Integrated Corridor Management Modeling Results Report: Dallas, Minneapolis, and San Diego

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16. Abstract

This executive summary documents the analysis methodologies, tools, and performance measures used to analyze Integrated Corridor Management (ICM) strategies; and presents high-level results for the successful implementation of ICM at three Stage 2 Pioneer Sites, including 1) the U.S. 75 corridor in Dallas, Texas; 2) the I-15 corridor in San Diego, California; and 3) the I-394 corridor in Minneapolis, Minnesota. The executive summary provides an overall summary of benefits, followed by brief descriptions of the corridors, operational conditions and ICM strategies, analyzed, and summaries of estimated benefits for each corridor. It also provides a summary of the analysis methodology employed in the three sites, including model calibration methodology, analysis for different operational conditions, performance measures, analysis plans, and calculation of ICM benefits. Reports providing detailed summaries of analysis approaches used at each of the sites, and benefits, are also provided.

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Introduction

The United States Department of Transportation initiated research at eight Pioneer Sites in 2005 to explore the potential for Integrated Corridor Management (ICM) to transform transportation corridor[1] performance. The vision of ICM is that metropolitan areas will realize significant improvements in the efficient movement of people and goods through aggressive and proactive integration and management of major transportation corridors. Three sites undertook analysis, modeling, and simulation (AMS) to explore whether applying ICM strategies such as ramp metering, congestion pricing, signal optimization, transit priority, and enhanced traveler information to a transportation corridor in a truly active and integrated manner could improve mobility, reliability, and environmental impacts of transportation corridors.

The AMS sites examined the implications of implementing a host of ICM strategies applied under conditions of varying demand along a transportation corridor. The analysis encompassed freeway, arterial, and transit facilities along the defined corridors and examined effects of ICM strategies applied under conditions of high, medium, and low demand. Sites assessed the effects of ICM strategies both with and without traffic incidents (the largest cause of unexpected congestion) and other scenarios.

Findings across all three sites suggest that ICM will increase reliability and reduce travel time, delays, fuel consumption, and emissions in transportation corridors. Further, the benefits of ICM appear to scale with travel demand and are especially meaningful under scenarios that unexpectedly constrain supply, such as traffic incidents.

1. ICM benefits overall corridor performance—All three sites saw improvements to mobility, reliability, fuel consumption and emissions.
   ICM is most impactful under conditions of high demand and severe traffic incidents.
2. ICM generates substantially positive net fiscal benefits—Benefits outweighed system costs at all three sites within the first year.
3. ICM AMS generated improved analysis tools and methods for corridors.
4. ICM AMS positions sites for best value implementation of ICM, continuous improvement and provides a platform for longer-term decision support systems.

The AMS effort demonstrated that ICM is highly fiscally beneficial, with all three sites experiencing net positive returns on the estimated cost of ICM. Benefits outpaced implementation costs of ICM within the first year and continued to generate returns that far outpaced management and operations costs over the life of the system. In short, ICM AMS helps managers *invest in the right ICM strategies, invest with confidence, increase the effectiveness of, and continuously improve their ICM implementation*.

This Executive Summary presents the results of AMS conducted to estimate potential benefits of ICM in three metropolitan corridors. It summarizes the operational conditions and ICM strategies analyzed in each corridor. It also summarizes the analysis methodology employed in the three sites, including model

[1] The Transportation Research Board broadly defines a "corridor" as a "geographic area that accommodates travel or potential travel." Transportation Research Board, National Research Council: NCHRP Report 435, "Guidebook for Transportation Corridor Studies: A Process for Effective Decision-Making," Washington, D.C., 1999.

calibration criteria used, different operational conditions and performance measures assessed, and calculation approaches used to determine ICM benefits. More information on the ICM AMS methodology, the specific approaches used, and the results from each of the Pioneer Sites can be found in the documents listed in the "Additional Resources" section at the end of this document.

