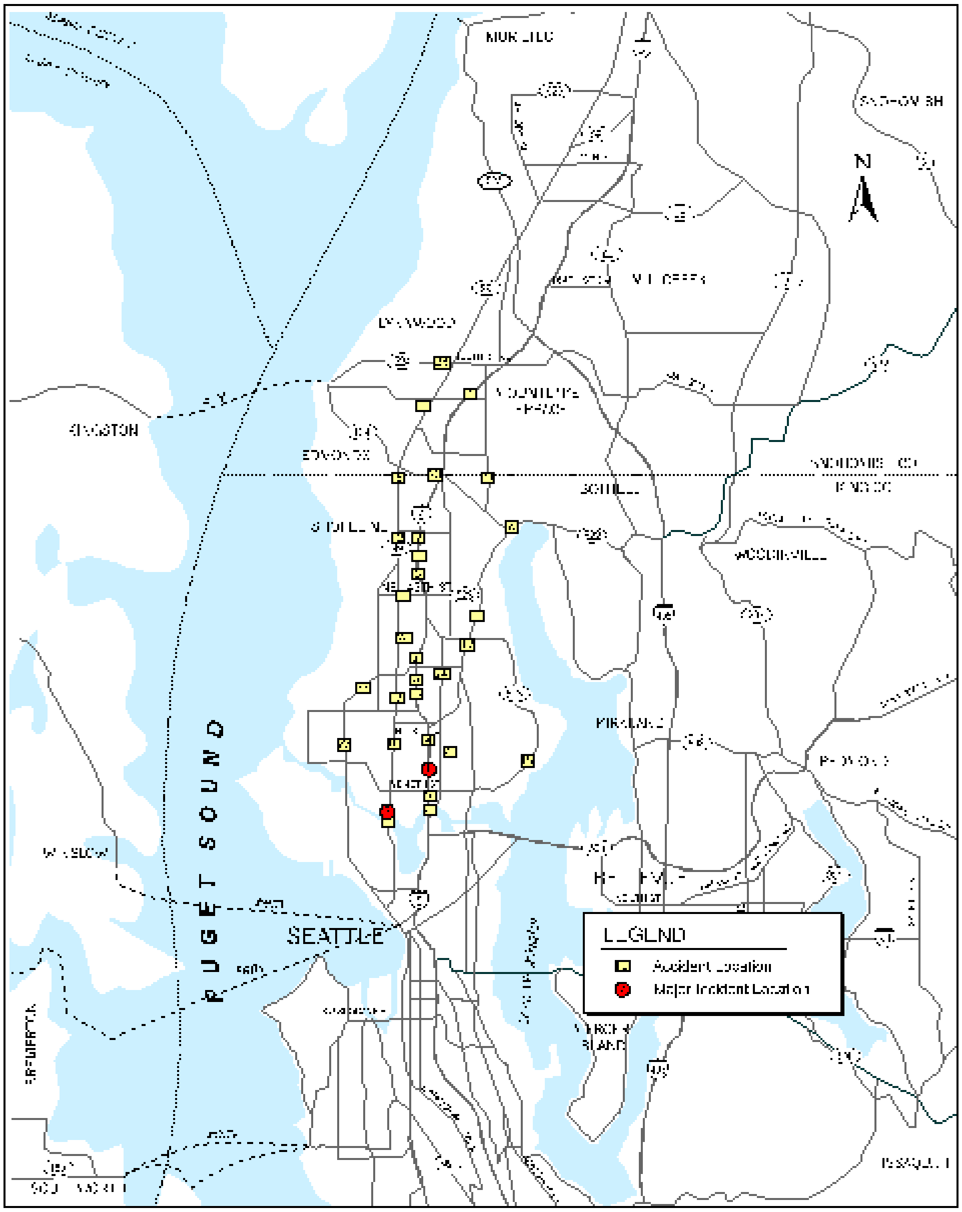

Figure 7-18. Accident and Incident Locations

Table 7-16. Model Representations Used To Analyze ITS Strategies

ITS Elements	Model Representation: Regional Planning Model (EMME/2) — Regional Impacts; Average or "Perceived" Conditions	Combination	Subarea Travel Simulation Model (INTEGRATION) — Subarea Impacts; Variation in Conditions; Information Content; Traffic Operations
ATMS			
Traffic Management Centers		X	
North Seattle ATMS (Comm. Infra)		X	
TOD/existing signal systems		X	
Ramp meters (I-5)		X	
Freeway surveillance			X
Coordinated/adaptive signal system (arterial plus freeway ramps)		X	
Support for EMS priority			
Expanded surveillance system (CCTV, loops, probes, etc.)			X
TMC/ comm. system upgrade		$X_{indirect}$	
EMS/ IMS Improvements			$X_{indirect}$
Existing EMS/ Incident Mngmt Systems			$X_{indirect}$
AVL dispatching, Mayday support			$X_{indirect}$
ATIS			
Freeway based real-time conditions			X
SWIFT operational test			X
Public display devices (VMS, kiosks)			X
Basic pre-trip planning (Internet)			X
Limited HAR			X
Expand/ enhance public display devices (VMS, kiosks, etc.)			X
Broadcast traveler info. systems*			X
Interactive traveler info. systems*			X
Multi-modal pre-trip planning*			X
Dynamic route guidance*			X
APTS			
Advanced transit management	$X_{indirect}$		
Transit priority system		X	

response to road/traffic conditions are initially represented in the simulation side[2]. In subsequent model iterations impact of ATIS elements on average “perceived” conditions found in the transportation system may be “fed back” and represented in the regional networks.

A more detailed description of each of the ITS elements and their representation in the integrated forecasting process follows. In each of the “with ITS” options for the study, the ITS elements are represented as they would logically be implemented in conjunction with the “build” option under study and the method described below is then applied.

7.7.1 Advanced Traffic Management Systems (ATMS)

Advanced Traffic Management Systems (ATMS) provide traffic monitoring, surveillance, and controls to allow the traffic system to operate more efficiently by responding to changes in road/traffic conditions in a timely fashion and managing the traffic operations as a system rather than as a group of isolated intersections and signals. ATMS systems improve both the system’s response to varying conditions and the system’s performance under average or expected conditions. Consequently, the ATMS impacts are represented in both the regional model system and the subarea simulation model. How this is done is explained more fully below.

Because each of the ATMS elements works closely with the others to provide an integrated traffic management system, the ATMS services are bundled together and analyzed based upon the function they perform. For example, very little benefit accrues from surveillance until its information is used to adjust the signal/control system for traffic operations. The details of the ATMS elements assumed in each of the alternatives are described in Chapter 6. The ATMS system assumed for the base and the system for ITS Rich each has a different level of surveillance, integration of controls, and performance.

Baseline ATMS

For the ATMS base level of service, ramp meters are explicitly represented in both the regional and simulation systems. In addition, the simulation subnetwork also models signal system control and network surveillance.

<u>Ramp</u> <u>Metering</u> Seattle has an extensive network of ramp meters supporting the freeway system throughout the region. Within the North Corridor ramp meters exist in both the base and build alternatives along I-5. Figure 7-19 provides a schematic of a ramp meter and its impacts on the transportation system. As shown the ramp meters have two types of effects. (1) They remove/reduce the conflicts on the main traffic lanes due to merging and weaving of

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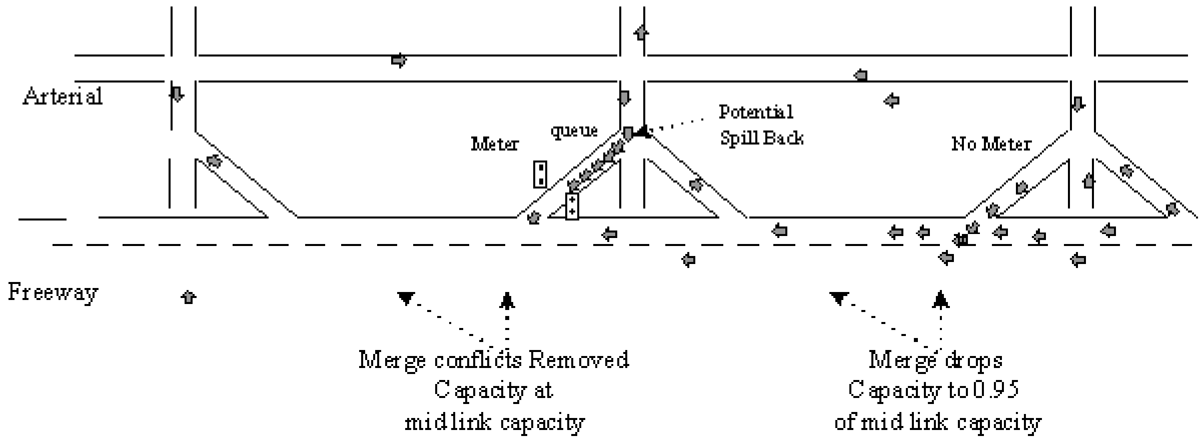
2 Note that some ITS services such as route guidance are directly represented in the simulation. Others are indirectly represented by estimating their impact on the link parameters and coding this impact into the simulation. One example is AVL dispatching and Mayday Support, which is reflected through reduced incident duration times.



For Ramp Meter:

$$time_{ramp} = time_{flow} + time_{queue} + time_{accel/decel}$$

where:

$time_{ramp}$ = total time for ramp meter link
$time_{flow}$ = time from normal volume delay calculation
$time_{queue}$ = time spent in queue
$time_{accel/decel}$ = time difference due to acceleration / deceleration vs. traversing the link at a constant speed.

Figure 7-19. Ramp Meter Representation

the ramp traffic entering the facility downstream of the ramp. (2) They introduce delay, queueing, and potential queue spill back on adjacent links for traffic using the ramp.

The improved capacity on the mainlanes was captured in the regional network by first properly reflecting the downstream capacity reduction due to weaving in the base coding conventions of the subarea. Thus, in the base networks all downstream links of ramps without ramp metering were identified and their capacity reduced by 5% (Van Aerde & Baker, 1996). This coding convention was incorporated into the base validation as well. When a ramp meter exists or is added to the system, the downstream capacity of the mainlanes is then returned tothe mid-link throughput capacity as defined by PSRC. Thus, the improved level of service offered by the ramp meters is represented and the bottlenecks caused by ramps without meters are also properly reflected.

The time associated with the ramp meters themselves has three components: the normal travel time through the link, the delay due to queuing, and the time due to acceleration and deceleration (Kurth & At van den Hout, 1996). An average meter rate of 4 seconds per vehicle (900 veh/hr) was assumed for each meter. As volumes go beyond 900 vehicles per hour, it was also assumed that the ramp would be flushed to prevent backups and signficant delays (queue delay greater than 2 minutes). A simple queing formula was used to calculate the queueing delay for volumes less than 900 veh/hr. For rates over the metered maximum, the additional time per new vehicle was presumed constant (same slope as the additonal delay caused by the increase of 700 to 800 vehicles per hour).

Signal Control. Signal timing plans in the North Corridor follow representative cycle lengths obtained from the 1995 North Seattle ATMS document. This document also identified the current level of jurisdictional cooperation along important arterial corridors such as SR 99 (Aurora Ave.). In the SR 99 case, there were three pieces of the arterial where signal plans and offsets were coordinated for support of peak period flow. Initial figures for phase splits for the peak period were determined using information provided by the ATMS document. Since this information was not available for all of the 150 signals and the phasing complexity of some intersections exceeded INTEGRATION's capabilities, an average peak period phase split was determined for other signals through the application of Webster's formula. These signal plans are considered fixed for the duration of the AM peak period in the base case and are not changed in the event of incidents or other network events.

Network Surveillance. Surveillance is modeled along the current WSDOT plan for I-5. Flow and speed data are considered to be updated in real-time and data for I-5 is made available to ATIS users.

ITS Rich ATMS

A bundle of ATMS elements which represents a much higher functionality is provided for the ITS Rich and other build with ITS alternatives. These alternatives assume the deployment of Coordinated/Adaptive Signal Control systems in the corridor (including coordination between ramp meters and adjacent arterial signalization) and an expanded network surveillance capability.

Coordinated/Adaptive Signal Control. Three levels of signal control (primary corridor, secondary corridor, and grid control) are described in Section 6 for the representation of the Coordinated/Adaptive Signal Control System. Initial assumptions based upon past Mitretek analyses for each level of control on capacities and speeds are shown in Table 7-17. There are slight differences in the parameters coded within the steady state regional networks and the simulation networks. These differences are due to the explicit representation of the signal system and queues with the INTEGRATION process. The steady state parameters are consistent with EMME/2, but the adaptive aspect of the control is handled in more detail in INTEGRATION. Since transit priority implies that the cross street green time will be affected in some manner (through extended green times for the buses), the characteristics of the road segments that cross a transit priority corridor are adversely impacted.

Table 7-17. Coordinated/Adaptive Signal Control Network Assumptions

Designation	EMME/2		INTEGRATION			
	Free Flow Speed	Capacity	Free Flow Speed	Speed at Capacity	Capacity	Signal Strategy
Priority Corridor (SR 99)	5%	4%	5%	2%	3%	DCO Level 1 Corridor
Priority Corridor (other)	10%	9%	10%	5%	6%	DCO Level 1 Corridor
Secondary Corridor	7%	6%	7%	3%	3%	DCO Level 2 Corridor
Grid Control Area	5%	3%	5%	2%	0	Isolated Adaptive
Perpendicular to Transit Priority	0	-5%	0	0	-5%	--

Notes:

1. DCO (Dynamic Corridor Optimization) is a set of adaptive signal control strategies analogous to those implemented in SCOOT. DCO Level 1 Corridor simply means it is optimized first, DCO Level 2 is optimized second, and so on.
2. Priority Corridor assumes maintenance of cross-traffic along links at some minimum level of acceptability.
3. Secondary Corridor assumes maintenance of cross-traffic along links at no worse than pre-ATMS deployment.
4. Grid Control Area assumes more efficient allocation of green-time along link without directional preference.
5. Links designated as Perpendicular to a Transit Priority have capacity reduced by 5% -- this is additive to any other designation.
6. Grid Control Area designation is NOT additive to Priority Corridor or Secondary Corridor designation.
7. Changes in Free Flow Speed and Speed At Capacity are the result of efficiencies obtained along the link controlling minor intersection signalization.
8. Changes in Capacity are the result of control efficiencies along the link and at the link end (major intersection). INTEGRATION models the link end (major intersection) explicitly and so the capacity increase is lower than in EMME/2.

The corridor control levels (primary and secondary) are modeled within the Dynamic Corridor Optimization (DCO) algorithm available in INTEGRATION. This is a Mitretek heuristic technique for finding the most congested corridor within a network and then optimizing offsets along the direction of the corridor with the most delay. After the control settings at these intersections have been determined, the heuristic searches for the second worst corridor and optimizes it under the constraint that previously optimized intersections may not be altered. The technique has been demonstrated to outperform fixed timing plans optimized for the steady-state when demand levels or directionality deviate from the expected steady-state conditions (Mitretek Systems, June 1996).

Primary corridors are modeled as a subset of corridors in the network and are optimized before any other corridors are considered. Secondary corridors represent another subset that receives optimization priority over all but Primary corridors in the network. In the grid control, corridors are not selected (i.e., progression offsets are not computed), but signal phasing follows an isolated adaptive optimization scheme.

Expanded Network Surveillance. Network surveillance for incident management and ATIS support is assumed to have expanded onto many of the major arterial segments of the network. All areas are considered under surveillance for these two functions where Coordinated/Adaptive Signal Control has been implemented. In addition, a population of dynamic route guided vehicles (10% of all vehicles) are assumed to be configured to act as travel time probes in the network. Every time a guided vehicle completes a link in the network, its experienced travel time is transmitted to the traffic management center.

7.7.2 Incident and Emergency Management Systems (EMS)

Incidents by their definition do not appear in the average condition regional travel network. In the simulation model incidents are introduced as part of the representative day scenarios. A typical incident's location and duration is simulated and the simulation outputs are compared to a incident free run.

When an incident management system is active, a 15% reduction in the duration of the incident blockage is assumed within the simulation. The Houston Transtar project reports a 15% reduction in blockage duration (Mitretek Systems, October 1997). In the base case the incident management is presumed to exist along the I-5 facility and reflect the impact of video camera coverage along I-5. Thus, the reduction in incident duration is applied only to I-5 in the Baseline alternative. In the ITS Rich and other build alternatives with ITS the surveillance and incident management coverage is presumed to extend throughout the system. Thus, in these alternatives, the 15% reduction in incident duration is assumed to extend to all these areas compared to only along I-5 in the base case.

7.7.3 Advanced Traveler Information Systems (ATIS)

Traveler information systems reduce the information gap between the perceived conditions of the transportation system and the actual conditions of the system as it exists when the traveler is making travel decisions. The regional forecasting process typically presumes that travelers know about the travel choices available and are making their decisions based on up to date and correct information. Consequently, the regional travel system is ill suited for the initial examination of the impacts of ATIS. On the other hand the INTEGRATION simulation package has been designed to address many of the ATIS functions. As described below the subarea simulation is where the initial simulation of the ATIS elements is carried out. Results are then fed back to the regional system to capture the travel pattern shifts that may be caused by these services. As in the ATMS analysis the elements of the ATIS work closely with one another and are bundled together for analysis.

Baseline ATIS

The levels of ATIS capability modeled in the base case include background (no ATIS), advisory-only en route traveler information, and advisory-only pre-trip traveler information.

Background. The modeling of background vehicles is an important part of estimating the benefits of ATIS user services. If these vehicles are routed extremely inefficiently then the underlying congestion will be overstated and the benefits attributable to ITS overstated. Mitretek's approach in modeling these vehicles follows techniques developed to establish as efficient an assignment as possible for these vehicles in the expected case. Under the assumption of non-incident conditions throughout the network, the paths of the background vehicles are determined using a multi-path feedback routing strategy. This means that every three minutes, one subset of 20% of all background vehicles are allowed to adjust their routes to the evolving network conditions during the simulation run that represents the average or expected day. Thus, this adjustment process reflects a familiar driver's adjustment to the changes in network congestion that he/she has experienced on a recurring basis at different points and times in the network.

Once a set of routing patterns are determined for the expected (no-incident) case, these patterns are saved externally. In all scenario cases run in INTEGRATION, these patterns are followed by the background vehicles even though there may be changes in travel demand or network capacity that render their previous routings inefficient.

Advisory-Only En Route Traveler Information. The drivers of these vehicles represent experienced travelers in the network who alter their regular routes in response to broadcast traffic reports, public display devices such as variable message signs, or cellular phone traffic information systems. In all cases the information provided to the traveler is simply that congestion exists at a point in the network and some qualitative description of the severity of the delay (minor, moderate, major). The response modeled for these travelers to such information is to modify the expected set of link travel times for the incident links by some gross measure and choose new best routes (based on experience), which may include diversion around the incident site.

Advisory-Only Pre-Trip Traveler Information. This set of travelers are the pre-trip counterparts to the en route information responders. These travelers may make the decision to change mode or route prior to beginning their routes in response to information provided on network conditions via the Internet, television, or telephone-based systems. In all cases the information provided is advisory-only, giving gross estimates of travel delay at geographic locations in the network. The response of these travelers is modeled by adjusting the expected travel congestion patterns by gross estimates of delay and allowing the travelers to alter mode and route choices at the trip start. Once the trip is underway no further alteration to mode or route is allowed.

Mode shifting is modeled with the HOVSHIFT framework described in Section 7.4. In the base case the HOVSHIFT and the INTEGRATION assignment are allowed to iterate to equilibrium under expected travel demand and network capacity. The resultant time-variant mode splits between single occupant and carpool vehicles represent baseline or expected conditions. Weather or other effects may impact realized demand or capacity, however. In
alternative that provides multi-modal traveler information, travelers that have a trip planning user service may make mode choices, based on predicted roadway trip times for their origin, destination, and time of departure. Travelers without this user service make a mode choice based solely on expected conditions.

ITS Rich ATIS

Four information levels are modeled in the ITS Rich alternative with INTEGRATION: background, advisory-only en route traveler information, personalized pre-trip planning, and dynamic route guidance.

Background. These drivers are modeled identically to the base case.

Advisory-Only En Route Traveler Information. This information level is modeled using the same procedures outlined for the base case except that the information provided from the augmented surveillance system is more comprehensive.

Personalized Pre-Trip Planning. Travelers using this service are modeled using the HOVSHIFT framework. In contrast to the values supplied in the base case advisory-only service, highly accurate link travel times throughout the network are made available to the mode choice model. For example, in modeling an incident in the base case, link delay might be estimated by simply doubling the travel time on a particular link for the duration of the blockage. In the ITS Rich case, measured delay on the incident link and all upstream facilities impacted by the incident are updated in real time.

Dynamic Route Guidance. Vehicles equipped with this user service receive updates every five minutes on network conditions. Vehicles receiving this information may reroute during the simulation when faster paths are identified for origin-destination pairs. All route-guided vehicles follow the fastest computed paths. The guided vehicles are also assumed to act as travel time probes in the network.

7.7.4 Advanced Public Transit Systems (APTS)

Advanced Public Transit Systems (APTS) apply smart technologies to the transit operations, management, and service to the passenger. The APTS elements and their assumed levels of implementation are described in Section 6. There are two classes of APTS services that have been incorporated into the analysis for the study. The Advanced Transit Management bundle of services includes automatic vehicle locations systems and advanced routing and scheduling programs, which lead to more efficient and reliable transit service. Transit Priority systems also lead to more reliable service and faster travel times.

Advanced Transit Management. Advanced transit management systems are designed to provide more efficient and reliable transit service to the passenger by improving transit operations. For example, automated vehicle location systems provide up-to-date infomation on where transit vehicles are in the system and allow extra buses to be dispatched quickly as problems develop and buses to be re-directed as platooning occurs. Transit management systems have been known to improve on-time performance by as much as 23 percent and also reduce the number of peak pullouts needed to provide the route service (Mitretek Systems, October 1997).

The improvement in the reliability of service may be represented in the regional travel forecasting process in two ways. First is the estimation of wait times for initial boardings and transfer times. The formula for estimation of wait times when variation is service occurs is:

$$tw = \frac{(h^2 + \sigma^2)}{2h}$$

where:

$tw =$ wait time

$h =$ scheduled headway

$\sigma =$ the standard deviation in headway

(source Ortuzar & Willumsen, 1990)

In order to capture the benefits of more regular service, the standard deviation in service within the transit service being modeled must first be measured. Then the change in standard deviation caused by improving the reliability can be input and the resultant mode choice shift captured. Second, the mode choice models can be re-estimated with a transit reliability variable included. However, this is a more ambitious task since it tries to take into account how people value the reliability of service and was not attempted as part of this study.

The impact of transit management system implementation has been reported to be an increase of from 1 to 2% in ridership across the system (FTA, 1996). When the above formula was applied within the regional model system using a 20% change in on-time performance, the ridership increased in the range of 12.5 to 13.5 %. This level of increase was considered unreasonable. It was concluded that the 20% in on-time performance reported should not be viewed as a 20% change in the standard deviation and additional data collection must be carried out to estimate the correct shift in standard deviation due to these services. Thus, while the formula and process are deemed correct, they were not applied. Instead, a post-processing shift in transit mode share of 1% is applied to account for the impact of the advanced transit management systems.

Transit Priority. Seattle is currently planning to implement transit priority in at least two corridors as part of the transportation improvement program and Seattle SmartTrek. The specific transit priority systems assumed for each alternative are described in Section 6. Transit priority is incorporated into the regional analysis by improving the running times of the transit vehicles as they travel over the transit priority corridors.

To represent transit priority within the study, two levels of transit priority service were assumed. The first assumes that the vehicles are operating in mixed flow and, while they have priority, may still be caught in a traffic signal queue if it extends through several signal cycles. Based upon field data and simulation runs used in the design of the transit priority system for Seattle, Parsons Brinckerhoff Quade & Douglas (PBQD) has estimated a 30% savings in delays due to signals for buses on transit priority lines in mixed flow. The second level assumes that the buses can bypass the queues and congestion at the signals through an HOV lane or special bypass lanes fortified and widened at each signal. This ability to bypass allows the travel time savings to increase and therefore PBQD estimated 40% savings in delay per signal for the HOV with bus bypass.

While these procedures have been described separately, all of the ITS elements are simulated at one time in order to capture the combined impacts (positive or negative) of the complete system. The changes in ridership and other MOE's are then compared to the costs of the alternative.

7.8 Cost Methodology and Assumptions

The representation of the traditional and ITS elements and the process used to estimate their travel impacts have now been discussed The other major element in an MIS or corridor study is the estimation of costs for all alternatives on a comparable basis. This section provides the general approach and assumptions used to estimate both the Capital and Operating and Maintenance costs of both the traditional and ITS elements found in each alternative. In general, the methods and assumptions used for the Case Study follow the cost estimation principles outlined in the NTI Training Program for Major Investment Studies: MIS Desk Reference (National Transit Institute, Parsons Brinckerhoff Inc., 1996). Keeping with the approach provided within the Desk Reference, the training course itself, and the ITS and costing issues discussed in Section 3, the general cost estimating methodology assumptions which were used are as follows:

7.8.1 General Assumptions/Comments

In general, the costs that were estimated for each alternative include the capital and operating and maintenance costs which would be borne by the transportation provider ***net*** of those included in the Do-Nothing/TSM base case. That is, the cost estimate for a build alternative included only the incremental capital and operating and maintenance costs (or cost savings) that differ from the Do-Nothing/TSM alternative. Total systemwide costs for the alternatives were not developed. For example, the HOV/Busway alternatives (with and without ITS) include the option of "Upgrading HOV Lanes on Freeway" where the capital cost is less than adding a new HOV lane and the incremental maintenance cost is zero since this option assumes the existence of a general purpose lane already being maintained. Exceptions to this case were the transit capital and operations and maintenance costs, for which total costs for the Do-Nothing/TSM baseline were calculated. These calculations were made because transit costs for alternatives that included ITS elements would be less than the baseline.

The level of detail/accuracy for the cost estimates is at a programming level. The focus was to establish enough detail and accuracy to enable an unbiased comparison between alternatives rather than to identify the absolute amount of money needed to fund the alternative. In addition, these costs, particularly those for ITS components, reflect the prevailing conditions and existing ITS treatments in the Seattle/Puget Sound area. Adjustments to these estimates may be appropriate for application to other regions.

Costs were developed from the most recent sources available at the time of research (Spring 1997). For consistency, all costs are expressed in constant 1995 dollars. Where possible, industry-specific indices were used for converting cost data expressed in other years' dollars to 1995. Otherwise, the U. S. Bureau of Labor Statistics Consumer Price Urban Index for the Seattle area was used to make the conversion to 1995 dollars.

Regional sources for cost data were used wherever practical. In cases where such regional data were not available, national data sources were used.

Several ITS elements are broader in scope than the I-5 North Corridor limits. Examples included traffic management, transit management, and incident management. For these elements, only the proportionate share of system costs attributable to the corridor operations was allocated to the cost estimate. Two methods for allocating costs were used. Where the corridor alternative required expansion of an existing facility, capital and O&M costs for add-ons such as a computer or part-time employee were estimated. For elements where no regional system existed, the total system capital and O&M cost was estimated and a proportionate cost was allocated to the corridor. The proportionate share in this case was generally determined by comparing the corridor area to the regional area. It is also noted that incremental capital and O&M cost estimates for ITS elements will vary by location. Each urban area will be different and the analyst must assess what infrastructure is in place in the region to support ITS implementation in the study area or corridor. For example, the central Puget Sound region already has a lot of supporting ITS infrastructure in place so these estimates reflect costs added at the margins to a great degree. Other areas may have little if anything in place and it will be more of a challenge deciding what is a regional investment versus a corridor investment.

7.8.2 Capital Cost Assumptions/Comments

Capital cost items were established for whole facility components of alternatives where practical. For example, a representative cost per mile was used as the unit of measurement for estimating the capital cost of a roadway rather than developing and applying detailed unit prices for each roadway construction element such as asphalt per ton.

Capital cost unit prices included the construction cost, along with an assumption for associated costs for engineering, construction administration, and contingency. Right-of-way acquisition costs were estimated as separate items.

Assumed percentages for engineering, construction administration, and contingencies were 15 percent, 15 percent and 25 percent of construction costs, respectively. Because there are no consistent, defensible sources of information suggesting different rates for different types of capital improvements, the same rates were used for all improvements. These relatively high rates reflect lack of definition for the improvements at the early planning stage and are consistent with rates used for planning studies.

Where practical, prior capital cost estimates by others were utilized for improvements that are a part of the alternatives. An example is the cost estimates developed for the Puget Sound HOV Direct Access studies. Assumptions and background from prior capital cost estimates were reviewed and adjustments were made, where necessary, to make the estimates consistent with the methodology used for other cost items for the Seattle ITS Case Study.

Economic life assumptions for capital cost items reflect consideration of the functional obsolescence, the technological obsolescence, and the physical integrity of the facility. Therefore, the assumed economic lives for all cost items were generally shorter than the physical life for the item. This is because the facility may have outlived its usefulness, require major upgrades, or become technologically obsolete to the point that the item becomes inefficient and/or incompatible.

Note that some of alternative's components involve periodic refurbishment costs that do not clearly fall into either the categories of initial capital costs or routine annual operations and maintenance costs. Examples may include pavement overlays or equipment replacement that occur only at periodic intervals. To the extent possible, these costs have been captured in the capital rather than O&M cost estimates, either specifically in the capital cost amount or implicitly in the assumed economic life of the component.

Each capital cost was annualized by determining what annual amount in constant 1995 dollars, if paid over the number of years in the economic life, would in sum have a present values equal to the capital cost when discounted using a real discount rate of seven percent. The selection of a seven percent real discount rate was based on the current recommendation by the Office of Management and Budget for public transportation projects with federal funding (FHWA and FTA, 1996).

7.8.3 O&M Cost Assumptions/Comments

Operations and maintenance costs estimates were estimated as the sum of routine annual maintenance (e.g., parts, labor, maintenance services), regular annual operations (e.g., energy, labor), and other O&M activities expressed in an annualized amount. The amounts were scaled to the applicable facility size.

O&M costs were estimated using one of two methods. For items in quantity where unit costing made sense and planning level estimates were available from existing sources, unit O&M costs were applied to the expected component quantities to yield the annual O&M costs. Given a scarcity of unit cost information and the complexity of estimating incremental O&M costs for some elements, other components' annual O&M costs were estimated as a percent of the capital costs, based on experience in existing areas/applications. In these cases, an attempt was made to differentiate in the percentage of capital cost used by element. For example, based on WSDOT information O&M costs for highway facilities including roads and bridges are typically estimated at 1.0 percent of capital costs. An investigation of recent bridge projects indicate that for structures alone, O&M costs are actually closer to 0.5 percent. Hence, the 0.5 percent factor was applied to estimate interchange O&M costs, since the majority of interchange capital costs are due to structures. However, for the alternative in which lanes were added to an existing bridge structure, the incremental O&M cost was estimated at only 0.25 percent of capital since a significant amount of O&M was already occurring for the existing bridge.

Net transit operations and maintenance costs were estimated by developing a simplified model using revenue hours of operation as the independent variable. King County Metro cost and revenue hour data were used to derive the rate.

Highway facilities and fiber optic communications cable are both maintenance examples with cost estimates on a per-unit (miles) basis. Similarly, the labor involved in operating reversible HOV lanes or movable barriers was also estimated on a per mile basis. The maintenance for an in-bus AVI transponder serves as an example of the percent of capital cost method as part-specific maintenance data for such items are not readily available.

A summary of cost items, units of measure, economic life, and data sources is provided in Table 7-18. Key references for the cost data are listed at the end of the table.

7.9 Cost of Alternatives

In Section 7.8, an overview of the cost methodology and assumptions for estimating the capital, operating and maintenance costs for each alternative was provided. All costs are presented in constant 1995 dollars. The cost estimates include only those that would be borne by the transportation provider *net* of those included in the Do-Nothing/TSM base case, and the level of detail/accuracy for cost estimates is at a programming level. This section summarizes the results of the cost analysis. More detailed worksheets providing the

Table 7-18. Capital / O&M Cost Assumptions for Case Study (multiple pages)

ITEM	DESCRIPTION	UNIT CAPITAL	UNIT O&M	ECONOMIC LIFE (YEARS)	DATA SOURCE
HIGHWAY/TRANSIT FACILITIES					
SOV FACILITIES					
Expressway Conversion	Conversion of unlimited access arterial to partial access control; add 2 lanes	per mile	per mile	20	Capital-Build up based upon cost components of typical project; O&M-Houston Division of TxDOT
Limited Access Widening	Widening of full access controlled freeway; add 2 lanes	per mile	per mile	20	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-Houston Division of TxDOT
Interchange (full or half)	Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	per each	percent of capital cost	30	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB analysis
Grade Separated Crossing	Grade separated crossing of two roads without ramp connections; for Expressway	per each	percent of capital cost	30	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB analysis
HOV/TRANSIT FACILITIES					
New HOV Lanes on Freeway	Add barrier separated HOV lanes to existing freeway	per mile	per mile	20	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB analysis
Upgrade HOV Lanes on Freeway	Upgrade existing HOV lanes to barrier separated lanes on a freeway	per mile		20	Capital-Build up based upon cost components of typical project; O&M-Incremental costs assumed negligible
New HOV Lanes on Deck-Truss Bridge	Add HOV lanes to deck-truss bridge/no barrier or buffer separation	per foot	percent of capital cost	30	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB analysis
New HOV Lanes on Expressway	Add HOV lanes to expressway/no barrier or buffer separation	per mile	per mile	20	Capital-Build up based upon cost components of typical project; O&M-Houston Division of TxDOT
New HOV Contra-Flow Reversible Lane on Freeway Express Lanes	Add HOV moveable barrier-separated lane	per mile	per mile	20	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/San Diego Coronado Bridge

Table 7-18. Capital / O&M Cost Assumptions for Case Study (multiple pages)

ITEM	DESCRIPTION	UNIT		ECONOMIC LIFE (YEARS)	DATA SOURCE
		CAPITAL	O&M		
HIGHWAY/TRANSIT FACILITIES					
Arterial Transit Lanes/Two Directions	Add HOV/transit lanes to an existing arterial	per mile	per mile	20	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Arterial Transit Lanes/Reversible	One center reversible lane	per mile	per mile	20	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/TTI
HOV Direct Access/Local Half Reversible Drop	Direct ramps between express lanes and local street	per each	per each	30	Capital-Adapted from prior P.S. HOV study estimates; O&M-Houston Division of TxDOT/TTI
HOV Direct Access/Local Half Drop	Direct ramps between median freeway HOV lanes and local street	per each	percent of capital cost	30	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Full Texas T	Direct ramps between median freeway HOV lanes and local street	per each	percent of capital cost	30	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Half Drop to Outside	Direct ramps between outside general purpose freeway lanes and local street	per each	per at-grade ramp mile	30	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Local Full In-Line	Direct ramps between median HOV lanes and in-line station w/ pedestrian link	per each	per at-grade ramp mile	30	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Fwy-to-Fwy	Direct ramps between freeways to/from one direction and another (e.g. between east and north)	per each	percent of capital cost	30	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates

Table 7-18. Capital / O&M Cost Assumptions for Case Study (multiple pages)

ITEM	DESCRIPTION	UNIT CAPITAL	UNIT O&M	ECONOMIC LIFE (YEARS)	DATA SOURCE
HIGHWAY/TRANSIT FACILITIES					
HOV Direct Access/Fwy-to-Fwy Reversible	Direct reversible ramp between median HOV lanes and express lanes	per each	per each	30	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT/Houston Division of TxDOT/TTI
Park and Ride Lot	Parking facility including bus transit shelter and pedestrian enhancements	per parking stall	per 100 stalls	20	Capital-Averaged from WSDOT examples; O&M-Based on Houston Division of TxDOT figures
Transit Bus - 40 foot Diesel or 60 foot Diesel Articulated	Standard intracity transit bus	per vehicle	per thousand revenue vehicle hours	12	Capital-King County/Metro; O&M-King County/Metro
Transit Bus - 60 foot Dual Power Articulated	Special bus for use in downtown Seattle transit tunnel	per vehicle	per thousand revenue vehicle hours	12	Capital-King County/Metro; O&M-based upon annual vehicle hours times cost per vehicle hour
RIGHT-OF-WAY					
R/W Adjacent to Arterial	Right-of-way acquisition costs along expressways and arterials in north Seattle	per acre	Not Applicable	100	Capital-Input from WSDOT; O&M-NA
R/W Adjacent to Freeway	Right-of-way acquisition costs along freeways in north Seattle	per acre	Not Applicable	100	Capital-Input from WSDOT; O&M-NA
R/W Takes/Damages	Typical extra cost to cover relocations and/or damages	per parcel	Not Applicable	100	Capital-Input from WSDOT; O&M-NA

Table 7-18. Capital / O&M Cost Assumptions for Case Study (multiple pages)

ITEM	DESCRIPTION	UNIT CAPITAL	UNIT O&M	ECONOMIC LIFE (YEARS)	DATA SOURCE
ITS/TRAFFIC SYSTEMS					
SURVEILLANCE					
Detection Loops	In-pavement loops and cables to nearest controller.	per mile	per mile	10	Capital-Build up based upon cost components of typical projects; O&M-TTI
Closed Circuit TV Camera	Monitor traffic operations along State's Routes	per each	per each	10	Capital-WSDOT; O&M-TTI
Automatic Vehicle Identification/Roadside Equipment	Roadside equipment to identify bus, check schedule and provide transit priority at traffic signal	per signal	per signal	10	Capital-King County/Metro; O&M-TTI
Automatic Vehicle Location/Field Equipment	Field differential GPS stationary site to provide fixed location information to compensate for topography and buildings	per site	percent of capital cost	10	Capital-Denver Regional Transit District; O&M-estimated
Data Station	Support detection system	per each	percent of capital cost	10	Capital-WSDOT; O&M-TTI
TRAVELER INFORMATION					
Variable Message Signs	VMS on overhead structures	per each	per each	10	Capital-WSDOT; O&M-TTI
Fixed HAR & Controllers	Highway Advisory Radio site located at strategic locations as a part of traffic management system	per each	per each	10	Capital-WSDOT; O&M-TTI
Kiosk	Located at transit centers	per each	per each	10	Capital-King County/Metro; O&M-TTI
COMMUNICATION					
Fiber-Optic Cable	For extended freeway surveillance systems	per mile	per mile	10	Capital-WSDOT; O&M-TTI
Fiber-Optic Hubs	Interchange fiber-optic lines	per each	per each	10	Capital-WSDOT; O&M-TTI
Twisted Pair	For extended adaptive traffic control systems	per mile	per mile	10	Capital-WSDOT; O&M-TTI

Table 7-18. Capital / O&M Cost Assumptions for Case Study (multiple pages)

ITEM	DESCRIPTION	UNIT CAPITAL	UNIT O&M	ECONOMIC LIFE (YEARS)	DATA SOURCE
ITS/TRAFFIC SYSTEMS					
TRAFFIC CONTROL					
Coordinated/Adaptive Signal System - Local Controller	Replace existing controllers and cabinets at major intersections	per controller	per controller	10	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Coordinated/Adaptive Signal System - Master Controller	Tie local controllers to the system	per controller	per controller	10	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Ramp Metering	Freeway entrance ramp metering	per each	per each	10	Capital-WSDOT; O&M-TTI
TRAFFIC MANAGEMENT					
Computers & Hardware	For adaptive signal system and additional freeway system management where applicable	per each	per each	5	Capital and O&M-National Architecture Studies
Software (various)	For adaptive signal system	per each	per each	5	Capital and O&M-National Architecture Studies
Communications Extension	For linkage to adaptive traffic control systems	per mile	per mile	10	Capital-WSDOT; O&M-TTI
TRANSIT MANAGEMENT					
Computers & Hardware for AVL System	Computer system to receive and process AVL polling data from buses and provide location, schedule adherence, and incidence information to dispatchers	per each	percent of capital cost	10	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Software	Software for AVL Controller and Dispatch Stations	per each	percent of capital cost	10	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Facilities and Communications	Radio communications to receive AVL data, and dispatch stations including CRTs and microcomputers	per each	percent of capital cost	10	Capital-Denver Regional Transit District: O&M-National Architecture Studies

Table 7-18. Capital / O&M Cost Assumptions for Case Study (multiple pages)

ITEM	DESCRIPTION	UNIT CAPITAL	UNIT O&M	ECONOMIC LIFE (YEARS)	DATA SOURCE
ITS/TRAFFIC SYSTEMS					
TRANSIT VEHICLE INTERFACES					
In-vehicle Transponder for AVI	Transponder device located on buses used to identify bus at roadside readers at for signal priority treatment	per bus	percent of capital cost	10	Capital- King County/Metro; O&M- National Architecture Studies
In-vehicle AVL Equipment	AVL on-board equipment for establishing vehicle location, assessing schedule status, and interfacing with	per bus	per bus	10	Capital- Denver Regional Transit District: O&M- TTI
INCIDENT MANAGEMENT					
Central Tracking/Dispatch	Central tracking system/software and Mayday software/GIS integration; dispatch system.	per each	percent of capital cost	10	Capital- WSDOT: O&M-National Architecture Studies
In-vehicle Dynamic Route Guidance	For tracking system and route guidance to provide faster response to incidents	per each	percent of capital cost	10	Capital- Rockwell Path Master system plus add- on items; O&M- National Architecture Studies
USER DISBENEFITS					
Pre-Trip Planning Services	Interactive fixed-end trip planning service; 10% of travelers; no capital cost beyond baseline	Not Applicable	per subscription		Capital- NA; O&M- Mitretek assumption
Personal Dynamic Route Guidance	In-vehicle equipment costs include GPS, map database, communications transceiver, processor, GUI, and display	per device	per subscription	7	Capital- National Architecture Studies; O&M- Mitretek assumption

REFERENCES:

TransCore- Interim Handbook on ITS Within the Transportation Planning Process, TransCore (formerly JHK & Associates), December 1996, Appendix E.
WSDOT- TSMC SC & DI Operations/Implementation Plan, WSDOT, October 1994.
TTI- Guidelines for Funding Operations and Maintenance of ITS/ATMS, Texas Transportation Institute, November 1996.
National Architecture Studies- ITS Architecture Cost Analysis, Federal Highway Administration/Joint Architecture Team, June 1996.
King County/Metro- King County transit operator, Dan Overguard/David Cantay/Mike Voris, May 1997.
Denver RTD- Denver Regional Transit District, Lou Ha, June 1997.
Houston Division of TxDOT - Estimates provided for the Katy Highway MIS

estimated cost of each component of an alternative are included in the Appendix B. The alternatives were described in Chapter 6. In this section, cost differences among alternatives are highlighted and explained by comparing the differences in capital improvements and operating strategies associated with the different alternatives. First, however, recommendations regarding how these costs should and should not be used are offered.

7.9.1 Use of Cost Estimates.

The cost estimates provided in this case study have been developed to illustrate how ITS could be considered in the transportation planning process. They are not, however, meant to represent the costs of *actual* alternatives being considered in the Seattle area. The approach to this study was to base it in reality by conducting a case study of an actual metropolitan area (i.e. Seattle), rather than rely a on a hypothetical transportation network. It is important to keep in mind, however, that while the baseline network is based in reality, many of the items included in the alternatives considered are improvements that have not been, and will likely not be, seriously considered in the region. For example, the Busway/HOV Alternative in this case study assumes barrier-separated HOV lanes on I-5 from downtown Seattle to SR-526 and barrier-separated HOV lanes on parts of SR-99, including the Aurora Bridge. WSDOT's long-range HOV plan calls for freeway HOV lanes on the north corridor of I-5 to Everett, but it does not currently call for *barrier separated* freeway HOV lanes. As will be described in more detail, reconfiguring and building I-5 HOV lanes so that they are barrier separated represents a significant portion of the total Busway/HOV Alternative cost. Additionally, this case study is not intended to provide a means for comparing costs of general SOV capacity improvements to general HOV capacity improvements in the Seattle region. This is particularly important since, in this case study, capital improvements in the HOV/Busway Alternative were made to approximately 60 miles of roadway on four facilities, while in the SOV Capacity Expansion Alternative, capital improvements were made to only about 17 miles of roadway on two facilities. And as was described previously, many of the improvements included in these alternatives are not being seriously considered by the region as viable options. Nevertheless, this analysis does provide a good example of how ITS can be included in an MIS planning process—which is the objective of this study.

7.9.2 Total Capital Costs

Capital cost estimates for each of the alternatives are summarized in Table 7-19. They include construction costs as well as an assumption for associated costs such as engineering, construction administration, and contingency. The cost for right-of-way acquisition was estimated as a separate cost item. The cost estimates for each of the build alternatives include only those elements which differ from the Baseline Alternative. ITS Rich Alternative: As described in Chapter 6, the ITS Rich Alternative consists of an aggressive implementation of ITS strategies in the North Corridor and includes traffic management and surveillance, and incident and emergency management strategies. It is estimated that the ITS Rich Alternative would cost about $33 million beyond those committed projects which have been included in the Baseline Alternative. Note that in this alternative, the costs for HOV/transit facilities and services are expected to decrease by about $4.8 million relative to the Baseline Alternative. Costs for HOV/transit facilities decrease because in this alternative the transit system is operating more efficiently. Therefore, fewer new buses are required to maintain the service levels represented in the Baseline Alternative. This is a relatively low cost alternative in

Table 7-19. Incremental Capital Cost Estimates by Alternative - North Seattle Case Study

	Investment Category	ITS Rich Total Capital Cost	SOV Capacity Increase Total Capital Cost	SOV Capacity Inc. + ITS Total Capital Cost	HOV Busway Total Capital Cost	HOV Busway + ITS Total Capital Cost
FACILITY	SOV FACILITIES	–	$246,108K	$246,108K	–	–
	HOV/TRANSIT FAC./SERVICES	($4,765K)	($290K)	($6,080K)	$772,036K	$767,776K
	RIGHT-OF-WAY	–	$90,600K	$90,600K	$96,010K	$96,010K
ITS / TRAFFIC SYSTEMS	SURVEILLANCE	$8,599K	–	$9,466K	–	$8,599K
	TRAVELER INFORMATION	$2,075K	–	$2,950K	–	$2,075K
	COMMUNICATION	$11,180K	$330K	$14,296K	$330K	$11,180K
	TRAFFIC CONTROL	$5,770K	–	$6,058K	–	$5,770K
	TRAFFIC MANAGEMENT	$938K	–	$1,173K	–	$938K
	TRANSIT MANAGEMENT	$950K	–	$950K	–	$950K
	TRANSIT VEHICLE INTERFACES	$7,688K	–	$7,669K	–	$8,711K
	INCIDENT MANAGEMENT	$616K	–	$616K	–	$616K
	Total Capital Costs*	$33,051K	$336,748K	$373,804K	$868,376K	$902,625K

* Relative to Baseline

comparison to the two more capital-intensive infrastructure alternatives—the SOV Capacity Expansion and the HOV/Busway Alternatives. Relatively high cost elements of the ITS Rich Alternative include the following:

- Communication system ($11M)
- Surveillance system ($8.6M)
- Transit vehicle interface ($8M)
- Traffic control ($6M)

SOV Capacity Expansion Alternative: The SOV Capacity Expansion Alternative provides for the conversion of SR-99 north of N 59th Street to an expressway for a distance of 14 miles. The total incremental capital cost of the SOV Capacity Expansion Alternative is estimated at $337 million beyond the Baseline Alternative, including over $90 million for right-of-way acquisition. However, the costs for HOV/transit facilities and services are expected to decrease by about $0.3 million relative to the Baseline Alternative. Costs for HOV/transit facilities decrease because the transit system is operating more efficiently on SR-99 so fewer new articulated buses are required. This alternative also includes the widening of a 3 mile section of SR 525 between SR-99 and I-5. High cost construction elements of the SOV alternative include the following:

- Conversion of 14 miles of urban arterial to urban expressway ($86M)
- Construction of nine new urban expressway interchanges ($96M)
- Construction of new grade separated arterial crossings of the expressway at nine locations ($44M)

SOV Capacity Expansion Plus ITS Alternative: The capital cost estimated for the SOV Capacity Expansion Alternative Plus ITS is $374 million. This alternative includes about $37.1 million for implementation of ITS elements similar to the ITS Rich but designed to complement the SOV Capacity Expansion. The level of investment in communications and traffic management for the SOV Capacity Expansion Alternative is slightly higher than that associated with the ITS Rich Alternative since the SOV Capacity Expansion includes additional roadway that would require some additional ITS costs. In this alternative, the costs for HOV/transit facilities and services are expected to decrease by about $6 million relative to the Baseline Alternative, for the same reasons that these costs decrease in the ITS Rich Alternative.

HOV/Busway Alternative: The HOV/Busway Alternative includes a continuous, barrier-separated HOV lane on I-5 from downtown Seattle to SR-526 in South Everett by year 2020 (about 25 miles). It also includes implementation of barrier-separated HOV lanes on SR-526 and SR-99 (from downtown Seattle to N 59th St), 14 miles of arterial HOV lanes on SR-99 extending north from N 59th St, a freeway-to-freeway HOV connector and various direct access ramps. This alternative also includes transit improvements, including a transit lane on SR-522; the addition of several new regional express bus routes with frequent service; and construction of several park-and-ride lots. The construction and modification of HOV lanes along SR-99 (about 18 miles) represents the most significant cost in this alternative. Costs for widening the SR-99 bridge alone are estimated at about $47 million; estimates for implementing barrier separated HOV lanes on SR-99 from downtown to N 59th Street are about $29 million; and 14 miles of new arterial HOV lanes along SR-99 is expected to cost more than $102 million. In addition, the upgrading of 15 miles of HOV lanes on I-5 so that they are barrier separated increases the cost estimate for this alternative by about $114 million since each HOV lane requires its own 10 foot shoulder inside the barrier.

This alternative is a comprehensive package of improvements affecting over 60 miles of HOV lanes on I-5, SR-99, SR-522, and SR-526. The incremental cost of the HOV/Busway Alternative relative to the Baseline Alternative is estimated at $868 million, which makes it the most costly alternative. In this case study capital improvements in the HOV/Busway Alternative were made to over 60 miles of roadway on four facilities, while in the SOV Capacity Expansion Alternative capital improvements were made to about 17 miles of roadway on only two facilities. Therefore, these case study estimates should *not* be used to compare general SOV capacity improvements to general HOV capacity improvements.

High cost construction elements of the HOV/Busway alternative include the following:

- Construction of 25 miles of new arterial transit lanes, two directions ($183M)

- Upgrade of 15 miles of paint-stripe separated HOV lanes to barrier-separated lanes, two directions, which require an additional 10 feet of right-of-way in each direction inside the barrier ($114M)

- Construction of 9 miles of new freeway barrier-separated HOV lane, two directions ($79 M)

- Modification of the I-5/I-405 interchange to accommodate direct freeway-to-freeway HOV connector ramps ($71M)

- Construction of two "Texas-T" interchanges for direct access into the HOV lanes ($62M)

- Construction of four miles of barrier-separated HOV contra-flow lane on the I-5 Express Lane Roadway between the University District and downtown Seattle, including a transit-only ramp accessing the lane from NE 42nd Street ($57M)

- Widening of the quarter-mile long Aurora Bridge on SR-99 for the addition of HOV lanes in both directions ($47M)

Other high cost estimate items include $48M for an additional 119 new transit vehicles necessary for provision of the increased transit service proposed. Note that right-of-way costs that have been estimated for the two capital-intensive alternatives did not differ significantly. It might seem counterintuitive that right-of-way costs for the SOV Capacity Expansion and HOV/Busway Capacity Expansion Alternatives were about the same since the HOV/Busway Alternative included improvements to many more lane miles than the SOV Alternative. The reason for this similarity is that the SOV Capacity Expansion alternative required about three times as much right-of-way on SR-99 than the HOV/Busway alternative required on SR-99. In addition, because SR-99 is more developed than I-5, right-of-way costs on SR-99 are expected to be higher than right-of-way costs on I-5.

HOV/Busway Plus ITS Alternative: This alternative includes the HOV/Busway Alternative plus essentially the same communications and traffic management investments presented in the ITS Rich Alternative. The communication element is comparable in cost to the ITS Rich Alternative with a slightly higher investment in the transit vehicle interface component. Note that the HOV/transit facilities and services cost in this alternative is about $4 million less than the corresponding cost in the HOV/Busway alternative. These costs are reduced because in the HOV/Busway Plus ITS Alternative fewer new buses are required due to the transit operating efficiencies created by the ITS improvements. Overall, however, the additional investment in ITS elements for the HOV/Busway Plus ITS Alternative would cost an estimated $34 million dollars more than the HOV/Busway Alternative.

7.9.3 Annualized Capital Costs and Annual Operating and Maintenance Cost Estimates

Estimated annualized capital costs and annual operating and maintenance costs are shown in Table 7-20. All costs are the incremental costs relative to the No Action/TSM Baseline Alternative. The annualized capital costs take into account the expected life of the various capital components of each alternative. A seven percent discount rate was used to reflect the cost of capital.

The estimated annualized capital cost of the ITS Rich Alternative is about $4.8 million per year relative to the Baseline Alternative. The two more capital-intensive alternatives — the SOV Capacity Expansion and the HOV/Busway Alternatives—have estimated annualized capital costs of $27.5 million and $78.1 million, respectively. When the complementary ITS elements are added to these alternatives, the additional annualized capital cost for the SOV Capacity Expansion Plus ITS is estimated at $5.5 million and for the HOV/Busway Alternative Plus ITS, $5 million.

Relatively speaking, the operating and maintenance costs are not anticipated as a large cost factor for the ITS Rich Alternative. The ITS Rich Alternative is expected to actually reduce transit operating costs relative to the No Action/TSM Baseline alternative by about $2.6 million due to the increased efficiencies of transit run times resulting from the ITS strategies. The investment in ITS/Traffic Systems would add about $3.3 million in O&M costs relative to the Baseline. The net impact of the ITS Rich Alternative on O&M costs relative to the Baseline Alternative is an additional $704,000.

Table 7-20 Annualized Incremental Capital, Operations & Maintenance Cost Estimates - North Seattle Case Study

	Investment Category	ITS Rich		SOV Capacity Increase		SOV Capacity Inc. + ITS		HOV Busway		HOV Busway + ITS	
		Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M	Capital	O&M
FACILITY	SOV FACILITIES	–	–	$21,096K	$964K	$21,096K	$964K	–	–	–	–
FACILITY	HOV/TRANSIT FAC./SERVICES	($601K)	($2,600K)	($36K)	$61K	($765K)	($4,598K)	$71,305K	$39,092K	$70,769K	$34,255K
FACILITY	RIGHT-OF-WAY	–	–	$6,349K	–	$6,349K	–	$6,729K	–	$6,729K	–
ITS / TRAFFIC SYSTEMS	SURVEILLANCE	$1,224K	$440K	–	–	$1,347K	$470K	–	–	$1,224K	$440K
ITS / TRAFFIC SYSTEMS	TRAVELER INFORMATION	$296K	$407K	–	–	$421K	$560K	–	–	$296K	$407K
ITS / TRAFFIC SYSTEMS	COMMUNICATION	$1,592K	$71K	$47K	–	$2,036K	$105K	$47K	–	$1,592K	$71K
ITS / TRAFFIC SYSTEMS	TRAFFIC CONTROL	$821K	$170K	–	–	$863K	$183K	–	–	$821K	$170K
ITS / TRAFFIC SYSTEMS	TRAFFIC MANAGEMENT	$217K	$817K	–	–	$272K	$1,021K	–	–	$217K	$817K
ITS / TRAFFIC SYSTEMS	TRANSIT MANAGEMENT	$135K	$123K	–	–	$135K	$123K	–	–	$135K	$123K
ITS / TRAFFIC SYSTEMS	TRANSIT VEHICLE INTERFACES	$1,095K	$1,245K	–	–	$1,092K	$1,242K	–	–	$1,240K	$1,419K
ITS / TRAFFIC SYSTEMS	INCIDENT MANAGEMENT	$87K	$32K	–	–	$87K	$32K	–	–	$87K	$32K
	Total Annual Incremental Costs*	$4,866K	$704K	$27,456K	$1,025K	$32,933K	$101K	$78,081K	$39,092K	$83,110K	$37,733K

** Relative to Baseline*

Similarly, O&M costs are not expected to be a large factor for the SOV Capacity Expansion Alternative; the increase in O&M costs over the Baseline Alternative is estimated at about $1 million, which is associated with the additional lanes of SOV capacity. The SOV Capacity Expansion Plus ITS is estimated to reduce transit operating costs by $4.6 million. However, additional ITS O&M costs are incurred because of the additional lanes of SOV capacity. The net result is that the SOV Capacity Expansion Plus ITS has estimated incremental O&M costs over the Baseline Alternative of $101,000.

Incremental O&M costs for the HOV/Busway Alternative are estimated at over $39 million. This includes the additional O&M costs associated with roadway widening, construction of direct access ramps, and additional park and ride lots. Not surprisingly, the largest contributor to the incremental O&M costs is the additional transit operating and maintenance costs relative to the Baseline Alternative, which are a direct result of the increase in transit routes, runs and associated fleet size. The HOV/Busway Alternative Plus ITS would have estimated incremental O&M costs relative to the Baseline of $37.8 million. This is slightly lower than the incremental costs of the HOV/Busway Alternative since this alternative has lower transit operating costs due to increased transit system efficiencies.

8. Process Validation

Validation of the travel analysis process is an important step in any Major Investment Study (MIS) since it is used to verify that: (1) the transportation supply is being correctly represented within the simulation networks and models (links, travel times and costs, of getting from origin to destination for each mode); and (2) the resultant forecast use of the system is reasonable (mode share, link volumes, transit boardings, alightings, and loads). If these can be shown to match observed data on system performance and facility use, then it can be presumed that the models are representing the traveler's response to system conditions within reason. Again, the MIS process is typically carried out using regional network models and the traditional four-step travel forecasting process. Validation is as, or more, important when conducting an MIS that includes a sub-area simulation since these simulation models require data at higher levels of detail and accuracy. Simulation models also add the complexity of dealing with the time variation of conditions.

Using 1990 conditions, a validation of both the regional travel forecasts and the sub-area simulation was carried out for the case study. At the regional level, the regional travel forecasting model and data sets for 1990 in EMME/2 format were obtained from Puget Sound Regional Council (PSRC). The enhancements described in Section 7 were implemented and new model runs were then made. The results were validated to the original PSRC 1990 model outputs. For use at the sub-area level, 1990 networks and travel demand data sets in INTEGRATION format were derived from the regional forecasting system. Additional information on the time variation of flows and congestion build up was then collected, and the simulation was adjusted to reflect both the ebb and flow of traffic entering the system. This was done along each major route and the shift in use of facilities across the simulation period was accounted for. Each validation effort is explained below.

8.1 EMME/2 Regional Model Validation

The initial EMME/2 regional model, networks, and data were obtained from PSRC, and acted as a starting point for developing the case study analysis process. The EMME/2 network coding and other elements were modified as described in Section 7. The regional model validation was then carried out for 1990 to make sure that the enhancements made to the system did not introduce any undue sensitivities or unexplainable results. Since the goal of the case study was not to develop a new regional model system it was presumed that the PSRC 1990 model was validated within acceptable limits. Therefore, a revalidation of the PSRC 1990 model was not conducted. The case study regional model validation, therefore:

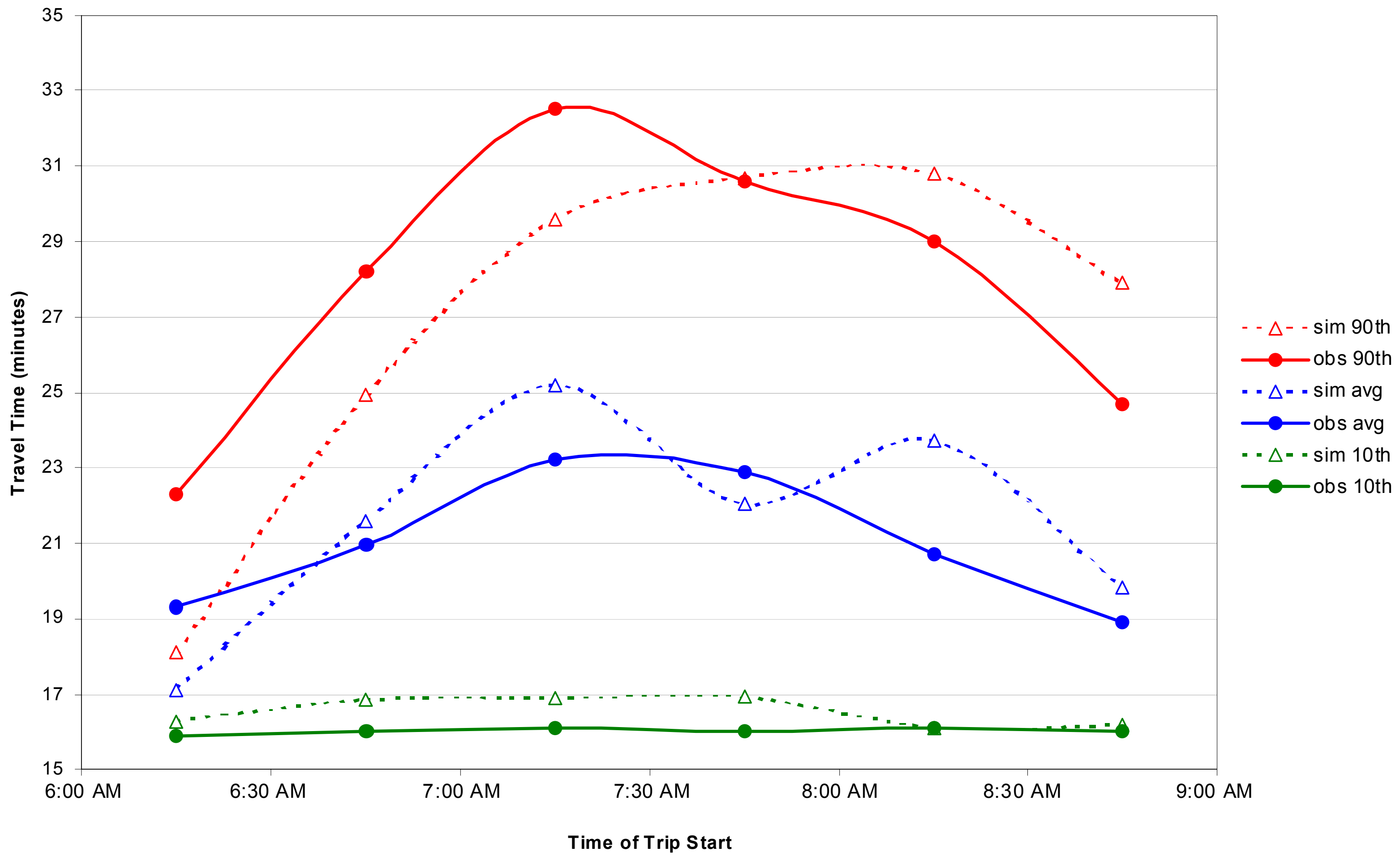


Figure 8-5. System Variability Calibration, Southbound I-5, Alderwood Mall to Mercer Street

runs over the 30 representative day scenarios (described in Section 7.6). 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 in a like fashion 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 8-5 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 8-4 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 90^{th} 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 90^{th} percentile simulated data is lower in the early peak 7:00-7:30 AM period. Esecially for the 90^{th} 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 an increased number, or more serious, accidents on the freeway later in the peak period than those occurring over the calibration data period, 1997-98.

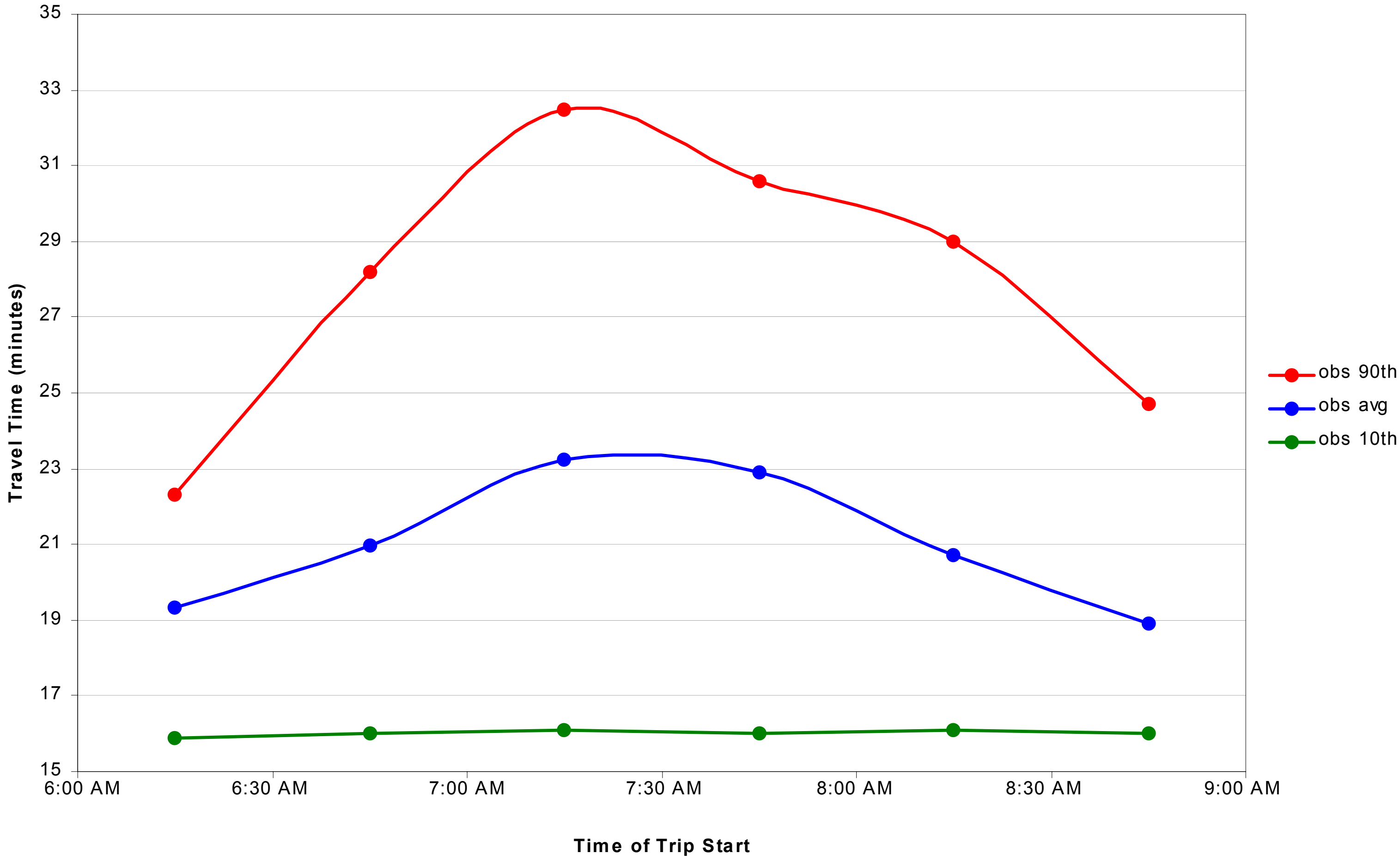


Figure 8-4. Observed Travel Time Variability, I-5 Freeway (Alderwood Mall to Mercer Street)

- Used the PSRC 1990 estimated travel demand as a base for comparison focusing on 24 hour screen line volumes, sector-to-sector travel patterns, mode shares, and corridor travel times.
- Performed comparison to the same scale that was used in the PSRC validation process (Technical Report MTP-12, PSRC, September 1994).
- Used information on 24 hour screen line counts, other volumes, and U.S. Census Journey-to-Work data for validation checks.

The detailed validation analyses were carried out by the local subcontractor, PBQD, for the case study. Several iterations were performed and the final results provided in "ITS Case Study Final Model Validation Results: December 23, 1996" (PBQD, 1996). The following checks were made throughout the validation process:

- Point-to-point travel time comparisons from major origins/destination within the study area to/from the region. Travel times only varied slightly and stayed within 1 minute of the original model results.
- Hour screenline volume comparisons between the original model and actual ground counts. The screenline volumes within the study area varied by no more than 2%. All screenlines capturing North-South movement along the corridor are within 10% of observed 1990 counts.
- AM Peak period transit volumes at selected screenlines (East-West movements crossing Lake Washington, North-South movements crossing the Seattle Ship Canal, and North-South movements at N. 185th street). These transit volumes remained very close to the original model results with the largest change of -300 out of 22,915 transit trips occurring at the Ship Channel.
- Sector-to-sector Home Based Work Transit Mode Shares. These values were compared both with the original model results and to the 1990 Census Journey-to-Work data. The within-study-area mode splits to the CBD remained unchanged. The models tended to predict a slightly higher transit mode share than reported in the Journey-to-Work data. This result is reasonable given the difference in trip definition between the Journey-to-Work data and Home Based Work trips (Journey-to-Work also includes trips with additional stops while going to work, while pure Home Based Work trips include only direct home-to-work travelers).
- Sector-to-sector Daily Transit Trips. The sector-to-sector daily transit trips result from two factors: (1) the change in trip distribution, and (2) the change in mode share. Overall transit trips remained the same between the two model systems. On a sector basis the trips did vary as a result of the shift in trip distribution while mode share remained relatively constant.

- Sector-to-sector Daily Total Person Trips. Trip distribution takes into account both congested travel time (for work trips) and uncongested time (for other trips) in the network. Sector-to-sector trip differences were mostly within 1-2% with some smaller absolute interchanges shifting slightly more (no interchange shifted more than 6%). Due to the more detailed coding and ramp volume delay functions there was a slight reduction of trips from the Study Corridor to the CBD and areas south and an increase to the areas east of Lake Washington.

It was concluded that, while the additional network coding shifted volumes slightly, no major changes in travel demand were introduced with the enhanced system. In some instances the match to ground counts resulting from the detailed coding actually improved as routes were more realistically represented. In general, the modified system performed at the same level of accuracy as the original model with similar results.

8.2 INTEGRATION Sub-Area Simulation Model Validation

Once the regional model system had been validated, networks and demand data were generated for the sub-area simulation from the EMME/2 network database and static trip table. At this point a second calibration effort was carried out for the simulation subarea. Unlike a typical simulation calibration effort, the process in the Seattle case was constrained by two data sets. First, the simulation should preserve as much as possible the flavor of the regional EMME/2 model (in terms of O-D trip patterns and network geometry). Second, the simulation should also generate dynamic speed and volume estimates consistent with observed data where such data are available.

A validation effort compared against the steady-state regional model flows and travel times does not allow for an examination of time dynamic effects in the simulation sub-area. Since the travel simulation captures the time variant and operational aspects of the transportation system performance within the simulation sub-area, observed data must be available that provide measures of network performance throughout the peak period. To exclude a constraint for consistency with the regional model is also problematic, particularly with regard to feedback between the two models. This approach differs from a typical simulation validation effort which would begin with the derivation of a new O-D trip pattern which better fit the observed link flow data. This newly derived trip pattern might be “seeded” with the static regional pattern, but the derivation process can result in significant alterations in an effort to better fit observed data. For example, these alterations might include the elimination of longer trips for shorter ones, or fewer or greater numbers of trips in the network overall.

Therefore, the goal of this effort was to produce a set of simulation inputs which are both consistent with the regional modeling link geometrics and O-D travel patterns and produce outputs that accurately reflect observed speed and flow data.

Ideally, a rich set of validation data, both average-condition and time-variant would be available for concurrent validation of both the simulation and the regional planning model simultaneously. However, this may never be a practical consideration in the near-term given that a complete regional validation would then be required for every MIS considered within a region.

The calibration effort was performed with respect to four target data sets:

- Regional model screenline counts
- Temporal and geographic location of recurrent AM peak period bottlenecks (determined from WSDOT FLOW observations and camera shots)
- Observed three-hour total volume counts from 1990 (16 stations)
- Average 30-minute peak period travel time estimates for I-5 freeway (16 month period

The calibration process began with the screenline volume check on a static daily trip table. At that time, a time variant flow pattern was introduced. In each step, a set of parameters was chosen to vary to calibrate the system. Finally, the results from the last calibration test (average intra-day travel times) were then re-examined with respect to the previous data. The refinements introduced in each step did not invalidate previous validations.

8.3 Screenline Volume Validation

Of the more than fifty PSRC primary regional screenlines, six are wholly contained within the simulation subarea. Of these, four were selected to compare peak period volumes. These four were screenlines (Table 8-1) which extended across the subarea in an east-west direction and but did not extend outside of the subarea (#35, #38, #41, #42). The other two screenlines (#36, #40) are short North-South screenlines which extend only to three or fewer links. These screenlines were considered too focused to be included in this analysis given that a more detailed link flow analysis based on observed time-variant data was to be performed.

The peak-period volumes from the simulation and the regional model were quite close – within 8% in all cases (Table 8-1). This is to be expected since the trip table used by the simulation was derived directly from the regional model. Large errors would have indicated a problem in the trip table conversion process. The relatively small errors obtained can be attributed to the fact that most but not all trips were completed within the peak simulation period, while the regional model assumes all trips finish.

To compensate for this differential, average hourly flow on the simulated screenline links were identified and then scaled up to the three-hour peak period modeled in EMME/2.

Table 8-1. **Validation Against Regional Screenline**

Screenline Number	Screenline Description	Target	Simulated	Pct. Absolute
35	Ship Channel	91156	88020	3.40%
38	Northgate	74901	72892	2.68%
41	SR 523	61859	56937	7.96%
42	SR 104	47862	47030	1.74%

Further, some variation in generated vehicles is to be expected in the simulation because of round off errors introduced when the continuous trip flow data from the planning model is converted into discrete vehicle entities for simulation.

Assessment of Congestion Location and Timing. At this point a time-variant demand curve was introduced to the static trip tables obtained from the regional model. The basis for this pattern for this demand curve was derived from the Highway Capacity Manual (HCM) data on urban travel demand peaking. Again, the continuous rise and fall of the HCM data had to be approximated in discrete periods of demand for use in the INTEGRATION simulation. This pattern was refined by adjusting the relative peaking of the curve when compared with observed bottlenecks in the simulated network. The final peaking pattern developed is illustrated in Figure 8-1 shown here as trip starts during the AM peak period. This time-variant demand pattern generates 231,000 vehicles in the peak period, compared with the

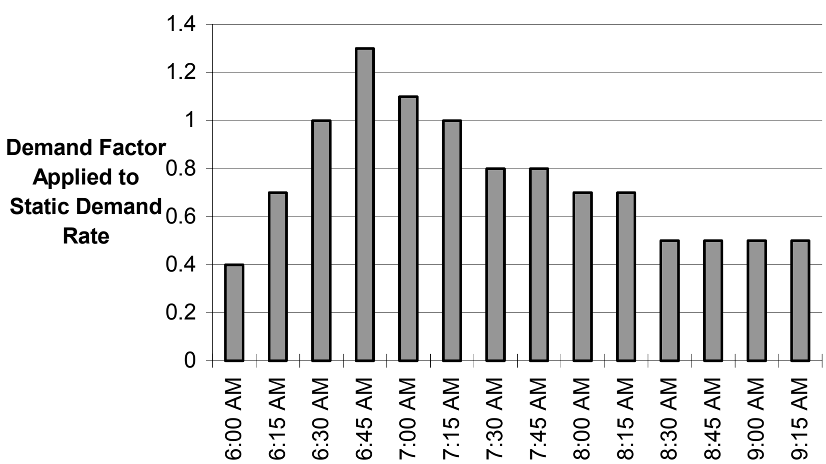
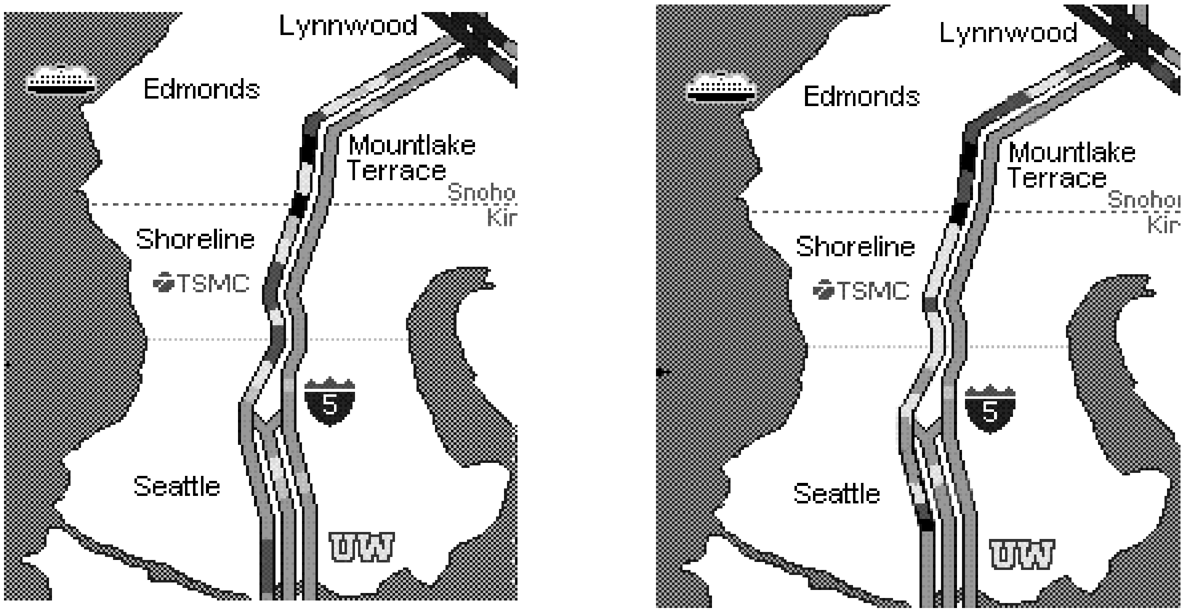


Figure 8-1. Time-Variant Demand Peaking Pattern

235,000 vehicles predicted in the regional model. The slight differences is attributable to integer round-off error, a non-trivial problem when a large number of the 40,000 origin-destination flow rate entries have fewer than 20 trips per hour associated with them. O-D exchanges with fewer than 10 vehicles per hour were modeled with invariant demand in order to keep the number of time variant flow entries associated with O-D pairs under the simulation limit of 40,000.

In order to calibrate the time-variant demand curve, Mitretek archived information from the WSDOT website (http://www.wsdot.wa.gov) on traffic conditions for a sample of days in 1997. The WSDOT website offers detailed information on vehicle density along I-5 in the study corridor. This information is presented to website visitors as color-coded segments with qualitative labels ranging from "stop and go" to "wide open" depending on vehicle density. A close quantitative examination of vehicle densities was not undertaken with this data given the change in travel demand and network capacity between our 1990 base year and the 1997 data. However, the data were useful in determining where bottlenecks typically form and the length of queues under recurrent and non-recurrent conditions. The color-coded map showing the approximate site and extent of delay can be compared against maps generated from the 1990 simulated network under similar conditions (Figure 8-2). In this case, Figure 8-2 reflects a non-incident, recurrent congestion case. A captured color image
was taken from the WSDOT website (3/11/97) and converted to gray scale. The darker the gray color along the freeway, the higher the vehicle density. The second image has been altered to reflect simulated output from INTEGRATION.

During three of the mornings precipitation was a factor in system capacity (from snow, rain and/or fog), while three days had clear weather. Two of the days featured accidents (one major, one minor) along I-5 in the southbound direction. From the non-incident data, an assessment of where delay occurs on a recurrent basis can be identified. In both the simulation and along southbound I-5 during the AM peak periods archived, congestion begins to build early in the rush hour (6:40 AM - 7:15 AM). This congestion occurs north of 220th street first, and then in the interchanges between Northgate and 175th street. Simulated delays build in this early period because of heavy mainline volume having to absorb significant (albeit metered) on-ramp flows. A check of camera shots from this period via the WSDOT website suggests that this is a typical cause of recurrent slowdown in the early rush period. In the 7:15-7:30 AM time frame, the interchanges north of the ship channel (45th Street, 50th Street and the interchange just south of 65th Street) also begin to slow from heavy volume. The southbound express lanes through this area are typically not congested, although where additional flow joins the express lanes above SR 522 some delay occurs beginning in the merge area. By 8:00 AM simulated (and observed) delays can be found along the length of the southbound mainline I-5 facility. The HOV lane modeled sees no significant delay except at access and egress points along I-5 where merging with mainline traffic cannot be avoided. In this mid-to-late rush hour regime, the congestion and



Observed Conditions 7:03 3/11/97   Simulated Conditions 7:00-7:15 AM

Figure 8-2. Location of Bottlenecks, Early AM Peak, Non-Recurrent Conditions

delay along SR 99 increase in the simulation, although no observed data are available to validate this effect. Northbound along I-5, recurrent congestion reported via the WSDOT website are not typically significant. The simulation generates similar results throughout the peak period.

8.4 Calibration Against Observed and Simulated Flow Rates

To provide a more quantitative validation of simulated conditions, availability was identified data by jurisdiction and facility type. A primary source of data was WSDOT traffic counts (flow data) for the calendar year 1990 along the I-5 freeway. These data were available in 15 minute time periods throughout more than 200 AM peak periods in 1990. Second, WSDOT spot counts along SR 99 (fewer than ten days) were also analyzed to characterize AM flow rates. In all, four locations along I-5 (including express lanes) and eight locations along SR 99 were identified for analysis. Average observed flow (OBS) in vehicles per hour (VPH) at these points in the network are presented in Table 8-2 alongside the average simulated flow in the same period (6:30 AM - 9:30 AM). Error at each location is expressed as the absolute value of the simulated flow minus the target flow. The average error statistic reported is the average absolute error taken over the ten locations with each location weighted equally.

Table 8-2. **Simulated and Observed Flow Rates in the Simulation Subarea**

Facility	Location	Direction	Simulated (VPH)	Target Flow (VPH)	Error
I-5	Ship Ch.	NB	5407	4774	13% HI
I-5	Ship Ch.	SB	6861	6067	13% HI
I-5	195th	NB	2291	3278	30% LO
I-5	195th	SB	6167	5538	11% HI
SR 99	Aur. Br.	NB	1520	1500	1% HI
SR 99	Aur. Br.	SB	2996	3633	18% LO
SR 99	175th	NB	687	892	23% LO
SR 99	175th	SB	1763	1335	32% HI
SR 99	200th	NB	529	525	1% HI
SR 99	200th	SB	1563	1362	15% HI
		Average Absolute Error		15.7%	

Before any calibration effort was performed, the average error was 35-40%, primarily from large undercounts (low simulated volumes) along SR 99. Two calibration techniques were employed, one for arterials and one for freeways. For the SR 99 arterial, signal timing plans were adjusted for phase split to provide more green time for north and southbound traffic. The adjusted timings retained the cycle length parameters outlined in the North Seattle ATMS evaluation document. This helped to bring the signalized sections of SR 99 closer to observed counts.

Freeway calibration involved manipulation of two types of parameters. First, manipulation of signalization parameters (cycle lengths and phasing) at a few key off-ramp facilities were implemented. Second, we altered volume-speed functions for the "artificial links" linking distant origins and destinations to the subarea. By adjusting a link to be slightly faster under a range of flow conditions South of downtown Seattle but near the I-5 connection point, average flow northbound on I-5 crossing the ship channel was improved. These techniques were less successful for the 195th and 175th stations since these interchanges are located centrally in the network and the effect of changing conditions along the border have limited impact in the center of the network.

In addition to the average peak period flows for these selected links, an analysis of time-variant flow rates was undertaken at a subset of stations. Simulated (flows) by 30-minute intervals were examined against a set of days with no incidents or major weather events from 1990. A sample of such a comparison is provided as Figure 8-3 for I-5 southbound near 130th Street. In this figure, the relative rise and fall of volume on the facility can be

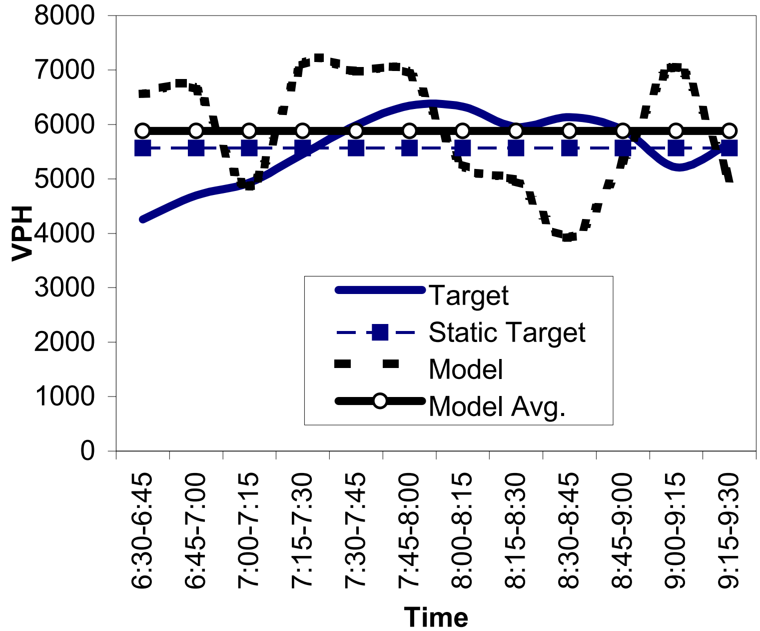


Figure 8-3. Sample Time-Variant Link Volume, Simulated vs. Observed

compared between the simulation and the observed data. The observed time variant flow rates ("target") rise and fall in a pattern that is not closely matched by the time-variant rates ("model") obtained from simulation. For individual links in the network, the match between time-variant flows can be inexact, even though the averages may be quite close as is the case here near 130th street. Note that the peak period average observed flow rate ("static target") is closely matched by the peak period average flow rates obtained in simulation ("model avg.). At this point, a typical approach for calibration would be to alter the O-D demand pattern on an individual entry basis; that is, adjust individual flow rates independently within time-variant O-D pattern. However, for this analysis we chose to omit this step given the restriction to remain consistent with the O-D trip table.

8.5 Peak Period Travel Time Variability Calibration

Time-variant modifications to the subarea demand pattern were calibrated to data describing trip time variability, as will be demonstrated in Section 9. 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.

The primary data source for calibrating the within-peak travel time came from estimates of travel time delivered by the Microsoft Sidewalk service at regular intervals in the AM peak

period over a 16 month period from June 1997 to October 1998. 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.

The calibration data for southbound (peak direction) travel between Alderwood Mall and Mercer Street on I-5 is illustrated in Figure 8-4. Average travel time between these two points (15.3 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 8-4). 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 conditions associated with some of the worst congestion encountered throughout 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 travel time estimates obtained from Microsoft Sidewalk are not as accurate as data provided from a dedicated probe-vehicle travel time study because they are based on estimates of speed from link detector data collected every quarter mile. 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.

Although the calibration of within-day travel time in the training process is important in establishing reasonable habitual route patterns for commuters and travel time profiles for the overall system, the calibration of day-to-day travel times requires a complete set of

9. Alternatives Evaluation

The results of the alternatives evaluation are presented in this section. First, three one-page impact summary tables are presented in Section 9.1, covering: Do Nothing/TSM vs. ITS Rich, SOV Capacity Expansion vs. SOV + ITS, HOV/Busway vs. HOV/Busway + ITS. These summary tables provide high-level characterizations of each alternative. After this summary, each of the three pair-wise comparisons is examined in detail. Sections 9.2 (Do Nothing/TSM vs. ITS Rich), 9.3 (SOV vs. SOV + ITS), and 9.4 (HOV/Busway vs. HOV/Busway + ITS) contain a regional impact subsection, a subarea impact subsection, cost detail, and a statement of environmental implications.

9.1 Impact Summary Tables

Table 9-1 summarizes the Do Nothing/TSM and ITS Rich alternatives. The Do Nothing/TSM alternative is compared to the performance of the 1990 validation network. By the year 2020, significantly higher travel demand at the regional level is projected. This large increase in regional travel demand is mirrored by a 41% increase in subarea travel. Given that no additional capacity has been implemented in the subarea, the result is that the subarea experiences significantly worse travel delays and higher travel times than currently observed. The impact of the ITS Rich alternative is made with respect to the 2020 Do Nothing/TSM (also referred to here as the Baseline alternative). The impact of the ITS Rich alternative at the regional level includes a shift from personal vehicle to transit and additional travel demand being drawn to the subarea. The subarea itself still experiences delay, but at a reduced rate, while travel time variability is restored to 1990 norms.

Table 9-2 summarizes the SOV Capacity Enhancement alternative (SOV) and the SOV Capacity Enhancement Plus ITS (SOV + ITS) alternative. The SOV alternative is characterized (vs. Baseline) at the regional level as providing faster travel times, particularly for trips that utilize the upgraded SR99 facility. At the subarea level, the upgraded SR99 facility shows vulnerability to congestion under weather or heavy demand cases. The result is that an expected improvement in annualized throughput and travel time is not realized. The SOV + ITS alternative (compared to SOV) mitigates to some degree the congestion conditions along SR99 under poor weather and heavy demand conditions, and provides a significant increase in annual subarea throughput. At the regional level, the ITS improvements increase total trip length and bring additional demand into the subarea.

Table 9-3 summarizes the HOV/Busway alternative and the HOV/Busway Plus ITS alternative (HOV + ITS). At the regional level, the HOV alternative (compared to Baseline) features an overall shift to transit trips and a decrease in daily auto VMT and VHT. Freeway performance in general purpose lanes are observed to be unreliable under weather scenarios. The HOV + ITS alternative is helpful for freeway-based travel in these weather scenarios, reallocating travel demand away from freeways and onto arterials. At the regional level, these improvements result in longer, faster trips as well as increased transit ridership.

Table 9-1. Alternatives Comparison Summaries: Do Nothing/TSM vs. ITS Rich

2020 Alternative Comparison Implications ITS Rich vs Nobuild/TSM		
Measure of Effectiveness	Impact of Do Nothing/TSM (Baseline) Compared to 1990 Validation Network	Impact of ITS Rich Comapred to Do Nothing/TSM (Baseline)
Alternative Summary		
Regional Travel: Trips, Mode Choice, Times, and Miles Traveled		
Daily Travel		
	Daily regional person trips grow by 62% from 1990 to 2020 This causes VMT to grow by 64.5% and VHT to grow due to congestion by 80.5% A shift to carpool and transit is also seen (+ 97% and +90% respectively compared to + 59% LOV growth)	Overall daily person trips remain the same Shift from personal vehicle to transit (Transit +1.01%) Improvements lead to longer trips (less trips within study area, more to/from study area)
AM Peak Period Travel		
AM Travel	Slightly larger % shifts are seen in the AM: Person trips (+ 62.84%), Carpools (+ 97%), Transit (+92%) AM VMT (+ 66.4%), AM VHT (+ 105%) Much more travel on a system that basically is the same as today!	Shifts in trip patterns and mode split similar to daily People travel farther in less time (improved speed) to/from/through subarea Diversion of trips to/through/from study area Diversion of trips to arterials (ATMS improvements)
Subarea Trips	An increase of 41% in vehicle trips to/from/through the subarea leading to severe congestion especially at the Ship Canal bridge crossings.	More vehicle trips to/from/through subarea (+3,300) Even with more vehicles speed is improved (3.85%) Longer trips are also made.
Sub Area Impacts: Delay Reduction, Reliability, and Level of Service		
AM Peak Period Travel		
	Highly congested system Higher travel times Significant increase in travel time variability	Travel time varability restored to circa 1990 validation network norms Higher throughput Slightly improved overall travel times
Capital & Operating Costs		
	HOV lanes added between 128th st. SE and SR526, limited interchange and arterial street improvements. Circa 1990 ITS deployments: web-based ATIS, fixed signal timing, ramp metering as deployed on I-5	Aggressive implementation of adaptive signal control, expanded traffic management and surveillance, incident management and transit priority in the I-5 study corridor.
Environmental Impacts		
	Likely worse: slower traffic, increase in stops	Mixed bag: fewer stops but longer, faster trips

Table 9-2. Alternatives Comparison Summaries: SOV without ITS vs. SOV with ITS

2020 Alternative Comparison Implications SOV Capacity Expansion + ITS versus SOV Capacity Expansion		
Measure of Effectiveness	Impact of SOV Capactiy Expansion Compared to Do Nothing/TSM (Base)	Impact of SOV Capacity Expansion + ITS Compared to SOV Capacity Expansion (ITS Alt)
Alternative Summary		
Regional Travel: Trips, Mode Choice, Times, and Miles Traveled		
Daily Travel		
	Overall daily person trips remain the same Shift to walk-to-transit trips within/from the corridor, but drop in long distance transit Park&Ride Drop in trips within study area and increase in trips to/from the subarea especially to CBD Increase in Daily VMT and Decrease in Daily VHT reflects upgrade of SR-99 to expressway and faster speeds	Overall daily person trips remain the same Increase in transit person trips (slightly less than ITSRICH increase), and concomittant drop in vehicle trips Further reduction in within subarea trips and increase in trips to/from subarea. Additional increase in trip length as travel within corridor improved.
AM Peak Period Travel		
AM Travel	Similar patterns as found in daily travel Slight shift in overall transit results from higher walk-to-transit and drop in longer drive-to-transit Much faster travel in SR-99 corridor causes overall decrease in travel times	Similar patterns as found in daily travel Increase in transit trips but again slightly less than seen in ITSRICH Overall increase in travel conditions seen by slightly longer trips in transit and vehicle trips, and improved times, speeds
Subarea Trips	Significant increase in vehicle trips to/from/through the subarea due to diversion to SR-99 Improvements in SR-99 cause increase in subarea average speeds	Additional vehicle trips diverted to the corridor are the greatest of any alternattive Slight improvement in congested speeds
Sub Area Impacts: Delay Reduction, Reliability, and Level of Service		
AM Peak Period Travel		
	Higher system demand Significant increase in travel time variability Throughput increase smaller than demand increase	Significant improvements in travel time variability and system throughput Changes particularly signficiant in weather or high demand scenarios
Capital & Operating Costs		
	Cost drivers are: Conversion of 14 miles of urban arterial to urban expressway Construction of nine new urban expressway interchanges Construction of nine new grade separated arterial crossings of the expressway	Capital costs to implement same elements as in ITS Rich slightly higher than for baseline due to increases in communications and traffic management costs.
Environmental Impacts		
	Likely marginally worse: increase in high-speed stops	Likely positive: many fewer high-speed stops

Table 9-3. Alternatives Comparison Summaries: HOV/Busway without ITS vs. HOV/Busway with ITS

2020 Alternative Comparison Implications HOV/Busway + ITS versus HOV/Busway		
Measure of Effectiveness	Impact of HOV/Busway Compared to Do Nothing/TSM (Base)	Impact of HOV/Busway + ITS Compared to HOV/Busway Alternative (ITS All)
Alternative Summary		
Regional Travel: Trips, Mode Choice, Times, and Miles Traveled		
Daily Travel		
	Overall daily person trips remain the same Overall shift to transit trips in both walk-to-transit and P&R trips (base alternative with most transit trips) Very slight drop in trips within study area and an increase in trips to/from the study area. Decrease in Daily auto VMT and VHT reflects the shift to transit and drop in auto trips Additional transit service is seen in the increase in Daily Transit VMT and VHT	Overall daily person trips remain the same Increase in transit person trips (slightly less than ITS RICH % increase), and concomittant drop in vehicle trips Alternative with highest level of daily transit trips Auto VMT and VHT increase as travel is diverted to subarea, Transit VMT remains the same as HOV without ITS but VHT decreases due to transit priority treatment Additional increase in trip length as travel with corridor improved
AM Peak Period Travel		
AM Travel	Similar patterns as found in daily travel Increase in transit VMT, VHT, and person trips Decrease in auto VMT, VHT, and person trips Very slight improvements in ave. travel time for all modes Diversion to corridor is insignificant since most changes to Transit and HOV service	Similar patterns as found in daily travel Highest overall AM transit trips, but percentage increase not as large as ITS RICH Overall AM trips are longer and faster.
Subarea Trips	Slight decrease in vehicle trips through the subarea due to increase in transit use (and no diversion) Slight increase in subarea average speeds (.3 mph)	About the same increase in subarea vehicle trips due to diversion as found in ITS RICH Overall subarea trips lower than ITS RICH due to lower subarea trips in HOV w o ITS Increase in average subarea speeds due to ITS and more reliable system (+1 mph)
Sub Area Impacts: Delay Reduction, Reliability, and Level of Service		
AM Peak Period Travel		
	Higher overall system travel demand Significant differential in travel time variability between HOV and non-HOV travel	Significant redcution in delay and travel time variability Good performance under poor weather conditions
Capital & Operating Costs		
	Significant costs associated with the upgrade of several road segments to: Barrier-separated HOV Modification of I-5/I-405 interchange to accommodate freeway-to-freeway HOV connector ramps Construction of two Texas-T interchanges for direct access into the HOV lanes	Capital costs to implement same elements as in ITS Rich about the same as in the baseline.
Environmental Impacts		
	Likely positive: fewer vehicle trips	Mixed bag: faster, longer trips with fewer stops

9.2 Do Nothing/TSM vs. ITS Rich

Table 9-4. Detailed Comparison Summary, ITS Rich vs. Do Nothing/TSM

2020 Alternative Comparison Summary ITS Rich vs. Do Nothing/TSM				
Measure of Effectiveness	Do Nothing/TSM (Base)	ITS Rich (ITS Alt.)	Change (ITS Alt-Base)	% Change (Chng/Base)
Regional Travel: Trips, Mode Choice, Times, and Miles Traveled				
Daily Travel				
Daily Person Trips[1]	16,457,503	16,457,503	0	0.00%
LOV Person Trips	15,864,028	15,859,486	-4,542	-0.03%
HOV Person Trips	72,291	72,120	-172	-0.24%
Transit Person Trips	469,721	474,450	4,728	1.01%
AM Peak Period Travel				
AM Person Trips				
LOV Person Trips	2,997,986	2,996,844	-1,142	-0.04%
HOV Person Trips	54,219	54,090	-129	-0.24%
Transit Person Trips	135,819	137,013	1,194	0.88%
AM Person Miles				
LOV Person Miles	30,699,202	30,733,958	34,756	0.11%
HOV Person Miles	1,246,552	1,243,886	-2,665	-0.21%
Transit Person Miles	1,225,991	1,235,389	9,398	0.77%
AM Person Hours				
LOV Person Hours	1,244,636	1,242,697	-1,939	-0.16%
HOV Person Hours	44,578	44,462	-117	-0.26%
Transit Person Hours	130,211	129,779	-433	-0.33%
AM Average Trip Times				
LOV Person Trip Time	24.91	24.88	-0.03	-0.12%
HOV Person Trip Time	49.33	49.32	-0.01	-0.02%
Transit Person Trip Time	57.52	56.83	-0.69	-1.20%
AM LOV Vehicle Trips	2,118,624	2,117,644	-980	-0.05%
AM LOV Vehicle Miles	19,889,222	19,924,660	35,438	0.18%
AM HOV Vehicle Trips	16,727	16,685	-42	-0.25%
AM HOV Vehicle Miles	377,503	376,585	-918	-0.24%
AM Subarea Trips				
LOV Vehicle Trips	332,673	336,005	3,332	1.00%
% of Region	15.70%	15.87%	0.16%	1.05%
HOV Vehicle Trips	4,930	4,887	-43	-0.86%
% of Region	29.47%	29.29%	-0.18%	-0.61%
LOV Vehicle Trip Speed	24.29	25.22	0.93	3.85%
Sub Area Impacts: Delay Reduction, Reliability, and Level of Service				
AM Peak Period Travel				
Throughput (finished trips)	171,719	179,146	7,427	4.3%
Delay Per Veh. Trip (min)	10.88	9.28	-1.60	-14.7%
Time Coef. Of Variation	0.31	0.22	-0.09	-29.0%
Risk of Severe Delay	7.4%	5.5%	-1.9%	-26.1%
% Slow Travel (< 20 mph)				
Freeways	14.7%	10.7%	-4.0%	-27.2%
Arterials	61.4%	50.5%	-10.9%	-17.8%
% Travel with > 1 stop/km				
Freeways	12.6%	11.6%	-1.0%	-7.9%
Arterials	26.8%	22.2%	-4.6%	-17.2%
Capital & Operating Costs				
Annual Capital Costs		$4,866	$4,866	NA
Annual O&M Costs		$643	$643	NA
Annual Total Costs		$5,509	$5,509	NA

1 Daily person trips from trip distribution. Person trips by mode may not sum to daily total due to rounding

9.2.1 Regional Travel: Trips, Times, Mode Choice, and Miles Traveled

A summary of regional Measures of Effectiveness (MOEs) comparing the ITS Rich and the Do Nothing/TSM alternatives follows, illustrating the findings from the regional model presented in Table 9-4**.** The regional MOEs include trip count, length, and mode statistics by vehicle and person for daily and AM peak period travel. Also detailed are AM peak period statistics on vehicle screen line volumes, regional and subarea mode shifts by vehicle and person, and average vehicle trip length and time by area. The predominant regional trends resulting from the ITS enhancements are relatively small in magnitude and include a shift from auto modes to transit, an increase in subarea trips, a decrease in regional trips, and an increase in average trip length. The magnitude of regional impacts should be viewed with respect to the size of the region compared to that of the subarea where ITS enhancements have been made. For instance, of the 2.1 million regional auto trips made in the AM peak only 0.3 million of them traverse the subarea for any portion of their trip, and less than 0.15 million of them traverse the subarea for their entire trip.