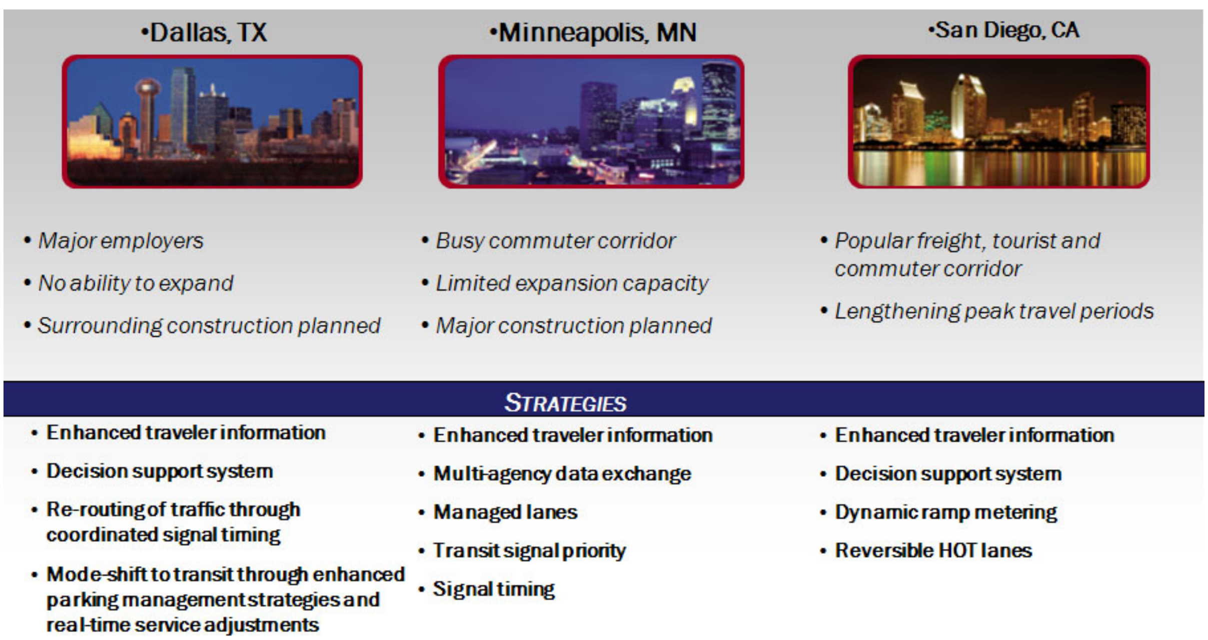
Scope of Analysis

The three Pioneer Sites that utilized the ICM AMS methodology to analyze the potential effects of ICM strategies in a multimodal metropolitan transportation corridor included Minneapolis, MN; Dallas, TX; and San Diego, CA. These corridors are geographically diverse metropolitan areas that share several characteristics and yet also have unique challenges. All three of the ICM AMS corridors:

- Carry commuters, freight, and leisure travelers;
- Experience twice-daily "peak" demand congestion due to traditional "rush hours";
- Are multimodal, comprising a primary freeway, parallel arterial roadways, and transit options (i.e., light rail and bus);
- Experience incidents, work zones, large special events such as concert and sports events, and other "non-recurring" congestion triggers.

Figure 1 summarizes some of the unique aspects of each of the ICM AMS corridors and the specific ICM strategies analyzed. These are presented in more detail in Section 3, Corridor-Specific Results.

Figure 1. Overview of the ICM AMS Pioneer Sites



[Source: Research and Innovative Technologies Administration, ITS JPO.]

The sites each considered a range of scenarios (common "non-recurrent" congestion triggers and different levels of travel demand) in order to analyze the potential effects and benefits of various combinations of ICM strategies. Table 1 summarizes the scenarios considered by the three AMS Sites. Table 2 summarizes the various ICM strategies the sites examined (such as enhanced traveler information, transmitting parking availability using dynamic message signs [DMS] on freeways, ramp metering, congestion pricing, etc.) under varying conditions of demand on freeways, arterials, and transit facilities.