Tables 9-5 through 9-7 summarize regional daily person and vehicle travel. The overall person trips used as inputs for the Do Nothing/TSM and ITS Rich alternatives are the same. Thus, the number of person trips for both alternatives remains the same. The APTS elements of the ITS Rich alternative increase the attractiveness of transit and prompt a 1.0% increase regionally in transit person trips. Correspondingly, there is a slight percentage decrease in non-carpool vehicle trips. The daily non-carpool vehicle miles increase by 0.20% while the daily non-carpool vehicle hours decrease by 0.13%, reflecting faster average regional travel speeds and longer average regional trip distances.

Important to note is that the majority of the carpool facilities and correspondingly carpool trips are within the subarea. Thus ITS enhancements impact a greater percentage of regional carpool trips than regional non-carpool trips. The number of carpool trips impacted is quite small. In fact, the number of impacted carpool trips is smaller than the round-off error. The point here is that with ITS enhancements to transit, daily carpool share does not increase at the regional level.

Tables 9-8 through 9-10 provide corresponding statistics for the AM peak period. Trends of transit share in the AM peak are similar to those of daily travel. Transit vehicle miles remain constant while vehicle hours decrease more than 2.0%, reflecting faster average transit vehicle speeds for the region during the AM peak. The decrease in AM peak non-carpool vehicle trips is not significant; however, the increase in corresponding vehicle miles traveled is significant, indicating longer trips for non-carpool vehicles in the AM peak. As in daily carpool trips, there is a decrease in the percentage of carpool vehicle from the Do Nothing/TSM to the ITS Rich Alternative. The magnitude of change, however, is not significant.

Tables 9-11 and 9-12 illustrate the impact of the ITS Rich elements on throughput and trips attracted (diverted) to the subarea that is represented in simulation. Table 9-11 presents the AM peak period trips to, from, and through the subarea. The number of AM peak non-carpool vehicle trips at the regional level decreases by less than 0.05%; however, the number of AM peak subarea trips increases by over 1.00%. This indicates that although ITS elements regionally have minimal impact, the elements make a significant change in subarea corridor use. Specifically, ITS elements in the subarea attract approximately 3,300 more non-carpool vehicles to use the subarea for some portion of their trip.

This diversion of trips to utilize the subarea is also reflected in the AM peak period screen line volumes shown in 9-1 Table 9-12 (Figure provides the location of each screen line). The screen line volumes show more noticeable percent changes than the overall regional travel measures as they capture more localized effects, mode split impacts, and travel diversion impacts. Screen line 43, Locust Way, shows the highest increase in travel (2.77%) reflecting the diversion of vehicles to SR522, which sees improved performance from the adaptive signal control system in the ITS Rich alternative.

Table 9-13 provides a breakout of the AM peak non-carpool vehicle trips that travel to, from, and through the subarea by origin and destination areas. The areas are defined as (1) the subarea, (2) the area south of the subarea within the North Corridor influence area, (3) the area north of the subarea within the North Corridor influence area, and (4) the area outside the North Corridor. These regions are mapped in Figure 9-2. Table 9-13 reveals how the number, length, and duration of trips are interrelated and interact due to ITS improvements.[19]

Most noticeable is that more of the trips originating from each of the four regions make use of the subarea for some portion of their trip in the ITS Rich alternative than in the Do Nothing/TSM alternative. Moreover, the trips making use of the subarea in the ITS Rich alternative are on average longer yet require significantly less travel time. Of the four defined areas, the South Corridor shows the greatest percentage increase in vehicle trips using the subarea. These trips are for the most part going northbound, are slightly shorter, and have a disproportionately greater travel time saving. The large travel time savings is attributable in part to trips being shorter, but moreover because in the Do Nothing/TSM alternative signal timing was fixed and promoting southbound travel whereas with ITS enhancements signals are actuated providing northbound traffic more proportionate green time. Trips from and to outside the corridor (area 4) increase while their average distance decreases. This is the result of new relatively shorter trips being attracted to the simulation area.

Table 9-14 details in person trip statistics the shift in subarea AM peak travel resulting from ITS enhancements. Figure 9-3 presents graphically the seven areas defined as (1) subarea, (2) South Corridor, (3) North Corridor, (4) King County, (5) Snohomish County, (6) Pierce South, and (7) Islands and Olympic Peninsula. As noted earlier the number of person trips is maintained constant from the Do Nothing/TSM to the ITS Rich alternative. The distribution of trips; however, changes as a result of the ITS enhancements. ITS prompts more person trips originating from the subarea to travel to adjacent areas (areas 2, 3, and 4). This increase in person trips from the subarea to other regions is offset by fewer within subarea person trips. Similarly, more person trips originating from the adjacent regions of the North Corridor, South Corridor, and King County are made to the subarea.

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19 Both impacts of the regional recurrent delay analysis and the rolled up travel time impacts of the simulation representative day analysis are captured in the trip time values.

In summary, the ITS Rich Alternative impacts are small but significant at the regional level. Impacts are much more pronounced within the subarea where ITS options are exercised. The predominant trends are a shift to transit mode, increased corridor mobility, a funneling of trips from surrounding regions through the subarea, an overall lengthening of trips, and an overall decrease in trip times. Redistribution of regional travel is also small but significant as demonstrated by Table 9-14. The number of trips with origin and destination in the subarea decreases whereas the number of trips originating in the subarea and traveling to other areas increases.

Table 9-5. Daily Person and Vehicle Trip Comparisons

Regional Travel: Daily Person and Vehicle Trips				
Measure	Do Nothing /TSM	ITS Rich	Change (ITS Rich - Do Nothing / TSM)	% Change
Daily Trips				
Person Trips	16,457,503	16,457,503	0	0.00%
Non-Carpool Vehicle Trips	12,088,806	12,084,852	-3,954	-0.03%
Carpool Vehicle Trips	22,303	22,247	-56	-0.25%
Transit Person Trips	469,721	474,450	4,728	1.01%

Table 9-6. Daily Vehicle Miles and Hours Traveled

Regional Travel: Daily Vehicle Miles and Hours Traveled				
Measure	Do Nothing /TSM	ITS Rich	Change (ITS Rich - Do Nothing / TSM)	% Change
Daily Vehicle Miles Traveled				
Non-Carpool	100,253,432	100,454,224	200,792	0.20%
Carpool	499,558	497,668	-1,890	-0.38%
Transit	136,110	136,110	0	0.00%
Daily Vehicle Hours Traveled				
Non-Carpool	3,399,374	3,395,090	-4,284	-0.13%
Carpool	14,710	14,662	-48	-0.32%
Transit	8,281	8,103	-179	-2.16%

Table 9-7. Daily Person Miles and Hours Traveled

Regional Travel: Daily Person Miles and Hours Traveled				
Measure	Do Nothing /TSM	ITS Rich	Change (ITS Rich - Do Nothing / TSM)	% Change
Daily Person Miles Traveled				
Non-Carpool	145,666,160	145,877,296	211,136	0.14%
Carpool	1,651,381	1,645,851	-5,531	-0.33%
Transit	3,595,936	3,635,568	39,632	1.10%
Daily Person Hours Traveled				
Non-Carpool	4,867,437	4,861,511	-5,927	-0.12%
Carpool	48,471	48,448	-22	-0.05%
Transit	430,577	430,169	-408	-0.09%

9-8. AM Peak Person and Vehicle Trip Comparison

Regional Travel: AM Peak Period Person and Vehicle Trips				
Measure	Do Nothing /TSM	ITS Rich	Change (ITS Rich - Do Nothing / TSM)	% Change
AM Peak Period Trips				
Person Trips	3,188,024	3,187,947	-77	0.00%
Non-Carpool Vehicle Trips	2,118,624	2,117,644	-980	-0.05%
Carpool Vehicle Trips	16,727	16,685	-42	-0.25%
Transit Person Trips	135,819	137,013	1,194	0.88%

Table 9-9. AM Peak Vehicle Miles and Hours Traveled

Regional Travel: AM Peak Period Vehicle Miles and Hours Traveled				
Measure	Do Nothing /TSM	ITS Rich	Change (ITS Rich - Do Nothing / TSM)	% Change
AM Peak Vehicle Miles Traveled				
Non-Carpool	19,889,222	19,924,660	35,438	0.2%
Carpool	377,503	376,585	-918	-0.24%
Transit	34,419	34,419	0	0.00%
AM Peak Vehicle Hours Traveled				
Non-Carpool	815,335	813,872	-1,464	-0.2%
Carpool	13,498	13,482	-15	-0.11%
Transit	2,173	2,129	-45	-2.05%

Table 9-10. AM Peak Person Miles and Hours Traveled

Regional Travel: AM Peak Period Person Miles and Hours Traveled				
Measure	Do Nothing /TSM	ITS Rich	Change (ITS Rich - Do Nothing / TSM)	% Change
AM Peak Person Miles Traveled				
Non-Carpool	30,699,202	30,733,958	34,756	0.1%
Carpool	1,246,552	1,243,886	-2,665	-0.21%
Transit	1,225,991	1,235,389	9,398	0.77%
AM Peak Person Hours Traveled				
Non-Carpool	1,244,636	1,242,697	-1,939	-0.2%
Carpool	44,578	44,462	-117	-0.26%
Transit	130,211	129,779	-433	-0.33%

Table 9-11. AM Peak Regional and Subarea Vehicle Trips

Regional And Sub-Area Vehicle Trips: AM Peak Period				
	Do Nothing /TSM	ITS Rich	Change (ITS Rich - Do Nothing / TSM)	% Change
Regional Non-Carpool	2,118,624	2,117,644	-980	-0.05%
SubArea Non-Carpool	332,673	336,005	3,332	1.00%
% SubArea Non-Carpool	15.70%	15.87%		
Regional Carpool	16,727	16,685	-42	-0.25%
SubArea Carpool	4,930	4,887	-43	-0.86%
% SubArea Carpool	29.47%	29.29%		

Table 9-12. AM Peak Screen Line

AM Peak Period Screen Line Volumes (Vehicles)			
Screen Line	Do Nothing/TSM	ITS Rich	% Change
Ship Channel (35)	107,771	110,188	2.24%
Lake Washington (32)	44,082	44,509	0.97%
County Line (42)	74,988	76,236	1.66%
Locust Way (43)	57,991	59,598	2.77%
128th Street SW (46)	78,000	79,152	1.48%

Table 9-13. AM Peak Non-Carpool Trips To, From, and Through the Subarea

2020 AM Peak Period Non-Carpool Vehicle Travel To, From, Through Simulation Area									
	Do Nothing/TSM			ITS Rich			% Change		
	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time
From:									
1 = Subarea	211,606	5.68	14.99	211,847	5.75	14.29	0.11%	1.17%	-4.62%
2 = Corridor South	15,877	7.33	16.44	16,433	7.29	13.69	3.51%	-0.44%	-16.75%
3 = Corridor North	41,272	10.15	30.28	42,192	10.23	29.24	2.23%	0.80%	-3.43%
4 = Outside Corridor	63,919	49.39	115.92	65,533	49.12	112.61	2.53%	-0.55%	-2.86%
To:									
1 = Subarea	234,006	8.99	24.43	234,608	9.04	23.22	0.26%	0.48%	-4.98%
2 = Corridor South	42,851	14.45	36.00	43,795	14.31	34.40	2.20%	-0.96%	-4.43%
3 = Corridor North	15,284	14.24	36.87	15,823	14.75	36.37	3.53%	3.57%	-1.35%
4 = Outside Corridor	40,533	48.19	105.31	41,779	48.06	103.83	3.07%	-0.27%	-1.41%
Overall	332,673	14.71	36.35	336,005	14.85	35.32	1.00%	0.90%	-2.84%

Distance in Miles, Time in Minutes

Table 9-14. AM Peak Non-Carpool Person Trips From and To the Subarea

2020 AM Peak Person Trips From and To the Simulation Area							
From 1 to	Do Nothing /TSM	ITS Rich	% Change	To 1 From	Do Nothing /TSM	ITS Rich	% Change
1	312,069	308,726	-1.07%	1	312,069	308,726	-1.07%
2	83,200	85,486	2.75%	2	22,696	23,738	4.59%
3	12,830	13,028	1.54%	3	64,681	65,869	1.84%
4	27,881	28,790	3.26%	4	32,010	33,429	4.43%
5	760	744	-2.11%	5	21,010	20,941	-0.33%
6	532	513	-3.57%	6	19,620	19,463	-0.80%
7	353	339	-3.97%	7	11,914	11,833	-0.68%
Overall	437,626	437,626	0.00%	Overall	484,000	484,000	0.00%

1=Subarea, 2=South Corridor, 3=North Corridor, 4=King, 5=Snhomish, 6=Pierce South, 7=Islands+Olympic P.

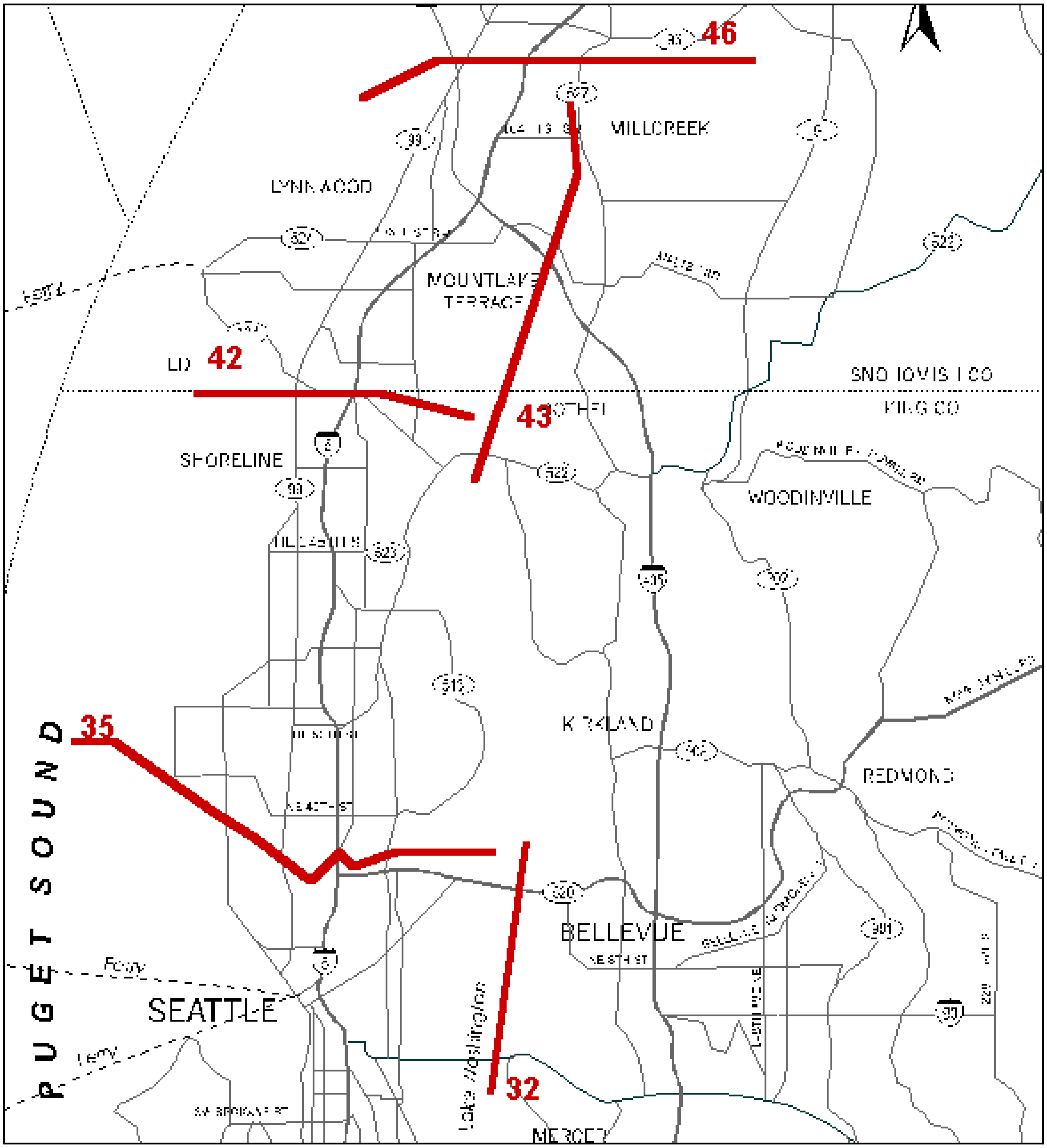

Figure 9-1. Screen Line Locations

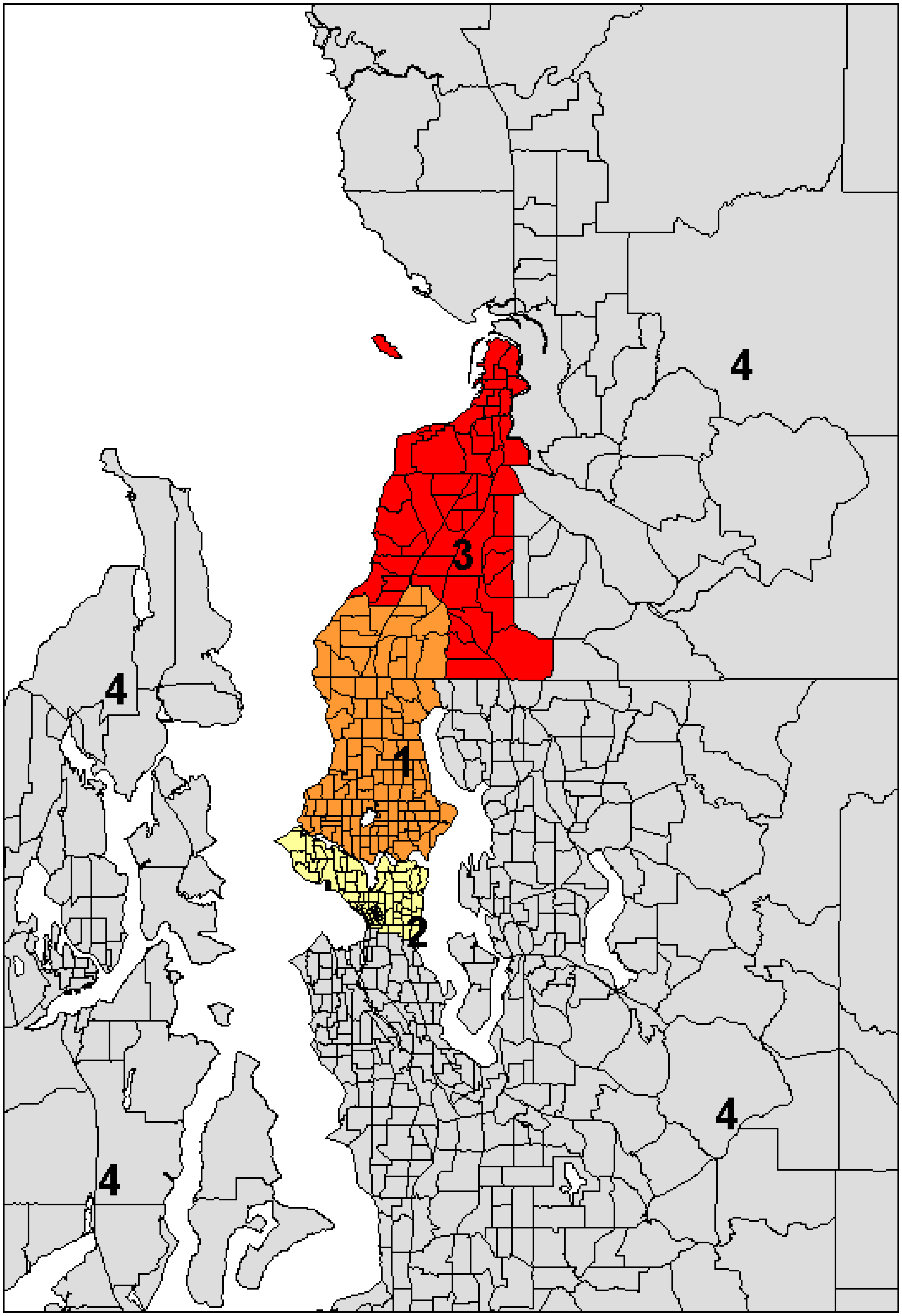

Figure 9-2. Regional Area Definitions for AM Non-Carpool Vehicle Statistics

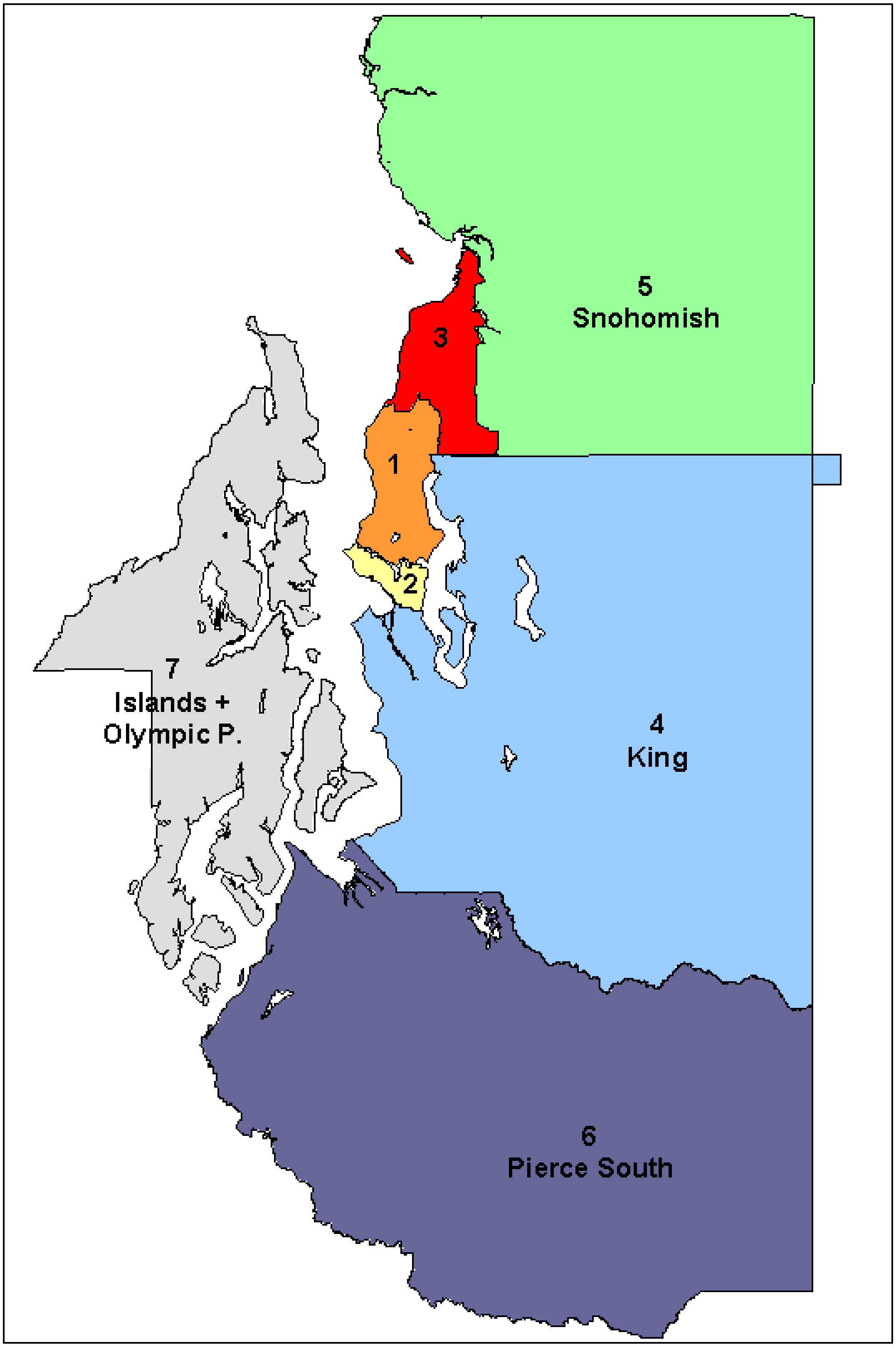

Figure 9-3. Regional Area Definition for AM Person Trip Statistics

9.2.2 Sub Area Impacts: Reliability, Delay Reduction, and Travel Speed

Overall, the addition of ITS enhancements to the Do Nothing/TSM alternative reduces traveler delay, increases throughput, and makes a significant cut in travel time variability. The largest impacts are seen in scenarios that feature heavy demand, weather impacts, major incidents or a combination of these factors. Marginal but still positive impacts can be observed under conditions close to average demand, clear weather, and few accidents in the system.

The measures used to characterize system impacts derived from the subarea simulation are delay reduction, throughput, coefficient of trip time variation, risk of significant delay, travel by speed-range, and expected number of stops per km of travel. Annualized impacts are reported for each of these measures. Further, for delay reduction, throughput, and risk of a significant delay, a probability mapping of the scenario set is used to highlight the conditions under which ITS had the largest impact.

<u>Probability Mapping</u>: 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 9-4 and 9-5. These figures show the 30 scenarios organized in two dimensions by changes in roadway capacity 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.

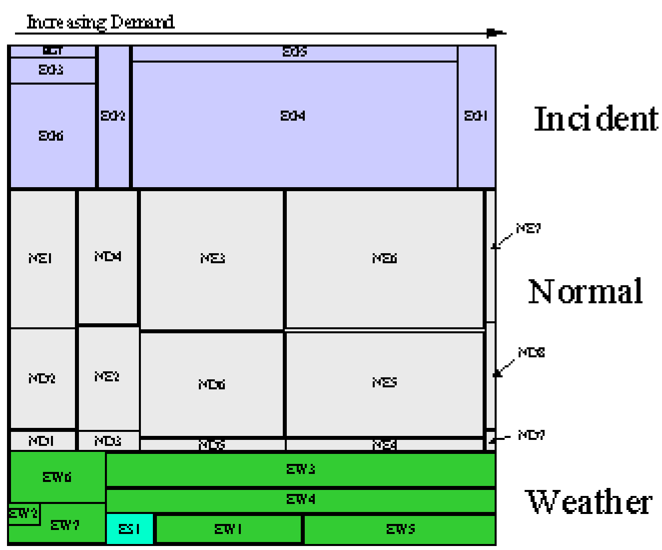

Figure 9-4. Evaluation Scenarios Shaded by Roadway Supply Impacts

In Figure 9-4, 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 plus accidents). 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.

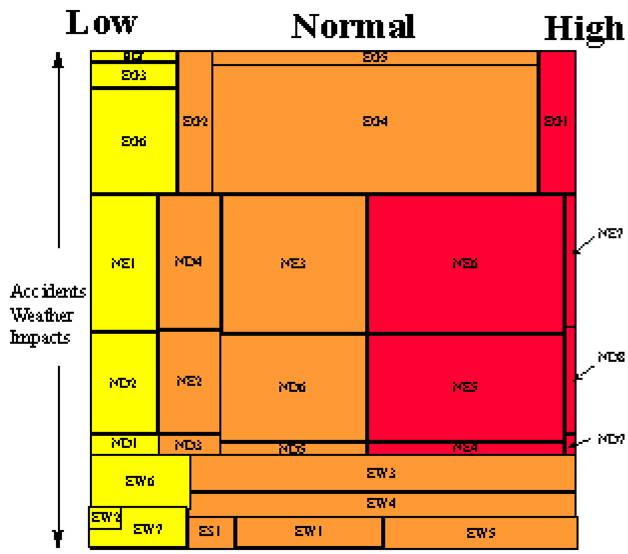

Figure 9-5. Evaluation Scenarios Shaded by Travel Demand Impacts

Figure 9-5 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% or greater reduction in expected demand), Normal (demand within plus/minus 10% of average), and High (a 10% or higher increase in expected demand). 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.

<u>Measures of Effectiveness</u>: Subarea measures of effectiveness are derived from the simulation model analysis. Trip data is collected from all vehicles that begin trips in the network between 6:15 AM and 8:30 AM. For these trips, 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 from the Baseline case as a percentage of Baseline average delay. *Throughput* measures the number trips starting in the 6:15 AM and 8:30 AM time frame that can finish before the end of the peak period at 9:30 AM. A trip is considered to be at *risk of significant delay* when the trip time in a particular scenario exceeds either 125% of free flow travel time or is 12 minutes longer than free flow travel time. Delay reduction, risk of delay, and throughput measures are calculated for each scenario. An annualized figure is then calculated by computing a weighted average of across all scenarios. Each scenario has a weight equal to its relative probability of occurrence.

System *coefficient of trip-time variation* is calculated by first examining the variation in travel times across all scenarios for each origin-destination pair. Next, an average system variation is then calculated by summing across all origin-destination pairs, weighted by the number of trips associated with the origin-destination pair. The square root of average system variation is then calculated to provide the standard deviation of average system travel time. This standard deviation is divided by the annualized mean system travel time to compute the coefficient of variation. The coefficient of variation is the primary measure of travel time reliability in this study.

Link data is collected in the simulation regarding travel speeds and stops. Speed data is archived every 15 minutes of simulated time for every link in the network in the AM peak period (6:00 – 9:30 AM). Average travel speed observed in the simulation during the preceding time interval is archived whenever a vehicle traverses a link. These link-speeds are then collected by facility type (freeway, expressway, arterial) over the network and logged weighted by link-length (kilometers). This is performed for each scenario and then summed for an annual average using the scenario weights. These 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 every 15 minutes by facility type. The expected *number of stops per vehicle-kilometer of travel* is calculated by first computing an annual number of stops by facility type and then dividing by the total amount of travel (in vehicle-kilometers) by facility type. We employ the simulation-generated stop data as an indicator of the "smoothness" of travel under the various alternatives.

<u>Delay Reduction</u>. Impacts of the ITS Rich alternative are illustrated here as delay reductions with respect to the Do Nothing/TSM alternative. These impacts are presented by scenario in terms of minutes of delay reduction (Figure 9-6) and in terms of percentage reduction (Figure 9-7). Figure 9-6 illustrates the conditions where the ITS Rich alternative is the most effective in terms of minutes of delay saved per traveler. Under these conditions (high demand, clear weather, and accidents in the system) the ITS Rich alternative reduces delay with respect to the Do Nothing/TSM alternative by 5-6 minutes per traveler. The ITS Rich alternative is also effective at reducing delay under poor weather conditions, particularly in cases with large numbers of accidents. A more modest (0-1 minutes), but still positive, reduction in delay can be observed near the center of the probability mapping, corresponding to average travel demand, clear weather and few accidents.

Figure 9-7 illustrates the conditions under which the ITS Rich alternative is most effective in the elimination of travel delay on a percentage basis from the Do Nothing/TSM alternative. Here, under conditions of lower-than-expected travel demand, clear weather, and accident conditions, the ITS Rich alternative eliminates as much as 50% of travel delay. Note that under conditions of heavy demand or poor weather, the ITS Rich alternative reduces delay by a smaller proportion (20-30%). However, there is so much more delay in the system under these conditions, reducing delay even 20-30% translates into several minutes of delay savings per vehicle.

On an annualized basis, average traveler delay is reduced by 1.6 minutes per traveler per day, from 10.88 to 9.28 minutes per traveler per day. This represents a 14.7% reduction in traveler delay during a calendar year.

Throughput. Figure 9-8 illustrates the increase in throughput realized by the ITS Rich alternative with respect to the Do Nothing/TSM alternative. Again, the ITS Rich alternative performs best in scenarios with large numbers of accidents, high demand, or weather conditions. However, this performance at the extremes compared with other conditions is less pronounced than for the delay reduction measures. The fact that throughput improvements are not as dramatic in the extreme cases is explained by the overall increase in subarea travel demand in the ITS Rich case generated at the regional level (see Section 9.2.1). This additional travel demand adds roughly 3% to travel demand in all scenarios for the ITS Rich case. The ITS Rich alternative is able to translate the increased travel demand into satisfied throughput because of the increased efficiency of the transportation system.

On an annualized basis, throughput in the ITS Rich alternative increases to 179,149 vehicles per AM peak period (6:15 – 8:30 AM trip starts) from 171,719 vehicles. This increase of 7,430 vehicles per peak period represents an increase in throughput of 4.3%.

Risk of Significant Delay. The risk of significant delay measure illustrates the reliability of the transportation system under the worst delay conditions. Trips that experience high delay relative to free-flow conditions beyond a reasonable buffer period (here 25% of free flow time or 12 minutes) are considered to be at risk of a significant delay. This measure discounts small reductions in delay and highlights cases where travelers are likely to benefit in a significant and recognizable manner.

Figure 9-9 illustrates the conditions under which the risk of significant delay has been significantly reduced in the ITS Rich alternative relative to the Do Nothing/TSM alternative. The ITS Rich alternative is most effective in combinations of heavy demand and incident conditions, reducing the number of trips at risk of significant delay by 10% or more.

On annualized basis, the percentage of trips at risk of significant delay is reduced by nearly a third to 5.5% in the ITS Rich alternative compared to 7.4% in the Do Nothing/TSM alternative.

Coefficient of Trip-Time Variation. The coefficient of trip-time variation in the Do Nothing/TSM alternative is 0.31. Applying this to a trip with an expected duration of one hour (normally distributed), a traveler would have to budget just over an hour and half to arrive at the trip destination on-time 95% of the time. In the ITS Rich case, the coefficient of trip-time variation is reduced to 0.22. Under the constraints of our example one-hour trip, the same traveler would have to budget an hour and 21 minutes to arrive at the trip destination on-time 95% of the time.

Percentage of Vehicle-Km of Travel By Speed Range. Figure 9-10 illustrates the impact of the ITS Rich alternative on travel speeds by facility over a calendar year. The percentage of travel by speed range for each of the facility types (freeway, expressway, urban arterial, and HOV lane) is plotted with the Do Nothing/TSM and ITS Rich alternatives shown side-by-side. Overall, the ITS Rich alternative can be characterized as providing faster travel across all of the facility types. In particular, slow travel (<20 mph) is reduced significantly for the freeway, expressway and urban arterial facilities in the ITS Rich alternative.

Expected Number of Stops per Vehicle-KM of Travel. Figure 9-11 illustrates the impact of the ITS Rich alternative on the stops per vehicle-km over a calendar year. The percentage of travel logged with corresponding number of stops per kilometer of travel is plotted with the Do Nothing/TSM and ITS Rich alternatives shown side-by-side. Overall, the ITS Rich alternative can be characterized as providing smoother travel, particularly for freeway, HOV lanes, and expressway facilities.

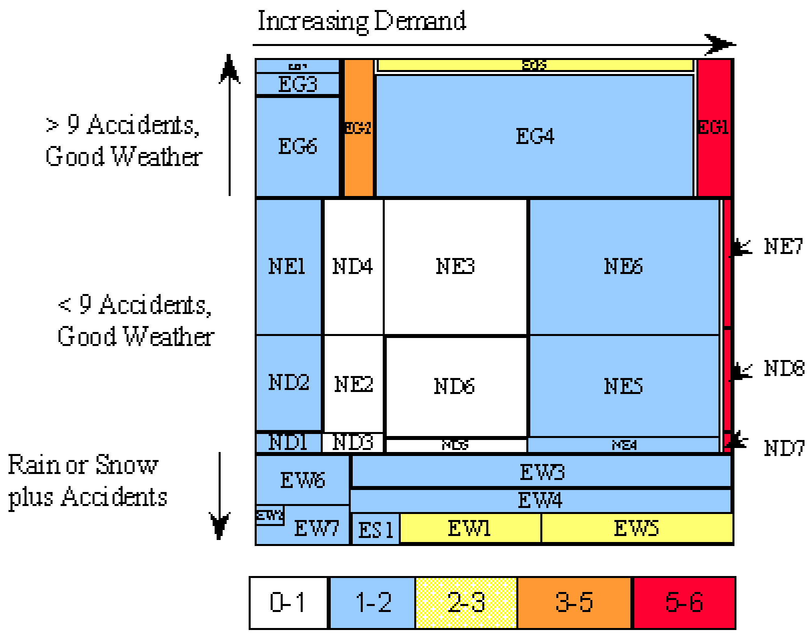

Figure 9-6. Minutes of Delay Reduction: ITS Rich vs. Do Nothing/TSM

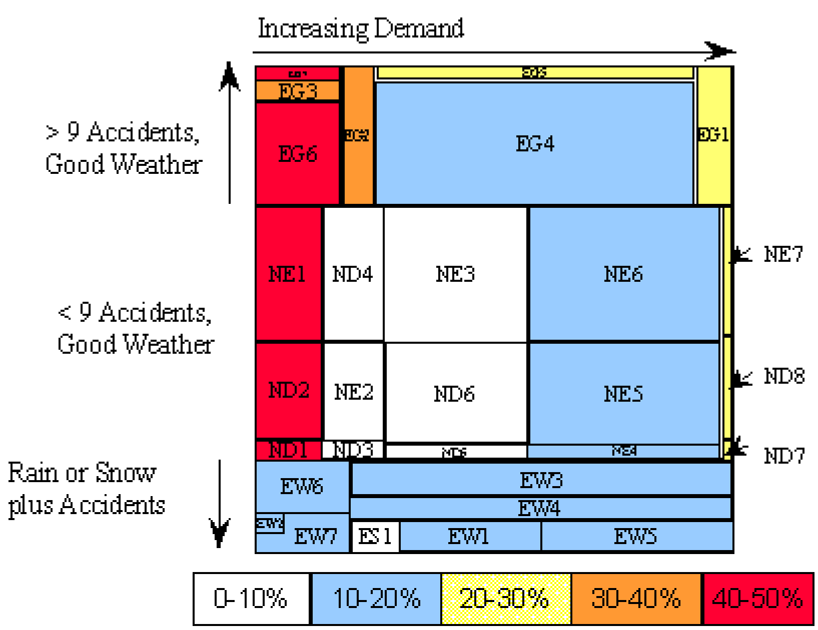

Figure 9-7. Percent Delay Reduction: ITS Rich vs. Do Nothing/TSM

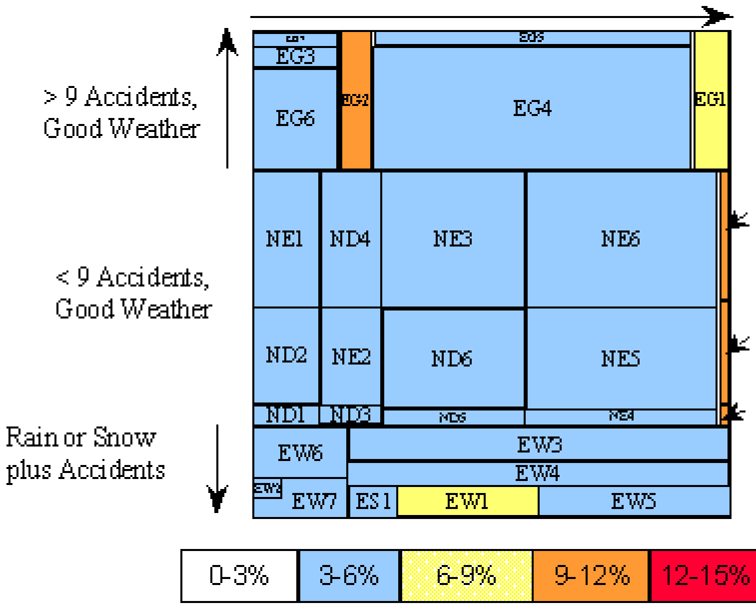

Figure 9-8. Increase in Throughput: ITS Rich vs. Do Nothing/TSM

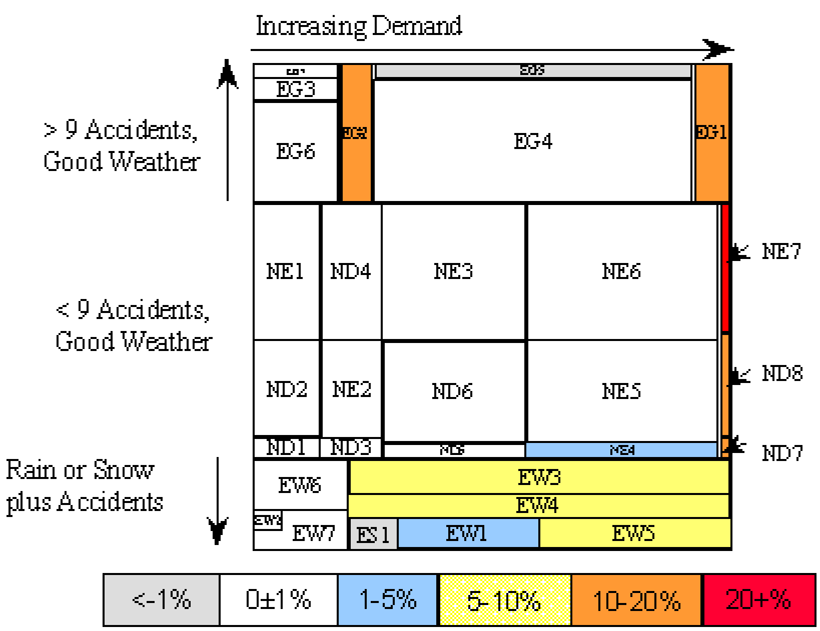

Figure 9-9. Reduced Risk of Travel Delay: ITS Rich vs. Do Nothing/TSM

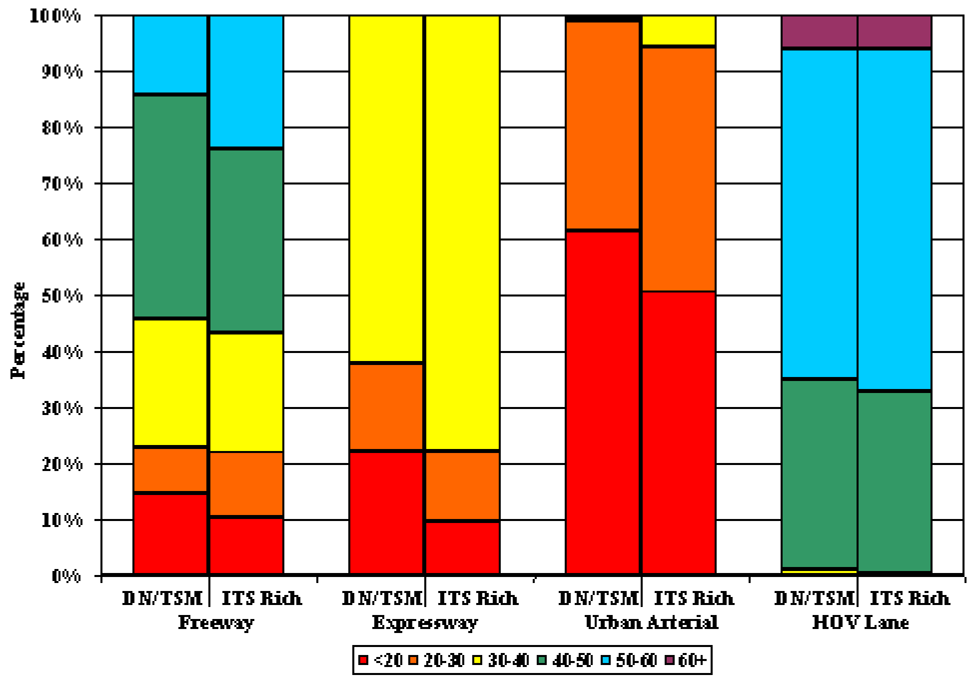

Figure 9-10. Vehicle-Km of Travel by Speed-Range: ITS Rich vs. Do Nothing/TSM

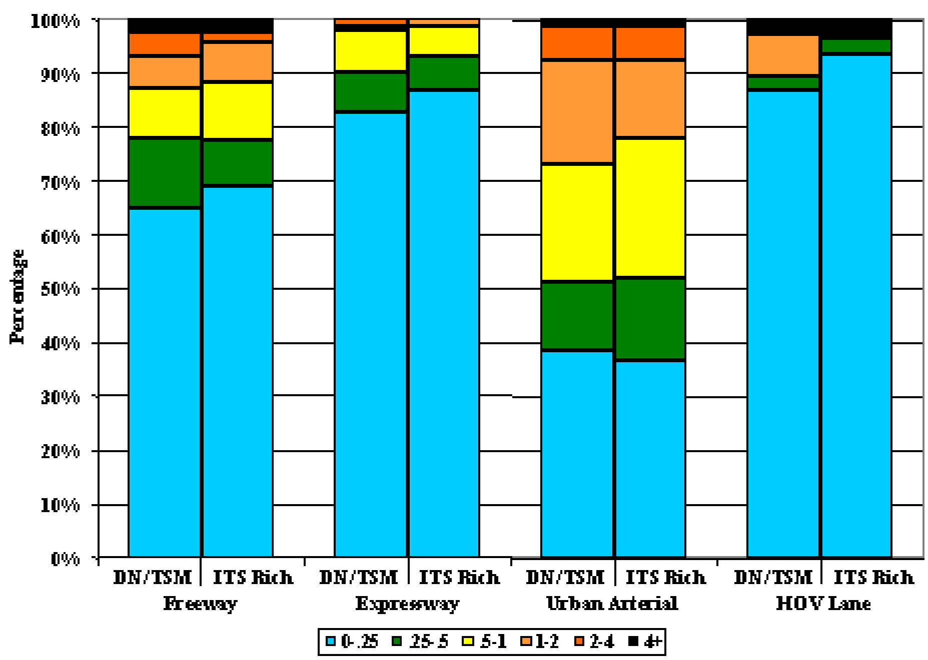

Figure 9-11. Stops Per Vehicle-Km of Travel: ITS Rich vs. Do Nothing/TSM

9.2.3 Capital & Operating Costs

As described in Chapter 6, the ITS Rich Alternative consists of an aggressive implementation of ITS strategies in the North Corridor and includes traffic management and surveillance, and incident and emergency management strategies. It is estimated that the ITS Rich Alternative would cost about $33 million beyond those committed projects which have been included in the Baseline Alternative. Note that in this alternative, the costs for HOV/transit facilities and services are expected to decrease by about $4.8 million relative to the Baseline Alternative. Costs for HOV/transit facilities decrease because in this alternative the transit system is operating more efficiently. Therefore, fewer new buses are required to maintain the service levels represented in the Baseline Alternative. This is a relatively low cost alternative in comparison to the two more capital-intensive infrastructure alternatives—the SOV Capacity Expansion and the HOV/Busway Alternatives. Relatively high cost elements of the ITS Rich Alternative include the following:

- Communication system ($11M)
- Surveillance system ($8.6M)
- Transit vehicle interface ($8M)
- Traffic control ($6M)

The estimated annualized capital cost of the ITS Rich Alternative is about $4.8 million per year relative to the Baseline Alternative. The two more capital-intensive alternatives — the SOV Capacity Expansion and the HOV/Busway Alternatives — have estimated annualized capital costs of $27.5 million and $78.1 million, respectively. When the complementary ITS elements are added to these alternatives, the additional annualized capital cost for the SOV Capacity Expansion Plus ITS is estimated at $5.5 million and for the HOV/Busway Alternative Plus ITS, $5 million.

Relatively speaking, the operating and maintenance costs are not anticipated as a large cost factor for the ITS Rich Alternative. The ITS Rich Alternative is expected to actually reduce transit operating costs relative to the No Action/TSM Baseline alternative by about $2.6 million due to the increased efficiencies of transit run times resulting from the ITS strategies. The investment in ITS/Traffic Systems would add about $3.3 million in O&M costs relative to the Baseline. The net impact of the ITS Rich Alternative on O&M costs relative to the Baseline Alternative is an additional $704,000.

9.2.4 Environmental Implications

No explicit environmental evaluation was conducted as a part of this study. However, implications for environmental impacts can be made from selected results. At the regional level, one result for the ITS Rich alternative is that although transit mode share is increased, longer auto trips result in a net increase in daily VMT of 198,902 miles from 100,752,990 to 100,951,892, a 0.20% increase. In the AM peak, VMT increases at roughly the same rate, 0.17%. At the regional level, then, the implications from the ITS Rich alternative is that overall travel increases. This increase in VMT implies increased emissions.

At the subarea level, however, the implications for emissions are generally positive. Travel takes place at generally higher speed, and low-speed travel is significantly reduced. For example, travel under 20 mph is cut by 4% for freeways and 11% for arterial facilities in the ITS Rich alternative when compared to the Do Nothing/TSM alternative. The number of stops per vehicle-km of travel is also reduced in the ITS Rich alternative by 1.0% for freeways and by 4.6% for arterials. A reduction in low-speed travel and less frequent stopping overall implies that emissions may be reduced from smoother traffic flow in the subarea.

The best characterization of environmental impacts at this point is that of a mixed bag. Regional VMT increases while subarea travel is smoother. How these two measures can be combined and compared is currently a research topic. With the advent of new modal emissions models like those under development at Virginia Tech and the University of California-Riverside, the relative importance of smoothed travel versus more travel can be quantitatively addressed.

9.3 SOV Capacity Expansion vs. SOV Capacity Expansion Plus ITS

Table 9-15. Detailed Comparison Summary, SOV + ITS vs. SOV

2020 Alternative Comparison Summary SOV Capacity Expansion + ITS versus SOV Capacity Expansion				
Measure of Effectiveness	SOV (Base)	SOV + ITS (ITS Alt)	Change (ITS Alt-Base)	% Change (Chng/Base)
Regional Travel: Trips, Mode Choice, Times, and Miles Traveled				
Daily Travel				
Daily Person Trips[1]	16,457,506	16,457,503	-3	0.00%
LOV Person Trips	15,863,987	15,860,125	-3,862	-0.02%
HOV Person Trips	72,150	71,942	-208	-0.29%
Transit Person Trips	469,817	473,840	4,023	0.86%
AM Peak Period Travel				
AM Person Trips				
LOV Person Trips	2,997,958	2,997,011	-947	-0.03%
HOV Person Trips	54,113	53,963	-150	-0.28%
Transit Person Trips	135,846	136,843	997	0.73%
AM Person Miles				
LOV Person Miles	30,793,398	30,816,234	22,836	0.07%
HOV Person Miles	1,247,586	1,241,449	-6,137	-0.49%
Transit Person Miles	1,229,272	1,238,916	9,645	0.78%
AM Person Hours				
LOV Person Hours	1,235,309	1,232,928	-2,381	-0.19%
HOV Person Hours	44,773	44,460	-313	-0.70%
Transit Person Hours	130,443	130,062	-381	-0.29%
AM Average Trip Times				
LOV Person Trip Time	24.72	24.68	-0.04	-0.16%
HOV Person Trip Time	49.64	49.43	-0.21	-0.42%
Transit Person Trip Time	57.61	57.03	-0.59	-1.02%
AM LOV Vehicle Trips	2,117,831	2,117,036	-795	-0.04%
AM LOV Vehicle Miles	19,970,192	19,994,882	24,690	0.12%
AM HOV Vehicle Trips	16,687	16,637	-49	-0.30%
AM HOV Vehicle Miles	377,280	375,379	-1,901	-0.50%
AM Subarea Trips				
LOV Vehicle Trips	337,340	339,758	2,417	0.72%
% of Region	15.93%	16.05%	0.12%	0.75%
HOV Vehicle Trips	4,951	4,890	-61	-1.23%
% of Region	29.67%	29.39%	-0.28%	-0.94%
LOV Vehicle Trip Speed	25.14	25.92	0.78	3.11%
Sub Area Impacts: Delay Reduction, Reliability, and Level of Service				
AM Peak Period Travel				
Throughput (finished trips)	168,338	185,565	17,227	10.2%
Delay Per Veh. Trip (min)	13.86	11.65	-2.21	-15.9%
Time Coef. Of Variation	0.39	0.30	-0.10	-24.5%
Risk of Severe Delay	18.3%	8.5%	-9.8%	-53.5%
% Slow Travel (< 20 mph)				
Freeways	22.1%	10.9%	-11.2%	-50.7%
Arterials	81.3%	53.8%	-27.5%	-33.8%
% Travel with > 1 stop/km				
Freeways	11.7%	10.3%	-1.4%	-12.0%
Arterials	34.7%	23.6%	-11.1%	-32.0%
Capital & Operating Costs				
Annual Capital Costs	$27,456	$32,933	$5,477	19.95%
Annual O&M Costs	$2,461	$1,537	-$924	-37.55%
Annual Total Costs	$29,917	$34,470	$4,553	15.22%

1 Daily person trips from trip distribution. Person trips by mode may not sum to daily total due to rounding

9.3.1 Regional Travel: Trips, Times, Mode Choice, and Miles Traveled

This section details the change in regional impacts resulting from the SOV with ITS alternative as compared to the SOV alternative. The regional MOEs include trip count, length, and mode statistics by vehicle and person for daily and AM peak period travel. Also detailed are AM peak period statistics on vehicle screen line volumes, regional and subarea trip shifts by vehicle and person, and average vehicle trip length and time by area. In addition, comparisons are made, when relevant, between the SOV and SOV with ITS set of alternative and the set of Do Nothing/TSM and ITS Rich alternatives.

The predominant trends resulting from ITS enhancements to the subarea, given that SR99 has been upgraded from a signalized arterial to an expressway, are similar to those in the Do Nothing/TSM to ITS Rich transition. Regional impacts are relatively small in magnitude given that the subarea where ITS implementation is proposed is a small subset of the region as a whole. Impacts on trips traversing the subarea, however, are significant. Regional trends from implementing ITS, given the SOV enhancements, include a shift from auto modes to transit, an increase in subarea vehicle trips, a decrease in regional vehicle trips, and an overall shift toward longer trips.

Tables 9-16 through 9-18 summarize the daily person and vehicle travel for the region. The same overall person trip productions and attractions were used as inputs for all alternatives. Thus, the number of person trips remains the same but trips are reoriented. By implementing APTS elements on top of SOV infrastructure, transit service speeds increase by almost 2% regionally. Regional daily transit use increases taking trips away from the auto modes. Transit use also shifts toward commuters with longer trips. The shift to transit from ITS implementation given SOV enhancements, however, is not as strong as the shift to transit from the Do Nothing/TSM to ITS Rich alternatives. This outcome is reasonable given travelers have more attractive auto options via the SR99 upgrade.

By introducing ITS elements to the SOV alternative non-carpool vehicle trips decrease slightly at the regional level. Daily non-carpool auto miles, however, increase by 0.15% while daily non-carpool auto hours decrease by 0.10%, reflecting faster average vehicle travel speed and longer average trip distance at the regional level. Also relevant is that given the infrastructure improvement in SR99, regional daily non-carpool vehicle miles increases by 0.47% and vehicle hours decrease by 0.19% when comparing the SOV to the Do Nothing/TSM alternative (comparison of Table 9-7 and 9-17). These statistics indicate that the SOV infrastructure does spur longer trips but still reduces trip duration at a regional level.

Tables 9-19 through 9-21 provide regional statistics for the AM peak period corresponding to the daily statistics presented above. Trends of transit share in the AM peak are similar to those of daily transit travel. Transit share increases, transit service is faster, and more long trips make use of the transit mode. AM peak-period non-carpool vehicle trips decrease; but compared to the total trip volume, the decrease is not significant. With the addition of ITS capabilities to the SOV infrastructure, non-carpool trips are slightly longer and faster in the AM peak period at the regional level. Carpool trips at the regional level during the AM peak are slightly shorter and faster. As in daily carpool trips, there is a decrease in the percentage of carpool vehicles from the SOV to the SOV with ITS alternative. The magnitude of change, however, is not significant.

Tables 9-22 and 9-23 illustrate the impact of ITS components on throughput and trips attracted (diverted) to the subarea given the SOV infrastructure is in place. Table 9-22 presents the AM peak period vehicle trips to, from, and through the subarea. The number of AM peak non-carpool vehicle trips at the regional level decreases by less than 0.04%; however, the number of AM peak subarea trips increases by over 0.72%. This indicates that although the corridor ITS elements are masked when overall regional statistics are examined, they make a significant change in subarea corridor travel. Specifically, ITS elements in the subarea attract approximately 2,360 more vehicles to use the subarea for some portion of their trip.

This significant diversion of trips to utilize the subarea is also reflected in the AM peak period screen line volumes shown in Table 9-23 (Figure 9-1 provides the location of each screen line). The screen line volumes show more noticeable percent changes than the overall regional travel measures as they capture more localized effects, mode split impacts, and travel diversion impacts. Screen line 43, Locust Way, shows the highest increase in travel (2.66%) reflecting the attraction to SR 522 caused by the ATMS signal improvements.

A comparison of the Do Nothing/TSM and SOV alternatives demonstrates that the upgrade of SR99 from a signalized arterial to an expressway has attracted significantly greater traffic through the subarea in the AM peak period. The SR99 upgrade increases the capacity of the facility and therefore attracts more vehicles. The screen line volume for County Line increases by almost 13%, and screen line volumes for Ship Channel and 128th Street SW increase by 4.0% and 5.8% respectively from the Do Nothing/TSM alternative to the SOV alternative (comparison of Table 9-12 to 9-23).

Table 9-24 provides a breakout of the AM peak non-carpool vehicle trips that travel to, from, and through the subarea by origin and destination areas. The areas are defined as (1) the subarea, (2) the area south of the subarea within the North Corridor influence area, (3) the area north of the subarea within the North Corridor influence area, and (4) the area outside the North Corridor. These regions are mapped in Figure 9-2. Table 9-24 reveals how the number, length, and duration of trips are interrelated and interact due to ITS improvements.[20]

Most noticeable is that more of the vehicle trips originating from each of the four regions make use of the subarea for some portion of their AM peak-period trips in the SOV with ITS alternative than in the SOV alternative. Moreover, the vehicle trips making use of the subarea are on average longer yet require significantly less travel time in the SOV with ITS alternative as compared to the SOV alternative. For the AM peak, vehicle trips from and to outside the corridor (area 4) which traverse the subarea increase in number while decreasing in average distance. This is because more short trips are attracted to travel through the simulation area.

Of the four defined areas, the South Corridor shows the greatest percentage increase in vehicle trips using the subarea. The trips being diverted to use the simulation area are shorter. They are for the most part going northbound and have a disproportionately greater travel time saving.

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20 Both impacts of the regional recurrent delay analysis and the rolled up travel time impacts of the simulation representative day analysis are captured in the trip time values.

The travel time reduction occurs because in the SOV alternative signal timing on facilities other than SR99 was fixed and biased toward southbound travel whereas with ITS enhancements signals are actuated providing northbound traffic more proportionate green time. A comparison of AM peak non-carpool vehicle trips between the Do Nothing/TSM and the SOV alternatives reveals that SR99 improvements have induced an average increase in trip length of 3.94% compared to an average increase in trip time of only 0.41% for trips traversing the subarea. Furthermore, the increases in vehicle trips, average length and average time reduction of vehicles traversing the subarea are greater when introducing ITS to the Do Nothing/TSM alternative than introducing ITS to the SOV alternative (comparison of Table 9-13 and 9-24).

Table 9-25 details in person trip statistics the shift in subarea AM peak travel resulting from ITS enhancements. Figure 9-3 presents graphically the seven regions. The distribution of trips changes as a result of the ITS enhancements to prompt more trips from the subarea to south-east adjacent regions (areas 2 and 4). This increase in trips from the subarea to areas 2 and 4 is offset by fewer trips remaining entirely within the subarea or traveling elsewhere. With ITS, more person trips from the adjacent regions of the North Corridor, South Corridor, and King County are made to the subarea during the AM peak period.

In summary, introduction of ITS to the SOV alternative causes small but significant impacts at the regional level. These include a shift to transit mode, increased corridor mobility, a funneling of trips from surrounding regions through the subarea, an average lengthening of trips, and an average decrease in trip time. Redistribution of travel causes more trips from the subarea to enter adjacent areas, and causing more trips from adjacent areas to enter the subarea. The impacts of ITS in general were less pronounced given the SR99 upgrade in the SOV alternative than in the Do Nothing/TSM alternative.

Table 9-16. SOV/SOV With ITS Daily Person and Vehicle Trip Comparison

Regional Travel: Daily Person and Vehicle Trips				
Measure	SOV	SOV with ITS	Change (SOV with ITS - SOV)	% Change
Daily Trips				
Person Trips	16,457,506	16,457,503	-3	0.00%
Non-Carpool Vehicle Trips	12,084,388	12,081,290	-3,098	-0.03%
Carpool Vehicle Trips	22,249	22,183	-66	-0.30%
Transit Person Trips	469,817	473,840	4,023	0.86%

Table 9-17. SOV/SOV With ITS Daily Vehicle Miles and Hours Traveled

Regional Travel: Daily Vehicle Miles and Hours Traveled				
Measure	SOV	SOV with ITS	Change (SOV with ITS - SOV)	% Change
Daily Vehicle Miles Traveled				
Non-Carpool	100,723,216	100,872,464	149,248	0.15%
Carpool	499,408	496,470	-2,938	-0.59%
Transit	136,282	136,282	0	0.00%
Daily Vehicle Hours Traveled				
Non-Carpool	3,392,935	3,388,261	-4,674	-0.1%
Carpool	14,730	14,637	-93	-0.63%
Transit	8,280	8,127	-154	-1.85%

Table 9-18. SOV/SOV With ITS Daily Person Miles and Hours Traveled

Regional Travel: Daily Person Miles and Hours Traveled				
Measure	SOV	SOV with ITS	Change (SOV with ITS - SOV)	% Change
Daily Person Miles Traveled				
Non-Carpool	146,256,496	146,409,472	152,976	0.1%
Carpool	1,652,651	1,643,251	-9,399	-0.57%
Transit	3,611,342	3,648,774	37,432	1.04%
Daily Person Hours Traveled				
Non-Carpool	4,853,145	4,844,476	-8,669	-0.2%
Carpool	48,551	48,277	-274	-0.56%
Transit	431,567	431,219	-348	-0.08%

Table 9-19. SOV/SOV With ITS AM Peak Person and Vehicle Trip Comparison

Regional Travel: AM Peak Period Person and Vehicle Trips				
Measure	SOV	SOV with ITS	Change (SOV with ITS - SOV)	% Change
AM Peak Period Trips				
Person Trips	3,187,917	3,187,816	-100	0.00%
Non-Carpool Vehicle Trips	2,117,831	2,117,036	-795	-0.04%
Carpool Vehicle Trips	16,687	16,637	-49	-0.30%
Transit Person Trips	135,846	136,843	997	0.73%

Table 9-20. SOV/SOV With ITS AM Peak Vehicle Miles and Hours Traveled

Regional Travel: AM Peak Period Vehicle Miles and Hours Traveled				
Measure	SOV	SOV with ITS	Change (SOV with ITS - SOV)	% Change
AM Peak Vehicle Miles Traveled				
Non-Carpool	19,970,192	19,994,882	24,690	0.1%
Carpool	377,280	375,379	-1,901	-0.50%
Transit	34,458	34,458	0	0.00%
AM Peak Vehicle Hours Traveled				
Non-Carpool	809,453	808,014	-1,439	-0.2%
Carpool	13,555	13,469	-87	-0.64%
Transit	2,171	2,132	-39	-1.81%

Table 9-21. SOV/SOV With ITS AM Peak Person Miles and Hours Traveled

Regional Travel: AM Peak Period Person Miles and Hours Traveled				
Measure	SOV	SOV with ITS	Change (SOV with ITS - SOV)	% Change
AM Peak Person Miles Traveled				
Non-Carpool	30,793,398	30,816,234	22,836	0.1%
Carpool	1,247,586	1,241,449	-6,137	-0.49%
Transit	1,229,272	1,238,916	9,645	0.78%
AM Peak Person Hours Traveled				
Non-Carpool	1,235,309	1,232,928	-2,381	-0.2%
Carpool	44,773	44,460	-313	-0.70%
Transit	130,443	130,062	-381	-0.29%

Table 9-22. SOV/SOV With ITS AM Regional and Subarea Vehicle Trips

Regional And Sub-Area Vehicle Trips: AM Peak Period				
	SOV	SOV with ITS	Change (SOV with ITS - SOV)	% Change
Regional Non-Carpool	2,117,831	2,117,036	-795	-0.04%
SubArea Non-Carpool	337,340	339,758	2,417	0.72%
% SubArea Non-Carpool	15.93%	16.05%		
Regional Carpool	16,687	16,637	-49	-0.30%
SubArea Carpool	4,951	4,890	-61	-1.23%
% SubArea Carpool	29.67%	29.39%		

Table 9-23. SOV/SOV With ITS AM Peak Screen Line Vehicle Volumes

AM Peak Period Screen Line Volumes (Vehicles)			
Screen Line	SOV	SOV with ITS	% Change
Ship Channel (35)	112,046	114,011	1.75%
Lake Washington (32)	43,400	44,046	1.49%
County Line (42)	84,609	85,031	0.50%
Locust Way (43)	56,714	58,222	2.66%
128th Street SW (46)	82,554	82,261	-0.35%

Table 9-24. SOV/SOV With ITS AM Peak Non-Carpool Vehicle Trips To, From & Through the Subarea

2020 AM Peak Period Non-Carpool Travel To, From, Through Simulation Area									
	SOV			SOV with ITS			% Change		
	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time
From:									
1 = Simulation area	211,257	5.86	14.92	211,537	5.91	13.94	0.13%	0.87%	-6.55%
2 = Corridor South	16,037	7.40	16.37	16,507	7.39	13.32	2.93%	-0.15%	-18.63%
3 = Corridor North	43,648	10.90	30.19	43,869	10.92	31.54	0.51%	0.20%	4.48%
4 = Outside Corridor	66,398	50.09	114.19	67,845	49.76	111.29	2.18%	-0.65%	-2.53%
To:									
1 = Simulation area	234,159	9.22	24.19	234,508	9.26	23.52	0.15%	0.37%	-2.80%
2 = Corridor South	44,551	14.39	34.53	45,350	14.32	31.61	1.79%	-0.50%	-8.47%
3 = Corridor North	16,317	16.78	41.58	16,399	17.01	42.40	0.50%	1.36%	1.98%
4 = Outside Corridor	42,313	49.25	104.75	43,501	48.94	102.54	2.81%	-0.64%	-2.11%
Overall	337,340	15.29	36.50	339,758	15.39	35.63	0.72%	0.62%	-2.41%

Distance in Miles, Time in Minutes

Table 9-25. SOV/SOV With ITS AM Peak Non-Carpool Person Trips From and To the Subarea

2020 AM Peak Period Person Trips From and To the Simulation Area							
From 1 to	SOV	SOV with ITS	% Change	To 1 from	SOV	SOV with ITS	% Change
1	309,140	306,571	-0.83%	1	309,140	306,571	-0.83%
2	85,634	87,190	1.82%	2	22,658	23,617	4.23%
3	13,035	13,003	-0.25%	3	66,968	67,398	0.64%
4	28,205	29,289	3.84%	4	32,209	33,605	4.33%
5	750	737	-1.73%	5	21,508	21,467	-0.19%
6	517	502	-2.90%	6	19,644	19,524	-0.61%
7	345	334	-3.19%	7	11,873	11,817	-0.47%
Overall	437,626	437,626	0.00%	Overall	484,000	484,000	0.00%

1=Simulation Area, 2=South Corridor, 3=North Corridor, 4=King, 5=Snhomish, 6=Pierce South, 7=Islands+Olympic P.

9.3.2 Sub Area Impacts: Reliability, Delay Reduction, and Travel Speed

At the subarea level, the addition of ITS to the SOV Expansion alternative significantly reduces travel time variability, improves throughput, and reduces traveler delay. As in the Baseline vs. ITS Rich pair-wise comparison, the largest impacts are seen in heavy demand and extreme weather cases with small but still positive impacts in scenarios closer to average demand, clear weather and no accident conditions. While delay reduction and travel time variability improvements are similar to those seen in the Baseline vs. ITS Rich comparison, the increase in annualized subarea throughput is significantly higher for the SOV + ITS Rich vs. SOV comparison (10.2% vs. 4.3%).

The magnitude of the ITS impacts in the SOV expansion case was a surprise relative to our *a priori* expectations. Given that SR99 had been upgraded to a grade-separated expressway facility with no signal control of any type along its length, we had expected that the impacts of the adaptive signal control system would be lessened on a corridor-wide basis. Given that one of the key components of our ITS enhancements would have a lessened impact, we might expect a smaller impact of deploying the overall package of ITS enhancements. However, particularly examining the impact on throughput, one may argue that the impact of ITS is actually higher in the SOV capacity expansion case than in the Baseline (Do Nothing) case.

The reason for ITS having a large impact in this case is that the SOV Capacity expansion alternative and the upgrade SR99 expressway facility can be characterized as having "brittle" performance. When travel demand is close to average conditions or lighter than average and weather conditions are clear, the new SR99 expressway facility efficiently handles traffic along its length, both in terms of through movements and traffic exiting at grade-separated interchanges with the adjacent arterial grid. Travel times in these cases are improved for trips that typically use SR99. When the travel demand is high or capacity is reduced from weather impact, the upgraded SR99 facility's performance breaks down to a point that travel times actually exceed those associated with the pre-upgrade signalized arterial facility.

SR99 Expressway breakdown is a function of the narrow right-of-way accorded the new facility. The number of opportunities to exit the upgraded SR99 expressway facility and access the adjacent arterial grid are reduced since only a subset of the signalized intersections along its length have been converted to grade-separated interchanges. This results in high off-ramp utilization along SR99. Reliance on these off-ramps becomes problematic because they are relatively short and end with signals. These short ramps cannot hold many vehicles attempting to exit SR99, and if signal controllers at their terminus are set to relative long cycles, then we see periodic queue spillback into the expressway facility. The simulation model accurately reacts by severely crimping expressway carrying capacity when this condition occurs, resulting in backups in the SR99 expressway mainline. These periodic breakdowns become persistent breakdown conditions when travel demand is high or under poor weather scenarios.

ATMS control as implemented in the SOV + ITS alternative helps to mitigate the impact of SR99 breakdown. In these cases the adaptive signal control system senses the queue buildup on the off-ramp and extends the ramp's green phase to flush vehicles off of the ramp/mainline and onto the arterial grid. The minor arterials see worsened service as the green phase for the off-ramp is progressively extended, but from a system perspective, keeping the SR99 mainline from breaking down is the most critical factor in reducing overall delay.

Note that the brittleness of the SOV alternative could not have been predicted using only the regional model. Under average conditions, the SOV alternative appears to have ample capacity at the SR99 interchanges. Since the regional model does not consider the periodic queue growth from traffic signals or spillback, a breakdown along SR99 does not occur. Clearly there are non-ITS solutions to the off-ramp problem: wider right of way at interchanges, revised interchange design, more interchanges, etc. However, it is likely that these issues would not have been addressed until the engineering design phase of the alternative. Knowing at the planning phase that the new SOV facility had this performance characteristic is a critical element either tailoring the alternative definition or in the comparison of alternatives.

Delay Reduction. Impacts of the SOV + ITS alternative are illustrated as delay reductions with respect to the SOV Capacity Expansion alternative. Figure 9-12 illustrates the conditions where the addition of ITS was most effective in terms of absolute minutes of delay saved per traveler. The largest delay reduction occurs in scenarios with incidents on SR99 (EG2) or I-5 (EG1), heavy demand scenarios (NE4, NE5, NE7, ND7, ND8), and weather/accident combination scenarios (ES1 and EW4).

Figure 9-13 illustrates delay reduction from ITS taken on a percentage basis with respect to the SOV alternative. The highest delay reduction is in the 20-30% range in cases with major incidents (EG1, EG2) or high demand (NE4, NE5).

On an annualized basis, average traveler delay is reduced by 2.2 minutes per traveler per day, from 13.86 to 11.65 minutes per traveler per day. This represents a 15.9% reduction in traveler delay per year.

Throughput. Figure 9-14 illustrates the increase in throughput realized by the SOV + ITS alternative relative to the SOV alternative. Increases of 12-15% can be observed in high demand cases, regardless of accidents or weather impacts. This increase in throughput is related to the breakdown conditions experienced along SR99 under the SOV alternative, which is most sensitive to higher-than-average travel demand.

On an annualized basis, throughput in the SOV + ITS alternative increases to 185,565 vehicles per AM peak period (6:15 – 8:30 AM trip starts) from 168,338 vehicles. This increase of roughly 13,223 vehicles per peak period represents an increase in throughput of 10.2%.

Risk of Significant Delay. Figure 9-15 illustrates the conditions under which the risk of significant delay has been significantly reduced from the addition of ITS to the SOV alternative. The risk of significant delay is much higher in the SOV alternative than in the Baseline alternative because of the SR99 breakdown phenomenon.

On an annualized basis, the percentage of trips at risk of significant delay is reduced by more than half to 8.5% in the SOV + ITS alternative compared to 18.3% in the SOV alternative. Note that the reduced risk of significant delay associated with the SOV + ITS case is higher than the Baseline (Do Nothing) alternative (8.5% vs. 7.4%) indicating that ITS mutes but does not eliminate breakdown conditions on SR99.

Coefficient of Trip-Time Variation. The coefficient of trip-time variation in the SOV alternative is 0.39. Applying this to a trip with an expected duration of one hour (normally distributed), a traveler would have to budget just over an hour and 39 minutes to arrive at the trip destination on-time 95% of the time. In the SOV + ITS case, the coefficient of trip-time variation is reduced to 0.30. The addition of ITS returns subarea travel to roughly the same level of travel time reliability associated with the Baseline (Do Nothing) alternative (.30 vs. .31). Under the constraints of our example one-hour trip, a traveler would have to budget an hour and 29 minutes in the SOV + ITS case to arrive at the trip destination on-time 95% of the time.

Percentage of Vehicle-Km of Travel By Speed Range. Figure 9-16 illustrates the impact of the SOV + ITS alternative on travel speeds by facility over a year. The percentage of travel by speed range for each of the facility types (freeway, expressway, urban arterial, and HOV lane) is plotted with the SOV and SOV + ITS alternatives shown side-by-side. Overall, the SOV + ITS alternative can be characterized as providing faster travel across all of the facility types. In particular, slow travel (<20 mph) is reduced significantly for the freeway, expressway and urban arterial facilities in the SOV + ITS alternative.

Expected Number of Stops per Vehicle-KM of Travel. Figure 9-17 illustrates the impact of the SOV + ITS alternative on the stops per vehicle-km over a calendar year. The percentage of travel logged with corresponding number of stops per kilometer of travel is plotted with the SOV and SOV + ITS alternatives shown side-by-side. Overall, the SOV + ITS alternative can be characterized as providing smoother travel, particularly for freeway, arterial, and expressway facilities.

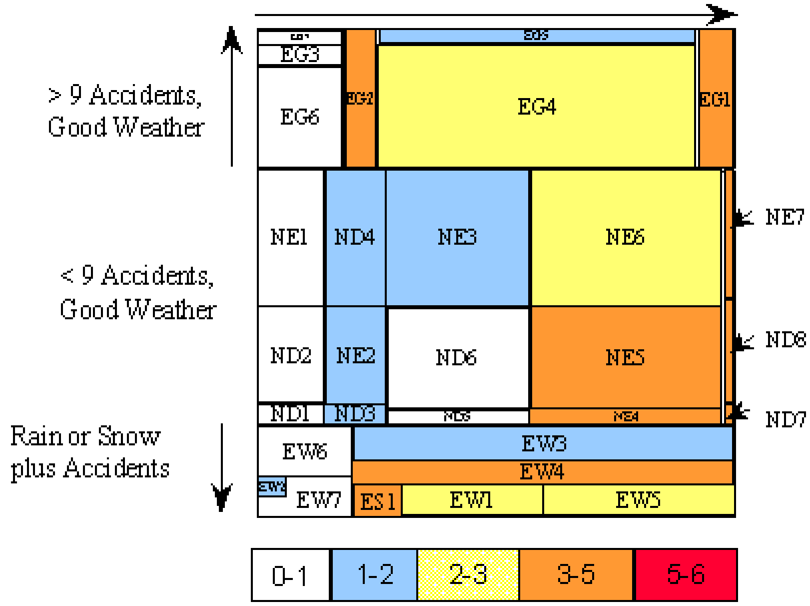

Figure 9-12. Minutes of Delay Reduction: SOV + ITS vs. SOV

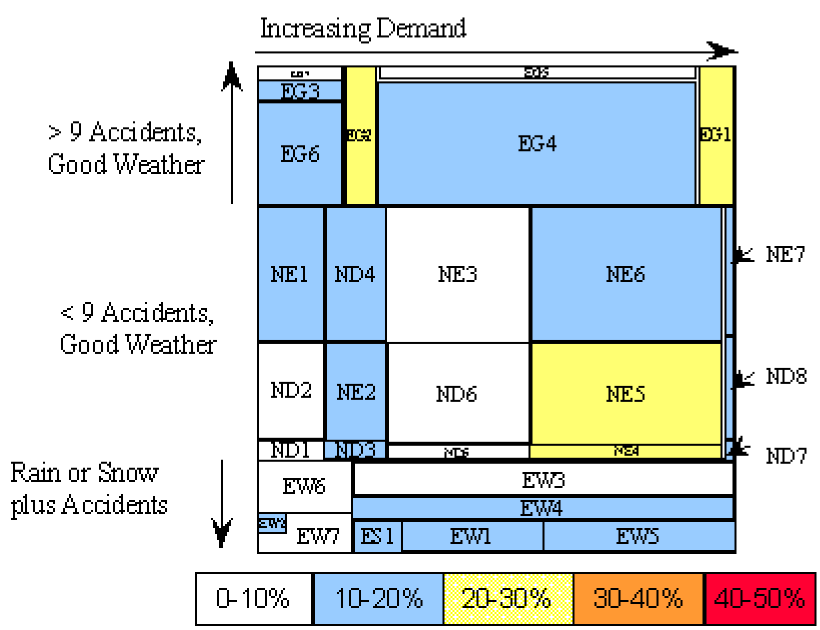

Figure 9-13. Percent Delay Reduction: SOV + ITS vs. SOV

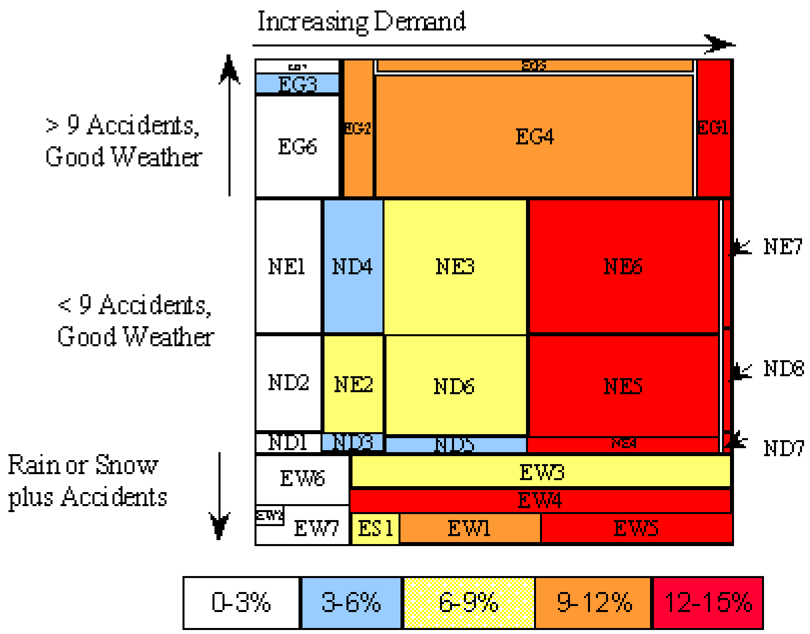

Figure 9-14. Increase in Throughput: SOV + ITS vs. SOV

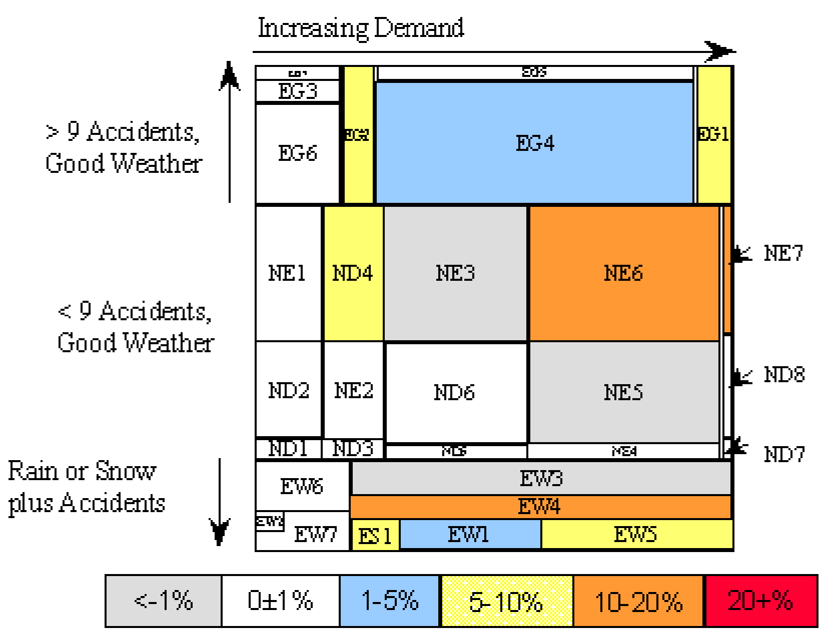

Figure 9-15. Reduced Risk of Travel Delay: SOV + ITS vs. SOV

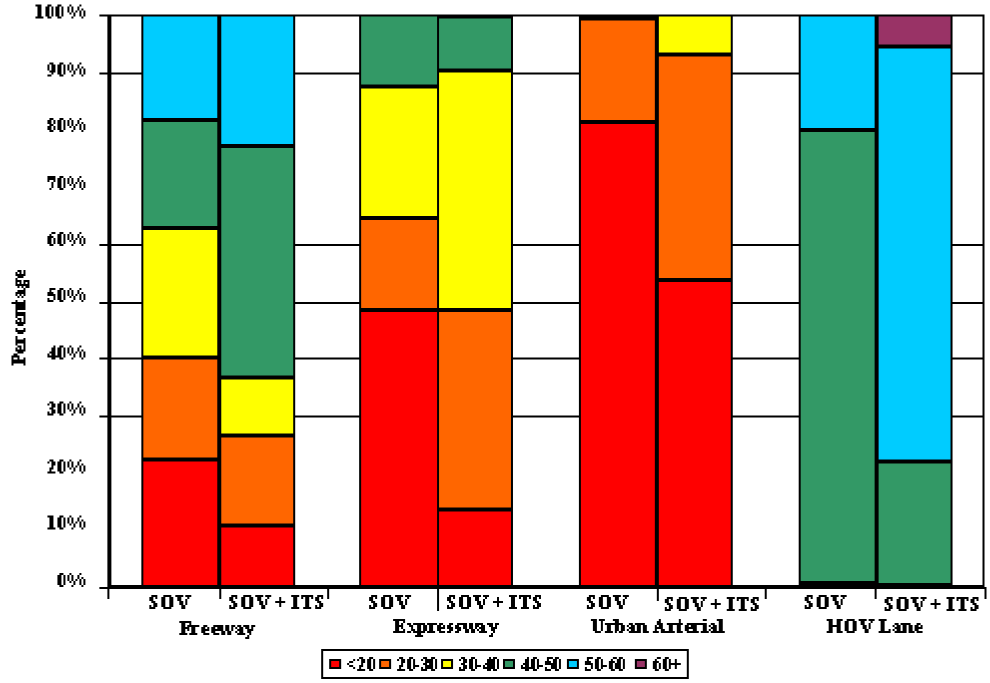

Figure 9-16. Vehicle-Km of Travel by Speed-Range: SOV + ITS vs. SOV

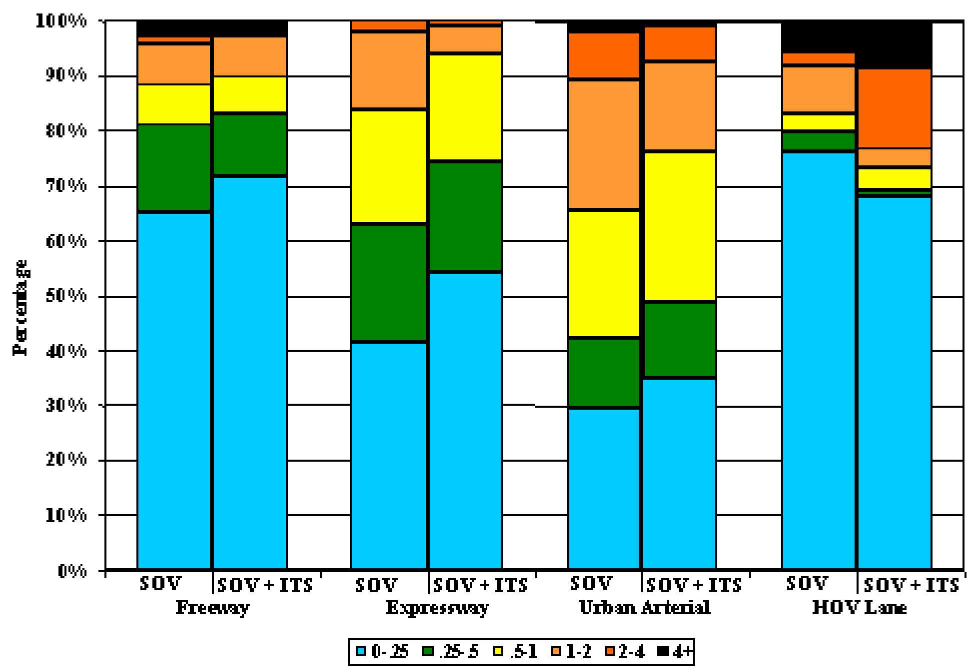

Figure 9-17. Stops Per Vehicle-Km of Travel: SOV + ITS vs. SOV

9.3.3 Capital & Operating Costs

The SOV Capacity Expansion Alternative provides for the conversion of SR99 north of N 59th Street to an expressway for a distance of 14 miles. The total incremental capital cost of the SOV Capacity Expansion Alternative is estimated at $337 million beyond the Baseline Alternative, including over $90 million for right-of-way acquisition. However, the costs for HOV/transit facilities and services are expected to decrease by about $0.3 million relative to the Baseline Alternative. Costs for HOV/transit facilities decrease because the transit system is operating more efficiently on SR99 so fewer new articulated buses are required. This alternative also includes the widening of a 3 mile section of SR 525 between SR99 and I-5. High cost construction elements of the SOV alternative include the following:

- Conversion of 14 miles of urban arterial to urban expressway ($86M)
- Construction of nine new urban expressway interchanges ($96M)
- Construction of new grade separated arterial crossings of the expressway at nine locations ($44M)

The capital cost estimated for the SOV Capacity Expansion Alternative Plus ITS is $374 million. This additional $37.1 million over the SOV alternative alone for implementation of ITS. The ITS elements here are similar to those in the ITS Rich alternative but designed to complement the SOV Capacity Expansion. The level of investment in communications and traffic management for the SOV Capacity Expansion Alternative is slightly higher than that associated with the ITS Rich Alternative since the SOV Capacity Expansion includes additional roadway that would require some additional ITS costs. In this alternative, the costs for HOV/transit facilities and services are expected to decrease by about $6 million relative to the Baseline Alternative, for the same reasons that these costs decrease in the ITS Rich Alternative.

As with ITS Rich, O&M costs are not expected to be a large factor for the SOV Capacity Expansion Alternative. The increase in O&M costs over the Baseline Alternative is estimated at about $1 million per year, which is associated with the additional lanes of SOV capacity. The SOV Capacity Expansion Plus ITS is estimated to reduce transit operating costs by $4.6 million. However, additional ITS O&M costs are incurred because of the additional lanes of SOV capacity. The net result is that the SOV Capacity Expansion Plus ITS has estimated incremental O&M costs over the Baseline Alternative of $101,000.

9.3.4 Environmental Implications

No explicit environmental evaluation was conducted as a part of this study. However, implications for environmental impacts can be made from selected results. At the regional level, one result for the SOV + ITS alternative is that although transit mode share is increased, longer auto trips result in a net increase in AM peak VMT of 0.15%. At the regional level, the implications from the SOV + ITS alternative is that overall travel increases. This increase in VMT implies increased emissions.

At the subarea level, however, the implications for emissions are generally positive. Travel takes place at generally higher speed, and low-speed travel is significantly reduced. For example, travel under 20 mph is cut by 50% for freeways and 34% for arterial facilities in the SOV + ITS alternative when compared to the SOV alternative. The number of stops per vehicle-km of travel is also reduced in the SOV + ITS alternative by 12% for freeways and by 32% for arterials. A reduction in low-speed travel and less frequent stopping overall implies that emissions may be reduced from smoother traffic flow in the subarea.

9.4 HOV/Busway vs. HOV/Busway Plus ITS

Table 9-26. Detailed Summary, HOV/Busway vs. HOV/Busway Plus ITS

2020 Alternative Comparison Summary HOV/Busway + ITS versus HOV/Busway				
Measure of Effectiveness	HOV/Busway (Base)	HOV/Busway + ITS (ITS Alt.)	Change (ITS Alt-Base)	% Change (Chng/Base)
Regional Travel: Trips, Mode Choice, Times, and Miles Traveled				
Daily Travel				
Daily Person Trips[1]	16,457,504	16,457,500	-4	0.00%
LOV Person Trips	15,858,202	15,853,849	-4,353	-0.03%
HOV Person Trips	71,906	71,794	-112	-0.16%
Transit Person Trips	475,929	480,387	4,458	0.94%
AM Peak Period Travel				
AM Person Trips				
LOV Person Trips	2,995,711	2,994,653	-1,058	-0.04%
HOV Person Trips	53,929	53,845	-84	-0.16%
Transit Person Trips	138,243	139,317	1,074	0.78%
AM Person Miles				
LOV Person Miles	30,629,646	30,672,288	42,642	0.14%
HOV Person Miles	1,234,344	1,231,956	-2,388	-0.19%
Transit Person Miles	1,300,269	1,308,937	8,668	0.67%
AM Person Hours				
LOV Person Hours	1,240,424	1,237,867	-2,557	-0.21%
HOV Person Hours	43,782	43,689	-93	-0.21%
Transit Person Hours	132,048	131,904	-143	-0.11%
AM Average Trip Times				
LOV Person Trip Time	24.84	24.80	-0.04	-0.17%
HOV Person Trip Time	48.71	48.68	-0.03	-0.06%
Transit Person Trip Time	57.31	56.81	-0.50	-0.88%
AM LOV Vehicle Trips	2,117,059	2,116,098	-961	-0.05%
AM LOV Vehicle Miles	19,849,334	19,887,816	38,482	0.19%
AM HOV Vehicle Trips	16,637	16,609	-28	-0.17%
AM HOV Vehicle Miles	373,763	372,918	-845	-0.23%
AM Subarea Trips				
LOV Vehicle Trips	331,981	335,297	3,316	1.00%
% of Region	15.7%	15.8%	0.16%	1.04%
HOV Vehicle Trips	4,870	4,853	-17	-0.35%
% of Region	29.3%	29.2%	-0.05%	-0.18%
LOV Vehicle Trip Speed	24.42	25.41	0.99	4.07%
Sub Area Impacts: Delay Reduction, Reliability, and Level of Service				
AM Peak Period Travel				
Throughput (finished trips)	177,260	183,858	6,599	3.7%
Delay Per Vehicle Trip	13.03	10.43	-2.60	-19.9%
Time Coef. Of Variation	0.27	0.22	-0.05	-17.1%
Risk of Severe Delay	8.3%	5.2%	-3.0%	-36.8%
% Slow Travel (< 20 mph)				
Freeways	14.6%	8.3%	-6.3%	-43.2%
Arterials	57.9%	50.7%	-7.2%	-12.4%
% Travel with > 1 stop/km				
Freeways	14.2%	14.0%	-0.2%	-1.4%
Arterials	25.7%	25.7%	0.0%	0.0%
Capital & Operating Costs				
Annual Capital Costs	$78,081	$83,110	$5,029	6.44%
Annual O&M Costs	$44,418	$43,521	-$897	-2.02%
Annual Total Costs	$122,499	$126,631	$4,132	3.37%

1 Daily person trips from trip distribution. Person trips by mode may not sum to daily total due to rounding.

9.4.1 Regional Travel; Trips, Times, Mode Choice, and Miles Traveled

This section details the change in regional impacts resulting from the HOV/Busway with ITS alternative as compared to the HOV/Busway alternative, summarized in Table 9-26. Note the infrastructure enhancements of this alternative include a barrier-separated HOV facility on I5, an arterial HOV facility on SR99, and 13 new regional express bus routes. The regional MOEs include trip count, length, and mode statistics by vehicle and person for daily and AM peak period travel. Also detailed are AM peak period statistics on vehicle screen line volumes, regional and subarea trip shifts by vehicle and person, and average vehicle trip length and time by area. In addition, comparisons are made, when relevant, from the HOV/Busway and HOV/Busway with ITS set of alternative to the set of Do Nothing/TSM and ITS Rich alternatives and the set of SOV and SOV with ITS alternatives.

The predominant trends resulting from ITS enhancements to the subarea, given the HOV/Busway infrastructure and services, are similar to those in the Do Nothing/TSM to ITS Rich transition. Regional impacts are relatively small in magnitude given that the subarea where ITS implementation is proposed is a small subset of the region as a whole. Impacts on trips traversing the subarea, however, are larger. Regional trends from implementing ITS, given the HOV/Busway enhancements, include a shift from auto modes to transit, an increase in subarea vehicle trips, a decrease in regional vehicle trips, and an overall shift toward longer and faster trips.

Tables 9-27 through 9-29 summarize the daily person and vehicle travel for the region. The same overall person trip productions and attractions were used as inputs for all alternatives. Thus, the number of person trips remains the same but trips are reoriented. By implementing ITS elements on top of HOV/Busway infrastructure, transit service speeds increase by 1.8% regionally. Regional daily transit use increases, taking trips away from the auto modes. Transit use also shifts toward commuters with longer trips. Even though HOV/Busway with ITS has the highest transit ridership of all the alternatives considered, the shift to transit from ITS implementation given HOV/Busway enhancements is not as strong as the transit shift from the Do Nothing/TSM to ITS Rich alternative. This is reasonable since the HOV/Busway alternative already has 1.3% more transit riders than the Do Nothing/TSM alternative due to its additional transit service. The transit shift from ITS implementation given HOV/Busway enhancements is greater than the shift toward transit resulting from the installation of ITS to the SOV alternatives since in the SOV alternative the auto mode also benefits from the capacity improvement.

By introducing ITS elements to the HOV/Busway alternative non-carpool vehicle trips decrease slightly at the regional level. The change in carpool vehicle trips is not statistically significant. Daily non-carpool auto miles, however, increase by 0.24% while daily non-carpool auto hours decrease by 0.10%. Daily carpool auto miles decrease by 0.11% while daily carpool auto hours decrease by 0.43%. These statistics indicate faster average auto travel speed and longer average trip distance at the regional level.

The 14 new regional express bus routes in the HOV/Busway alternative increase the regional daily transit miles by 15.5% or 21,000 miles and decrease the daily auto miles by 136,000 from the Do Nothing/TSM alternative (comparison of Table 9-6 and Table 9-28). The daily person miles for transit use increases by 180,000 whereas the person miles for auto use decreases by 240,000 from the Do Nothing/TSM to the HOV/Busway alternative (comparison of Table 9-7 and Table 9-29). These statistics indicate that the attractiveness of the HOV infrastructure is overshadowed by the attractiveness of the transit enhancements in the HOV/Busway alternative.

Tables 9-30 through 9-32 provide regional statistics for the AM peak period corresponding to the daily statistics presented above. Trends of regional transit share in the AM peak are for the most part similar to those of daily transit travel. Transit share increases and transit service is faster with the implementation of ITS to the HOV/Busway alternative. One difference is that more short trips make use of the transit mode in the AM peak. With the addition of ITS capabilities to the HOV/Busway infrastructure, non-carpool vehicle trips decrease; but compared to the total trip volume, the decrease is not significant. These trips are slightly longer and faster. Carpool trips at the regional level during the AM peak are slightly shorter and faster. As in the daily carpool vehicle trips, the magnitude of change in regional AM peak period carpool vehicle trips is not significant.

Tables 9-33 and 9-34 illustrate the impact of ITS components on throughput and trips attracted (diverted) to the subarea given the HOV/Busway infrastructure is in place. Table 9-33 presents the AM peak period vehicle trips to, from, and through the subarea. The number of AM peak non-carpool vehicle trips at the regional level decreases by less than 0.05%; however, the number of AM peak subarea trips increases by 1.00%. This indicates that although the corridor ITS elements are masked when overall regional statistics are examined, they do make a significant change in subarea corridor travel. Specifically, ITS elements in the subarea attract approximately 3,320 more vehicles to the subarea for some portion of their trip over the HOV/Busway alternative. This is approximately the same shift as seen in ITS Rich versus the Do Nothing/TSM alternatives.

The HOV/Busway alternative has the fewest number of subarea corridor vehicle trips compared to all other alternatives (comparison of Table 9-11, Table 9-22, and Table 9-33). In this alternative passengers shift to transit regionally and no diversion of vehicle trips to the subarea takes place. With ITS enhancements to the HOV/Busway alternative a diversion of vehicle trips to the subarea does occur. Still, the total number of vehicle trips through the subarea is less than the SOV alternatives and the ITS Rich alternative.

The diversion of trips to utilize the subarea is also reflected in the AM peak period screen line volumes shown in Table 9-34 (Figure 9-1 provides the location of each screen line). The screen line volumes show more noticeable percent changes than the overall regional travel measures as they capture more localized effects, mode split impacts, and travel diversion impacts. The Ship Channel and Locust Way screenlines show the highest increase in travel reflecting the attraction caused by the ATMS signal improvements.

Table 9-35 provides a breakout of the AM peak non-carpool vehicle trips that travel to, from, and through the subarea by origin and destination areas. The areas are defined as (1) the subarea, (2) the area south of the subarea within the North Corridor influence area, (3) the area north of the subarea within the North Corridor influence area, and (4) the area outside the North Corridor. These regions are mapped in Figure 9-2. Table 9-35 reveals how the number, length, and duration of trips are interrelated and interact due to ITS improvements.[21]

Also of note in Table 9-35 is that more of the vehicle trips originating from each of the four regions make use of the subarea for some portion of their AM peak period trips in the HOV/Busway with ITS alternative than in the HOV/Busway alternative. Moreover, the vehicle trips making use of the subarea are on average longer yet require significantly less travel time.

Table 9-36 details in person trip statistics the shift in subarea AM peak travel resulting from ITS enhancements. Figure 9-3 presents graphically the seven regions. The distribution of trips changes as a result of the ITS enhancements to prompt more trips from the subarea to the immediately adjacent regions (2,3, and 4). This increase in trips from the subarea to adjacent regions is offset by fewer trips remaining entirely within the subarea or traveling elsewhere. With ITS, more person trips from the adjacent regions are also made to the subarea during the AM peak period.