Table 1. ICM Scenarios Considered by AMS Sites

ICM Scenarios	Dallas	Minneapolis	San Diego
No Incident	✓	✓	✓
Freeway Incident (Major)	✓	✓	✓
Freeway Incident (Minor)	✓	✓	
Arterial Incident (Major)		✓	✓
Arterial Incident (Minor)		✓	
Special Event		✓	✓
Transit Incident			✓
Weather Conditions		✓	
Disaster Response			✓

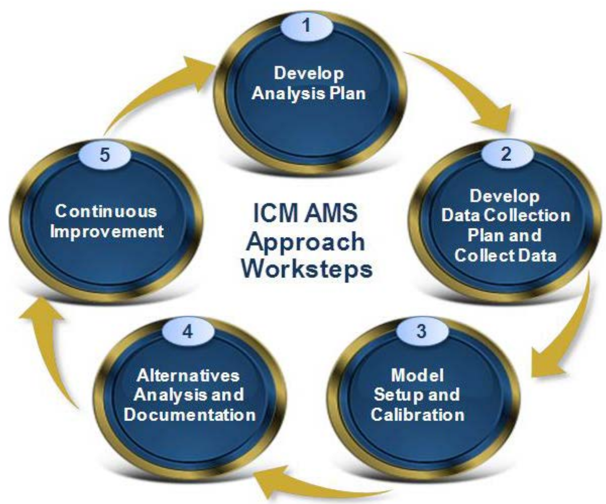
Table 2. ICM Strategies Examined by AMS Sites

ICM Strategies	Dallas	Minneapolis	San Diego
Enhanced Traveler Information			
Earlier Dissemination		✓	✓
Enhanced DMS	✓	✓	✓
Comparative, Multimodal (pre-trip and en-route)	✓	✓	✓
Decision Support System	✓		✓
Traffic Management			
Ramp Metering			✓
Selective Closures (Freeway)		✓	
Signal Timing Optimization	✓	✓	✓
Multi-Agency Data Exchange		✓	
Managed Lanes			
HOT		✓	✓
Transit Management			
Parking Space Availability Information	✓	✓	
Capacity Increases (Increased Transit Service Frequency)	✓		✓
Station Parking Expansion	✓		
Transit Priority		✓	
Bus Rapid Transit (BRT)			✓

Overview of Methodology

The AMS pioneer sites each followed a common approach to ICM AMS. Figure 2 depicts the ICM AMS approach developed through the USDOT ICM Initiative to assist corridor managers in forecasting and assessing the potential benefits and implications of ICM in their corridors of interest. The methodology was first applied to a test corridor (I-880 in Oakland, CA), where it was validated prior to its use by the Pioneer Sites.[2] Unlike traditional corridor studies, which often focus on a specific element of a corridor (i.e., a freeway or freeway and frontage road during a specific time of day), the ICM AMS methodology is comprehensive. It permits analysis of different operational conditions across time and modes and across a large enough geographic area to absorb all impacts.

Figure 2. ICM AMS Approach



[Source: Research and Innovative Technologies Administration, ITS JPO.]

The sites first developed an analysis plan (step 1), where they identified the specific aspects of their ICM systems they were most interested to model. Because resources were limited, they had to focus on corridor dynamics of greatest interest. For example, Minneapolis was originally interested to evaluate ICM benefits both for traffic incidents as well as special events and weather disruptions. Due to data availability and demand patterns on the corridor, they decided to focus the modeling on the morning rush hour. Most special events occur in the evening hours, and while the region does experience sometimes severely disruptive weather patterns, travelers have warning for most of these and are able to make alternate travel plans. They therefore decided to focus their modeling resources on scenario combinations involving traffic

[2] For more information on the test corridor, please see USDOT, "Integrated Corridor Management (ICM) Analysis, Modeling, and Simulation (AMS) Experimental Plan for the Test Corridor," http://www.its.dot.gov/icms/resources/doc_details.cfm?document_id=15&from=search.