In summary, introduction of ITS to the HOV/Busway alternative, causes small but significant impacts at the regional level. These include a significant shift to transit mode, increased corridor mobility, a funneling of trips from surrounding regions through the subarea, an average lengthening of trips, and an average decrease in trip time. Redistribution of travel is significant, causing more trips from the subarea to enter adjacent areas, and causing more trips from adjacent areas to enter the subarea. The introduction of 13 regional express bus routes in the HOV/Busway alternative attracted a significant number of person trips away from the auto modes to transit use.

Table 9-27. HOV/HOV with ITS Daily Person and Vehicle Trip Comparison

Regional Travel: Daily Person and Vehicle Trips				
Measure	HOV	HOV with ITS	Change (HOV with ITS - HOV)	% Change
Daily Trips				
Person Trips	16,457,504	16,457,500	-4	0.00%
Non-Carpool Vehicle Trips	12,084,794	12,080,870	-3,924	-0.03%
Carpool Vehicle Trips	22,183	22,145	-38	-0.17%
Transit Person Trips	475,929	480,387	4,458	0.94%

21 Both impacts of the regional recurrent delay analysis and the rolled up travel time impacts of the simulation representative day analysis are captured in the trip time values.

Table 9-28. HOV/HOV with ITS Daily Vehicle Miles and Hours Traveled

Regional Travel: Daily Vehicle Miles and Hours Traveled				
Measure	HOV	HOV with ITS	Change (HOV with ITS - HOV)	% Change
Daily Vehicle Miles Traveled				
Non-Carpool	100,122,416	100,367,616	245,200	0.24%
Carpool	494,465	493,561	-904	-0.18%
Transit	157,143	157,143	0	0.00%
Daily Vehicle Hours Traveled				
Non-Carpool	3,395,397	3,391,096	-4,301	-0.1%
Carpool	14,451	14,418	-33	-0.23%
Transit	9,160	8,998	-162	-1.77%

Table 9-29. HOV/HOV with ITS Daily Person Miles and Hours Traveled

Regional Travel: Daily Person Miles and Hours Traveled				
Measure	HOV	HOV with ITS	Change (HOV with ITS - HOV)	% Change
Daily Person Miles Traveled				
Non-Carpool	145,443,216	145,725,936	282,720	0.2%
Carpool	1,633,970	1,632,132	-1,838	-0.11%
Transit	3,775,392	3,815,790	40,398	1.07%
Daily Person Hours Traveled				
Non-Carpool	4,861,765	4,849,621	-12,144	-0.2%
Carpool	47,696	47,492	-204	-0.43%
Transit	436,367	436,648	281	0.06%

Table 9-30. HOV/HOV with ITS AM Peak Person and Vehicle Trip Comparison

Regional Travel: AM Peak Period Person and Vehicle Trips				
Measure	HOV	HOV with ITS	Change (HOV with ITS - HOV)	% Change
AM Peak Period Trips				
Person Trips	3,187,883	3,187,816	-68	0.00%
Non-Carpool Vehicle Trips	2,117,059	2,116,098	-961	-0.05%
Carpool Vehicle Trips	16,637	16,609	-28	-0.17%
Transit Person Trips	138,243	139,317	1,074	0.78%

Table 9-31. HOV/HOV with ITS AM Peak Vehicle Miles and Hours Traveled

Regional Travel: AM Peak Period Vehicle Miles and Hours Traveled				
Measure	HOV	HOV with ITS	Change (HOV with ITS - HOV)	% Change
AM Peak Vehicle Miles Traveled				
Non-Carpool	19,849,334	19,887,816	38,482	0.19%
Carpool	373,763	372,918	-845	-0.23%
Transit	39,974	39,974	0	0.00%
AM Peak Vehicle Hours Traveled				
Non-Carpool	812,342	811,015	-1,327	-0.2%
Carpool	13,264	13,239	-25	-0.19%
Transit	2,410	2,372	-38	-1.57%

Table 9-32. HOV/HOV with ITS AM Peak Person Miles and Hours Traveled

Regional Travel: AM Peak Period Person Miles and Hours Traveled				
Measure	HOV	HOV with ITS	Change (HOV with ITS - HOV)	% Change
AM Peak Person Miles Traveled				
Non-Carpool	30,629,646	30,672,288	42,642	0.1%
Carpool	1,234,344	1,231,956	-2,388	-0.19%
Transit	1,300,269	1,308,937	8,668	0.67%
AM Peak Person Hours Traveled				
Non-Carpool	1,240,424	1,237,867	-2,557	-0.2%
Carpool	43,782	43,689	-93	-0.21%
Transit	132,048	131,904	-143	-0.11%

Table 9-33. HOV/HOV with ITS AM Peak Regional and Subarea Vehicle Trips

Regional And Sub-Area Vehicle Trips: AM Peak Period				
	HOV	HOV with ITS	Change (HOV with ITS - HOV)	% Change
Regional Non-Carpool	2,117,059	2,116,098	-961	-0.05%
SubArea Non-Carpool	331,981	335,297	3,316	1.00%
% SubArea Non-Carpool	15.68%	15.85%		
Regional Carpool	16,637	16,609	-28	-0.17%
SubArea Carpool	4,870	4,853	-17	-0.35%
% SubArea Carpool	29.27%	29.22%		

Table 9-34. HOV/HOV with ITS AM Peak Screen Line Volumes

AM Peak Period Screen Line Volumes (Vehicles)			
Screen Line	HOV	HOV with ITS	% Change
Ship Channel (35)	107,166	109,796	2.45%
Lake Washington (32)	43,728	44,556	1.89%
County Line (42)	74,242	75,458	1.64%
Locust Way (43)	57,802	59,407	2.78%
128th Street SW (46)	76,266	76,962	0.91%

Table 9-35. HOV/HOV with ITS AM Peak Non-Carpool Vehicle Trips To, From & Through the Subarea

2020 AM Peak Period Non-Carpool Vehicle Travel To, From, and Through Simulation Area									
	HOV			HOV with ITS			% Change		
	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time	Vehicle Trips	Average Distance	Average Time
From:									
1 = Simulation area	211,243	5.67	14.89	211,612	5.74	14.38	0.17%	1.20%	-3.41%
2 = Corridor South	15,903	7.24	16.18	16,430	7.23	13.04	3.32%	-0.12%	-19.41%
3 = Corridor North	41,243	10.11	29.93	41,836	10.15	27.89	1.44%	0.42%	-6.80%
4 = Outside Corridor	63,592	49.67	115.98	65,420	49.31	112.23	2.87%	-0.73%	-3.23%
To:									
1 = Simulation area	233,786	8.96	24.26	234,386	9.03	22.91	0.26%	0.75%	-5.55%
2 = Corridor South	42,129	14.12	34.84	43,055	14.03	33.58	2.20%	-0.63%	-3.62%
3 = Corridor North	15,412	14.40	37.23	15,857	14.85	37.67	2.88%	3.13%	1.19%
4 = Outside Corridor	40,654	48.62	105.76	42,000	48.28	103.65	3.31%	-0.70%	-2.00%
Overall	331,981	14.73	36.18	335,297	14.86	35.09	1.00%	0.93%	-3.02%

Distance in Miles, Times in Minutes

Table 9-36. HOV/HOV with ITS AM Peak Non-Carpool Person Trips From and To the Subarea

2020 AM Peak Period Person Trips From and To the Simulation Area							
From 1 to	HOV	HOV with ITS	% Change	To 1 from	HOV	HOV with ITS	% Change
1	311,961	308,727	-1.04%	1	311,961	308,727	-1.04%
2	83,417	85,404	2.38%	2	22,805	23,797	4.35%
3	12,782	12,962	1.41%	3	64,988	65,796	1.24%
4	27,821	28,938	4.01%	4	31,930	33,535	5.03%
5	760	743	-2.24%	5	20,927	20,895	-0.15%
6	532	512	-3.76%	6	19,528	19,440	-0.45%
7	353	339	-3.97%	7	11,861	11,810	-0.43%
Overall	437,626	437,625	0.00%	Overall	484,000	484,000	0.00%

1=Simulation Area, 2=South Corridor, 3=North Corridor, 4=King, 5=Snhomish, 6=Pierce South, 7=Islands+Olympic P.

9.4.2 Sub Area Impacts: Reliability, Delay Reduction, and Travel Speed

Overall, the addition of ITS to the HOV/Busway alternative reduces traveler delay, increases throughput, and cuts travel time variability. The largest impacts are seen in weather, high demand, and incident cases. Small but still positive impacts on delay and throughput are observed under average demand and lower-than-average travel demand days.

The HOV Busway alternative can be characterized as the most reliable of the three non-ITS alternatives – that is, the measure of travel time variability is lower than in the Baseline (Do Nothing) or the SOV alternatives. However, there is still significant delay in the transportation system, particularly for non-HOV travelers. The HOV alternative is particularly sensitive to weather impacts, especially on freeway facilities. Overall freeway loading in the general-purpose lanes can be observed to be higher and runs "at the margins" for a substantial portion of the peak period. When weather conditions bring down the effective carrying capacity of the freeway and increased freeway congestion results, the adaptive ITS components (ATIS and adaptive traffic signal control on the arterials) are able to redistribute demand more efficiently in the HOV + ITS alternative. Because of the large number of days where weather is a factor in Seattle, this addition of ITS results in a substantial reduction in system delay with respect to the HOV alternative (19.9%). The overall roadway system is not as heavily utilized as in the SOV alternative, however, so improvements from the addition of ITS in the HOV alternative in throughput are modest in comparison (3.7% vs. 10.2%).

The measures used to characterize system impacts derived from the subarea simulation are delay reduction, throughput, coefficient of trip time variation, risk of significant delay, travel by speed-range, and expected number of stops per km of travel. Annualized impacts are reported for each of these measures. Further, for delay reduction, throughput, and risk of a significant delay, the probability mapping of the scenario set is used to highlight the conditions under which ITS had the largest impact.

Delay Reduction. Figure 9-18 and 9-19 illustrate the effectiveness of ITS in weather related conditions for the HOV alternative. The highest levels of absolute delay reduction occur in combinations of weather and average-to-above-average demand conditions (EW1, EW3, EW5, ES1), heavy demand (ND7, ND8, NE7), and in the two major incident scenarios (EG1, EG2).

On an annualized basis, average traveler delay is reduced by 2.6 minutes per traveler per day, from 13.03 to 10.43 minutes per traveler per day. This represents a 19.9% reduction in traveler delay during a calendar year.

Throughput. Figure 9-20 illustrates the increase in throughput realized by the addition of ITS to the HOV alternative. Throughput improvements are highest in the heavy demand cases (ND7, ND8, NE7), as well as in the set of weather scenarios.

On an annualized basis, throughput in the HOV + ITS alternative increases to 183,858 vehicles per AM peak period (6:15 – 8:30 AM trip starts) from 177,260 vehicles. This increase of roughly 6,599 vehicles per peak period represents an increase in throughput of 3.7%.

Risk of Significant Delay. Figure 9-21 illustrates the conditions under which the risk of significant delay has been significantly reduced in the HOV + ITS alternative. Highest impact can be seen in heavy demand and weather cases. Small increases in risk can be observed for a few scenarios featuring average demand and a few accidents (NE3, NE4, NE5). This is likely the result of the adaptive ITS systems over-reacting to relatively small pertubations in the system. In these cases, ATIS users may be making unwarranted diversions end up increasing risk of severe delay.

On annualized basis, the percentage of trips at risk of significant delay is reduced to 5.2% in the HOV + ITS alternative compared to 8.3% in the HOV alternative.

Coefficient of Trip-Time Variation. The coefficient of trip-time variation in the HOV alternative is 0.27. Applying this to a trip with an expected duration of one hour (normally distributed), a traveler would have to budget just over an hour and 27 minutes to arrive at the trip destination on-time 95% of the time. In the HOV + ITS case, the coefficient of trip-time variation is reduced to 0.23. Under the constraints of our example one-hour trip, the same traveler would have to budget an hour and 23 minutes to arrive at the trip destination on-time 95% of the time.

Percentage of Vehicle-KM of Travel By Speed Range. Figure 9-22 illustrates the impact of the HOV + ITS alternative on travel speeds by facility over a calendar year. The percentage of travel by speed range for each of the facility types (freeway, expressway, urban arterial, and HOV lane) is plotted with the HOV and HOV + ITS alternatives shown side-by-side. Overall, the HOV + ITS alternative can be characterized as providing faster travel across all of the facility types, but with largest impact on freeway facilities. Low-speed freeway travel (<20 mph) is reduced by 43% in the HOV + ITS alternative.

Expected Number of Stops per Vehicle-KM of Travel. Figure 9-23 illustrates the impact of the HOV + ITS alternative on the stops per vehicle-km over a calendar year. The percentage of travel logged with corresponding number of stops per kilometer of travel is plotted with the HOV and HOV + ITS alternatives shown side-by-side. Overall, the HOV + ITS alternative can be characterized as providing smoother travel, particularly for freeway, HOV lanes, and expressway facilities.

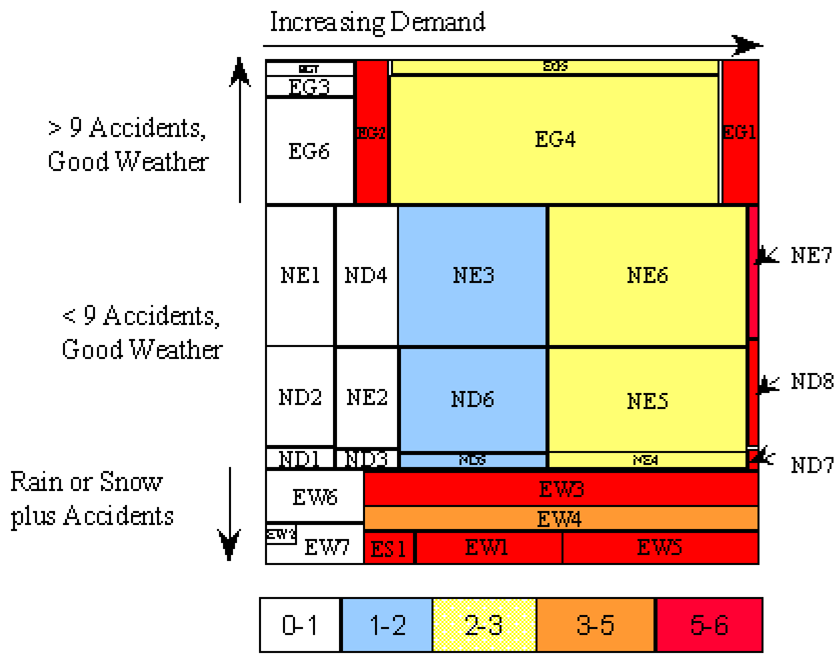

Figure 9-18. Minutes of Delay Reduction: HOV + ITS vs. HOV

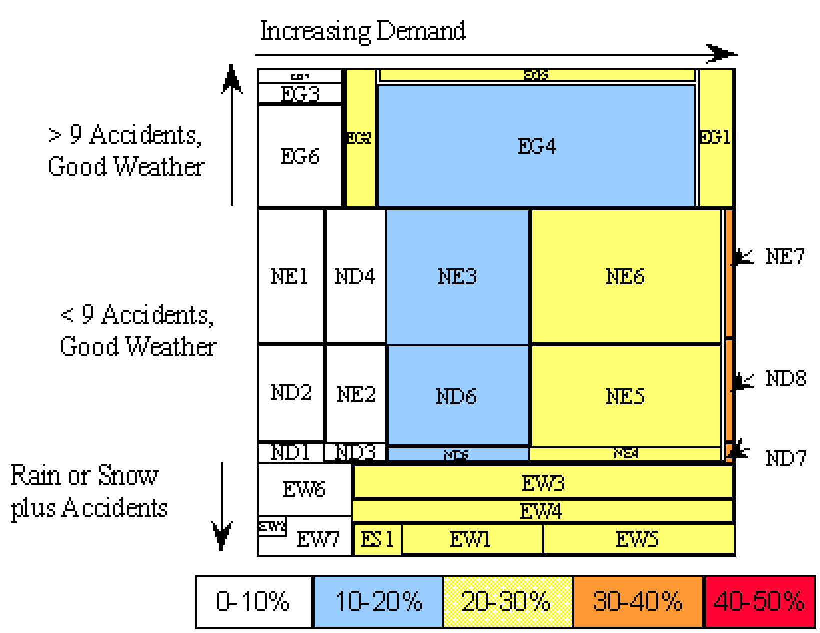

Figure 9-19. Percent Delay Reduction: HOV + ITS vs. HOV

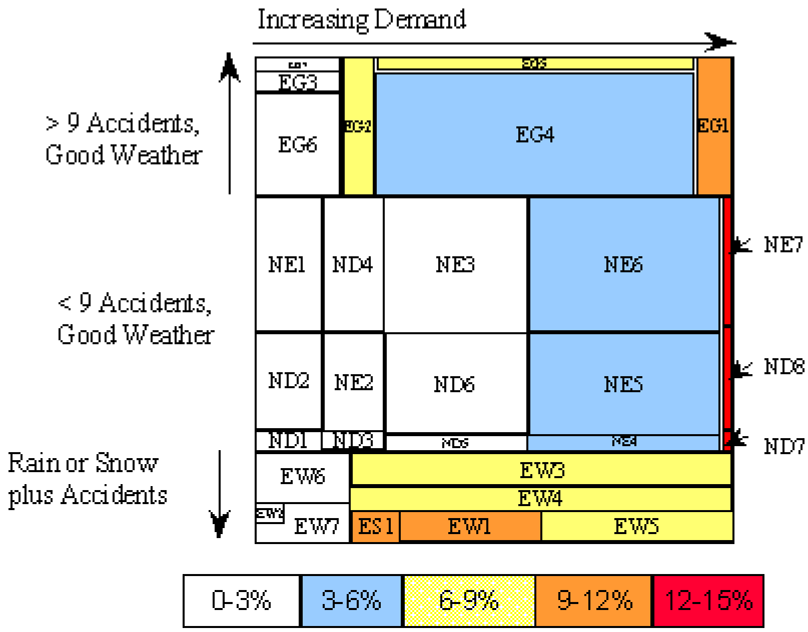

Figure 9-20. Increase in Throughput: HOV + ITS vs. HOV

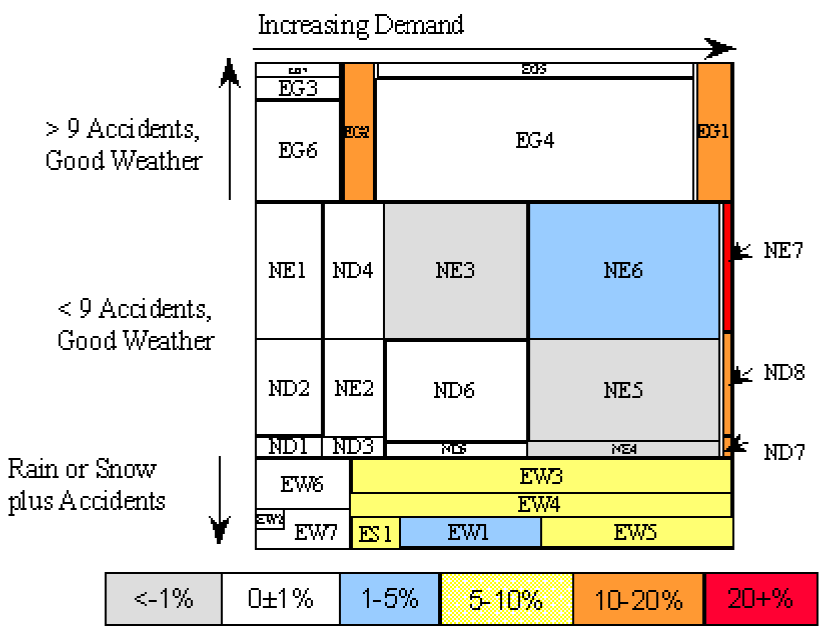

Figure 9-21. Reduced Risk of Travel Delay: HOV + ITS vs. HOV

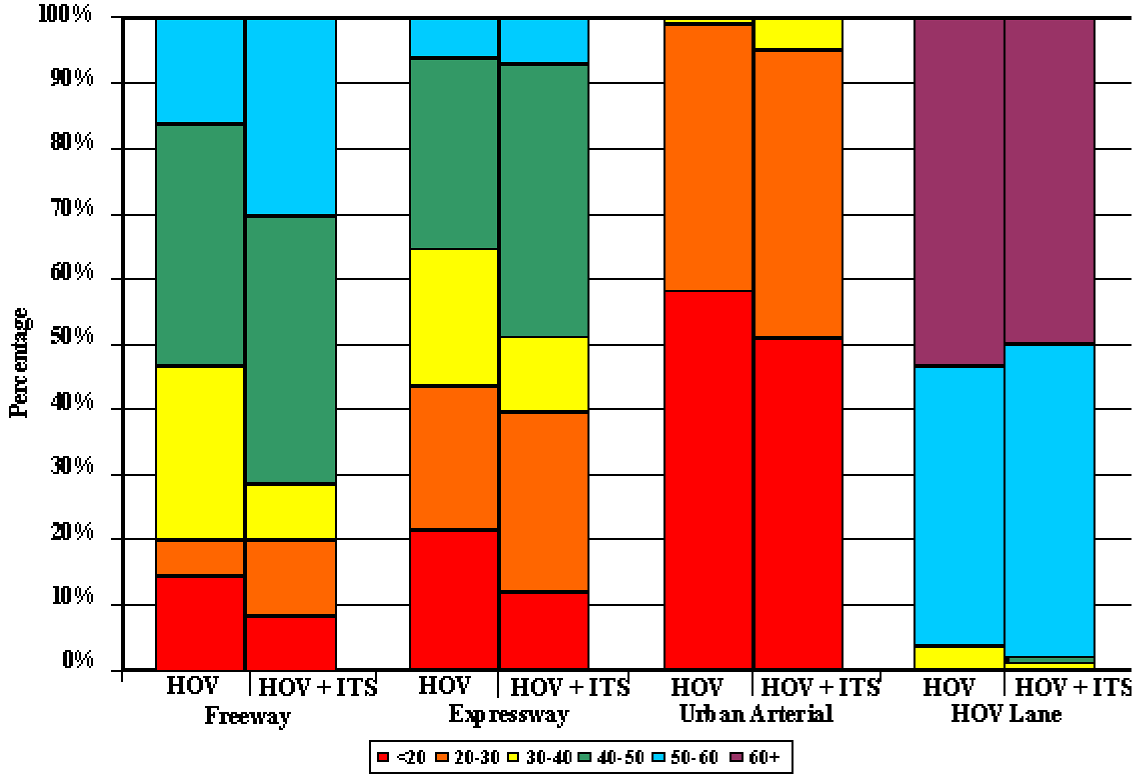

Figure 9-22. Vehicle-Km of Travel by Speed-Range: HOV + ITS vs. HOV

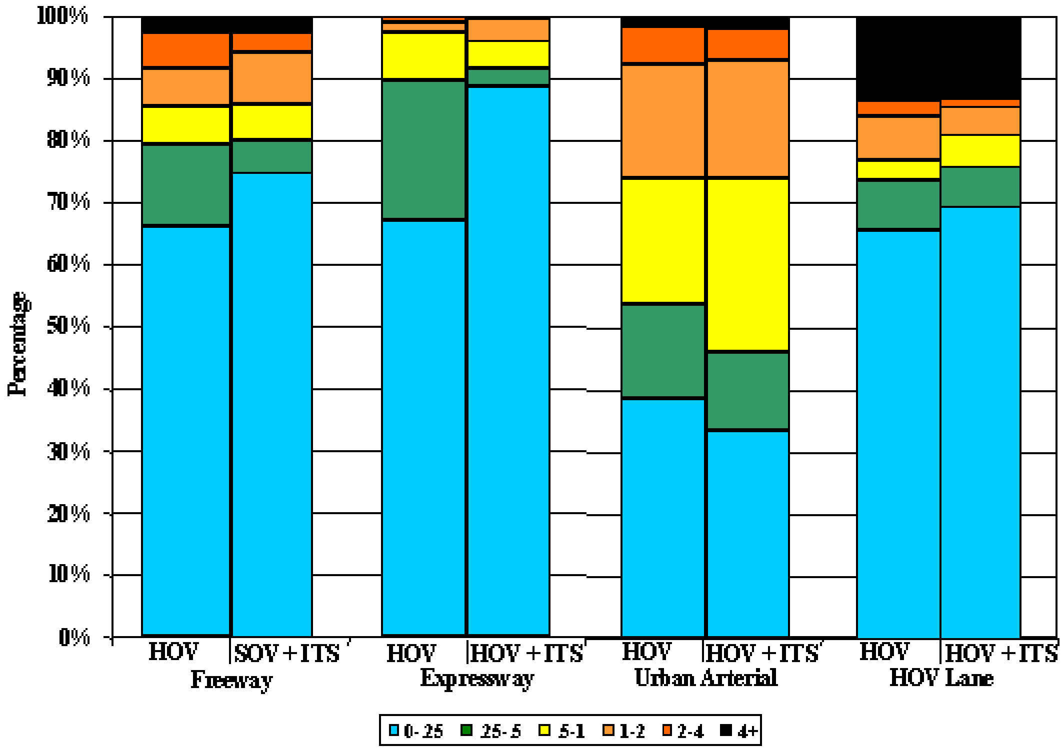

Figure 9-23. Stops Per Vehicle-Km of Travel: HOV + ITS vs. HOV

9.4.3 Capital & Operating Costs

The HOV/Busway Alternative includes a continuous, barrier-separated HOV lane on I-5 from downtown Seattle to SR526 in South Everett by year 2020 (about 25 miles). It also includes implementation of barrier-separated HOV lanes on SR526 and SR99 (from downtown Seattle to N 59th St), 14 miles of arterial HOV lanes on SR99 extending north from N 59th St, a freeway-to-freeway HOV connector and various direct access ramps. This alternative also includes transit improvements, including a transit lane on SR522; the addition of several new regional express bus routes with frequent service; and construction of several park-and-ride lots. The construction and modification of HOV lanes along SR99 (about 18 miles) represents the most significant cost in this alternative. Costs for widening the SR99 bridge alone are estimated at about $47 million; estimates for implementing barrier separated HOV lanes on SR99 from downtown to N 59th Street are about $29 million; and 14 miles of new arterial HOV lanes along SR99 is expected to cost more than $102 million. In addition, the upgrading of 15 miles of HOV lanes on I-5 so that they are barrier separated increases the cost estimate for this alternative by about $114 million since each HOV lane requires its own 10 foot shoulder inside the barrier.

This alternative is a comprehensive package of improvements affecting over 60 miles of HOV lanes on I-5, SR99, SR522, and SR526. The incremental cost of the HOV/Busway Alternative relative to the Baseline Alternative is estimated at $868 million, which makes it the most costly alternative. As was described previously, however, many of the items included in the HOV/Busway Alternative are improvements that have not been seriously considered by the Washington State Department of Transportation or others. In addition, in this case study capital improvements in the HOV/Busway Alternative were made to over 60 miles of roadway on four facilities, while in the SOV Capacity Expansion Alternative capital improvements were made to about 17 miles of roadway on only two facilities. Therefore, this case study should *not* be used to compare general SOV capacity improvements to general HOV capacity improvements.

High cost construction elements of the HOV/Busway alternative include the following:

- Construction of 25 miles of new arterial transit lanes, two directions ($183M)
- Upgrade of 15 miles of paint-stripe separated HOV lanes to barrier-separated lanes, two directions, which require an additional 10 feet of right-of-way in each direction inside the barrier ($114M)
- Construction of 9 miles of new freeway barrier-separated HOV lane, two directions ($79 M)
- Modification of the I-5/I-405 interchange to accommodate direct freeway-to-freeway HOV connector ramps ($71M)
- Construction of two “Texas-T” interchanges for direct access into the HOV lanes ($62M)

- Construction of four miles of barrier-separated HOV contra-flow lane on the I-5 Express Lane Roadway between the University District and downtown Seattle, including a transit-only ramp accessing the lane from NE 42nd Street ($57M)
- Widening of the quarter-mile long Aurora Bridge on SR99 for the addition of HOV lanes in both directions ($47M)

Other high cost estimate items include $48M for an additional 119 new transit vehicles necessary for provision of the increased transit service proposed. Note that right-of-way costs that have been estimated for the two capital-intensive alternatives did not differ significantly. It might seem counterintuitive that right-of-way costs for the SOV Capacity Expansion and HOV/Busway Capacity Expansion Alternatives were about the same since the HOV/Busway Alternative included improvements to many more lane miles than the SOV Alternative. The costs were about the same since the SOV Capacity Expansion alternative required about three times as much right-of-way on SR99 as the HOV/Busway alternative. Because SR99 is more developed than I-5, right-of-way costs on SR99 are expected to be higher than right-of-way costs on I-5.

The HOV/Busway Plus ITS Alternative includes the HOV/Busway Alternative plus essentially the same communications and traffic management investments presented in the ITS Rich Alternative. The communication element is comparable in cost to the ITS Rich Alternative with a slightly higher investment in the transit vehicle interface component. Note that the HOV/transit facilities and services cost in this alternative is about $4 million less than the HOV/transit facilities and services cost in the HOV/Busway alternative. These costs are reduced because in the HOV/Busway Plus ITS Alternative fewer new buses are required due to the transit operating efficiencies created by the ITS improvements. Overall, however, the additional investment in ITS elements for the HOV/Busway Plus ITS Alternative would cost an estimated $34 million dollars more than the HOV/Busway Alternative.

Incremental O&M costs for the HOV/Busway Alternative are estimated at over $39 million. This includes the additional O&M costs associated with roadway widening, construction of direct access ramps, and additional park and ride lots. Not surprisingly, the largest contributor to the incremental O&M costs is the additional transit operating and maintenance costs relative to the Baseline Alternative, which are a direct result of the increase in transit routes, runs and associated fleet size. The HOV/Busway Alternative Plus ITS would have estimated incremental O&M costs relative to the Baseline of $37.8 million. This is slightly lower than the incremental costs of the HOV/Busway Alternative since this alternative has lower transit operating costs due to increased transit system efficiencies.

9.4.4 Environmental Implications

No explicit environmental evaluation was conducted as a part of this study. However, implications for environmental impacts can be made from selected results. At the regional level, one result for the HOV + ITS alternative is that although transit mode share is increased, longer auto trips result in a net increase in daily VMT of 198,902 miles from 100,122,416 to 100,367,616, a 0.24% increase. In the AM peak, VMT increases at roughly the same rate, 0.19%. At the regional level, then, the implications from the HOV + ITS alternative is that overall travel increases. This increase in VMT implies increased emissions.

At the subarea level, however, the implications for emissions are generally positive. Travel takes place at generally higher speed, and low-speed travel is significantly reduced. For example, travel under 20 mph is cut by 43% for freeways and 12% for arterial facilities in the HOV + ITS alternative when compared to the HOV alternative. The number of stops per vehicle-km of travel is also reduced in the HOV + ITS alternative by 1.4% for freeways. A reduction in low-speed travel and less frequent stopping overall implies that emissions may be reduced from smoother traffic flow in the subarea.

10. Lessons Learned: Issues and Observations

What are the lessons learned from the Seattle Case Study and the advice that can be given to others wishing to conduct similar corridor analyses incorporating ITS? This section provides Mitretek insights from the Case Study and other similar efforts. The lessons learned are categorized into eight topic areas which are:

- Alternative definition
- Model integration and consistency
- Large scale simulation issues
- Scenario development
- Feedback
- Costing
- Data Issues
- Resource use and analysis effort.

Each topic is detailed in the subsections that follow.

10.1 Alternative Definition

This section provides a few observations concerning lessons learned in the definition of alternatives for a corridor study, and in particular the sensitivity to and addition of ITS elements in each alternative.

ITS services and elements may exist in each alternative or investment option, including the DoNothing/TSM baseline. Defining the ITS-portion of the alternatives can be thought of as an additional layer to (or extension of) the traditional capacity or service enhancements. As with traditional elements, these ITS investment options should logically build or develop from the do-nothing, to the TSM, to the build options, with each level including the elements of the previous option. In order to discriminate between ITS investment options, the study team paid particular attention to which ITS elements were already a part of the Seattle north corridor baseline, and which were to be defined as part of the builds (ITS Rich and the two traditional builds). ITS services can and in many cases should be considered as part of all potential alternatives, particularly the TSM option(s), where ITS is a natural fit. A significant level of effort is needed to adequately define the ITS options if the goal is to be able to distinguish their impact on the relevant performance measures. In addition, the visibility of ITS should be such that it is easy to distinguish which specific ITS elements are in each alternative. Future efforts should be cognizant of these factors and be sure to properly define ITS in each of the alternatives, including accounting for the ITS elements in the baseline options.

ITS services can be logically grouped into investment bundles or packages in the alternatives. ITS covers a broad spectrum of services or strategies for operating and managing transportation systems. The study team found that grouping like services together (ATMS services, ATIS services, APTS services, and Emergency and Incident Management services) helped to simplify decisions on which particular combinations of elements were involved in any given alternative. **The ITS services or investment packages can and should be tailored to complement the characteristics and policy objectives of any given build alternative**. In our case study, these principles were used, since the build with ITS alternatives generally carried the same ITS enhancements as the ITS Rich alternative (a common package), with minor tailoring to optimize the operating performance and mold to the physical characteristics of the build.

<u>Private sector and market assumptions for services such as ATIS must be carefully addressed in defining the alternatives</u>. The study team encountered the issue of estimating market penetration for ITS services that depend upon the purchase of communications devices or other equipment by the individuals using them. Market demand models for personalized travel information and route guidance equipment are not available, or are just in their development stages. Consequently, separate levels of market penetration for these services were assumed as part of the alternative definition in this study. The alternatives also need to have clear assumptions regarding the private sector provision of ITS services such as ATIS or personal mayday/collision notification systems. Alternatives defined under this premise should have documented assumptions regarding public and private sector roles and cost recovery mechanisms that will factor into the analysis of alternatives. Because the horizon year for such a corridor study is often 20 years, these assumptions may be perceived as speculative. In our study, we did assume that the private sector would provide ATIS services and that user fees (e.g., monthly charges) would be used to recover costs, at least for the advanced pre-trip planning and dynamic route guidance services. However, since this is a research case study and is not supporting an investment decision in Seattle, there is no real risk involved if our assumptions do not materialize.

<u>The system characteristics of ITS need to be properly accounted for when defining alternatives in a corridor planning study</u>. In addition to roadside and end user equipment, central system functions and communications system(s) must exist, or be included in the alternatives, to implement ITS services within a corridor. The center functions are centralized and their impacts may not be limited to any given corridor. There may be substantial initial and startup costs associated with implementing these center systems. Thus, positioning these ITS elements within the alternatives and then allocating the fraction of their costs which the corridor must bear (in relationship to the region) will influence the outcome of the analysis. In our study, the issue of start-up costs was not as pronounced, because the existing ITS infrastructure allowed for an analysis of system “extensions” or minor additions to support the proposed ITS services.

<u>Level of Detail</u>. The analysis of costs and benefits (or transportation impacts) establish the required level of detail and help to refine the alternatives, both for ITS and traditional elements. **The study team found that thinking through the detail needed for modeling and providing cost estimates forced decisions which helped to further specify the alternatives. For example, the cost analysis forced decisions on hardware, software, communications, and traffic management operators, while the regional and simulation modeling helped establish the assumed operating characteristics of the alternatives**

(frequency of updates, level of information provided, etc.). As with any similar study, consistency is needed between the assumptions used in the cost analysis and the modeling (benefits) analysis.

Alternative Refinement. The use of a simulation analysis can be used to refine and tailor the alternatives to achieve significant performance improvements. In our study, we found that conducting the simulation analysis resulted in a number of refinements to the alternatives, both of the ITS and traditional build elements. For example, the final ATMS system that was used as part of the ITS Rich alternative was changed from the initial system. Through simulation, we discovered that a form of gridlock control (a different algorithm and operating strategy) was required in and around the University District. This feature was designed, tested and added to the set of final ATMS strategies. Implementation of this feature led to significant improvements in the throughput and travel time results. Without the use of simulation, we would not have been able to discover and define this improved ATMS approach.

10.2 Model Integration and Consistency

If there is an area where Mitretek learned the most in conducting the Seattle Case Study it is that of integration and consistency between the regional forecasting process and sub-area system simulation. Significant "lessons" occurred in several areas. First is the need to analyze and merge the network coding requirements of the two systems as early in the study as possible. Simple automatic conversion routines are unlikely to work. Second, how each model system defines the volume / delay relationship on the network and capacity of the system must also be accounted for in the development of the integrated process. Regional models allow volumes to exceed capacity to show system deficiencies and latent demand. System simulations treat capacity as absolute and cannot account for future scenarios where demand greater than the system can carry is predicted. Third, are the issues and lessons concerning the sub-area windowing/scoping and the interface between the two model systems. Traffic simulations typically cannot address a complete region in their analyses. They provide more detailed information on a sub-area of the region represented in the regional process. Information on the travel patterns and network performance of the sub-area must be transferred from the regional process to the simulation and back again. Last, is the need for calibration/validation of the integrated system. The system simulation validation must account for the regional model information in its validation. The regional model validation must account for changes in coding requirements and network performance provided by the simulation. Each of these areas is discussed separately below.

10.2.1 Network Coding

The network coding process and some of its issues were described previously in Section 7.3.3: Transportation Service Representation. This section focuses on the observations / lessons learned during the Case Study that we did not necessarily understand at the beginning of the effort. These include both affirmation of the importance of some assumptions, and new observations. The importance of carefully analyzing the networks, the existing regional coding processes and the simulation model requirements during the study design cannot be over-emphasized. Hopefully, if the insights and issues discussed below are addressed early in the project design the pitfalls and problems encountered (and overcome) as part of the Seattle Case study can be avoided in future efforts.

Regional Forecasting and Simulation Model Parameter Assessment. A critical first step is a detailed evaluation of the coding requirements and assumptions of the regional forecasting and simulation packages to be used. This should include a one-to-one comparison of all network parameters and limits as well as an evaluation of the behavioral assumptions within each model (How does each model handle overloads, multiple class assignments, minimum path selection, etc.). The more that is known and accounted for at the beginning of the project the fewer the problems will be as the project progresses.

While a comparison was made early in the project between the PSRC Regional Model network coding in EMME/2 and the INTEGRATION 1.5x simulation model requirements, a number of coding issues still arose as the project progressed. These included:

- Impact of very short link coding. The regional (EMME/2) networks used “dummy” links (0.01 miles) to connect general purpose and HOV lanes, and to help represent access configurations. The coded 0.01 miles were greater than the supposed minimum link length of the INTEGRATION simulation model (0.005 km). However, the simulation model stores vehicles on the link itself and a vehicle cannot be on more than one link at a time (no partial vehicles). Thus, when a link is very short only one vehicle can be processed through it per simulation time step and a virtual bottleneck is created. This problem was not overcome until a practical minimum of 0.15 km (0.09 miles) was used for all link lengths. In Micro simulations, short link lengths may also introduce unreasonable weaving / following behavior because of the link level look ahead function required for lane changes.
- Maximum link length. There was effectively no restriction in the regional model system and a limit of 6.0 km in the simulation. This had its most significant impact on the external approach links which tied the rest of the region to the sub-area in the focused simulation network.
- Differences in turn penalties and restrictions. These are allowed and coded on all intersection movements in the regional networks. The simulation model allowed only one movement from a link to be restricted at a time. The impacts of the differences in turning movement representation were discovered late in the alternative development and required adjusting the node/link representation and topology of the intersections affected. Special care must be taken to account for turning movement coding issues at the beginning of the process especially when specific alternatives may depend on turning representation (HOV alternatives and access management).
- Maximum links in/out of a node. The simulation model allowed 9 links in/out of a node whether the links were zone connectors or not. This was inconsistent with

the regional network coding especially for the external link connectors from the region to the sub-area. Special coding conventions had to be developed to adjust for this.

- Centroid connector coding. Special attention should be spent on how each model represents zones and their connection to the network. Regional models usually use special nodes (zones) and connectors. Simulation systems may allow vehicles to originate or be destined to any node. In older versions of INTEGRATION the internal assumption was that all zone connectors have a length of 0.1 m. INTEGRATION made this assumption to force all access points to a zone to have the same impedance. However, regional zonal geography may be coded in the networks which necessitates different lengths. The INTEGRATION version used for the Seattle Case Study was adjusted to account for this. Also, one should understand the impacts of centroid connectors connected at mid-block versus at intersections (corner connectors). Corner connectors may have severe impacts on intersection throughput in simulation models.
- Length, Speed, Time relationships. Most regional model systems code link impedance (time) directly and do not require a consistent link length to be coded. This is especially true for ramps, zone connectors, and other special links. Calculated speeds in these cases may be misleading and/or unrealistic. On the other hand, simulation systems often use distance and speed to derive impedance and require realistic geographic (Euclidean) network representation to operate correctly. Significant effort was made to make sure the networks met the additional Euclidean coding requirements of the simulation system.
- Network units and compounding error aggregation. As one converts from one coding scheme to another, special attention must be given to insuring that overall distances and times along a route remain the same. This issue arose in two ways. First, as interchange coding was added to the regional networks and minimum link lengths adjusted for simulation there was a tendency to increase the overall length and time along a route. Checks had to be made to ensure that this did not occur. Second, as the networks were converted from English to metric units truncation tended to reduce overall distance along a route. Again, special checks had to be carried out to account for this.

Consequently, networks had to be re-coded and/or new conversion processes developed as each of the above issues were addressed. A formal review of the model parameters and assumptions to be used in a study as part of the study design is therefore recommended. Some specific parameters to check are:

- Default units for distance, time, and speed
- Link Length minimum and maximum
- Link Speed minimum and maximum
- Link Time minimum and maximum (may not be the same as derived using the minimum and maximum lengths and speeds)
- Link Capacity definition, minimum, and maximum

- Number of lanes, minimum and maximum
- Number of legs in/out of a node
- Coding/treatment of turning movements and prohibitions
- Node and link numbering conventions
- Allowable mode or vehicle type conventions
- Link type definitions
- Node type definitions
- Centroid connection coding conventions (path restrictions, mid block connections, direct demand generation, etc.)
- Link Volume/Delay function parameters
- Node Volume/Delay function parameters
- Additional parameters required by the system simulation and not found in the regional networks, or vice-versa (jam density, speed at capacity, signal timing, etc.)

As much as possible inconsistencies between the regional forecasting and simulation model coding parameters should be resolved and coding procedures acceptable to both developed. If necessary, re-coding of the regional networks within the area covered by the simulation should be carried out. This is essential to minimize validation and consistency issues later in the process.

Network Topology And Level of Detail. After the parameters and the impacts of each model's assumptions have been assessed the topology and detail required for each must be examined. Again, the Seattle Case Study experience showed that it is **critical that the network representation within the study area be exactly the same** (or as close as possible) for both the regional and simulation model systems. This will usually require additional detail to be added to the regional networks. For example in the Seattle Case Study each interchange had to be expanded from a single node in the original networks to show all ramps and overpasses (see Section 7). Lessons learned in this effort are described below.

- Generic interchange and network expansion routines are not recommended. Initially, a set of interchange types were defined and an attempt was made to develop a generic interchange expansion procedure. As the work progressed it was found that each interchange's configuration was different enough to make this approach impractical. If the differences were ignored and generic configurations used the simulation did not perform realistically. Therefore each interchange had to be examined and expanded individually. This proved to be a time consuming but critical effort.
- Simulation capacity constraints can cause bottlenecks due to zonal representation/centroid connections. As discussed in the next section simulation models treat "capacity" differently than regional flow based models. In simulation models capacity can never be exceeded. Practically, this means that the simulation models are much more sensitive to local gridlock due to high volumes entering the network from zonal access points than regional models. The initial regional assignment should be examined for congested conditions at or around zone access points. Additional centroid connectors should be added to existing zones, or zones disaggregated into smaller zones if it looks like they will cause excessive loading on the links they connect to. Also, signalized intersections in general should not have zone connectors attached to them. Last, where possible, the number of zones

connecting to an individual intersection should be minimized. This is important since simulations often do not give equal priority to all connections, and a large zone connector may effectively dominate an intersection and restrict the access from all other zones during the simulation. A cursory zonal access and capacity evaluation during network development can avoid significant network issues later in the analysis phase of a project.

Network Resolution and Its Impact on Parameters. In developing the network coding one must also decide on the network resolution/detail and determine its impact on the coding parameters. This can mean developing additional link types and facility representations. In the Seattle Case Study, for example, the new facility types that were defined and coded included ramp meters, high speed ramps, low speed ramps, and local access links. Each had different characteristics that were important to separate in the sub-area simulation.

The network resolution also impacts what the coded link characteristics of each model system represent and the capacities and other parameter conversion between them . Figure 10-1, and Table 10-1. provide some of the differences between regional planning and simulation models that need to be accounted for in the coding.

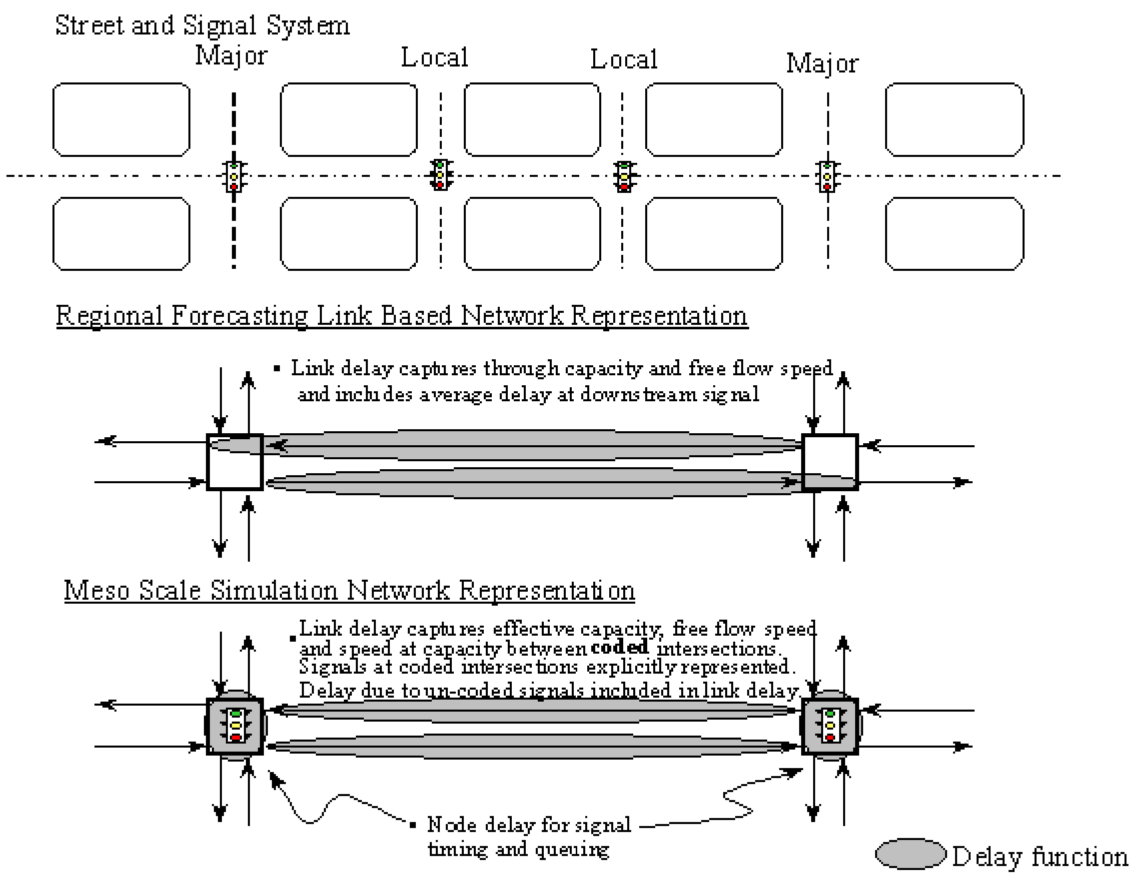

Figure 10- 1. Link Representation and Network Resolution

Table 10-1. Regional Planning versus Simulation Model Comparison

Regional Planning Model	Simulation Model
Macroscopic	Mesoscopic/Microscopic
Static "Flow" Oriented	Dynamic: specific representation of operations and vehicles through time
Link based impedance functions	Mid block link, and intersection impedances, queuing
Replicates corridor "through" conditions	Captures conditions at each location
Each link independent. Characteristics do not depend on conditions/flow on other links	Represents queues and spillbacks from link to link. Each link's performance can depend on the flows of other links
Coded characteristics represent "average" conditions and operations (e.g. signal timings)	Represents conditions and signal operations at each specific time

As can be seen in Figure 10-1 regional model link characteristics are usually based on average through conditions. Coded capacities and speeds are designed to reflect travel **through** the corridor. On the other hand the coded parameters in simulation models depend on the resolution of the network and which intersections are explicitly coded and which are not. Intersection capacities, signal timings, and queuing are coded at the intersection nodes. Link capacities and speeds represent the "effective" mid block conditions of the link excluding the coded intersections but accounting for the background intersections not captured in the network detail. As more or less network resolution is coded these mid-block parameters will change. The resolution of the network and what is NOT represented explicitly in the simulation therefore needs to be understood when developing the network coding and the conversion of parameters from the regional planning models.

Accounting For Additional Simulation Variables. Last is the need to code additional variables required for simulations but not used by regional planning models. These include such parameters as speed at capacity, jam density, intersection control type (uncontrolled, stop sign, isolated signal, coordinated signal), and priority / signal coordination corridors. Even though these are not needed in the regional model system, it is highly recommended that variables representing them be developed and added to the regional network databases. This allows automated conversion routines to be developed. Also, and perhaps more importantly, it allows the information to be mapped and displayed in comparison with other regional network variables. Most simulation tools now available are very weak in the geographic display of the networks and their input variables. On the other hand this one of the strengths of most regional model systems and/or GIS systems.

10.2.2 Network Capacity and Trip Deferral

Large increases in forecast travel demand are more likely to present modeling problems in the simulation analysis than in the regional flow-based analysis. Link volume-to-capacity ratios exceeding 1.0 or 2.0 are routinely dealt with in a regional model such as EMME/2 where travel time is calculated by a closed form equation in the flow-based assignment module. In a simulation model, however, when demand exceeds link capacity the result is queue formation. Queue formation and dissipation is handled routinely by the simulation engine if the over saturation conditions do not persist indefinitely. However, the regional model projects steady-state demand for a peak period. Therefore, if over-saturation is indicated for a particular link in the regional model, it is by definition an "indefinite" over-saturation situation for the simulation model. The dynamic assignment function in the simulation is helpful in dealing with such situations, rerouting vehicles for some period of time from paths containing over-saturated links to less congested facilities. Even with dynamic assignment the simulation may report uncontrolled queue growth in forecast networks with high travel demand. This uncontrolled growth can have a substantial negative impact on overall corridor modeling by distorting overall sub-area delay and substantially overstating travel times for particular origin-destination pairs.

Demand overload can either be a localized phenomenon constrained to a particular persistent bottleneck link or a function of complete screenline saturation. Localized bottlenecks are always a feature in models of congested urban roadway system, but in some cases the delays associated with these bottlenecks are unrealistically large. This occurs for a variety of reasons. In some cases it is because there is some error in coding for the particular link. In other cases near the edges of the network, long queues occur when origins producing large numbers of trips are not adequately linked into several alternative entry points into the main network. Where network access or network errors have been addressed, a flatter distribution of travel demand over the peak period is often utilized to represent an aggregated time shifting earlier and later in the peak period.

In the North Corridor, this technique was used to accurately balance demand along I-5 southbound in the AM peak period. Another potential adjustment is the deferral of some travel demand into the off-peak period where peak period travel speeds are particularly slow. In this study, we used a threshold of 10 miles per hour as a minimum acceptable speed when determining whether a portion of origin-destination travel demand flow should be deferred to the off-peak period. This is helpful in addressing unreasonable delays from individual origin-destination pairs. Finally, feedback to the regional model with respect to trip distribution also blunts the impact of origin-destination pairs with high delay. The use of these techniques is highly dependent on overall network travel demand. In the 2020 DoNothing/TSM Baseline case, nearly 5% of all travel demand is deferred into the off-peak. In comparison, the validation test suite, based on circa 1997 conditions, sees almost no deferral at all (0.2% of trips) because the overall travel demand is much lighter than in the 2020 time frame.

10.2.3 Interface and Sub-Area Windowing

The interface and sub-area windowing process used in the case study is described in Section 7.5. It concerns the process of sizing and windowing/focusing the sub-area simulation network and system, and then developing the procedures to transfer the regional forecast networks and data to the simulation process (and possibly back again). This section first describes the lessons learned and issues regarding simulation sizing and then windowing/focusing, and finally the network conversion.

<u>Simulation Area Sizing</u>. From the model parameter analysis and comparison (see Section 10.2.1) one should know the limits of the sub-area simulation model system chosen for use in a corridor study and the likely constraints that will be encountered. For the Seattle Case study the number of links and the maximum simulated vehicles turned out to be the critical factors.

Sub-area simulation models often have link and node limits much lower than those in the regional networks used for regional forecasting. Consequently, the network coding conventions and sub-area sizing need to take these limits into account. First, expansion of single intersection nodes to detailed interchanges and the addition of mid-block centroid connectors can significantly increase the number of nodes and links in a sub-area. A cloverleaf interchange expansion for example can add anywhere from 4 to 12 nodes and 12 to 20 links to the network. Every mid-block connection adds at least a node and two links. Second, the horizon year network must be used, and allowances must be made for the unique coding associated with each alternative. In alternative comparisons it is important not to reuse node and link numbers to represent different locations and facilities in separate alternatives. In sizing the sub-area, an estimate therefore needs to be made of the additional coding that may be required to examine the proposed alternatives. It is not unrealistic to expect an additional 20% requirement in sub-area nodes and links will need to be reserved for alternative coding. Last, sketch network and external zone connector requirements cannot be ignored in the overall node and link limits.

Sizing the sub-area to account for the sub-area simulation travel demand limits is more complicated than accounting for network constraints. Many simulation models place limits either on the total number of vehicles (trips) during the simulation period, or the number of vehicles on the network at any particular time. At the time of simulation network sizing, the INTEGRATION Version 1.5 simulation model was constrained to represent no more than 350,000 vehicles during the simulation period (this was later increased to 450,000 vehicles during the study). Sizing the sub-area to account for this constraint required developing routines in the regional process to track all vehicles traveling over any link in the network within a potential sub-area boundary. Important considerations and lessons learned that must be accounted for in determining the size of the sub-area are:

- Base the analysis on the maximum demand horizon year that will be investigated (2020 for the Seattle Case Study)
- Account for the maximum demand variation seen in the representative day scenarios for event or seasonal demand patterns
- Account for the diversion in routing due to the alternatives under consideration demand
- Account for the time variation in demand during the simulation period. This is more important for simulation models that are constrained by the number of vehicles on the network at any particular time
- Travel from neighboring zones that remains on centroid connectors and never appears on the simulation road network can be excluded.

In order to take these factors into account one must size the sub-area for an average horizon year demand that is substantially lower than the simulation model limit. This should be no more than 70 – 75 % of the limit and depending on the network and study possibly lower.

Windowing/Focusing. Once the sub-area has been sized the focused network and zone structure must be developed (see Section 7.5). Again, window extraction where the sub-area is simply cut out of the regional network should not be used to evaluate ITS impacts since it does not account for route diversion between entry points, or the value of information to the traveler. As shown in Figure 10-2 a focused network has three areas:

- The sub-area. This includes the zone and network detail required for simulation, and is the primary area of concern for the study. All trips to/from/through the sub-area are included in the simulation
- The Sketch Area. This provides a critical buffer area of zones and links for distribution of travel into the sub-area. Sketch network should be included where the entry into the sub-area may change due to the congestion in the sketch area caused by sub-area tirps. In the case study the Seattle CBD sketch network was included for this reason. Sketch network also needs to be included to capture the relative impedances of different routes to the sub-area and avoid bottlenecks at the sub-area boundaries. This became an issue in the northern boundary of the sub-area during the case study.
- The External Region. This area covers the remainder of the regional forecast area. Aggregate zones are defined based upon how travelers may enter the network, and on maintaining the general characteristics of the overall trip. It is presumed that the sub-area trips travelling through the external area are a minor percentage of the travel in the area and will not cause a significant shift in congestion or routes to/from the sub-area.

There are several additional factors that should be considered in developing the focused system. First, the capacity of the links in the sketch network should represent the respective share of capacity these vehicles have as compared to other trips. Vehicles traveling through the sketch network should experience the residual capacity reductions due to the impact of those vehicles that travel through the area but do not interact with the simulation network. It should not be assumed that the modeled vehicles have 100% of the capacity of these links. For example, if 25% of the vehicles represented on a sketch area link enter the simulation area they should experience an effective capacity reduction equal to the capacity used by 75% of the vehicles not modeled.

Second, the sketch network near the simulation area must allow for correct routing paths to be assigned using the simulation. One issue that was learned early on is that the relative impeadances due to link length need to be maintained throughout the sketch area. For example, access distance or time from sketch network nodes to the simulation area must remain relative in order to maintain the correct routing strategies. Thus, relative travel times between nodes in the sketch network and the simulation area should be maintained.

Third, the simulation period should also be compared with the trips in motion. When using a focused network it may require a significant amount of simulation time for vehicles to enter the simulation or analysis area. For example, the farther the demand originates from the simulation area the earlier the demand generation should peak. This allows the heavy demand to reach the network during the simulation study start time rather than having a major portion of the demand not appearing until much later in the peak period than normally would occur.

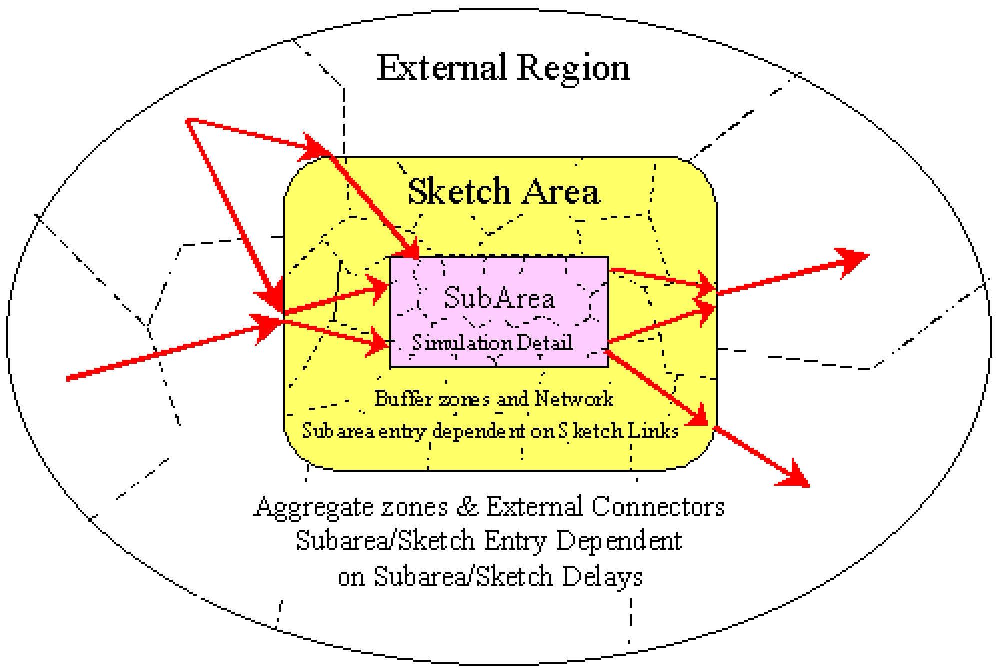

Figure 10-2. Simulation Focusing and Sketch Network Definition

Network and Demand Conversions. In developing a process to convert the networks and demand from the regional process (EMME/2) to the sub-area simulation (INTEGRATION) there where several compatibility issues that needed to be addressed. Automated procedures were developed that accounted for most of them; however, a few are best solved by editing the files directly. Issues were also learned concerning converting several different alternatives and the relationships that need to be maintained between them. The major lessons are summarized here and could be applied to other similar studies.

- External link lengths – EMME/2 is capable of modeling long links, however in simulations lengths are often restricted and the differences must be accounted for by splitting the regional network links. This can be particularly true when constructing sketch networks. Increased areal coverage and sketch network link lengths may also require increasing the simulation time to allow vehicles to reach the study area.

- EMME/2 uses an implicit representation of capacity changes for signal control at intersections. In simulations, signals are directly modeled and considerations for capacity effects need to be included. To account for this in INTEGRATION, capacity of links that exited to a signal was increased inversely proportional to the percentage of the green time the link could discharge during a cycle. As a rule-of-thumb, capacity of all links with signal control should be doubled. These same adjustments in capacity should be made for all build alternatives and then additional improvements superimposed to account for ATIS adaptive signal control or other strategies.

- When coding networks, Tables of Equivalent (TOE) nodes and links between the planning and simulation models need to be developed. These TOE's must account for multiple alternatives and simulation networks. Node and link numbers should not be recycled between alternatives. Node or link numbers should represent the same node or link in every network. Thus, if they exist in one network but not in a second, the number does not appear in the second network.

- Simulations are inherently data hungry. It was found in building simulation networks that several default parameters had to be established that were not included in EMME/2 networks. These included:
  - Platoon Dispersion Factors: These are used to estimate how platoons of vehicles progress through the network.
  - Speeds at Capacity and Jam Density: Speed at capacity, Free flow speed, and jam density are used to determine vehicle speeds on link as a function of the flow rates. In the Seattle Case Study speed at capacity was set as a percentage of free flow speed of the link which was obtained from EMME/2. Jam density was set to a default 120 vehicles per kilometer.
  - Capacity adjustment factor: The direct conversion of freeway link capacities tended to produce capacities for freeway links in simulation that were too low since percent trucks, directional factors and other average factors are often included in the regional capacity calculations. This produced artificial bottlenecks on freeway links. To correct for this the capacities of all freeway links were increased by 25%.
  - Signal timing plans: Signal plans were unavailable to implement in the simulation. However there is method that can be used to develop plans using the INTEGRATION simulation model. Once a base network and static demand had been developed, all signals can be coded with a default cycle length and phase split. Offsets can also be easily be calculated. Using the INTEGRATION adaptive control algorithms the base network can be run using the static demand and allowing timing plans to adapt. If the simulation time is sufficient enough to allow the network to stabilize a final signal timing plan can then be copied from the INTEGRATION output and used as the starting or fixed timing plan for future simulations. After completing this, only a few signal-timing plans may still need to be manually adjusted.

- Demand Conversions: In conversion of demand from the regional model to the simulation, total vehicle counts are subject to truncation of trips and bucket rounding is required to preserve correct totals. This was found to be especially true for zones with trips to many destinations. It also occurred when creating dynamic demands from static demands. In all cases this resulted in a significant reduction in trips being generated in INTEGRATION verses the demand provided by EMME/2 model. Even with bucket rounding a global demand-scaling factor was required for the demand conversion process to match overall trips. The factor was adjusted by scenario to produce vehicle generation numbers that were compatible between the models.

10.2.4 Integrated System Validation/Calibration

Some of the most important lessons learned from the Seattle Case Study regard the need for an integrated system validation/calibration. Any time a forecasting process is carried out it is important to apply the same procedures and coding principles used during its validation/calibration, or *revalidate*. This cannot be stressed enough when you are integrating a regional process with a sub-area simulation. Key points to remember when carrying out the revalidation are provided below.

Regional Model Revalidation. Regional model revalidation should be carried out any time network coding parameters have been modified or network detail added. At a minimum, the enhanced regional network forecasts should be adjusted to match the previous "validated" regional model outputs. Checks need to be made on district-to-district travel, screenlines and cordons in and out of the sub-area, critical link volumes, and travel times. This is the process described in Section 8.1 that was used for the Seattle Case Study. If possible, additional validation should also be carried out using the same data that is used for the sub-area simulation validation.

Another important aspect of the regional model re-validation is an elasticity verification on key dimensions impacted by ITS. It is often the case that variables exist in the regional model that are relatively stable when examining traditional alternatives but which shift noticeably when ITS is introduced. An example is the calculation of expected wait time for transit vehicles based upon the standard deviation in bus arrival times (see 7.7.4). Even though the standard deviation in arrival times parameter existed in Seattle's regional networks prior to the case study its value never varied. When it was adjusted to account for improved reliability of buses caused by Advanced Transit Management it created an unreasonably large shift in transit ridership (A 20 % improvement in bus on-time performance has been seen to produce about a 1% system ridership increase, however, the unadjusted model produces a 12.5 to 13.5% ridership increase). The adjustment process was consequently not used. Therefore, if specific regional network or model parameters are to be adjusted due to ITS, sensitivity analysis and reasonableness checks must be carried out to check if the resultant elasticity to these parameters is reasonable.

Sub-area Simulation Validation Dimensions. Validating an integrated process is fundamentally different from a validation typically carried out for a traffic simulation effort. In an integrated process the simulation must use the information provided to it by the regional process. This reduces the degrees of freedom and alters the types of adjustments that can be made in the simulation validation. Figure 10-3 highlights the relationship between the regional and sub-area simulation validation efforts.

The regional model must be validated for and provide:

- Overall zone to zone travel patterns (number of trips, peak/off peak)
- Mode choice and occupancies (General purpose auto person and vehicle tirps, HOV person and vehicle trips, transit trips)
- Screenline volumes of trips entering and exiting the sub-area during the simulation time period (AM Peak, PM Peak, or Midday).

The sub-area simulation must use the above information and at a minimum be validated for:

- Allocation of trips across the screenlines. Observed percentages of the screenline total across each link should be matched. Note that this is different than validating to the actual volumes on the links. If the total screenline volume does not match observed counts corrections must be made in the regional process and not in the simulation.
- The locations and duration of bottlenecks in the system.
- The time variance of volumes entering and exiting the network (trip start and end times) and on specific links.

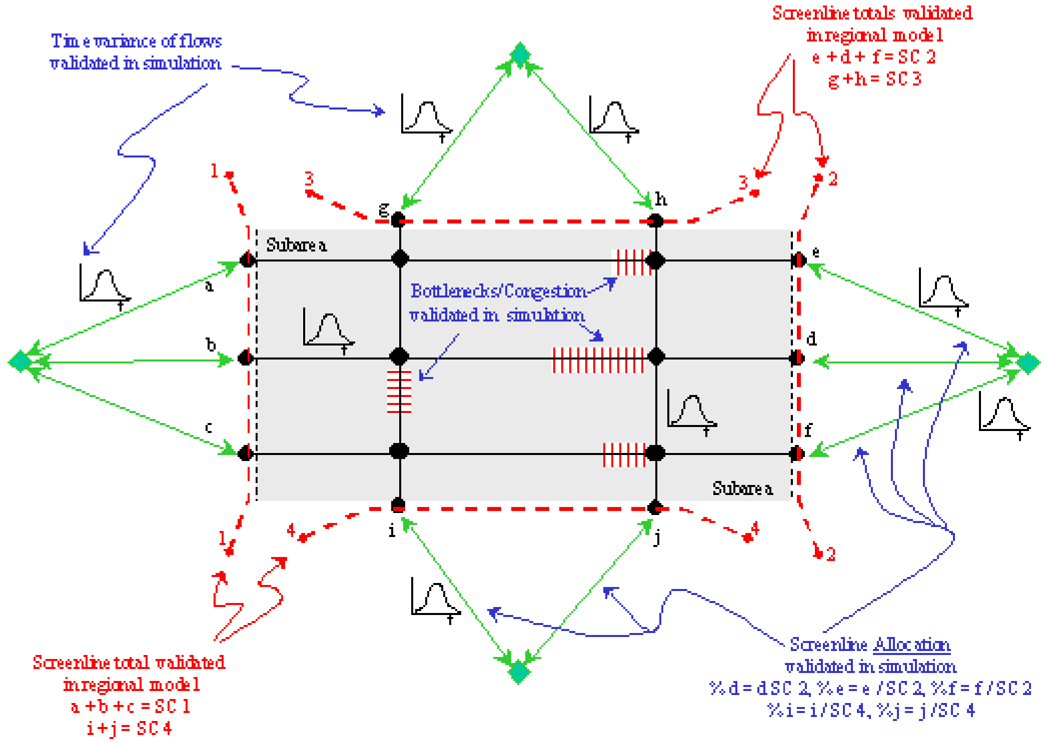

Figure 10-3. Regional and Sub-area Simulation Validation Relationships

While the allocation of trips across screenlines is part of the sub-area simulation validation (since the simulations are designed to represent traffic operations and queuing behavior while regional models typically do not.) there should be general consistency between the regional link volumes and the simulation volumes on each major facility. (At least within generally accepted tolerances for regional forecast validation by facility type. See the “Model Validation and Reasonableness Checking Manual” FHWA, 1997). An assessment of the consistency between major flows in the regional and simulation models should be made and each model re-validated until the differences are acceptable. If total screenline volumes do not match available data, re-examination of both models may also be called for.

Travel Time Variability Calibration. Over the course of the case study the importance of calibrating the sub-area simulation to both the travel times through the network under average conditions and the travel time variability throughout the year became more and more clear. The process used for the travel time variability calibration is described in Section 8.5. Highights are:

- Obtaining the data on non-average, or unusual conditions is crucial. If you are anticipating conducting a study in a corridor in the near future, **start the data collection now**. Collect data on volumes and travel times through the system. Do not ignore the days with unusual conditions including inclement weather, incidents and accidents, construction, and other disturbances. In fact, if it is possible it is recommended that more information be collected and saved for unusual events.
- Calibrate to the 90th percentile, average, and 10th percentile travel times through the system for different trip starting times. This validates the buildup of congestion within the period, and also the frequency of unusual conditions incorporated in the representative day scenario definitions.
- If the data are available it is highly desirable to check the reasonableness of the simulation assignments and travel times for sets of representative day scenarios where global parameters are adjusted. An example is wet and rainy inclement weather. Are the simulated volumes, travel times, and time variance of flows similar to observations under rainy conditions? If construction exists on a road segment for an extended period of time (several days / weeks to allow route patterns to adjust) does the simulation replicate observations when the construction restriction is coded?

These additional validation exercises will greatly increase the reliability of the simulation and the estimate of annual benefits from the representative day scenarios.

10.3 Large Scale Simulation Issues

Every traffic simulation has a unique modeling approach and each provides its own set of strengths and idiosyncrasies. In this case study, specific issues arose with the tasks of simulation modeling (particularly at the large scale represented). Resolutions of the major issues are discussed in the following section along with techniques to increase efficiency of implementing a large set of simulations. Mainly, four sets of issues are discussed: sizing of the study, process controls for simulation production, process controls for run verification, and integer assignment for dense networks. Lessons learned from this study's application of large-scale simulation are explored below.

10.3.1 Resource and Level of Effort Requirements

Resource and level of effort requirements depend on: the characteristics and size of the geographic area represented, the level of detail in network representation, the number of alternatives/variations to be modeled, and the variety of outcome measures to be gauged. In programming the project these must be factored with the capabilities of the simulation model, hardware and software constraints, data storage resources, and time limits for study completion. These four factors are nontrivial, interrelated, and should be evaluated concurrently to the extent possible in order to develop a reasonable study design. The study design must be executable with the available hardware and software and within the time and budget constraints for the effort.

Hardware Considerations. For the case study, the primary considerations were simulation limits and time resources. As discussed in the last subsection the sub-area used for simulation must be within the simulation model constraints for number of zones, nodes, links, and vehicles within the simulation period. These not only set the size of the network but also the computing requirements. For example in INTEGRATION Version 1.5, the vehicle demand constraint and number of zones proved to be the key factors in determining simulation's size and consequently the computing requirements. Once the sub-area network had been sized for software demand constraints the amount of Random Access Memory (RAM) needed to run peak period demands was determined. RAM had to be increased from 48MB on each simulation PC to greater than or equal to 96MB. At lower levels of RAM it was also observed that although RAM may be sufficient to run the software, the need to swap data from the RAM and the hard drive during simulation resulted in simulation slow down by a factor of 2.5 or greater. Also, six computers were used in this study, each with a CPU clock speed of 200 MHz or faster. Table 10-2 outlines the average network and computer parameters of the study.

Table 10-2. Study Simulation Network & Computing Parameters

Average Simulation Network Dimensions	Item Count
Node count	910
Link count	2,454
Maximum concurrent vehicle count on network	80,000
Maximum vehicle count of entire simulation	425,000
Computer Configurations	Run Time (Hours)
Configuration 1 – 200 MHz, 96 MB RAM, 6 GB HD	2.50
Configuration 2 – 400 MHz, 128 MB RAM, 8 GB HD	1.75
Configuration 3 – 450 MHz, 128 MB RAM, 10 GB HD	1.50

Processing Time Considerations. There is a direct tradeoff between hardware and processing time requirements. The six Pentium PCs along with their high levels of installed RAM enabled Mitretek to run 3.5 hours of simulation time in 1.5 to 2.5 hours of real time and to complete the hundreds of simulation runs designed for in the study. More important they allowed a full set of simulations for a representative day scenario to be carried out over a weekend. The reasonable run times also made the task of visual error checking and monitoring a simulation acceptable and management of the process easier.

The type of simulation process/software also impacts run times and resources. The same demand levels if run at a micro-simulation scale through software such as CORSIM or INTEGRATION 2.0 would increase real run time by a factor of 10 or more over the meso-scale analysis used here. Moreover, with such a scale of representation, the task of network calibration and demand validation would also increase in complexity by a factor of 10 or more. For this study, other factors contributing to the computing burden include the level of text/file output detail and graphical screen output updating.

Data Storage Considerations. Storage of input and output data is another major concern when working with the large-scale simulations. Table 10-3 gives an example of the average size of the set of input and output files for a run, scenario, and alternative. Note the maximum storage size estimates in Table 10-3 are based on a conservative estimate of the level of output and input variation that may be needed by a study.

For INTEGRATION, the most important input files to size data archiving needs include the demand, the time series link travel time, and the time varying routing path files. For this study 11 different demand outcomes, 18 different time variant link travel time outcomes, and a single time varying routing outcome were selected to represent variations in annual conditions for each alternative. The defining factors in the size of these files include the number of multipathing options chosen for vehicle routing, the number of vehicle classes/types, the number of interchanges, and the timing interval for instilling time variance. For example, by reducing the timing interval from 10 minutes to 5 minutes, the size of the time series link travel time and routing tree files would double.

Table 10-3. Example of Average Input and Output File Storage Requirements

Average Size of Data Files for the Seattle Case Study				
	Study Input Files		***Study Output Files***	
	Maximum	*Study*	*Maximum*	*Study*
One Simulation Run		85 MB	140 MB	50 MB
One Simulation Scenario[1]		85 MB	560 MB	200 MB
One Simulation Alternative[2]	2550 MB	175 MB[3]	16800 MB	6000 MB

1 Based on the use of four random trials to account for randomness in system
2 Based on the choice of representing annual variability via 30 scenarios for each alternative
3 Alternative based scenarios with 11 demand, 18 incident, and 18 varying link travel time options

For each simulation, an array of output can be specified. Identifying at the start of the study what data outputs are required for the study's specific needs will minimize archiving space. Additionally, the selection of the time variant frequency of specific output will directly impact the size of output files and consequently storage needs. For this study, input and output data from the six alternatives were stored in 10 JAZ drives each with a 1.0 GB storage capacity.

In summary, lessons learned in programming the study design are: to give adequate consideration to the computation needs, particularly the hard drive, RAM, and storage capabilities; and to identify whether current computer and staff resources are sufficient to complete the quantity of analyses desired in the time available.

10.3.2 Process Controls for Simulation Production

Over 1,080 individual simulation runs totaling 1,600 computer hours were required to complete the simulations for this study. Each simulation run needs a unique set of input files, generates corresponding output files, and requires a variety of data output post-processing steps. In managing this large set of experiments, the use of a process control such as automated batch files is critical in verifying proper execution of experiments with minimal direct staff oversight. For this study, the practice was to execute batch files on Friday afternoons that would complete simulation sets by Monday morning. The week was then used to analyze output data and prepare and check the next set of batch files for simulation the next weekend.

Batch files were used to automate the process of organizing the set of required input, starting simulations, verifying simulation completion, archiving output, and conducting data pre/post processing tasks. In practice, however, after the tasks of network calibration and validation, simulation options were run on average 2.5 times due poor process controls early in the study. Common errors included incorrect input file specification, incorrect specification of output names or storage location, and improper ordering of batch execution commands. The use of a team checking process for batch file coding errors proved much more efficient than a single staff preparing and reviewing batch files.

The most critical components in simulation execution verification are the use of automated file and run naming conventions, time stamping of output files, and error message trapping within the batch coding. Naming conventions for this study required differentiation of files by alternative, scenario, random seed, and data type. Irregularities in time intervals between output files generated concurrently or in order flagged the occurrence of incomplete processes. Error message trapping protocols stopped the execution of the batch file under certain circumstances.

Another process developed to minimize simulation execution errors is the implementation of 'ghost runs.' A ghost run is the execution of a batch file with scenarios having significantly reduced simulation times to confirm that input data files are accessible, appropriate directory structures exist, the batch file executes fully, and output files archive correctly. Once the ghost run is performed, scenario simulation times are restored to actual times and the batch file is executed.

Also, for long batch execution set, Mitretek found effective the practice of pausing the batch file after the first completed simulation run or data processes set to verify that the output file set generated did not contain any obvious errors in its production of MOEs. Then, the batch file was run in its entirety. A final, quick check for unusual and error-driven results is the comparison of file sizes.

10.3.3 Process Controls for Run Verification

In conducting large-scale simulations, numeric listings and direct evaluation of the detailed information are unrealistic. In many circumstances the data is too large to import into standard spreadsheet packages. When they can be imported, the sheer number of data items can prove incomprehensible in identifying individual trip, facility type, or geographic patterns. Thus, researchers must turn to aggregate statistics and geographic level pattern analyses to verify that each simulation is reasonable.

The output format and types of data generated by the specific simulation model used in a study can greatly facilitate or hinder data analysis. Mitretek developed error-checking data post-processors to assess whether output data is reasonable. The first check for reasonableness of output data was to compare travel time and throughput values aggregated across the simulation period and origin-destination (OD) pairs among seeds, scenarios, and alternatives. Issues such as formatted reading, cross column differentiation, and OD pair matching were critical when developing programs for data analysis.

A second run verification check is to evaluate the performance of specific facilities along a corridor, and to evaluate the performance of parallel facilities. Measures specific to INTEGRATION include link speed and flow by time interval.

Of equal or greater importance are statistics to assess reasonableness in performance measures by important origin destination pairs across and within the simulation time period prior to full-scale batch-based simulation running. Measures of aggregate statistics or link subset verification can overlook or mask significant error in demand, routing or network supply allocation. Statistical measures may vary by simulation model used. Measures specific to INTEGRATION include average and variance in trip length, trip time, and number of trips completed and unfinished. Large variance in trip lengths may result from unrealistic switching between two very different route paths. Significant variance in trip time may indicate difficulties in vehicle entry into the network. These reasonableness checks are equally important after simulation when comparing alternatives and scenarios.

Statistical analyses were performed to pinpoint outlier data and errors in network coding and routing; however, the importance of geographic pattern analysis can not be overstated. Simulation models to date have had little support in the areas of geographic traffic pattern evaluation. For example, trips from two adjacent zones to a common destination should have similar travel characteristics. A third zone along the path of the two zones to the same destination should have proportionate trip statistics. Such patterns based on geography or facility type can not be gauged effectively without geographical representation, particularly for large areas. The absence of geographical analysis support was not as critical when simulations were limited to a handful of intersections or a relatively small corridor. When dealing with large regional areas, as is with this study, tools to verify geographic traffic patterns are instrumental during the network development, calibration, and validation phases as well as during the data output evaluation phase. Measures such as travel time from an important origin to all destinations or from all origins to a single destination mapped via color coded ranges are invaluable in identifying unusual and possibly incorrect occurrences in simulation coding.

For this study, MapInfo was used in later stages to map travel time from all origin zones to the Seattle CBD zone for specific alternatives. From the graphical representation, key observations as to the effectiveness of the sketch networks bringing trips into the simulation region were made. The use of MapInfo prior to full-scale simulation would have simplified the task of identifying insufficient network entry supply or improperly coded network characteristics. Comparisons between alternatives for measures such as trip time by origin to a specific destination can also serve as a reasonableness check on the impacts of infrastructure or ITS initiatives in place.

10.3.4 Integer Assignment Issue for Dense Networks

When working with large area and time variant demand representation in simulation models, the likelihood of generating OD pairs with very low demand increases. All else remaining constant, the greater the density of OD pairs, the greater the percentage of the OD pairs with very low demand. Low demand OD pairs, occurring in a highly time variant network system can cause great variance in performance outcomes. This is because departure time of the few vehicles of an OD pair can vary from one random trial to the next, and can translate to large variances in trip performance measures. If meso-scale and more detailed simulations were able to model non-integer vehicle counts, this would be a non-issue (as in the case of regional models) as fractional vehicles would be generated. To mitigate for this variability, a greater number of random trials (random seeds) may be required for an OD network with sparse demand. Figure 10-4 presents this relationship.

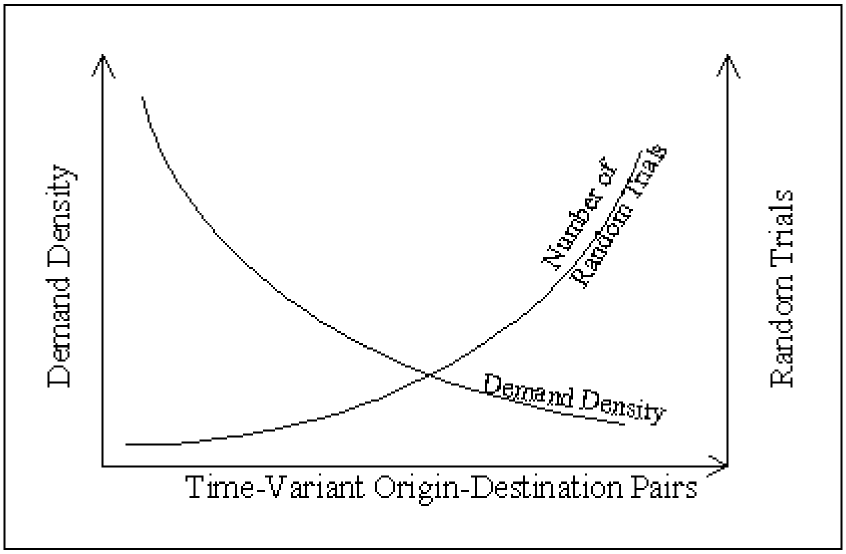

Figure 10-4. Generalized Relationship between Demand Density & OD Pairs

For the case study, the simulation period is 3.5 hours. OD pairs with a vehicle count less than 35 in the 3.5 hours of simulation (10 vehicles per hour) were found susceptible to high variability in outcomes. Statistics based on these small trip volumes are suspect and vulnerable to large variances. In conducting statistical analyses, attention should be given to whether the departure times of the small sets of vehicles for an OD pair are relatively similar. If departure times are not similar and the vehicle count is particularly small, one should consider omitting these outcomes from the time-variant statistical analyses.

For the average demand scenario in this study, about 84% of all OD pairs generate 35 or fewer vehicles. This 84% of all OD pairs, however, account for only 34% of the total traffic demand. This relationship is presented in Figure 10-5. Working with the INTEGRATION simulation model, four random seeds proved sufficient to mitigate the problem of low network demand density for most demand sets modeled.

10.4 Scenario Development

The development of the representative day scenarios is described in Section 7.6. The Seattle Case Study has established the importance of the representative day scenarios and capturing variation in conditions in analyzing the impacts of ITS strategies and their interaction with the traditional components of a corridor study (infrastructure improvements, transit service). Collecting the data for defining representative day scenarios, cleaning and analyzing it,

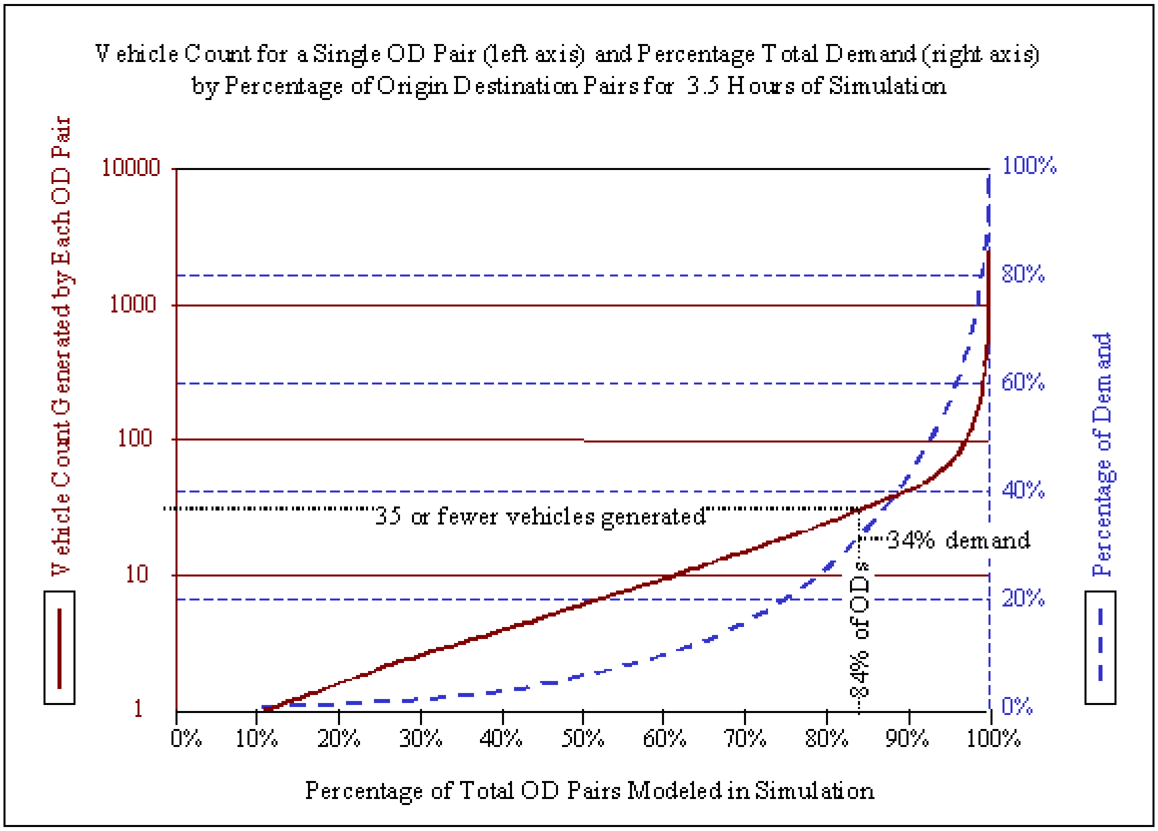

Figure 10-5. Relationship between OD Pairs, Vehicles Generated, & Total Demand

combining the components into a consistent database, and determining the scenario divisions is a extensive effort. Some of the lessons Mitretek learned during the Seattle Case study are described below.

Initial Data Cleaning. First, archival data for each scenario dimension is likely to come from different sources, be error prone, and inconsistent with other dimensions. Within each dimension it is critical that errors and noise in the data be removed as much as possible prior to the scenario development. Otherwise, correlations between variables can be hidden and/or unrealistic variation included in the analysis. Special care should be given to traffic volume data collected using automated traffic counters over an extended period of time and from multiple locations. Averaging the data per day from multiple locations and time points requires that all locations provide accurate information for all time periods, or missing/questionable data be carefully imputed. Similar issues on reliability and comparability of information can be found when multiple sources of accident/incident data are used. The more time that can be spent making sure the data is correct at the beginning of the effort the better.

An alternative to using archived information is to collect, analyze, and assemble the data from multiple sources as it occurs (weather, accidents/incidents, volumes, construction, etc.).

This ensures that each day's or peak period's information is combined, checked for consistency, and issues resolved when the information is fresh. If a study is being programmed for next year, start collecting and assembling the information today.

Period of Analysis. Second, one must understand the period on analysis and develop the representative day scenarios around this unit. The Seattle Case Study assembled the data and developed the scenarios for a typical weekday peak period in Seattle (this combined AM and PM peak periods in the scenario development). A different variation in conditions would have been observed, and different scenarios developed if the analysis had been carried out for a peak hour, the midday, or for a complete day. During the study design determine what variation needs to be captured in the analysis and organize the scenario data around this unit. In defining the period of analysis one should be aware of the following:

- Don't limit data to the time period in question, especially regarding volume and accident information. This is very important for reasonableness checking of the data, and examining the correlation between some of the dimensions such as incidents and volumes. In merging the dimension data by date and time slice it is often important to be able to examine what was happening before and after the analysis period, especially if there are spillover effects from one time slice to another. If you only collect the peak hour or period data you may be ignoring important information. Likewise, keeping data as disaggregate as possible for as long as possible in the analysis is recommended. For example, keep all traffic, accident and weather information at the 15 minute or hour level until after it has been combined rather than aggregating each to the peak three hours and then combining them into the scenario analysis database. This allows error checking to be performed if something looks suspicious.

- The greater the time period/aggregation the lower the correlation between variables. One of the surprises the data provided was the low correlation between peak period demand, weather, and accidents/incidents. Weekday peak periods were used as the aggregation level since they were the "representative day" unit of analysis. No correlation between peak period variables was greater than +- 0.15. At this aggregate definition of the representative days (study area wide and for daily peak periods) there are many intervening factors that reduce inter-relationships. Upon further investigation it was found that as the level of aggregation became finer the expected relationships between variables such as demand and accidents/incidents begin to emerge. For example, November 10, 1995 was the highest accident day in the scenario database with 59 accidents. As shown in Figure 10-6 there is a strong relationship between the accidents and an afternoon storm that developed. This is true even thought the averaged overall weather indicators for the day's peak periods did not show significantly bad weather overall. Consequently, one should not be surprised at relatively low correlations between scenario dimensions when analyzing and developing representative day scenarios for a study.

- Last, while the study design called for developing representative day scenarios based upon a generic weekday peak period when analyzed noticeable differences were found between morning and afternoon conditions. The probability of "weather" conditions was

Highest accident day on November 10, 1995 = 59 Accidents

10-Nov-95	Weather Indicators						
Time	Visibility	Visifac	Overcast	Wetness	Precip.	Wind Spd.	Accidents
Midnight	15	0	9	0	0	6	
1	15	0	9	0	0	7	AM
2	15	0	6	0	0	7	Night
3	15	0	10	0	0	6	1
4	15	0	10	0	0	7	
5	15	0	10	0	0	6	
6	15	0	8	0	0	4	
7	15	0	10	0	0	7	AM
8	20	0	10	0	0	7	Peak
9	20	0	10	0	0	6	1
10	20	0	10	0	0	5	
11	25	0	10	0	0	8	Midday
Noon	20	0	10	0	0	8	13
1	7	2	10	3	3	9	
2	7	2	10	6	3	8	
3	3	3	10	9	3	10	
4	6	3	10	10	3	9	PM
5	4	3	10	10	3	7	Peak
6	4	3	10	10	6	9	27
7	2.4	3	10	10	3	9	
8	2.8	3	10	10	3	8	PM
9	1.8	3	10	10	3	11	Night
10	2.1	3	10	10	3	10	17
11	2.1	3	10	10	3	15	

STORM!

Figure 10-6. Hourly Correlation of Weather and Accidents

25 % in the AM peak period and only 15% in the PM peak period. On the other hand the probability of a large number of accidents in the system (>= 9) was only 15.2% in the AM and 48.9% in the PM. Interestingly, the probability of an incident (serious event where a incident management team is called) was slightly higher in the AM at 6.0% versus 5.2% in the PM. Where the demand and analytic processes exist (time of day assignments by different periods of the day , AM, PM, Midday) it is a good idea to explore defining separate representative days for each time period. This however will increase significantly the number of simulations and effort required for the overall analysis.

<u>Scenario Imputation</u>. Simulation is expensive and time consuming. Therefore, there is a tradeoff between the number of representative day scenarios and the variation represented in the study and the time and cost required to analyze each alternative. For the Seattle Case Study 30 scenarios were defined to represent the variation in weekday peak period conditions and four random seeds were used to analyze each scenario. An alternative's analysis. therefore required 120 separate simulation runs.

The case study explored reducing the number of simulations carried out by using interpolation and extrapolation to generate the expected results of a representative day scenario based upon the relationships found between others. For example, we tried to derive the 0 accident case for low demand from the relationships between the 0 and 1-3 and 4-6 accident cases for medium demand. The relationships proved to be very non-linear and complex, and the imputation of results suspect. It is therefore recommended that a full set of simulations be carried out for each defined representative day scenario. This is the only way to insure that the variation represented by the scenarios is reliably captured in the analysis.

Rare Events and Variation in Their Impacts. The number of simulation runs needed to estimate the expected impacts of a representative day scenario containing truly rare events is also an issue. A scenario that contains a major incident may have a very low probability (For example EG1 in the Seattle Case study represents good weather, volume ratio = 1.089, and an incident and has a probability of 2.17%). Where the major incident occurs may change the benefits associated with ITS and require several simulations within the scenario to reliably estimate the expected benefits. The number of simulations and locations to simulate depends upon the network configuration and conditions under study. The analyst needs to examine the network configuration and data on the frequency of events by location to determine how many simulations are required to estimate the expected impacts of the alternative for the scenario. For example, two major incident locations were defined for the Seattle Case Study (one on I-5, and one on SR-99). Their locations were determined by looking at the frequency of incidents along the facilities and the likely diversions that the incidents would cause. Other networks may require more locations and possibly more simulation runs within each scenario to develop reliable results. A locational analysis of rare events such as incidents is therefore recommended as part of the scenario development. Professional judgement is also required on how the impacts may vary based on simulating different locations of an incident within a scenario. If the variation is great, then more simulations and seeds may be required.

10.5 Feedback

Feedback is the process of using the outputs of one step of the forecasting process as inputs to an earlier step in the process; e.g. feeding back the simulation model change in impedance / travel time to the regional model in order to adjust trip making and travel patterns. Some of the concerns associated with feedback have already been discussed in Section 7.5. Feedback was a issue that was raised during the Seattle Case Study and a feedback test between the DoNothing/TSM and ITS Rich Alternatives was conducted (with and without ITS). This subsection briefly describes the feedback analysis and some of the issues it raised. Feedback can occur at many different levels in the forecasting process, from assignment to mode split, from assignment and mode split into trip distribution and time of day, or even to trip generation and land use. Conceptually, feedback can also continue until a stable equilibrium between all of the components of the forecasting system is reached (The jury is still out on whether this is feasible or even if stability is ever really reached in the real world). The purpose of the feedback analysis in the Seattle Case Study was to capture the change in travel patterns caused by ITS' response to system variability and information provision accounted for in the sub-area simulation.

The approach taken for feedback in this study is predicated on the assumption that each model system is designed to measure and represent different phenomena: The regional model captures average daily and peak period recurrent conditions based upon equilibrium flows and provides overall travel patterns and mode choice to the sub-area; the simulation model captures the system variation and value of information and represents discrete travelers and conditions through time. Each model is calibrated/validated to meet its own assumptions, and has different internal interpretations of such things as impedance and delay. Consequently, one should not force consistency between absolute values of sub-area travel time and other measures provided by the two model representations. Rather the percent change in the annualized values from simulation caused by ITS should be fed back into the regional model. The feedback process used for the study is shown in Figures 10-7 and 10-8.

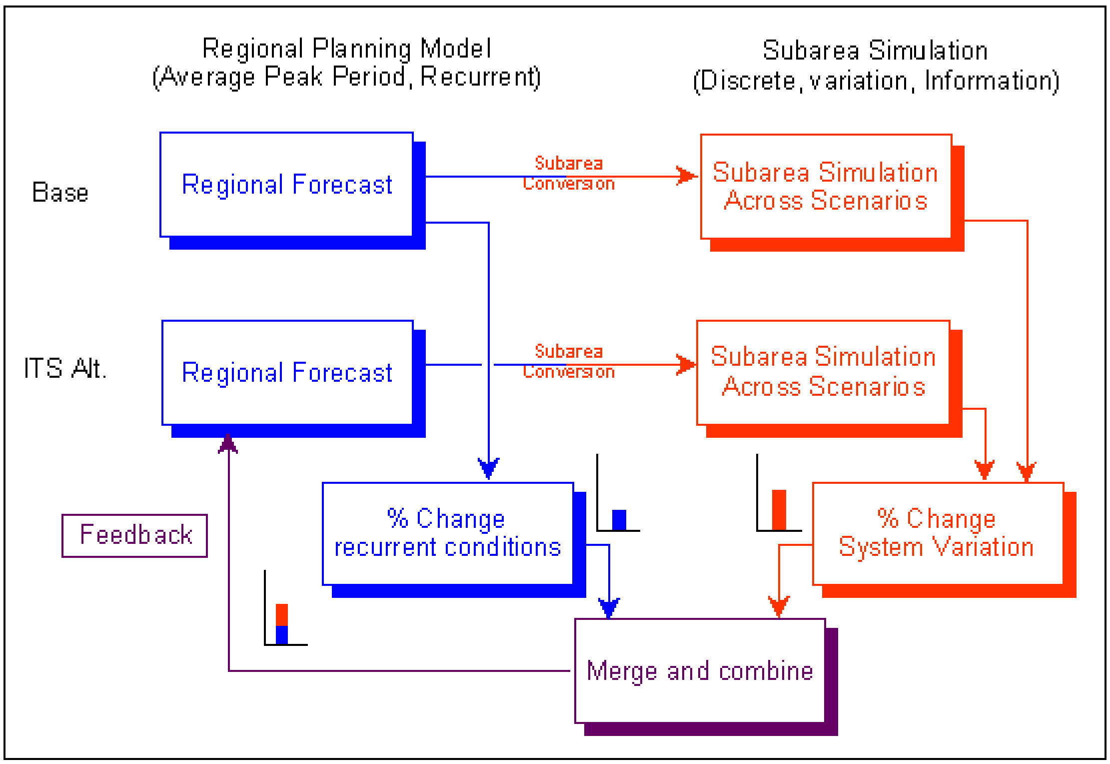

Figure 10-7. Seattle Case Study Feedback Process

As can be seen the feedback process assumes that the impacts of ITS on recurrent conditions are captured in the regional model and the impacts on non-recurrent conditions, system variation and information are captured by the simulation. In fact, as described in Section 7 recurrent condition feedback based upon network coding changes has already occurred in the regional model prior to the sub-area simulation. Between any two zones the portion of the regional model's trip's impedance due to travel within the sub-area is adjusted based upon percent change produced by the simulation model.