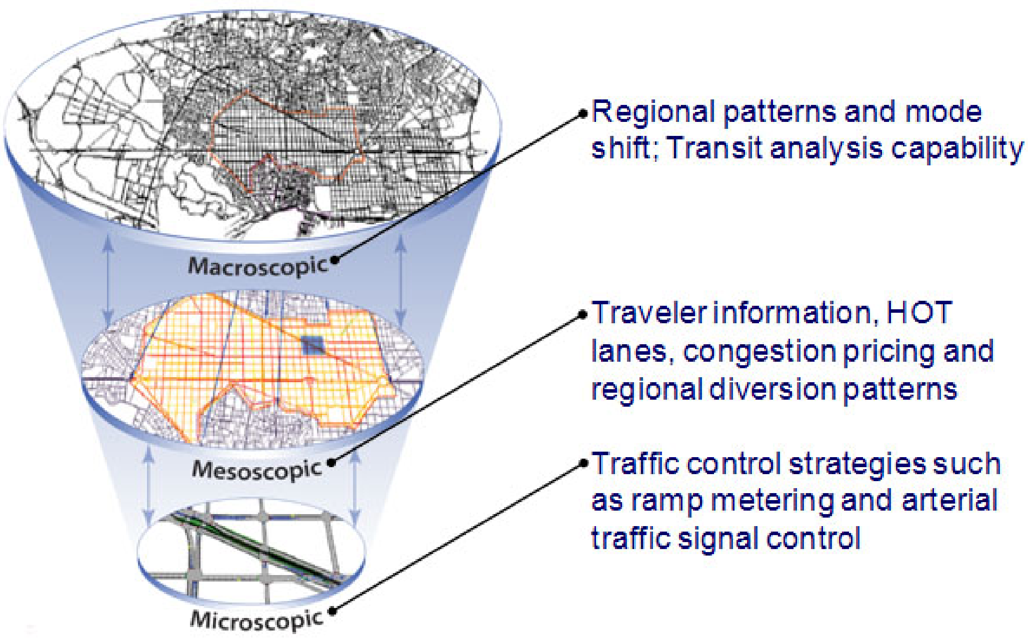
incidents on the major freeway and an arterial under varying demand conditions. The sites then developed a data collection plan and collected data (step 2). They selected the modeling tools and carefully calibrated the models (step 3) to reflect baseline and future realities and ran the models to analyze alternatives (step 4). Please see the ICM AMS Guide for more information about this approach. The ICM AMS Guide has been incorporated into the Federal Highway Administration (FHWA) Traffic Analysis Toolbox (Volume XIII) and Traffic Simulation Guidelines. This reference is provided under "Additional Resources."

Three Classes of Tools

One of the defining features of the ICM AMS methodology is that it helps agencies to understand system dynamics at the *corridor* level. It uses corridor-level performance metrics rather than facility-level metrics to evaluate and understand corridor performance. This is accomplished through the combined use of multiple classes of available modeling tools. Three classes of simulation modeling tools – macroscopic, mesoscopic, and microscopic – are considered essential components of the AMS methodology and were used for this analysis. Figure 3 presents a graphical depiction of the geographic scope and interrelationships between these tools.

The specific models developed for the different corridors involved significant tailoring. The sites used different combinations of these model types, depending on the scope, complexity, and questions to be answered within each corridor. The modeling of San Diego's ICM strategies, for example, utilized macroscopic and microscopic levels of modeling, whereas Minneapolis did not need microscopic simulation capabilities as the mesoscopic model was able to satisfy their large-scale modeling interests.

Figure 3. Geographic Scope and Analysis Capabilities of AMS Tools



[Source: Cambridge Systematics, Inc., September 2009.]

> *By combining aspects of micro, meso- and macro-simulation tools, the ICM AMS methodology enabled robust modeling of hypotheses under a range of operating conditions.*

The AMS methodology included macroscopic trip table manipulation for the determination of overall trip patterns, mesoscopic analysis of the impact of driver behavior in reaction to ICM strategies (both within and between modes), and microscopic analysis of the impact of traffic control strategies at roadway junctions (such as arterial intersections or freeway interchanges). The methodology also included a simple pivot-point mode shift model and a transit travel-time estimation module, interfaces between different tools, and a performance measurement/benefit-cost module.