Table 10-4 and Figure 10-9 summarize the results of the feedback test. As shown, merging the regional and sub-area results does alter the perceived average travel time to and from the sub-area. A 2.63% improvement in ITS Rich perceived travel times occurs when the simulation's accounting for variation and information is merged with the regional model's

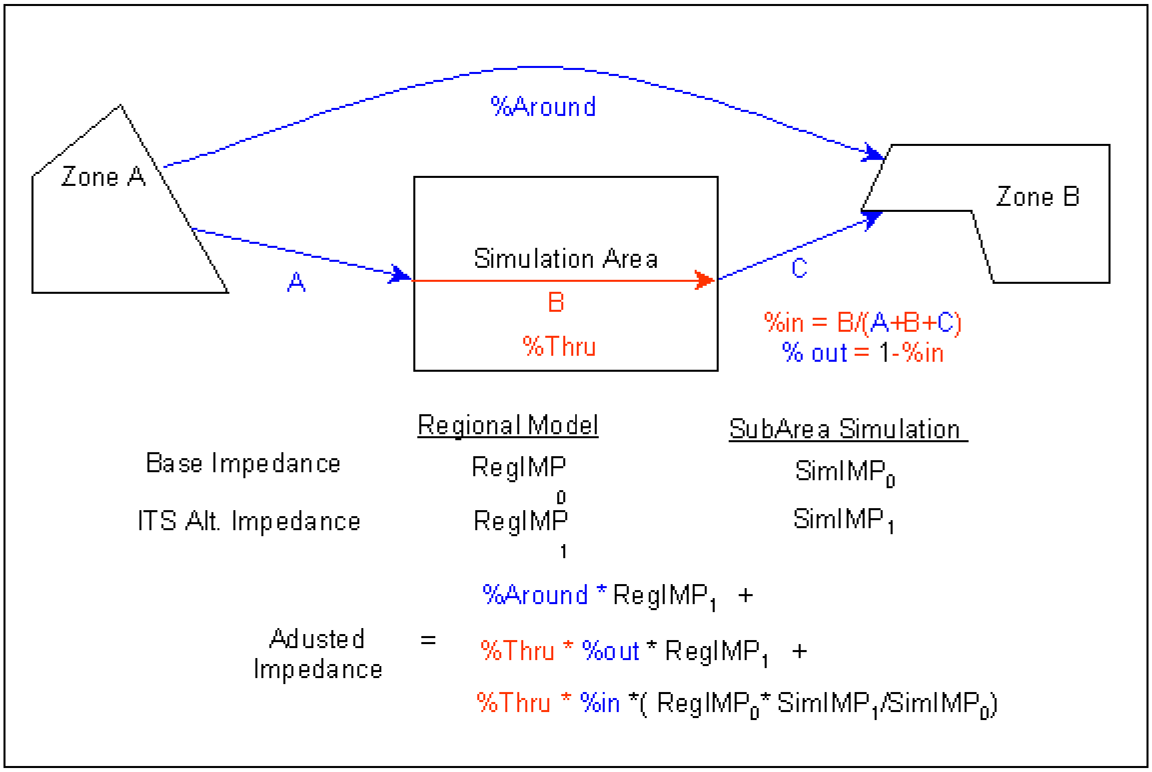

Figure 10-8. Feedback Origin - Destination Impedance Adjustment

Table 10-4. Seattle Case Study Impedance Change For Feedback

2020 AM Peak Period LOV Average Travel Time To, From, Through Simulation Area					
	(1)	(2)	(3)	% Change	
	DoNothing /TSM	ITS Rich Regional	ITS Rich Merged	(1) vs. (2)	(2) vs. (3)
From:					
1 = Simulation area	14.99	14.85	14.29	0.91%	3.75%
2 = Corridor South	16.44	16.06	13.69	2.31%	14.78%
3 = Corridor North	30.28	30.16	29.24	0.39%	3.05%
4 = Outside Corridor	115.92	114.52	112.61	1.21%	1.67%
To:					
1 = Simulation area	24.43	24.29	23.22	0.57%	4.43%
2 = Corridor South	36.00	35.04	34.40	2.66%	1.82%
3 = Corridor North	36.87	37.77	36.37	-2.44%	3.70%
4 = Outside Corridor	105.31	104.27	103.83	0.99%	0.43%
Overall	36.35	36.27	35.32	0.21%	2.63%

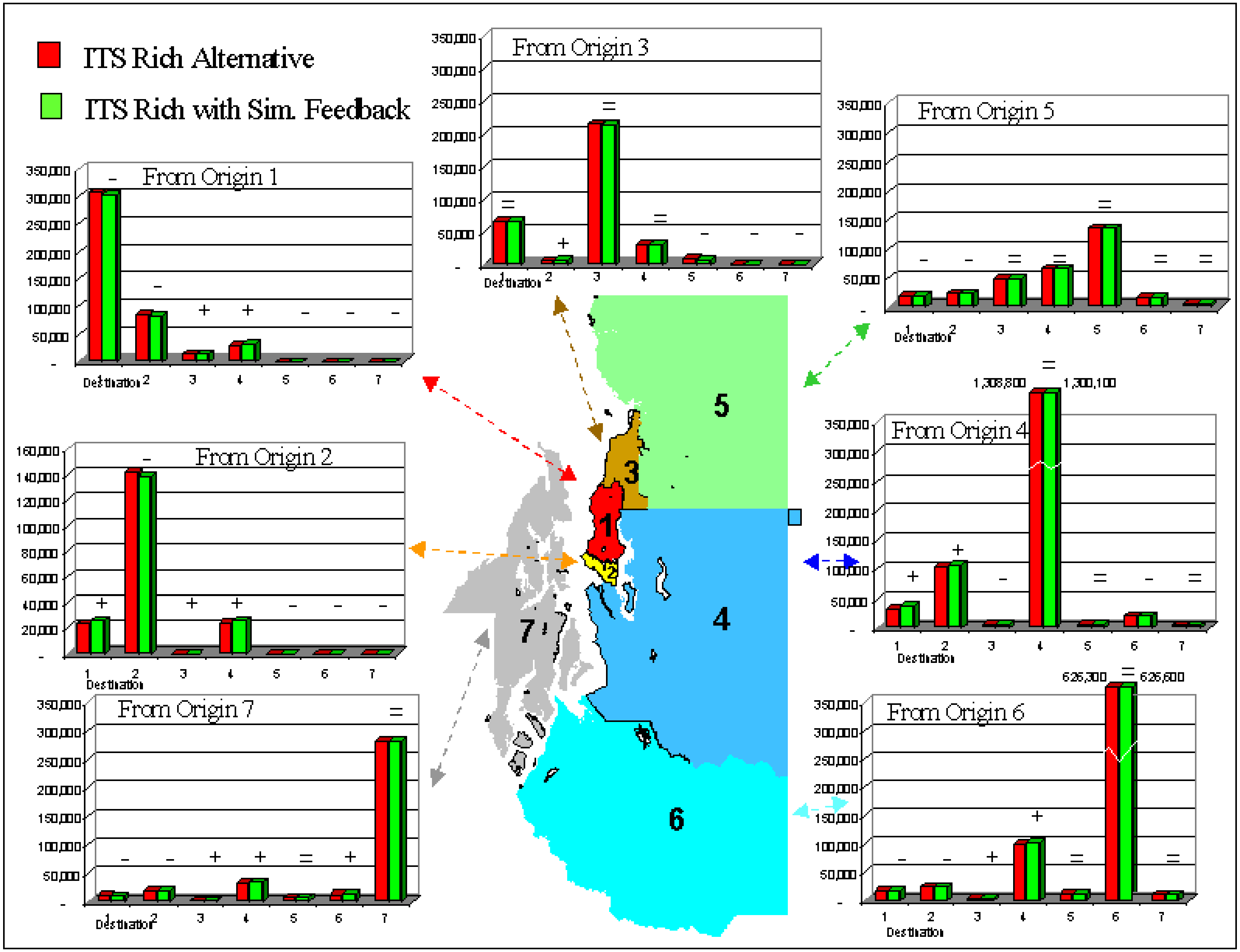

Figure 10-9. Impact of Feedback on Travel Patterns (ITS Rich With and Without Simulation Feedback)

treatment of recurrent conditions. This varies from a high of 14.78% change for trips from south of the corridor going north, to 0.43% for trips from the sub-area to outside the corridor.

Figure 10-9 shows the impact of feeding back the merged travel times to trip distribution to capture how shift in perceived travel impedances may impact travel patterns. Plus, minus, and equal signs are shown to indicate noticeable increases, decreases, and relatively equal trips to and from the seven summary areas. As shown, overall regional travel patterns remain stable before and after the simulation feedback. However, there are some expected shifts. Travel within the sub-area is slightly lower as people travel further due to perceived mobility improvements within the corridor. Likewise, trips from the south to the north increase as ITS helps remove the bottlenecks and provide more reliable travel against the peak direction (actuated demand responsive signals). Some of the issues and lessons learned associated with carrying out this feedback are discussed next.

Origin Destination Stability. When conducting feedback to the regional model, stability of the simulation results between each of the origin destination pairs becomes an important issue. As described in Subsection 10.3 for large simulations, the chance that a significant portion of the origin destination pairs will have a small number of trips between them increases. In the simulation model as the number of trips on an interchange becomes small (less than 10 an hour) the variation of starting times and conditions makes the observed times from the simulation more random. Other factors such as change in overall demand on the interchange, or access link restrictions, may also cause unjustifiable shifts in the impedance between two zones. It is therefore important to develop filtering procedures and validity checks on the percentage change in impedance with and without ITS when developing the feedback process. In the case study feedback, unreliable percentage changes between origins and destinations were first filtered based upon the number of trips and excessive shifts (greater than 20%). District-to-District percent change values derived from the valid interchanges were then assigned to the filtered origin destination pairs.

Over-saturation and Feedback. No feedback process will prove reliable when the simulation model is significantly over-saturated and the demand cannot be met within the simulated period. This is also true if there is gridlock over significant portions of the network in either the with or without ITS alternatives, or both. In the case study part of the network and demand refinement was analysis to ensure that these conditions did not exist in either alternative. If they did occur new operations and signal strategies were input, or trip deferral was implemented.

Estimation of Time Periods Outside Simulation (off-peak). An attempt was made to factor the off-peak percent change in impedance based upon the peak simulations of both the congested and uncongested (free flow) networks. While the absolute change in impedances in the congested system was larger than in the uncongested case surprisingly the ratios between with and without ITS impedances were similar (0.945 for congested, and 0.93 for uncongested). Consequently, using a factor of 1.0 was explored and rejected.

No feedback on times for offpeak conditions was carried out since when the scenario dimensions were examined it was found that offpeak accidents, weather conditions, construction, etc. have little correlation to peak conditions. The variation in the system is therefore significantly different between time periods, and the simulation results of one time periods should not be used or factored to estimate the percentage change in conditions for another. More research is needed to explore the relationships between peak and offpeak conditions and ITS benefits/impacts.

10.6 Costing

Lessons learned regarding costing of the alternatives derive mainly from the need for a cost component hierarchy/framework to provide a common basis for cost comparisons, and the impact on the cost analysis of how the alternatives are defined. These and other issues are discussed below.

Cost component hierarchy/framework and cost comparisons. One of the first issues encountered in the case study was how to develop a set of comparable ITS capital and operating/maintenance costs upon which to base the cost model development. It was found that many different cost accounting structures are used by the different agencies to allocate costs for the purchase of ITS equipment, refurbishment of equipment, operating the ITS service, replacement and maintenance. The costs may be part of the capital budget, operations, or maintenance depending on the agency's structure and historic breakdown of responsibilities. Also, whether existing communication lines and equipment are shared, the impact of leasing, and legacy systems greatly influenced how costs are reported within the agency. It was found that simply asking for the "cost of the ITS service and its operations" did not provide comparable information. This issue was not overcome until a cost component hierarchy and framework for the study was developed, allowing specific costs of the components to be collected and analyzed. It was found that having a costing framework and structure was crucial to consistently developing the overall costing methodology. Moreover, A nationally recognized costing structure and framework such as that found in the ITS National Architecture would be extremely useful in the sharing and comparison of cost data from around the country.

Cost model structure and ITS. Once the cost data were collected and adjusted to a common structure, costs models for the various components (both traditional and ITS) in each alternative were developed. Sketch techniques of estimating operating and maintenance costs as a percentage of capital costs are often developed based upon historical data for use in setting department budgets. These techniques were explored and found to be undesirable since they do not account for the changes in cost structure and the additional inter-relationships that ITS introduces. Consequently, estimating O&M costs based simply upon percent of capital costs was discouraged and only used when no other option was available. A much better option is to develop O&M cost models around the variables that are behind the O&M costs and that ITS may cause to change. For example, rather than estimating transit O&M costs based upon a percentage of the vehicle capital costs, a model was developed using revenue vehicle hours. Other studies have developed models based upon peak pullouts, revenue vehicle hours and revenue vehicle miles. Likewise, it is better to use an O&M model based upon lane-miles and vehicle-miles traveled for road systems rather than using percent capital costs. If only percent capital costs are used incorrect comparisons in the alternatives may result since an increase in capital costs would always lead to an increase in operating costs. Any O&M cost savings derived from ITS services are not accounted for in approaches using percent capital costs to estimate O&M.

<u>DoNothing vs. Build Alternative definitions and costs</u>. How the alternatives are defined can also have a profound impact on the cost estimation. In alternative analyses and major investment studies incremental costs are developed from the DoNothing, (baseline) alternative. This properly focuses on the differences between alternatives allowing a preferred option to be identified. Traditional alternatives and their components are usually very location specific, with a low percentage of regional system-wide shared elements. ITS services on the other hand are based upon information and other “systems” and usually have a high percentage of shared costs in control centers, communications, software, and other “center system” elements.

The DoNothing alternative is defined by the adopted long range regional plan and the **already approved** regional support systems. It is very important, therefore, to develop a corridor study with ITS components in close coordination with the regional plan and an overall ITS integration strategy (These have been called at various times ITS Regional Architectures, ITS Regional Frameworks, ITS Strategic Plans, or Integration Strategies). The regional ITS components such as the Transportation Control Centers can therefore properly be allocated to the regional system costs as part of the DoNothing alternative.

<u>Cost Allocation between the sub-area and region</u>. As more that center system decisions become part of the regional plan and therefore the DoNothing alternative the allocation of costs between the region and sub-area becomes less of a problem. However, in the case study the allocation of costs between the region and the sub-area still had to be addressed for some components. Several of the ITS elements are broader in scope than the I-5 North Corridor limits. Examples include traffic management, transit management, and incident management. For these elements, only the proportionate share of system costs attributable to the corridor operations was allocated to the cost estimate. Two methods for allocating these costs were used. Where the corridor alternative required expansion of an existing facility, the marginal capital and O&M costs for add-ons such as a computer or part-time employee were estimated. For elements where no regional system existed, the total system capital and O&M cost was estimated and a proportionate marginal cost was allocated to the corridor. The proportionate share in this case was generally determined by comparing the corridor area to the regional area.

It should also be noted that incremental capital and O&M cost estimates for ITS elements will vary by location. Each urban area will be different and the analyst must assess what infrastructure is in place in the region to support ITS implementation in the study area or corridor. For example, the central Puget Sound region already has a lot of supporting ITS infrastructure in place so these estimates reflect costs added at the margins to a great degree. Other areas may have little if anything in place and it will be more of a challenge deciding what is a regional investment versus a corridor investment and consequently would require more coordination between the regional ITS strategy and corridor decision.

<u>Economic life and technological obsolescence</u>. Economic life assumptions for capital cost items reflect consideration of the functional obsolescence, the technological obsolescence, and the physical integrity of the facility. Therefore, the assumed economic lives for all cost items were generally shorter than the physical life for the item. This is because the facility may have outlived its usefulness, require major upgrades, or become technologically obsolete to the point that the item becomes inefficient and/or incompatible.

10.7 Data Issues

The Seattle area is a data-rich environment for ITS analysis. Historical freeway flow and speed data is archived annually and distributed on CD, the PSRC panel survey includes questions on traveler usage of ATIS, and the Seattle area has been the subject of several survey research efforts on traveler behavior. These data sources (and others) were critical resources in this project and one of the reasons Seattle (and the North Corridor in particular) was chosen for this effort.

However, in the course of the study we have identified three areas where additional detailed data would have proven particularly valuable. These three areas are: more detailed travel behavior data, additional data in support of scenario generation, and archived flow and travel time data for arterial facilities.

Travel Behavior Data. One of the key themes in this study is identifying the utility of information provision when conditions differ from normal or expected conditions. In order to model traveler reaction to ATIS, we have made a range of assumptions about how travelers assign themselves to regular or habitual routes and the range of conditions under which they will divert from these habitual routes.

One data source we could not identify in the Seattle area was a study of how travelers integrate a range of travel experiences over time when settling into habitual routes. It had been our hope to be able to include both a measure of trip reliability in addition to average travel time when modeling this "settling-in" process. The concept of travelers choosing a slightly slower, but more reliable route is appealing not only in route selection but also in mode choice modeling. However, in the absence of reliable data on how travel time reliability is weighted with travel time performance in traveler decision making, we used a more conservative approach based only on travel time performance by origin-destination pair and time-of-departure during the AM peak period.

Likewise, a more refined modeling of traveler response to ATIS could be undertaken now given survey research data currently being collected as a part of the Seattle Metropolitan Model Deployment Initiative (MMDI) evaluation program. An example of where MMDI-related survey data will be useful resources is in the detailing of traveler responses based on the weather and congestion conditions reported on a particular day. For example, it is already clear that web-based ATIS usage may spike by factor of four when it is snowing in Seattle. Further, the ratio of web hits, page views and user sessions under these conditions indicate that how the traveler is accessing (and presumably using) this information is quite different from non-snow conditions. Travelers may be more likely to consider trip cancellation or mode shift responses than route choice under weather events, and if such relationships can be established this detail could be included in this kind of ATIS modeling. How these various travel choices are best nested under real-time decision making is also poorly understood. We have modeled route choice as the uniformly dominant traveler response, and it is likely that this assumption does not hold under all conditions.

Scenario Data. Under the highly congested conditions projected for the 2020 time frame in the North Corridor, relatively small swings in overall travel demand have significant impact on average system travel time. For example, in the 2020 baseline alternative, a seven percent increase in travel demand from the projected average raises average travel time by more than four minutes per vehicle from roughly 26 minutes per trip to 30 minutes per trip. A drop of four percent in travel demand results in average trip duration of just under 25 minutes of travel per vehicle in the AM peak. Given that these impacts are so significant, particular attention should be taken when estimating the range of travel demand variation in long-range forecast years. In this study, we used a composite of freeway loop detector station counts to identify sub-area demand variation. As with any field data source, these station data included loop malfunctions, miscounts and missing data. WSDOT had flagged many of these data points questionable, but not all. Weeding out outlier volume conditions and accounting for missing data points were important tasks in creating a reasonable estimate of travel demand variation.

Calibration Data. Archived freeway travel times taken over an 18-month period were the critical data in the calibration of overall travel variability in the North Corridor. Although I-5 is the largest and most important facility in the corridor, a similar kind of travel time variability analysis would have been helpful on a number of other key facilities, including SR99, SR522, and others. Although travel time estimation along arterial facilities is more difficult using loop detector data than on freeways, archiving this data would be helpful in balancing the arterial/freeway travel demand.

One observation about calibration from this effort is that the analyst seeking absolute conformity to calibration data is likely to be frustrated. Limitations of what a particular simulation model supports, error in calibration data, inconsistencies between flow and speed targets will always result in some error in calibration. The key to a successful calibration effort is identifying what level of calibration is required for the analysis, and the point at which additional model tweaking is fruitless. Calibration in this modeling effort created a network wherein average peak period flows at 14 stations (arterial and freeway) were reasonable (plus/minus 15 percent) and in which freeway travel times were accurately distributed (average plus variance) over the representative scenario set.

10.8 Resource Use and Analysis Effort

The question of "What would it take to apply the PRUEVIIN methodology to an alternatives analysis in another location" has arisen on a number of occasions. It is difficult to answer this question in the abstract but a few basic rules can be defined. To answer the question let's assume that we want to know the cost to add a sub-area simulation onto an existing or planned MIS. So we are only addressing the incremental costs of the sub-area simulation. The following discussion will address this question. A brief review of experiences from several other studies is followed by a discussion of how the resource and cost budgets were determined.

Comparative Experience. Mitretek has conducted several studies over the last several years that provide insights into the level of effort required for incorporating ITS into corridor analyses. These are:

- **The Seattle 2020 Case Study.** The case study discussed in this report was conducted over a period of several years, from July 1996 to July 1999. During this period we defined the scope of the study, selected the analysis tools, developed the PRUEVIIN methodology, applied this methodology in the Seattle area, and coordinated with both our Federal sponsor and the Seattle Advisory Panel. As indicated in the report the objective of the study was to develop an analysis framework that can be used for the assessment of ITS options as part of a Major Investment Study (MIS) for an horizon year of 2020. Various alternatives were defined to alleviate congestion in a major transportation corridor. These alternatives included traditional transportation construction projects, with and without ITS enhancements (see Section 6).

The PRUEVIIN methodology developed for the case study includes the merging of a traditional transportation-planning model (EMME/2) with a large-scale transportation network meso-simulation model (INTEGRATION 1.5). In all, a baseline and five alternatives were defined. The size of the network was 125 square miles, containing 2,200 links, and 165 signalized intersections. Over 350,000 trips were simulated during the 3.5 hour AM peak period. Eight measures of effectiveness were calculated for each alternative. As part of the process techniques were also developed to define and capture the inter-day and annual variability of traffic conditions (scenarios), and to assess the set of ITS services under these conditions. Two years of traffic, accident/incident, and weather data were analyzed to determine the representative day scenarios. A total of thirty representative-day scenarios were defined. For 30 scenarios, with 4 random seeds each, for six alternatives, and accounting for numerous re-runs, the Seattle 2020 case study resulted in over 1,080 simulation model runs.

- **Seattle Metropolitan Model Deployment Initiative (MMDI).** In parallel to the Seattle 2020 case study we also conducted the MMDI alternatives and sensitivity analysis in support of the overall MMDI evaluation program. Only one alternative was evaluated, but several sensitivity analyses were conducted using only the simulation model. The set of simulation experiments explored a range of values for key factors that were 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. These factors included level of market penetration for ATIS pre-trip planning services and the degree of coordination for traffic control. In total the MMDI analysis represented a 50% increase in the total number of scenario runs (1,800 total runs).

- **Detroit Corridor Study.** The Detroit corridor study was also underway during this period. The goals of the Detroit corridor study were to measure the impacts of implementing the existing ITS facilities, determine whether motorists' exhibit a bias toward freeways over arterials, and identify operational strategies that improve corridor throughput. The benefits from the existing ITS system are estimated through simulation. This was not feasible through a field test because corridor performance data prior to ITS implementation was not available. Simulation also provided an opportunity to 'game out' and fine-tune ITS strategies to increase corridor performance.

To evaluate ITS impacts, a micro-simulation model (INTEGRATION 2.0) of approximately 1700 nodes, 2900 links, 230 signals, 10 ramp meters, 5 changeable message signs, and mainline freeway detectors was generated to represent a 8-km by 5-km corridor approximately 2.5 km north-west of the Detroit Central Business District. The micro-simulation model of the John C. Lodge Corridor conveys over 45,000 trips per hour for a 2.0 hour PM peak period. A set of operations alternatives (signal coordination, ramp metering, etc.) and traffic scenarios (accidents, demand variation, construction, etc.) are simulated to reflect both the varying traffic conditions and differences in the effectiveness of alternatives. About 7 measures of effectiveness were calculated for each alternative, including link-based statistics on stops per vehicle-kilometer, average speed, and variance in speed; and trip-based statistics on trip time by driver type, throughput, and delay reduction. This study provided additional insight into the development and coding of transportation networks, and the development of a demand file without benefit of the planning model output.

Level of Effort Synthesis. Based on the experience derived from these three studies we have identified the skill set and labor hours required to apply a simulation model to these types of alternatives analyses. These results can be used to develop an initial cost estimate for other similar analyses. In the following estimates it is assumed that all of the normal MIS processes are being conducted as usual. The cost estimates identified here are only those to add the use of simulation modeling to the ongoing MIS process. All of the above studies were conducted with commercial off the shelf software and high-end PC's.

To develop a resource budget we conducted a review of all of the staff hours applied to these projects. We then subtracted out the time applied to the development and validation of the overall methodology (PRUEVIIN). For the remaining time we identified several skill categories and functional activities. As a result of this effort we determined that the required personnel skills to build and execute the models include:

- A Senior Principal Modeler (10+ years experience)
- A Senior Staff (3-10 years experience)
- Two junior support analyst (0-5 years experience).

The time budget for the sub-area simulation modeling process is approximately:

- 10% for scenario development
- 15% to build the transportation network in the model
- 15% to code the alternatives (baseline + 5 alternatives)
- 30% to calibrate the model to existing traffic data
- 15% to execute the model
- 15% to analyze and present the model results

As can be seen the most labor intensive part of the process is the calibration of the model. This includes the identification of the required calibration data, specification of a calibration plan, and conducting numerous model runs to achieve calibration goals. This type of analysis could be conducted with significant portions of the above staffing over a period of 9-12 months, and concurrent with other ongoing MIS activities.

In terms of a dollar budget we estimate that if a typical MIS costs on the order of a million dollars, the cost to add a sub-area simulation of the types indicated above would be on the order of $250,000 to $340,000 or an additional 25% to 34% increase in cost. It should be noted that the cost drivers in these types of analyses are the size of the sub-area network, the availability of data to conduct the model validation, and the number and complexity of the alternatives to be evaluated.

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Appendix A

Seattle Project Advisory Team

Seattle Project Advisory Team

Name	Agency
Mike Morrow	FHWA
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Ralph Cipriani	PSRC
Nick Roach	PSRC
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Ed Conyers	WSDOT/NW
Dave McCormick	WSDOT/NW Region
Miguel Gavino	WSDOT/OUM
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Nancy Neuerburg	King Co. Metro
Mark Hallenbeck	TRAC
Mike Normand	Community Transit
Ellen Bevington	King Co. Metro

Appendix B

Detailed Alternative Cost Worksheets

Annualized Incremental Capital, Operations & Maintenance Cost Estimates
North Seattle Case Study

	Investment Category	*ITS Rich*		*SOV Capacity Increase*		*SOV Capacity Inc. + ITS*		*HOV Busway*		*HOV Busway + ITS*	
		Capital	*O&M*	*Capital*	*O&M*	*Capital*	*O&M*	*Capital*	*O&M*	*Capital*	*O&M*
FACILIT	SOV FACILITIES	–	–	$21,096K	$964K	$21,096K	$964K	–	–	–	–
	HOV/TRANSIT FAC./SERVICES	($601K)	($2,600K)	($36K)	$61K	($765K)	($4,598K)	$71,305K	$39,092K	$70,769K	$34,255K
	RIGHT-OF-WAY	–	–	$6,349K	–	$6,349K	–	$6,729K	–	$6,729K	–
ITS / TRAFFIC SYSTEMS	SURVEILLANCE	$1,224K	$440K	–	–	$1,347K	$470K	–	–	$1,224K	$440K
	TRAVELER INFORMATION	$296K	$407K	–	–	$421K	$560K	–	–	$296K	$407K
	COMMUNICATION	$1,592K	$71K	$47K	–	$2,036K	$105K	$47K	–	$1,592K	$71K
	TRAFFIC CONTROL	$821K	$170K	–	–	$863K	$183K	–	–	$821K	$170K
	TRAFFIC MANAGEMENT	$217K	$817K	–	–	$272K	$1,021K	–	–	$217K	$817K
	TRANSIT MANAGEMENT	$135K	$123K	–	–	$135K	$123K	–	–	$135K	$123K
	TRANSIT VEHICLE INTERFACES	$1,095K	$1,245K	–	–	$1,092K	$1,242K	–	–	$1,240K	$1,419K
	INCIDENT MANAGEMENT	$87K	$32K	–	–	$87K	$32K	–	–	$87K	$32K
	Total Annual Incremental Costs*	$4,866K	$704K	$27,456K	$1,025K	$32,933K	$101K	$78,081K	$39,092K	$83,110K	$37,733K

** Relative to Baseline*

Incremental Capital Cost Estimates by Alternative
North Seattle Case Study

	Investment Category	*ITS Rich* *Total Capital Cost*	*SOV Capacity Increase* *Total Capital Cost*	*SOV Capacity Inc. + ITS* *Total Capital Cost*	*HOV Busway* *Total Capital Cost*	*HOV Busway + ITS* *Total Capital Cost*
FACILIT	SOV FACILITIES	–	$246,108K	$246,108K	–	–
FACILIT	HOV/TRANSIT FAC./SERVICES	($4,765K)	($290K)	($6,080K)	$772,036K	$767,776K
FACILIT	RIGHT-OF-WAY	–	$90,600K	$90,600K	$96,010K	$96,010K
ITS / TRAFFIC SYSTEMS	SURVEILLANCE	$8,599K	–	$9,466K	–	$8,599K
ITS / TRAFFIC SYSTEMS	TRAVELER INFORMATION	$2,075K	–	$2,950K	–	$2,075K
ITS / TRAFFIC SYSTEMS	COMMUNICATION	$11,180K	$330K	$14,296K	$330K	$11,180K
ITS / TRAFFIC SYSTEMS	TRAFFIC CONTROL	$5,770K	–	$6,058K	–	$5,770K
ITS / TRAFFIC SYSTEMS	TRAFFIC MANAGEMENT	$938K	–	$1,173K	–	$938K
ITS / TRAFFIC SYSTEMS	TRANSIT MANAGEMENT	$950K	–	$950K	–	$950K
ITS / TRAFFIC SYSTEMS	TRANSIT VEHICLE INTERFACES	$7,688K	–	$7,669K	–	$8,711K
ITS / TRAFFIC SYSTEMS	INCIDENT MANAGEMENT	$616K	–	$616K	–	$616K
	Total Capital Costs*	$33,051K	$336,748K	$373,804K	$868,376K	$902,625K

* *Relative to Baseline*

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: ITS Rich

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
HIGHWAY/TRANSIT FACILITIES															
SOV FACILITIES															
Expressway Conversion	per mile	6,142			20		per mile	11.2					Conversion of unlimited access arterial to partial access control; add 2 lanes	Two new lanes/6 lanes total; includes outside shoulders, sidewalks and pedestrian overcrossing structures; cost excludes interchanges & grade separations; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Limited Access Widening	per mile	1,831			20		per mile	11.2					Widening of full access controlled freeway; add 2 lanes	Construct divided highway; substantial earthwork and drainage system construction required; R/W related costs included in R/W cost items	Capital-Build up based upon cost components; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Interchange (full)	per each	10,631			30						0.5%		Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Interchange (half)	per each	7,442			30						0.5%		Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Grade Separated Crossing	per each	4,896			30						0.5%		Grade separated crossing of two roads without ramp connections; for Expressway	Crossing road crosses over expressway; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Subtotal															
HOV/TRANSIT FACILITIES															
New HOV Lanes on Freeway	per mile	8,780			20			11.2					Add barrier separated HOV lanes to existing freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Upgrade HOV Lanes on Freeway	per mile	7,616			20								Upgrade existing HOV lanes to barrier separated lanes on a freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items; Incremental O&M costs assumed negligible	Capital-Build up based upon cost components of typical project;
New HOV Lanes on Deck-Truss Bridge	per foot	16.1			30						0.25%		Add HOV lanes to deck-truss bridge/no barrier or buffer separation	Add truss arch section to support widening; sidewalks replaced; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
New HOV Lanes on Expressway	per mile	7,626			20			11.2					Add HOV lanes to expressway/no barrier or buffer separation	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; roadway and pedestrian crossing structures modified; excludes costs for bridge over ship canal; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
New HOV Contra-Flow Reversable Lane on Freeway Express Lanes	per mile	14,600			20		per mile	90					Add HOV moveable barrier-separated lane	Based upon cost estimate for I-5 Express Lanes/Ravenna-to-Howell HOV project; includes moveable barrier, and barrier-transfer machines and storage shed; additional O&M cost is included for reversible lane operation	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/San Diego Coronado Bridge
Arterial Transit Lanes/Two Directions	per mile	7,323			20			11.2					Add HOV/transit lanes to an existing arterial	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Arterial Transit Lanes/Reversable	per mile	6,240			20		per mile	17					One center reversable lane	Includes reconstruction of c&g and sidewalk; includes overhead lane control signal bridges; assumes removal of on-street parking; additional O&M cost is included for reversible lane operation; R/W related costs included in R/W cost items	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/TTI
HOV Direct Access/Local Half Reversable Drop	per each	6,400			30		per each	46					Direct access ramps between express lanes and local street	Based upon cost estimate for I-5/NE 50th Street direct access project; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT/TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: ITS Rich

ITEM	CAPITAL COST: UNIT	CAPITAL COST: UNIT COST ($K)	CAPITAL COST: QUANTITY	CAPITAL COST: TOTAL COST ($K)	CAPITAL COST: ECONOMIC LIFE (YEARS)	CAPITAL COST: ANNUALIZED COST ($K) (Interest Rate = 7.0%)	O & M COST, COMPUTED USING UNIT COSTS & QUANTITIES: UNIT	O & M COST, COMPUTED USING UNIT COSTS & QUANTITIES: UNIT COST ($K)	O & M COST, COMPUTED USING UNIT COSTS & QUANTITIES: QUANTITY	O & M COST, COMPUTED USING UNIT COSTS & QUANTITIES: ANNUAL COST ($K)	O & M COST, COMPUTED AS % OF CAPITAL COST: % OF CAPITAL COST	O & M COST, COMPUTED AS % OF CAPITAL COST: ANNUAL COST ($K)	DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
HOV Direct Access/Local Half Drop	per each	9,360			30						0.5%		Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/NE 145th Street direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Full Texas T	per each	31,140			30						0.5%		Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/Lynnwood Park-and-Ride direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Half Drop to Outside	per each	2,500			30		per at-grade ramp miles	11.2	0.5	6			Direct access ramps between outside general pupose freeway lanes and local street	Based upon cost estimate for SR525/164th Street SW direct access project; no widening or modifications to 164th Street crossing structure required	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Local Full In-Line	per each	2,970			30		per at-grade ramp miles	11.2	0.5	6			Direct access ramps between median HOV lanes and in-line station w/ pedestrian link	Based upon cost estimate for I-5/Mountlake Terrace direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Fwy-to-Fwy	per each	71,000			30						0.5%		Direct access ramps between freeways to/from one direction and another (e.g. between east and north)	Based upon cost estimate for I-5/I-405/SR525 NE Quadrant direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Fwy-to-Fwy Reversible	per each	11,870			30		per each	46					Direct access reversible ramp between median HOV lanes and express lanes	Based upon cost estimate for SR520/I-5 Express Lanes direct access project; includes access control gates; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT/Houston Division of TxDOT/TTI
Park and Ride Lot	per parking stall	6.1			20		per 100 stalls	2	25	50			Parking facility including bus transit shelter and pedestrian enhancements	Capital cost includes bus zone amenities, access improvements, stormwater detention, and landscaping.	Capital-Averaged from WSDOT examples;O&M-Based on Houston Division of TxDOT figures
Transit Bus - 40 foot Deisel	per vehicle	230	(8)	(1,840)	12	(232)	per thousand revenue vehicle hours	89	(25.4)	(2,261)			Standard intracity transit bus	For use on local service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Deisel Articulated	per vehicle	375	(3)	(1,125)	12	(142)	per thousand revenue vehicle hours	89	(3.0)	(267)			Standard intracity transit bus	For use on express service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Dual Power Articulated	per vehicle	900	(2)	(1,800)	12	(227)	per thousand revenue vehicle hours	89	(1.5)	(134)			Special bus for use in downtown transit tunnel	For use on express service routes which operate through the Seattle downtown transit tunnel.	Capital-King County/Metro;O&M-based upon annual vehicle hours times cost per vehicle hour
Subtotal				(4,765)		(601)				(2,600)					
RIGHT-OF-WAY															
R/W Adjacent to Arterial	per acre	900			100								Right-of-Way acquisition costs along expressways and arterials in north Seattle	Based upon typical costs for land along SR 99	Capital-Input from WSDOT; O&M-NA
R/W Adjacent to Freeway	per acre	500			100								Right-of-Way acquisition costs along freeways in north Seattle	Based upon typical costs for land along I-5	Capital-Input from WSDOT; O&M-NA
R/W Takes/Damages	per parcel	50.0			100								Typical extra cost to cover relocations and/or damages	Assumes posible costs to cure impacts from loss of access, or costs to relocate and re-establish business at a different location, or relocate resident.	Capital-Input from WSDOT; O&M-NA
Subtotal															
ITS/TRAFFIC SYSTEMS															
SURVEILLANCE															
Detection Loops	per mile	23.4	16	374	10	53	per mile	1.20	16	19			In-pavement loops and cables to nearest controller.	Four-lane per direction, install loop every half mile.	Capital-Build up based upon cost components of typical projects; O&M-TTI
Closed Circuit TV Camera	per each	25.0	26	650	10	93	per each	1.30	26	34			Monitor traffic operations along State's Routes	Install one every 1.2 mile per direction	Capital-WSDOT; O&M-TTI
Automatic Vehicle Identification/Roadside Equipment	per signal	25.0	235	5,875	10	836	per signal	1.50	235	353			Roadside equipment to identify bus, check schedule and provide transit priority at traffic signal	Includes reader, antenna, controller interface module, and local system communications. Transit vehicle equipment is listed separately.	Capital-King County/Metro; O&M-TTI
Automatic Vehicle Location/Field Equipment	per site	300	3	900	10	128					2%	18	Field differential GPS stationary site to provide fixed location information to compensate for topography and buildings	Assume 3 sites are needed. Transit vehicle and transit management equipment is listed separately.	Capital-Denver Regional Transit District; O&M-estimated
Data Station	per each	25.0	32	800	10	114					2%	16	To support detection	Install one station every half mile;O&M costs combined w/detection loops	Capital-WSDOT; O&M-TTI
Subtotal				8,599		1,224				406		34			
TRAVELER INFORMATION															
Variable Message Signs	per each	125	15	1,875	10	267	per each	4.00	15	60			VMS on overhead structures	Full matrix sign; includes controller and sign bridge structure	Capital-WSDOT; O&M-TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: ITS Rich

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
Fixed HAR & Controllers	per each	20.0	1	20	10	3	per each	1.00	1	1			Highway Advisory Radio site located at strategic locations run by WSDOT as a part of traffic management system	Add 1 new site at I-5/SR 99/SR 526	Capital-WSDOT; O&M-TTI
Kiosk	per each	18.0	10	180	10	26	per each	5.00	10	50			Located at transit centers	Install one kiosk per station	Capital-King County/Metro; O&M-TTI
Subtotal				2,075		296				111		296			
COMMUNICATION															
Fiber-Optic Cable	per mile	290	16	4,640	10	661	per mile	0.80	16	13			For extended freeway surveillance systems	Install along the I-5, SR526, SR526 and tie to existing WSDOT owned optic lines	Capital-WSDOT; O&M-TTI
Fiber-Optic Hubs	per each	110	3	330	10	47	per each	8.00	3	24			To interchange fiber-optic lines	Install one HUB per 3-5 miles	Capital-WSDOT; O&M-TTI
Twisted Pair	per mile	27.0	230	6,210	10	884	per mile	0.15	230	35			For extented adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal				11,180		1,592				71					
TRAFFIC CONTROL															
Coordinated/Adaptive Signal System - Local Controller	per controller	17.5	320	5,600	10	797	per controller	0.50	320	160			Replace existing controllers and cabinets at major intersections within study area	Basic O&M cost would remain the same as existing, except for cost related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Coordinated/Adaptive Signal System - Master Controller	per controller	10.0	14	140	10	20	per controller	0.50	14	7			To tie local controllers to the system	One master for every 20-25 local controller; O&M cost only related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Ramp Metering	per each	30.0	1	30	10	4	per each	3.00	1	3			Freeway entrance ramp metering station	O&M cost included equipment /hardware & timing plans	Capital-WSDOT; O&M-TTI
Subtotal				5,770		821				170					
TRAFFIC MANAGEMENT															
Computers & Hardware	per each	185	4	740	5	180	per each	170.00	4	680			For adaptive signal system and additional freeway system management where applicable	Assume one workstation, intergration and upgrades to existing signal control room; and one new employee each for Seattle, Lynnwood, WSDOT, and Everett	Capital and O&M-National Architecture Studies
Software (various)	per each	22.5	4	90	5	22	per each	34.00	4	136			For adaptive signal system	Included software installation, programing, and system analyst	Capital and O&M-National Architecture Studies
Communications Extension	per mile	27.0	4	108	10	15	per mile	0.15	4	1			For linkage to adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal				938		217				817					
TRANSIT MANAGEMENT															
Computers & Hardware for AVL System	per each	300	1	300	10	43					15%	45	Computer system to receive and process AVL polling data from buses and provide location, schedule adherance, and incidence information to dispatchers	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Software	per each	150.0	1	150	10	21					2%	3	Software for AVL Controller and Dispatch Stations	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Facilities and Communications	per each	500	1	500	10	71					15%	75	Radio communcations to receive AVL data, and dispatch stations including CRTs and microcomputers	Assume I-5 North Corridor allocation of 30 percent of the total cost. No additional dispatch staff needed.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Subtotal				950		135						123			
TRANSIT VEHICLE INTERFACES															
In-vehicle Transponder for AVI	per bus	0.6	408	245	10	35					2%	5	Transponder device located on buses used to identify bus at roadside readers at for signal priority treatment	All buses plus spares which are on routes which pass through transit priority intersections.	Capital-King County/Metro; O&M-National Architecture Studies
In-vehicle AVL Equipment	per bus	9.0	827	7,443	10	1,060	per bus	1.5	827	1,241			AVL on-board equipment for establishing vehicle location, assessing schedule status, and interfacing with driver	Consists of radio, vehicle logic unit, driver interface, radio antenna, and GPS antenna. All buses providing service in and through the I-5 North Corridor.	Capital-Denver Regional Transit District: O&M-TTI
Subtotal				7,688		1,095				1,241		5			
INCIDENT MANAGEMENT															
Central Tracking/Dispatch	per each	600	1	600	10	85					5%	30	Central tracking system/software and Mayday software/GIS integration; dispatch system.	System sized for I-5 North Corridor.	Capital-WSDOT:O&M-National Architecture Studies
In-vehicle Dynamic Route Guidance	per each	4.0	4	16	10	2					10%	2	For tracking system and route guidance to provide faster response to incidents	In-vehicle radio, GPS antenna, GPS route guidance system.	Capital-Rockwell Path Master system plus add-on items; O&M-National Architecture Studies
Subtotal				616		87						32			
GRAND TOTAL				33,051		4,866				215		489			

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: ITS Rich

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
Pre-Trip Planning Services	NA						per subscription	0.12	90,000	10,800			Interactive fixed-end trip planning service; 10% of travelers; no capital cost beyond baseline	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 2.33 trips/hh=1.86 mil persons; 75% eligible=900 k;10% penetration rate=90 k subscribers	Capital-NA; O&M-Mitretek assumption
Personal Dynamic Route Guidance	per device	0.8	113,000	90,400	7	16,774	per subscription	0.12	113,000	13,560			In-vehicle equipment costs include GPS, map database, communications transceiver, processor, GUI, and display	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 1.41 autos per hh=1.13 mil veh; 10% penetration rate=113 k veh	Capital-National Architecture Studies; O&M-Mitretek assumption

REFERENCES:

TransCore-Interim Handbook on ITS Within the Transportation Planning Process, TransCore (formerly JHK & Associates), December 1996, Appendix E.
WSDOT-TSMC SC & DI Operations/Implementation Plan, WSDOT, October 1994.
TTI-Guidelines for Funding Operations and Maintenance of ITS/ATMS, Texas Transportation Institute, November 1996.
National Architecture Studies-ITS Architecture Cost Analysis, Federal Highway Administration/Joint Architecture Team, June 1996.
King County/Metro-King County transit operator, Dan Overguard/David Cantay/Mike Voris, May 1997
Denver RTD-Denver Regional Transit District, Lou Ha, June 1997

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: SOV Capacity Expansion

ITEM	CAPITAL COST: UNIT	CAPITAL COST: UNIT COST ($K)	CAPITAL COST: QUANTITY	CAPITAL COST: TOTAL COST ($K)	CAPITAL COST: ECONOMIC LIFE (YEARS)	CAPITAL COST: ANNUALIZED COST ($K) (Interest Rate = 7.0%)	O & M COST, COMPUTED USING UNIT COSTS & QUANTITIES: UNIT	O & M COST, COMPUTED USING UNIT COSTS & QUANTITIES: UNIT COST ($K)	O & M COST, COMPUTED USING UNIT COSTS & QUANTITIES: QUANTITY	O & M COST, COMPUTED USING UNIT COSTS & QUANTITIES: ANNUAL COST ($K)	O & M COST, COMPUTED AS % OF CAPITAL COST: % OF CAPITAL COST	O & M COST, COMPUTED AS % OF CAPITAL COST: ANNUAL COST ($K)	DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
HIGHWAY/TRANSIT FACILITIES															
SOV FACILITIES															
Expressway Conversion	per mile	6,142	14	85,988	20	8,117	per mile	11.2	14	157			Conversion of unlimited access arterial to partial access control; add 2 lanes	Two new lanes/6 lanes total; includes outside shoulders, sidewalks and pedestrian overcrossing structures; cost excludes interchanges & grade separations; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Limited Access Widening	per mile	1,831	3	5,493	20	519	per mile	11.2	3	34			Widening of full access controlled freeway; add 2 lanes	Construct divided highway; substantial earthwork and drainage system construction required; R/W related costs included in R/W cost items	Capital-Build up based upon cost components; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Interchange (full)	per each	10,631	9	95,679	30	7,710	per each		9		0.5%	478	Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Interchange (half)	per each	7,442	2	14,884	30	1,199	per each		2		0.5%	74	Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Grade Separated Crossing	per each	4,896	9	44,064	30	3,551	per each		9		0.5%	220	Grade separated crossing of two roads without ramp connections; for Expressway	Crossing road crosses over expressway; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Subtotal				246,108		21,096				191		773			
HOV/TRANSIT FACILITIES															
New HOV Lanes on Freeway	per mile	8,780			20			11.2					Add barrier separated HOV lanes to existing freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Upgrade HOV Lanes on Freeway	per mile	7,616			20								Upgrade existing HOV lanes to barrier separated lanes on a freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items; Incremental O&M costs assumed negligible	Capital-Build up based upon cost components of typical project;
New HOV Lanes on Deck-Truss Bridge	per foot	16.1			30						0.25%		Add HOV lanes to deck-truss bridge/no barrier or buffer separation	Add truss arch section to support widening; sidewalks replaced; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
New HOV Lanes on Expressway	per mile	7,626			20			11.2					Add HOV lanes to expressway/no barrier or buffer separation	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; roadway and pedestrian crossing structures modified; excludes costs for bridge over ship canal; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
New HOV Contra-Flow Reversable Lane on Freeway Express Lanes	per mile	14,600			20		per mile	90					Add HOV moveable barrier-separated lane	Based upon cost estimate for I-5 Express Lanes/Ravenna-to-Howell HOV project; includes moveable barrier, and barrier-transfer machines and storage shed; additional O&M cost is included for reversible lane operation	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/San Diego Coronado Bridge
Arterial Transit Lanes/Two Directions	per mile	7,323			20			11.2					Add HOV/transit lanes to an existing arterial	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Arterial Transit Lanes/Reversable	per mile	6,240			20		per mile	17					One center reversable lane	Includes reconstruction of c&g and sidewalk; includes overhead lane control signal bridges; assumes removal of on-street parking; additional O&M cost is included for reversible lane operation; R/W related costs included in R/W cost items	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/TTI
HOV Direct Access/Local Half Reversable Drop	per each	6,400			30		per each	46					Direct access ramps between express lanes and local street	Based upon cost estimate for I-5/NE 50th Street direct access project; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-Houston Division of TxDOT/TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: SOV Capacity Expansion

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
HOV Direct Access/Local Half Drop	per each	9,360			30						0.5%		Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/NE 145th Street direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Full Texas T	per each	31,140			30						0.5%		Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/Lynnwood Park-and-Ride direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Half Drop to Outside	per each	2,500			30		per at-grade ramp miles	11.2	0.5	6			Direct access ramps between outside general pupose freeway lanes and local street	Based upon cost estimate for SR525/164th Street SW direct access project; no widening or modifications to 164th Street crossing structure required	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Local Full In-Line	per each	2,970			30		per at-grade ramp miles	11.2	0.5	6			Direct access ramps between median HOV lanes and in-line station w/ pedestrian link	Based upon cost estimate for I-5/Mountlake Terrace direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Fwy-to-Fwy	per each	71,000			30						0.5%		Direct access ramps between freeways to/from one direction and another (e.g. between east and north)	Based upon cost estimate for I-5/I-405/SR525 NE Quadrant direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Fwy-to-Fwy Reversible	per each	11,870			30		per each	46					Direct access reversible ramp between median HOV lanes and express lanes	Based upon cost estimate for SR520/I-5 Express Lanes direct access project; includes access control gates; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT/Houston Division of TxDOT/TTI
Park and Ride Lot	per parking stall	6.1			20		per 100 stalls	2	25	50			Parking facility including bus transit shelter and pedestrian enhancements	Capital cost includes bus zone amenities, access improvements, stormwater detention, and landscaping.	Capital-Averaged from WSDOT examples;O&M-Based on Houston Division of TxDOT figures
Transit Bus - 40 foot Deisel	per vehicle	230	2	460	12	58	per thousand revenue vehicle hours	89	3.0	267			Standard intracity transit bus	For use on local service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Deisel Articulated	per vehicle	375	(2)	(750)	12	(94)	per thousand revenue vehicle hours	89	(3.0)	(267)			Standard intracity transit bus	For use on express service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Dual Power Articulated	per vehicle	900			12		per thousand revenue vehicle hours	89					Special bus for use in downtown transit tunnel	For use on express service routes which operate through the Seattle downtown transit tunnel.	Capital-King County/Metro;O&M-based upon annual vehicle hours times cost per vehicle hour
Subtotal				(290)		(36)				61					
RIGHT-OF-WAY															
R/W Adjacent to Arterial	per acre	900	94.0	84,600	100	5,929							Right-of-Way acquisition costs along expressways and arterials in north Seattle	Based upon typical costs for land along SR 99	Capital-Input from WSDOT; O&M-NA
R/W Adjacent to Freeway	per acre	500			100								Right-of-Way acquisition costs along freeways in north Seattle	Based upon typical costs for land along I-5	Capital-Input from WSDOT; O&M-NA
R/W Takes/Damages	per parcel	50.0	120	6,000	100	420							Typical extra cost to cover relocations and/or damages	Assumes posible costs to cure impacts from loss of access, or costs to relocate and re-establish business at a different location, or relocate resident.	Capital-Input from WSDOT; O&M-NA
Subtotal				90,600		6,349									
ITS/TRAFFIC SYSTEMS															
SURVEILLANCE															
Detection Loops	per mile	23.4			10		per mile	1.20					In-pavement loops and cables to nearest controller.	Four-lane per direction, install loop every half mile.	Capital-Build up based upon cost components of typical projects; O&M-TTI
Closed Circuit TV Camera	per each	25.0			10		per each	1.30					Monitor traffic operations along State's Routes	Install one every 1.2 mile per direction	Capital-WSDOT; O&M-TTI
Automatic Vehicle Identification/Roadside Equipment	per signal	25.0			10		per signal	1.50					Roadside equipment to identify bus, check schedule and provide transit priority at traffic signal	Includes reader, antenna, controller interface module, and local system communications. Transit vehicle equipment is listed separately.	Capital-King County/Metro; O&M-TTI
Automatic Vehicle Location/Field Equipment	per site	300			10						2%		Field differential GPS stationary site to provide fixed location information to compensate for topography and buildings	Assume 3 sites are needed. Transit vehicle and transit management equipment is listed separately.	Capital-Denver Regional Transit District; O&M-estimated
Data Station	per each	25.0			10								To support detection	Install one station every half mile;O&M costs combined w/detection loops	Capital-WSDOT; O&M-TTI
Subtotal															
TRAVELER INFORMATION															
Variable Message Signs	per each	125			10		per each	4.00					VMS on overhead structures	Full matrix sign; includes controller and sign bridge structure	Capital-WSDOT; O&M-TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: SOV Capacity Expansion

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
Fixed HAR & Controllers	per each	20.0			10		per each	1.00					Highway Advisory Radio site located at strategic locations run by WSDOT as a part of traffic management system	Add 1 new site at I-5/SR 99/SR 526	Capital-WSDOT; O&M-TTI
Kiosk	per each	18.0			10		per each	5.00					Located at transit centers	Install one kiosk per station	Capital-King County/Metro; O&M-TTI
Subtotal															
COMMUNICATION															
Fiber-Optic Cable	per mile	290			10		per mile	0.80					For extended freeway surveillance systems	Install along the I-5, SR526, SR526 and tie to existing WSDOT owned optic lines	Capital-WSDOT; O&M-TTI
Fiber-Optic Hubs	per each	110		330	10	47	per each	8.00					To interchange fiber-optic lines	Install one HUB per 3-5 miles	Capital-WSDOT; O&M-TTI
Twisted Pair	per mile	27.0			10		per mile	0.15					For extented adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal				330		47									
TRAFFIC CONTROL															
Coordinated/Adaptive Signal System - Local Controller	per controller	17.5			10		per controller	0.50					Replace existing controllers and cabinets at major intersections within study area	Basic O&M cost would remain the same as existing, except for cost related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Coordinated/Adaptive Signal System - Master Controller	per controller	10.0			10		per controller	0.50					To tie local controllers to the system	One master for every 20-25 local controller; O&M cost only related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Ramp Metering	per each	30.0			10		per each	3.00					Freeway entrance ramp metering station	O&M cost included equipment /hardware & timing plans	Capital-WSDOT; O&M-TTI
Subtotal															
TRAFFIC MANAGEMENT															
Computers & Hardware	per each	185			5		per each	170.00					For adaptive signal system and additional freeway system management where applicable	Assume one workstation, intergration and upgrades to existing signal control room; and one new employee each for Seattle, Lynnwood, WSDOT, and Everett	Capital and O&M-National Architecture Studies
Software (various)	per each	22.5			5		per each	34.00					For adaptive signal system	Included software installation, programing, and system analyst	Capital and O&M-National Architecture Studies
Communications Extension	per mile	27.0			10		per mile	0.15					For linkage to adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal															
TRANSIT MANAGEMENT															
Computers & Hardware for AVL System	per each	300			10						15%		Computer system to receive and process AVL polling data from buses and provide location, schedule adherance, and incidence information to dispatchers	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Software	per each	150.0			10						2%		Software for AVL Controller and Dispatch Stations	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Facilities and Communications	per each	500			10						15%		Radio communcations to receive AVL data, and dispatch stations including CRTs and microcomputers	Assume I-5 North Corridor allocation of 30 percent of the total cost. No additional dispatch staff needed.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Subtotal															
TRANSIT VEHICLE INTERFACES															
In-vehicle Transponder for AVI	per bus	0.6			10						2%		Transponder device located on buses used to identify bus at roadside readers at for signal priority treatment	All buses plus spares which are on routes which pass through transit priority intersections.	Capital-King County/Metro; O&M-National Architecture Studies
In-vehicle AVL Equipment	per bus	9.0			10		per bus	1.5					AVL on-board equipment for establishing vehicle location, assessing schedule status, and interfacing with driver	Consists of radio, vehicle logic unit, driver interface, radio antenna, and GPS antenna. All buses providing service in and through the I-5 North Corridor.	Capital-Denver Regional Transit District: O&M-TTI
Subtotal															
INCIDENT MANAGEMENT															
Central Tracking/Dispatch	per each	600			10						5%		Central tracking system/software and Mayday software/GIS integration; dispatch system.	System sized for I-5 North Corridor.	Capital-WSDOT:O&M-National Architecture Studies
In-vehicle Dynamic Route Guidance	per each	4.0			10						10%		For tracking system and route guidance to provide faster response to incidents	In-vehicle radio, GPS antenna, GPS route guidance system.	Capital-Rockwell Path Master system plus add-on items; O&M-National Architecture Studies
Subtotal															
GRAND TOTAL				336,748		27,456				252		773			

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: SOV Capacity Expansion

ITEM	CAPITAL COST						O & M COST						DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
							COMPUTED USING UNIT COSTS & QUANTITIES				COMPUTED AS % OF CAPITAL COST				
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
Pre-Trip Planning Services	NA						per subscription	0.12					Interactive fixed-end trip planning service; 10% of travelers; no capital cost beyond baseline	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 2.33 trips/hh=1.86 mil persons; 75% eligible=900 k;10% penetration rate=90 k subscribers	Capital-NA; O&M-Mitretek assumption
Personal Dynamic Route Guidance	per device	0.8			7		per subscription	0.12					In-vehicle equipment costs include GPS, map database, communications transceiver, processor, GUI, and display	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 1.41 autos per hh=1.13 mil veh; 10% penetration rate=113 k veh	Capital-National Architecture Studies; O&M-Mitretek assumption

REFERENCES:

TransCore-Interim Handbook on ITS Within the Transportation Planning Process, TransCore (formerly JHK & Associates), December 1996, Appendix E.
WSDOT-TSMC SC & DI Operations/Implementation Plan, WSDOT, October 1994.
TTI-Guidelines for Funding Operations and Maintenance of ITS/ATMS, Texas Transportation Institute, November 1996.
National Architecture Studies-ITS Architecture Cost Analysis, Federal Highway Administration/Joint Architecture Team, June 1996.
King County/Metro-King County transit operator, Dan Overguard/David Cantay/Mike Voris, May 1997
Denver RTD-Denver Regional Transit District, Lou Ha, June 1997

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: SOV Capacity Plus ITS

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
HIGHWAY/TRANSIT FACILITIES															
SOV FACILITIES															
Expressway Conversion	per mile	6,142	14	85,988	20	8,117	per mile	11.2	14	157			Conversion of unlimited access arterial to partial access control; add 2 lanes	Two new lanes/6 lanes total; includes outside shoulders, sidewalks and pedestrian overcrossing structures; cost excludes interchanges & grade separations; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Limited Access Widening	per mile	1,831	3	5,493	20	519	per mile	11.2	3	34			Widening of full access controlled freeway; add 2 lanes	Construct divided highway; substantial earthwork and drainage system construction required; R/W related costs included in R/W cost items	Capital-Build up based upon cost components; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Interchange (full)	per each	10,631	9	95,679	30	7,710	per each		9		0.5%	478	Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Interchange (half)	per each	7,442	2	14,884	30	1,199	per each		2		0.5%	74	Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Grade Separated Crossing	per each	4,896	9	44,064	30	3,551	per each		9		0.5%	220	Grade separated crossing of two roads without ramp connections; for Expressway	Crossing road crosses over expressway; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Subtotal				246,108		21,096				191		773			
HOV/TRANSIT FACILITIES															
New HOV Lanes on Freeway	per mile	8,780			20			11.2					Add barrier separated HOV lanes to existing freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Upgrade HOV Lanes on Freeway	per mile	7,616			20								Upgrade existing HOV lanes to barrier separated lanes on a freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items; Incremental O&M costs assumed negligible	Capital-Build up based upon cost components of typical project;
New HOV Lanes on Deck-Truss Bridge	per foot	16.1			30						0.25%		Add HOV lanes to deck-truss bridge/no barrier or buffer separation	Add truss arch section to support widening; sidewalks replaced; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
New HOV Lanes on Expressway	per mile	7,626			20			11.2					Add HOV lanes to expressway/no barrier or buffer separation	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; roadway and pedestrian crossing structures modified; excludes costs for bridge over ship canal; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
New HOV Contra-Flow Reversable Lane on Freeway Express Lanes	per mile	14,600			20		per mile	90					Add HOV moveable barrier-separated lane	Based upon cost estimate for I-5 Express Lanes/Ravenna-to-Howell HOV project; includes moveable barrier, and barrier-transfer machines and storage shed; additional O&M cost is included for reversible lane operation	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/San Diego Coronado Bridge
Arterial Transit Lanes/Two Directions	per mile	7,323			20			11.2					Add HOV/transit lanes to an existing arterial	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Arterial Transit Lanes/Reversible	per mile	6,240			20		per mile	17					One center reversible lane	Includes reconstruction of c&g and sidewalk; includes overhead lane control signal bridges; assumes removal of on-street parking; additional O&M cost is included for reversible lane operation; R/W related costs included in R/W cost items	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/TTI
HOV Direct Access/Local Half Reversible Drop	per each	6,400			30		per each	46					Direct access ramps between express lanes and local street	Based upon cost estimate for I-5/NE 50th Street direct access project; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-Houston Division of TxDOT/TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: SOV Capacity Plus ITS

ITEM	CAPITAL COST: UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	O & M COST – COMPUTED USING UNIT COSTS & QUANTITIES: UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	O & M COST – COMPUTED AS % OF CAPITAL COST: % OF CAPITAL COST	ANNUAL COST ($K)	DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
HOV Direct Access/Local Half Drop	per each	9,360			30						0.5%		Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/NE 145th Street direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Full Texas T	per each	31,140			30						0.5%		Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/Lynnwood Park-and-Ride direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Half Drop to Outside	per each	2,500			30		per at-grade ramp miles	11.2	0.5	6			Direct access ramps between outside general purpose freeway lanes and local street	Based upon cost estimate for SR525/164th Street SW direct access project; no widening or modifications to 164th Street crossing structure required	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Local Full In-Line	per each	2,970			30		per at-grade ramp miles	11.2	0.5	6			Direct access ramps between median HOV lanes and in-line station w/ pedestrian link	Based upon cost estimate for I-5/Mountlake Terrace direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Fwy-to-Fwy	per each	71,000			30						0.5%		Direct access ramps between freeways to/from one direction and another (e.g. between east and north)	Based upon cost estimate for I-5/I-405/SR525 NE Quadrant direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Fwy-to-Fwy Reversible	per each	11,870			30		per each	46					Direct access reversible ramp between median HOV lanes and express lanes	Based upon cost estimate for SR520/I-5 Express Lanes direct access project; includes access control gates; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT/Houston Division of TxDOT/TTI
Park and Ride Lot	per parking stall	6.1			20		per 100 stalls	2	25	50			Parking facility including bus transit shelter and pedestrian enhancements	Capital cost includes bus zone amenities, access improvements, stormwater detention, and landscaping.	Capital-Averaged from WSDOT examples;O&M-Based on Houston Division of TxDOT figures
Transit Bus - 40 foot Diesel	per vehicle	230	(16)	(3,680)	12	(463)	per thousand revenue vehicle hours	89	(44.9)	(3,992)			Standard intracity transit bus	For use on local service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Diesel Articulated	per vehicle	375	(4)	(1,500)	12	(189)	per thousand revenue vehicle hours	89	(6.0)	(534)			Standard intracity transit bus	For use on express service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Dual Power Articulated	per vehicle	900	(1)	(900)	12	(113)	per thousand revenue vehicle hours	89	(1.5)	(134)			Special bus for use in downtown transit tunnel	For use on express service routes which operate through the Seattle downtown transit tunnel.	Capital-King County/Metro;O&M-based upon annual vehicle hours times cost per vehicle hour
Subtotal				(6,080)		(765)				(4,598)					
RIGHT-OF-WAY															
R/W Adjacent to Arterial	per acre	900	94	84,600	100	5,929							Right-of-Way acquisition costs along expressways and arterials in north Seattle	Based upon typical costs for land along SR 99	Capital-Input from WSDOT; O&M-NA
R/W Adjacent to Freeway	per acre	500			100								Right-of-Way acquisition costs along freeways in north Seattle	Based upon typical costs for land along I-5	Capital-Input from WSDOT; O&M-NA
R/W Takes/Damages	per parcel	50.0	120	6,000	100	420							Typical extra cost to cover relocations and/or damages	Assumes possible costs to cure impacts from loss of access, or costs to relocate and re-establish business at a different location, or relocate resident.	Capital-Input from WSDOT; O&M-NA
Subtotal				90,600		6,349									
ITS/TRAFFIC SYSTEMS															
SURVEILLANCE															
Detection Loops	per mile	23.4	37	866	10	123	per mile	1.20	37	44			In-pavement loops and cables to nearest controller.	Four-lane per direction, install loop every half mile.	Capital-Build up based upon cost components of typical projects; O&M-TTI
Closed Circuit TV Camera	per each	25.0	61	1,525	10	217	per each	1.30	61	79			Monitor traffic operations along State's Routes	Install one every 1.2 mile per direction	Capital-WSDOT; O&M-TTI
Automatic Vehicle Identification/Roadside Equipment	per signal	25.0	205	5,125	10	730	per signal	1.50	205	308			Roadside equipment to identify bus, check schedule and provide transit priority at traffic signal	Includes reader, antenna, controller interface module, and local system communications. Transit vehicle equipment is listed separately.	Capital-King County/Metro; O&M-TTI
Automatic Vehicle Location/Field Equipment	per site	300	3	900	10	128					2%	18	Field differential GPS stationary site to provide fixed location information to compensate for topography and buildings	Assume 3 sites are needed. Transit vehicle and transit management equipment is listed separately.	Capital-Denver Regional Transit District; O&M-estimated
Data Station	per each	25.0	42	1,050	10	149					2%	21	To support detection	Install one station every half mile;O&M costs combined w/detection loops	Capital-WSDOT; O&M-TTI
Subtotal				9,466		1,347				431		39			
TRAVELER INFORMATION															
Variable Message Signs	per each	125	22	2,750	10	392	per each	4.00	22	88			VMS on overhead structures	Full matrix sign; includes controller and sign bridge structure	Capital-WSDOT; O&M-TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: SOV Capacity Plus ITS

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
Fixed HAR & Controllers	per each	20.0	1	20	10	3	per each	1.00	1	1			Highway Advisory Radio site located at strategic locations run by WSDOT as a part of traffic management system	Add 1 new site at I-5/SR 99/SR 526	Capital-WSDOT; O&M-TTI
Kiosk	per each	18.0	10	180	10	26	per each	5.00	10	50			Located at transit centers	Install one kiosk per station	Capital-King County/Metro; O&M-TTI
Subtotal				2,950		421				139		421			
COMMUNICATION															
Fiber-Optic Cable	per mile	290	26	7,540	10	1,074	per mile	0.80	26	21			For extended freeway surveillance systems	Install along the I-5, SR526, SR526 and tie to existing WSDOT owned optic lines	Capital-WSDOT; O&M-TTI
Fiber-Optic Hubs	per each	110	6	330	10	47	per each	8.00	6	48			To interchange fiber-optic lines	Install one HUB per 3-5 miles	Capital-WSDOT; O&M-TTI
Twisted Pair	per mile	27.0	238	6,426	10	915	per mile	0.15	238	36			For extended adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal				14,296		2,036				105					
TRAFFIC CONTROL															
Coordinated/Adaptive Signal System - Local Controller	per controller	17.5	333	5,828	10	830	per controller	0.50	333	167			Replace existing controllers and cabinets at major intersections within study area	Basic O&M cost would remain the same as existing, except for cost related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Coordinated/Adaptive Signal System - Master Controller	per controller	10.0	14	140	10	20	per controller	0.50	14	7			To tie local controllers to the system	One master for every 20-25 local controller; O&M cost only related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Ramp Metering	per each	30.0	3	90	10	13	per each	3.00	3	9			Freeway entrance ramp metering station	O&M cost included equipment /hardware & timing plans	Capital-WSDOT; O&M-TTI
Subtotal				6,058		863				183					
TRAFFIC MANAGEMENT															
Computers & Hardware	per each	185	5	925	5	226	per each	170.00	5	850			For adaptive signal system and additional freeway system management where applicable	Assume one workstation, intergration and upgrades to existing signal control room; and one new employee each for Seattle, Lynnwood, WSDOT, and Everett	Capital and O&M-National Architecture Studies
Software (various)	per each	22.5	5	113	5	27	per each	34.00	5	170			For adaptive signal system	Included software installation, programing, and system analyst	Capital and O&M-National Architecture Studies
Communications Extension	per mile	27.0	5	135	10	19	per mile	0.15	5	1			For linkage to adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal				1,173		272				1,021					
TRANSIT MANAGEMENT															
Computers & Hardware for AVL System	per each	300	1	300	10	43					15%	45	Computer system to receive and process AVL polling data from buses and provide location, schedule adherance, and incidence information to dispatchers	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Software	per each	150.0	1	150	10	21					2%	3	Software for AVL Controller and Dispatch Stations	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Facilities and Communications	per each	500	1	500	10	71					15%	75	Radio communcations to receive AVL data, and dispatch stations including CRTs and microcomputers	Assume I-5 North Corridor allocation of 30 percent of the total cost. No additional dispatch staff needed.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Subtotal				950		135						123			
TRANSIT VEHICLE INTERFACES															
In-vehicle Transponder for AVI	per bus	0.6	406	244	10	35					2%	5	Transponder device located on buses used to identify bus at roadside readers at for signal priority treatment	All buses plus spares which are on routes which pass through transit priority intersections.	Capital-King County/Metro; O&M-National Architecture Studies
In-vehicle AVL Equipment	per bus	9.0	825	7,425	10	1,057	per bus	1.5	825	1,238			AVL on-board equipment for establishing vehicle location, assessing schedule status, and interfacing with driver	Consists of radio, vehicle logic unit, driver interface, radio antenna, and GPS antenna. All buses providing service in and through the I-5 North Corridor.	Capital-Denver Regional Transit District: O&M-TTI
Subtotal				7,669		1,092				1,238		5			
INCIDENT MANAGEMENT															
Central Tracking/Dispatch	per each	600	1	600	10	85					5%	30	Central tracking system/software and Mayday software/GIS integration; dispatch system.	System sized for I-5 North Corridor.	Capital-WSDOT:O&M-National Architecture Studies
In-vehicle Dynamic Route Guidance	per each	4.0	4	16	10	2					10%	2	For tracking system and route guidance to provide faster response to incidents	In-vehicle radio, GPS antenna, GPS route guidance system.	Capital-Rockwell Path Master system plus add-on items; O&M-National Architecture Studies
Subtotal				616		87						32			
GRAND TOTAL				373,804		32,933				(1,292)		1,393			

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: SOV Capacity Plus ITS

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
Pre-Trip Planning Services	NA						per subscription	0.12	90,000	10,800			Interactive fixed-end trip planning service; 10% of travelers; no capital cost beyond baseline	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 2.33 trips/hh=1.86 mil persons; 75% eligible=900 k;10% penetration rate=90 k subscribers	Capital-NA; O&M-Mitretek assumption
Personal Dynamic Route Guidance	per device	0.8	113,000	90,400	7	16,774	per subscription	0.12	113,000	13,560			In-vehicle equipment costs include GPS, map database, communications transceiver, processor, GUI, and display	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 1.41 autos per hh=1.13 mil veh; 10% penetration rate=113 k veh	Capital-National Architecture Studies; O&M-Mitretek assumption

REFERENCES:

TransCore-Interim Handbook on ITS Within the Transportation Planning Process, TransCore (formerly JHK & Associates), December 1996, Appendix E.
WSDOT-TSMC SC & DI Operations/Implementation Plan, WSDOT, October 1994.
TTI-Guidelines for Funding Operations and Maintenance of ITS/ATMS, Texas Transportation Institute, November 1996.
National Architecture Studies-ITS Architecture Cost Analysis, Federal Highway Administration/Joint Architecture Team, June 1996.
King County/Metro-King County transit operator, Dan Overguard/David Cantay/Mike Voris, May 1997
Denver RTD-Denver Regional Transit District, Lou Ha, June 1997

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: HOV/Busway

ITEM	CAPITAL COST						O & M COST						DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
							COMPUTED USING UNIT COSTS & QUANTITIES				COMPUTED AS % OF CAPITAL COST				
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
HIGHWAY/TRANSIT FACILITIES															
SOV FACILITIES															
Expressway Conversion	per mile	6,142			20		per mile	11.2					Conversion of unlimited access arterial to partial access control; add 2 lanes	Two new lanes/6 lanes total; includes outside shoulders, sidewalks and pedestrian overcrossing structures; cost excludes interchanges & grade separations; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Limited Access Widening	per mile	1,831			20		per mile	11.2					Widening of full access controlled freeway; add 2 lanes	Construct divided highway; substantial earthwork and drainage system construction required; R/W related costs included in R/W cost items	Capital-Build up based upon cost components; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Interchange (full)	per each	10,631			30						0.5%		Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Interchange (half)	per each	7,442			30						0.5%		Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Grade Separated Crossing	per each	4,896			30						0.5%		Grade separated crossing of two roads without ramp connections; for Expressway	Crossing road crosses over expressway; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Subtotal															
HOV/TRANSIT FACILITIES															
New HOV Lanes on Freeway	per mile	8,780	9	79,020	20	7,459	per mile	11.2	9	101			Add barrier separated HOV lanes to existing freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Upgrade HOV Lanes on Freeway	per mile	7,616	15	114,240	20	10,783	per mile		15				Upgrade existing HOV lanes to barrier separated lanes on a freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items; Incremental O&M costs assumed negligible	Capital-Build up based upon cost components of typical project;
New HOV Lanes on Deck-Truss Bridge	per foot	16.1	2,900	46,690	30	3,763					0.25%	117	Add HOV lanes to deck-truss bridge/no barrier or buffer separation	Add truss arch section to support widening; sidewalks replaced; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
New HOV Lanes on Expressway	per mile	7,626	3.75	28,598	20	2,699	per mile	11.2	4	42			Add HOV lanes to expressway/no barrier or buffer separation	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; roadway and pedestrian crossing structures modified; excludes costs for bridge over ship canal; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
New HOV Contra-Flow Reversible Lane on Freeway Express Lanes	per mile	14,600	3.9	56,940	20	5,375	per mile	101	3.9	395			Add HOV moveable barrier-separated lane	Based upon cost estimate for I-5 Express Lanes/Ravenna-to-Howell HOV project; includes moveable barrier, and barrier-transfer machines and storage shed; additional O&M cost is included for reversible lane operation	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/San Diego Coronado Bridge
Arterial Transit Lanes/Two Directions	per mile	7,323	25	183,075	20	17,281	per mile	11.2	25	281			Add HOV/transit lanes to an existing arterial	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Arterial Transit Lanes/Reversible	per mile	6,240	4	24,960	20	2,356	per mile	28	4	113			One center reversible lane	Includes reconstruction of c&g and sidewalk; includes overhead lane control signal bridges; assumes removal of on-street parking; additional O&M cost is included for reversible lane operation; R/W related costs included in R/W cost items	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/TTI
HOV Direct Access/Local Half Reversible Drop	per each	6,400	1	6,400	30	516	per each	46	1	46			Direct access ramps between express lanes and local street	Based upon cost estimate for I-5/NE 50th Street direct access project; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-Houston Division of TxDOT/TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: HOV/Busway

ITEM	CAPITAL COST						O & M COST						DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
							COMPUTED USING UNIT COSTS & QUANTITIES				COMPUTED AS % OF CAPITAL COST				
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
HOV Direct Access/Local Half Drop	per each	9,360	2	18,720	30	1,509					0.5%	94	Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/NE 145th Street direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Full Texas T	per each	31,140	2	62,280	30	5,019					0.5%	311	Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/Lynnwood Park-and-Ride direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Half Drop to Outside	per each	2,500	1	2,500	30	201	per at-grade ramp miles	11.2	0.5	6			Direct access ramps between outside general pupose freeway lanes and local street	Based upon cost estimate for SR525/164th Street SW direct access project; no widening or modifications to 164th Street crossing structure required	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Local Full In-Line	per each	2,970	1	2,970	30	239	per at-grade ramp miles	11.2	0.5	6			Direct access ramps between median HOV lanes and in-line station w/ pedestrian link	Based upon cost estimate for I-5/Mountlake Terrace direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Fwy-to-Fwy	per each	71,000	1	71,000	30	5,722					0.5%	355	Direct access ramps between freeways to/from one direction and another (e.g. between east and north)	Based upon cost estimate for I-5/I-405/SR525 NE Quadrant direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Fwy-to-Fwy Reversible	per each	11,870	1	11,870	30	957	per each	46	1	46			Direct access reversible ramp between median HOV lanes and express lanes	Based upon cost estimate for SR520/I-5 Express Lanes direct access project; includes access control gates; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT/Houston Division of TxDOT/TTI
Park and Ride Lot	per parking stall	6.1	2,480	15,128	20	1,428	per 100 stalls	2	25	50			Parking facility including bus transit shelter and pedestrian enhancements	Capital cost includes bus zone amenities, access improvements, stormwater detention, and landscaping.	Capital-Averaged from WSDOT examples;O&M-Based on Houston Division of TxDOT figures
Transit Bus - 40 foot Diesel	per vehicle	230	19	4,370	12	550	per thousand revenue vehicle hours	89	53.9	4,797			Standard intracity transit bus	For use on local service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Diesel Articulated	per vehicle	375	89	33,375	12	4,202	per thousand revenue vehicle hours	89	324.9	28,916			Standard intracity transit bus	For use on express service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Dual Power Articulated	per vehicle	900	11	9,900	12	1,246	per thousand revenue vehicle hours	89	38.4	3,418			Special bus for use in downtown transit tunnel	For use on express service routes which operate through the Seattle downtown transit tunnel.	Capital-King County/Metro;O&M-based upon annual vehicle hours times cost per vehicle hour
Subtotal				772,036		71,305				38,215		877			
RIGHT-OF-WAY															
R/W Adjacent to Arterial	per acre	900	33.4	30,060	100	2,107							Right-of-Way acquisition costs along expressways and arterials in north Seattle	Based upon typical costs for land along SR 99	Capital-Input from WSDOT; O&M-NA
R/W Adjacent to Freeway	per acre	500	103.8	51,900	100	3,637							Right-of-Way acquisition costs along freeways in north Seattle	Based upon typical costs for land along I-5	Capital-Input from WSDOT; O&M-NA
R/W Takes/Damages	per parcel	50.0	281	14,050	100	985							Typical extra cost to cover relocations and/or damages	Assumes posible costs to cure impacts from loss of access, or costs to relocate and re-establish business at a different location, or relocate resident.	Capital-Input from WSDOT; O&M-NA
Subtotal				96,010		6,729									
ITS/TRAFFIC SYSTEMS															
SURVEILLANCE															
Detection Loops	per mile	23.4			10		per mile	1.20					In-pavement loops and cables to nearest controller.	Four-lane per direction, install loop every half mile.	Capital-Build up based upon cost components of typical projects; O&M-TTI
Closed Circuit TV Camera	per each	25.0			10		per each	1.30					Monitor traffic operations along State's Routes	Install one every 1.2 mile per direction	Capital-WSDOT; O&M-TTI
Automatic Vehicle Identification/Roadside Equipment	per signal	25.0			10		per signal	1.50					Roadside equipment to identify bus, check schedule and provide transit priority at traffic signal	Includes reader, antenna, controller interface module, and local system communications. Transit vehicle equipment is listed separately.	Capital-King County/Metro; O&M-TTI
Automatic Vehicle Location/Field Equipment	per site	300			10						2%		Field differential GPS stationary site to provide fixed location information to compensate for topography and buildings	Assume 3 sites are needed. Transit vehicle and transit management equipment is listed separately.	Capital-Denver Regional Transit District; O&M-estimated
Data Station	per each	25.0			10						2%		To support detection	Install one station every half mile;O&M costs combined w/detection loops	Capital-WSDOT; O&M-TTI
Subtotal															
TRAVELER INFORMATION															
Variable Message Signs	per each	125			10		per each	4.00					VMS on overhead structures	Full matrix sign; includes controller and sign bridge structure	Capital-WSDOT; O&M-TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: HOV/Busway

ITEM	CAPITAL COST						O & M COST — COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST — COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
Fixed HAR & Controllers	per each	20.0			10		per each	1.00					Highway Advisory Radio site located at strategic locations run by WSDOT as a part of traffic management system	Add 1 new site at I-5/SR 99/SR 526	Capital-WSDOT; O&M-TTI
Kiosk	per each	18.0			10		per each	5.00					Located at transit centers	Install one kiosk per station	Capital-King County/Metro; O&M-TTI
Subtotal															
COMMUNICATION															
Fiber-Optic Cable	per mile	290			10		per mile	0.80					For extended freeway surveillance systems	Install along the I-5, SR526, SR526 and tie to existing WSDOT owned optic lines	Capital-WSDOT; O&M-TTI
Fiber-Optic Hubs	per each	110		330	10	47	per each	8.00					To interchange fiber-optic lines	Install one HUB per 3-5 miles	Capital-WSDOT; O&M-TTI
Twisted Pair	per mile	27.0			10		per mile	0.15					For extented adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal				330		47									
TRAFFIC CONTROL															
Coordinated/Adaptive Signal System - Local Controller	per controller	17.5			10		per controller	0.50					Replace existing controllers and cabinets at major intersections within study area	Basic O&M cost would remain the same as existing, except for cost related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Coordinated/Adaptive Signal System - Master Controller	per controller	10.0			10		per controller	0.50					To tie local controllers to the system	One master for every 20-25 local controller; O&M cost only related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Ramp Metering	per each	30.0			10		per each	3.00					Freeway entrance ramp metering station	O&M cost included equipment /hardware & timing plans	Capital-WSDOT; O&M-TTI
Subtotal															
TRAFFIC MANAGEMENT															
Computers & Hardware	per each	185			5		per each	170.00					For adaptive signal system and additional freeway system management where applicable	Assume one workstation, intergration and upgrades to existing signal control room; and one new employee each for Seattle, Lynnwood, WSDOT, and Everett	Capital and O&M-National Architecture Studies
Software (various)	per each	22.5			5		per each	34.00					For adaptive signal system	Included software installation, programing, and system analyst	Capital and O&M-National Architecture Studies
Communications Extension	per mile	27.0			10		per mile	0.15					For linkage to adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal															
TRANSIT MANAGEMENT															
Computers & Hardware for AVL System	per each	300			10						15%		Computer system to receive and process AVL polling data from buses and provide location, schedule adherance, and incidence information to dispatchers	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Software	per each	150.0			10						2%		Software for AVL Controller and Dispatch Stations	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Facilities and Communications	per each	500			10						15%		Radio communcations to receive AVL data, and dispatch stations including CRTs and microcomputers	Assume I-5 North Corridor allocation of 30 percent of the total cost. No additional dispatch staff needed.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Subtotal															
TRANSIT VEHICLE INTERFACES															
In-vehicle Transponder for AVI	per bus	0.6			10						2%		Transponder device located on buses used to identify bus at roadside readers at for signal priority treatment	All buses plus spares which are on routes which pass through transit priority intersections.	Capital-King County/Metro; O&M-National Architecture Studies
In-vehicle AVL Equipment	per bus	9.0			10		per bus	1.5					AVL on-board equipment for establishing vehicle location, assessing schedule status, and interfacing with driver	Consists of radio, vehicle logic unit, driver interface, radio antenna, and GPS antenna. All buses providing service in and through the I-5 North Corridor.	Capital-Denver Regional Transit District: O&M-TTI
Subtotal															
INCIDENT MANAGEMENT															
Central Tracking/Dispatch	per each	600			10						5%		Central tracking system/software and Mayday software/GIS integration; dispatch system.	System sized for I-5 North Corridor.	Capital-WSDOT:O&M-National Architecture Studies
In-vehicle Dynamic Route Guidance	per each	4.0			10						10%		For tracking system and route guidance to provide faster response to incidents	In-vehicle radio, GPS antenna, GPS route guidance system.	Capital-Rockwell Path Master system plus add-on items; O&M-National Architecture Studies
Subtotal															
GRAND TOTAL				868,376		78,081				38,215		877			

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: HOV/Busway

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
Pre-Trip Planning Services	NA						per subscription	0.12					Interactive fixed-end trip planning service; 10% of travelers; no capital cost beyond baseline	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 2.33 trips/hh=1.86 mil persons; 75% eligible=900 k;10% penetration rate=90 k subscribers	Capital-NA; O&M-Mitretek assumption
Personal Dynamic Route Guidance	per device	0.8			7		per subscription	0.12					In-vehicle equipment costs include GPS, map database, communications transceiver, processor, GUI, and display	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 1.41 autos per hh=1.13 mil veh; 10% penetration rate=113 k veh	Capital-National Architecture Studies; O&M-Mitretek assumption

REFERENCES:

TransCore-Interim Handbook on ITS Within the Transportation Planning Process, TransCore (formerly JHK & Associates), December 1996, Appendix E.
WSDOT-TSMC SC & DI Operations/Implementation Plan, WSDOT, October 1994.
TTI-Guidelines for Funding Operations and Maintenance of ITS/ATMS, Texas Transportation Institute, November 1996.
National Architecture Studies-ITS Architecture Cost Analysis, Federal Highway Administration/Joint Architecture Team, June 1996.
King County/Metro-King County transit operator, Dan Overguard/David Cantay/Mike Voris, May 1997
Denver RTD-Denver Regional Transit District, Lou Ha, June 1997

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: HOV/Busway Plus ITS

ITEM	CAPITAL COST						O & M COST						DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
							COMPUTED USING UNIT COSTS & QUANTITIES				COMPUTED AS % OF CAPITAL COST				
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
HIGHWAY/TRANSIT FACILITIES															
SOV FACILITIES															
Expressway Conversion	per mile	6,142			20		per mile	11.2					Conversion of unlimited access arterial to partial access control; add 2 lanes	Two new lanes/6 lanes total; includes outside shoulders, sidewalks and pedestrian overcrossing structures; cost excludes interchanges & grade separations; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Limited Access Widening	per mile	1,831			20		per mile	11.2					Widening of full access controlled freeway; add 2 lanes	Construct divided highway; substantial earthwork and drainage system construction required; R/W related costs included in R/W cost items	Capital-Build up based upon cost components; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Interchange (full)	per each	10,631			30						0.5%		Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
Interchange (half)	per each	7,442			30						0.5%		Grade separated crossing with access ramps connecting the crossing roadways; diamond configuration; for Expressway	Compressed diamond with retaining walls; crossing road crosses over expressway; includes signals at ramp terminals; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
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Subtotal															
HOV/TRANSIT FACILITIES															
New HOV Lanes on Freeway	per mile	8,780	9	79,020	20	7,459	per mile	11.2	9	101			Add barrier separated HOV lanes to existing freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M - Houston Division of TxDOT
Upgrade HOV Lanes on Freeway	per mile	7,616	15	114,240	20	10,783	per mile		15				Upgrade existing HOV lanes to barrier separated lanes on a freeway	Limited/no existing median to enable widening; includes bridge widenings for crossing structures and reconstruction of ramps at interchanges; R/W related costs included in R/W cost items; Incremental O&M costs assumed negligible	Capital-Build up based upon cost components of typical project;
New HOV Lanes on Deck-Truss Bridge	per foot	16.1	2,900	46,690	30	3,763					0.25%	117	Add HOV lanes to deck-truss bridge/no barrier or buffer separation	Add truss arch section to support widening; sidewalks replaced; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; validated using recent WSDOT estimate; O&M-WSDOT modified per PB estimates
New HOV Lanes on Expressway	per mile	7,626	3.75	28,598	20	2,699	per mile	11.2	4	42			Add HOV lanes to expressway/no barrier or buffer separation	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; roadway and pedestrian crossing structures modified; excludes costs for bridge over ship canal; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
New HOV Contra-Flow Reversible Lane on Freeway Express Lanes	per mile	14,600	3.9	56,940	20	5,375	per mile	101	3.9	395			Add HOV moveable barrier-separated lane	Based upon cost estimate for I-5 Express Lanes/Ravenna-to-Howell HOV project; includes moveable barrier, and barrier-transfer machines and storage shed; additional O&M cost is included for reversible lane operation	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/San Diego Coronado Bridge
Arterial Transit Lanes/Two Directions	per mile	7,323	25	183,075	20	17,281	per mile	11.2	25	281			Add HOV/transit lanes to an existing arterial	Reconstruction of sidewalks, drainage system and utilities; landscaping enhancements; R/W related costs included in R/W cost items	Capital-Build up based upon cost components of typical project; O&M - Houston Division of TxDOT
Arterial Transit Lanes/Reversible	per mile	6,240	4	24,960	20	2,356	per mile	28	4	113			One center reversible lane	Includes reconstruction of c&g and sidewalk; includes overhead lane control signal bridges; assumes removal of on-street parking; additional O&M cost is included for reversible lane operation; R/W related costs included in R/W cost items	Capital-Adapted from prior P.S. HOV study estimates; O&M - Houston Division of TxDOT/TTI
HOV Direct Access/Local Half Reversible Drop	per each	6,400	1	6,400	30	516	per each	46	1	46			Direct access ramps between express lanes and local street	Based upon cost estimate for I-5/NE 50th Street direct access project; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-Houston Division of TxDOT/TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: HOV/Busway Plus ITS

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
HOV Direct Access/Local Half Drop	per each	9,360	2	18,720	30	1,509					0.5%	94	Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/NE 145th Street direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Full Texas T	per each	31,140	2	62,280	30	5,019					0.5%	311	Direct access ramps between median freeway HOV lanes and local street	Based upon cost estimate for I-5/Lynnwood Park-and-Ride direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Local Half Drop to Outside	per each	2,500	1	2,500	30	201	per at-grade ramp miles	11.2	0.5	6			Direct access ramps between outside general pupose freeway lanes and local street	Based upon cost estimate for SR525/164th Street SW direct access project; no widening or modifications to 164th Street crossing structure required	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Local Full In-Line	per each	2,970	1	2,970	30	239	per at-grade ramp miles	11.2	0.5	6			Direct access ramps between median HOV lanes and in-line station w/ pedestrian link	Based upon cost estimate for I-5/Mountlake Terrace direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-Based on Houston Division of TxDOT figures
HOV Direct Access/Fwy-to-Fwy	per each	71,000	1	71,000	30	5,722					0.5%	355	Direct access ramps between freeways to/from one direction and another (e.g. between east and north)	Based upon cost estimate for I-5/I-405/SR525 NE Quadrant direct access project	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT modified per PB estimates
HOV Direct Access/Fwy-to-Fwy Reversible	per each	11,870	1	11,870	30	957	per each	46	1	46			Direct access reversible ramp between median HOV lanes and express lanes	Based upon cost estimate for SR520/I-5 Express Lanes direct access project; includes access control gates; assumes ½ mile of ramp maintenance with reversible ramp operations calculated on a per unit basis.	Capital-Adapted from prior P.S. HOV study estimates; O&M-WSDOT/Houston Division of TxDOT/TTI
Park and Ride Lot	per parking stall	6.1	2,480	15,128	20	1,428	per 100 stalls	2	25	50			Parking facility including bus transit shelter and pedestrian enhancements	Capital cost includes bus zone amenities, access improvements, stormwater detention, and landscaping.	Capital-Averaged from WSDOT examples;O&M-Based on Houston Division of TxDOT figures
Transit Bus - 40 foot Deisel	per vehicle	230	7	1,610	12	203	per thousand revenue vehicle hours	89	19.0	1,687			Standard intracity transit bus	For use on local service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Diesel Articulated	per vehicle	375	85	31,875	12	4,013	per thousand revenue vehicle hours	89	305.5	27,190			Standard intracity transit bus	For use on express service routes.	Capital-King County/Metro;O&M-King County/Metro
Transit Bus - 60 foot Dual Power Articulated	per vehicle	900	11	9,900	12	1,246	per thousand revenue vehicle hours	89	38.4	3,418			Special bus for use in downtown transit tunnel	For use on express service routes which operate through the Seattle downtown transit tunnel.	Capital-King County/Metro;O&M-based upon annual vehicle hours times cost per vehicle hour
Subtotal				767,776		70,769				33,378		877			
RIGHT-OF-WAY															
R/W Adjacent to Arterial	per acre	900	33.4	30,060	100	2,107							Right-of-Way acquisition costs along expressways and arterials in north Seattle	Based upon typical costs for land along SR 99	Capital-Input from WSDOT; O&M-NA
R/W Adjacent to Freeway	per acre	500	103.8	51,900	100	3,637							Right-of-Way acquisition costs along freeways in north Seattle	Based upon typical costs for land along I-5	Capital-Input from WSDOT; O&M-NA
R/W Takes/Damages	per parcel	50.0	281	14,050	100	985							Typical extra cost to cover relocations and/or damages	Assumes posible costs to cure impacts from loss of access, or costs to relocate and re-establish business at a different location, or relocate resident.	Capital-Input from WSDOT; O&M-NA
Subtotal				96,010		6,729									
ITS/TRAFFIC SYSTEMS															
SURVEILLANCE															
Detection Loops	per mile	23.4	16	374	10	53	per mile	1.20	16	19			In-pavement loops and cables to nearest controller.	Four-lane per direction, install loop every half mile.	Capital-Build up based upon cost components of typical projects; O&M-TTI
Closed Circuit TV Camera	per each	25.0	26	650	10	93	per each	1.30	26	34			Monitor traffic operations along State's Routes	Install one every 1.2 mile per direction	Capital-WSDOT; O&M-TTI
Automatic Vehicle Identification/Roadside Equipment	per signal	25.0	235	5,875	10	836	per signal	1.50	235	353			Roadside equipment to identify bus, check schedule and provide transit priority at traffic signal	Includes reader, antenna, controller interface module, and local system communications. Transit vehicle equipment is listed separately.	Capital-King County/Metro; O&M-TTI
Automatic Vehicle Location/Field Equipment	per site	300	3	900	10	128					2%	18	Field differential GPS stationary site to provide fixed location information to compensate for topography and buildings	Assume 3 sites are needed. Transit vehicle and transit management equipment is listed separately.	Capital-Denver Regional Transit District; O&M-estimated
Data Station	per each	25.0	32	800	10	114					2%	16	To support detection	Install one station every half mile;O&M costs combined w/detection loops	Capital-WSDOT; O&M-TTI
Subtotal				8,599		1,224				406		34			
TRAVELER INFORMATION															
Variable Message Signs	per each	125	15	1,875	10	267	per each	4.00	15	60			VMS on overhead structures	Full matrix sign; includes controller and sign bridge structure	Capital-WSDOT; O&M-TTI

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: HOV/Busway Plus ITS

ITEM	CAPITAL COST: UNIT	CAPITAL COST: UNIT COST ($K)	CAPITAL COST: QUANTITY	CAPITAL COST: TOTAL COST ($K)	CAPITAL COST: ECONOMIC LIFE (YEARS)	CAPITAL COST: ANNUALIZED COST ($K) (Interest Rate = 7.0%)	O & M COST COMPUTED USING UNIT COSTS & QUANTITIES: UNIT	O & M COST COMPUTED USING UNIT COSTS & QUANTITIES: UNIT COST ($K)	O & M COST COMPUTED USING UNIT COSTS & QUANTITIES: QUANTITY	O & M COST COMPUTED USING UNIT COSTS & QUANTITIES: ANNUAL COST ($K)	O & M COST COMPUTED AS % OF CAPITAL COST: % OF CAPITAL COST	O & M COST COMPUTED AS % OF CAPITAL COST: ANNUAL COST ($K)	DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
Fixed HAR & Controllers	per each	20.0	1	20	10	3	per each	1.00	1	1			Highway Advisory Radio site located at strategic locations run by WSDOT as a part of traffic management system	Add 1 new site at I-5/SR 99/SR 526	Capital-WSDOT; O&M-TTI
Kiosk	per each	18.0	10	180	10	26	per each	5.00	10	50			Located at transit centers	Install one kiosk per station	Capital-King County/Metro; O&M-TTI
Subtotal				2,075		296				111		296			
COMMUNICATION															
Fiber-Optic Cable	per mile	290	16	4,640	10	661	per mile	0.80	16	13			For extended freeway surveillance systems	Install along the I-5, SR526, SR526 and tie to existing WSDOT owned optic lines	Capital-WSDOT; O&M-TTI
Fiber-Optic Hubs	per each	110	3	330	10	47	per each	8.00	3	24			To interchange fiber-optic lines	Install one HUB per 3-5 miles	Capital-WSDOT; O&M-TTI
Twisted Pair	per mile	27.0	230	6,210	10	884	per mile	0.15	230	35			For extented adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal				11,180		1,592				71					
TRAFFIC CONTROL															
Coordinated/Adaptive Signal System - Local Controller	per controller	17.5	320	5,600	10	797	per controller	0.50	320	160			Replace existing controllers and cabinets at major intersections within study area	Basic O&M cost would remain the same as existing, except for cost related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Coordinated/Adaptive Signal System - Master Controller	per controller	10.0	14	140	10	20	per controller	0.50	14	7			To tie local controllers to the system	One master for every 20-25 local controller; O&M cost only related to maintain timing/data plans	Capital-Buildup based upon cost components of typical projects; O&M-TTI
Ramp Metering	per each	30.0	1	30	10	4	per each	3.00	1	3			Freeway entrance ramp metering station	O&M cost included equipment /hardware & timing plans	Capital-WSDOT; O&M-TTI
Subtotal				5,770		821				170					
TRAFFIC MANAGEMENT															
Computers & Hardware	per each	185	4	740	5	180	per each	170.00	4	680			For adaptive signal system and additional freeway system management where applicable	Assume one workstation, intergration and upgrades to existing signal control room; and one new employee each for Seattle, Lynnwood, WSDOT, and Everett	Capital and O&M-National Architecture Studies
Software (various)	per each	22.5	4	90	5	22	per each	34.00	4	136			For adaptive signal system	Included software installation, programing, and system analyst	Capital and O&M-National Architecture Studies
Communications Extension	per mile	27.0	4	108	10	15	per mile	0.15	4	1			For linkage to adaptive traffic control systems	Includes trench, conduit, wire, junction boxes	Capital-WSDOT; O&M-TTI
Subtotal				938		217				817					
TRANSIT MANAGEMENT															
Computers & Hardware for AVL System	per each	300	1	300	10	43					15%	45	Computer system to receive and process AVL polling data from buses and provide location, schedule adherance, and incidence information to dispatchers	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Software	per each	150.0	1	150	10	21					2%	3	Software for AVL Controller and Dispatch Stations	Assume I-5 North Corridor allocation of 30 percent of the total cost.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Facilities and Communications	per each	500	1	500	10	71					15%	75	Radio communcations to receive AVL data, and dispatch stations including CRTs and microcomputers	Assume I-5 North Corridor allocation of 30 percent of the total cost. No additional dispatch staff needed.	Capital-Denver Regional Transit District: O&M-National Architecture Studies
Subtotal				950		135						123			
TRANSIT VEHICLE INTERFACES															
In-vehicle Transponder for AVI	per bus	0.6	374	224	10	32					2%	4	Transponder device located on buses used to identify bus at roadside readers at for signal priority treatment	All buses plus spares which are on routes which pass through transit priority intersections.	Capital-King County/Metro; O&M-National Architecture Studies
In-vehicle AVL Equipment	per bus	9.0	943	8,487	10	1,208	per bus	1.5	943	1,415			AVL on-board equipment for establishing vehicle location, assessing schedule status, and interfacing with driver	Consists of radio, vehicle logic unit, driver interface, radio antenna, and GPS antenna. All buses providing service in and through the I-5 North Corridor.	Capital-Denver Regional Transit District: O&M-TTI
Subtotal				8,711		1,240				1,415		4			
INCIDENT MANAGEMENT															
Central Tracking/Dispatch	per each	600	1	600	10	85					5%	30	Central tracking system/software and Mayday software/GIS integration; dispatch system.	System sized for I-5 North Corridor.	Capital-WSDOT:O&M-National Architecture Studies
In-vehicle Dynamic Route Guidance	per each	4.0	4	16	10	2					10%	2	For tracking system and route guidance to provide faster response to incidents	In-vehicle radio, GPS antenna, GPS route guidance system.	Capital-Rockwell Path Master system plus add-on items; O&M-National Architecture Studies
Subtotal				616		87						32			
GRAND TOTAL				902,625		83,110				36,367		1,366			

SEATTLE I-5 NORTH MIS/COST ESTIMATE WORKSHEET-Alternative: HOV/Busway Plus ITS

ITEM	CAPITAL COST						O & M COST: COMPUTED USING UNIT COSTS & QUANTITIES				O & M COST: COMPUTED AS % OF CAPITAL COST		DESCRIPTION	ASSUMPTIONS	SOURCE FOR COST DATA
	UNIT	UNIT COST ($K)	QUANTITY	TOTAL COST ($K)	ECONOMIC LIFE (YEARS)	ANNUALIZED COST ($K) *(Interest Rate = 7.0%)*	UNIT	UNIT COST ($K)	QUANTITY	ANNUAL COST ($K)	% OF CAPITAL COST	ANNUAL COST ($K)			
Pre-Trip Planning Services	NA						per subscription	0.12	90,000	10,800			Interactive fixed-end trip planning service; 10% of travelers; no capital cost beyond baseline	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 2.33 trips/hh=1.86 mil persons; 75% eligible=900 k;10% penetration rate=90 k subscribers	Capital-NA; O&M-Mitretek assumption
Personal Dynamic Route Guidance	per device	0.8	113,000	90,400	7	16,774	per subscription	0.12	113,000	13,560			In-vehicle equipment costs include GPS, map database, communications transceiver, processor, GUI, and display	5.5 mil trips withn/thru study area x 6.87 = 800 k hh; 1.41 autos per hh=1.13 mil veh; 10% penetration rate=113 k veh	Capital-National Architecture Studies; O&M-Mitretek assumption

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