In the AMS methodology, macroscopic, mesoscopic, and microscopic traffic analysis tools interfaced with each other, passing trip tables and travel times back and forth until convergence was achieved between consecutive iterations that produced travel times and number of trips that differed less from one iteration to the next. Once convergence was achieved, performance measures were calculated and benefits (such as travel time savings) were evaluated and compared to deployment costs to produce benefit-cost ratios associated with each scenario/alternative. Overall, the microscopic and mesoscopic simulation models used accurately captured travel characteristics for the selected baseline years on all three corridors, including freeways, arterials, and transit. Table 3 showcases the models used at each level by the Pioneer Sites.

Table 3. Simulation Models Used by Pioneer Sites for ICM AMS

Tool Class	Dallas	Minneapolis	San Diego
Macroscopic (Travel Demand Models)	*North Texas Council of Governments TransCAD*	*Metro Modeling TP+*	*TransCAD*
Mesoscopic	*DIRECT-Supported by Southern Methodist University*	*DynusT-Supported by University of Arizona*	
Microscopic			*TransModeler Micro*

Timeframes Analyzed

Each of the three sites was assessed by developing a “baseline year” profile and a “future year” profile. The baseline year selected provided a robust, archived set of data that was gathered for the same time periods across the various facilities assessed (freeway, arterial, and transit services). Gathering data for the same time periods is crucial in this type of modeling to provide more consistent comparisons and a more complete picture of corridor performance.

Scenarios Analyzed

The Pioneer Sites each identified a number of “scenarios” they were interested in modeling. The scenarios generally entailed combinations of corridor demand conditions and congestion triggers, such as special events or traffic incidents, under which sites could envision implementing various ICM strategies. The theory behind the analysis was that key ICM impacts may be lost if only “normal” or “typical day” travel conditions were considered. For this reason, the sites identified specific operating condition scenarios that took into account both average- and high-travel demand on the corridor, with and without the nonrecurrent congestion trigger (such as traffic incidents). The AMS methodology supported the analysis of both recurrent and nonrecurrent congestion scenarios across the transportation network. The relative frequency of nonrecurrent conditions was important to estimate in this process and was estimated based on archived traffic conditions. Each site selected combinations of scenarios that offered bases for comparisons regarding the various combinations of ICM strategies and that reflected real-world challenges to corridor performance.

Performance Measures

The ICM AMS effort considered performance measures in the following five categories:

Mobility – Described how well the corridor moves people and freight. Three primary types of measures were used to quantify mobility, including travel time, delay, and throughput. Travel time and delay were calculated using model outputs to compare differences between baseline, pre-ICM conditions, and post-ICM conditions. Throughput was calculated by comparing travel times under the incident scenarios to those under no incident. The relative influence of ICM on reducing extreme travel times was estimated by comparing the percentage of trips under the same threshold travel time in both the pre- and post-ICM scenarios.

Reliability and Variability of Travel Time – Captured the relative predictability of the public's travel time. Unlike mobility, which measures how many people and goods are moving at what rate, the reliability/ variability measures focus on how mobility varies from day to day. Travel time reliability/variability was reported in terms of changes in the Planning Index and changes in the standard deviation of travel time. The Planning Index was defined as the extra time (or time cushion) that travelers must add to their average travel time when planning trips to ensure on-time arrival; on-time arrival assumes the 95th percentile of travel time distribution.

Emissions – Captured the impact on toxic emissions. Estimates were produced using emissions rates based on variables such as facility type, vehicle mix, and travel speed.

Fuel Consumption – Captured the impact on fuel consumption. Estimates were produced using fuel consumption rates based on variables such as facility type, vehicle mix, and travel speed.

Benefits and Cost Comparison – Measured the effectiveness of the investment relative to its cost. Planning-level cost estimates were prepared, including life-cycle costs (capital, operating, and maintenance costs). Costs were expressed in terms of the net present value of various components. Annualized costs represent the average annual expenditure that is expected in order to deploy, operate, and maintain the ICM improvement and replace (or redeploy) the equipment as each piece reaches the end of its useful life

Safety was not included in this effort as a measure because available safety analysis methodologies are not measurably sensitive to ICM strategies. At best, available safety analysis methods rely on crude measures, such as Volume-to-Capacity ratio, and cannot take into account ICM effects on smoothing traffic flow. Clearly, this is an area deserving new research. As such, no safety analysis was conducted as part of this effort.

Model Calibration

Before modeling ICM strategies, the sites undertook careful model calibration to ensure that the base scenarios represented reality as closely as possible, creating confidence in the scenario comparison. The sites used common model validation/calibration criteria that were identified for the modeling effort for highway, transit, and incident aspects of the various models.

The highway, transit, and traffic incident model validation/calibration criteria are shown in Table 4.

Table 4. Model Validation and Calibration Criteria

Validation Criteria and Measures	Acceptance Targets
HIGHWAY:	
• Traffic flows within 15% of observed volumes for links with peak-period volumes greater than 2,000 vph	• For 85% of cases for links with peak-period volumes greater than 2,000 vph
• Sum of all link flows	• Within 5% of sum of all link counts
• Travel times within 15%	• >85% of cases
• Visual Audits Individual Link Speeds: Visually Acceptable Speed-Flow Relationship	• To analyst's satisfaction
• Visual Audits Bottlenecks: Visually Acceptable Queuing	• To analyst's satisfaction
TRANSIT:	
• Light-rail station volumes within 20% of observed volumes	• For 85% of cases
• Light-rail park-and-ride lots – Parked cars in each lot – Total parked cars for all lots combined	 – Within 30% – Within 20%
TRAFFIC INCIDENTS:	
• Freeway bottleneck locations	• Modeled segments with bottlenecks consistent in location, design, and attributes of the representative roadway sections
• Duration of incident-related congestion	• Duration where observable within 25 percent
• Extent of queue propagation	• Should be within 20 percent
• Diversion flows	• Increase in ramp volumes where diversion is expected to take place.
• Arterial breakdown when incident.	• Signal cycle failures or lack of cycle failures.

Calculation of ICM Benefits

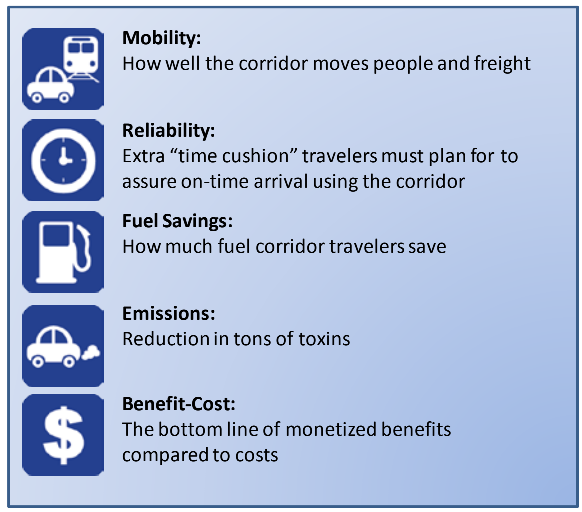
Once the sites ran the models, they then converted the saved travel time, increased travel time reliability, reduced fuel consumption, and reduced emissions production into monetized equivalents to allow for the direct comparison to the costs to install and operate the ICM system. These benefits were calculated on a facility basis by summarizing the person miles traveled (PMT) and person hours traveled (PHT) on individual links in the network to determine benefits to travelers. These benefits were estimated based on observations of which roadways and roadway types in the system see benefits from ICM deployment and which see conditions worsen. Travel time variance, which is defined as the total trip time variance, was calculated at the trip level.

For the identified ICM strategies, planning-level cost estimates were prepared, including life-cycle (10-year) costs and annualized costs. Costs were expressed in terms of the net present value of various components, including capital, operating, and maintenance costs. ICM benefits included saved travel time, increased travel time reliability, reduced fuel consumption, and reduced emissions production. All benefits were monetized to allow for a direct comparison to the costs to install and operate the ICM system. Specific steps involved in annualizing these benefits include the following:

1. Using AMS tools the analysis produced performance measures associated with the pre-ICM and post-ICM alternatives for the AM peak period. The differences in performance measures between the post-ICM and pre-ICM conditions were deemed the improvement in the analysis time period performance due to the introduction of ICM.
2. The resulting benefits for the AM peak period are then doubled to approximate the daily benefits under the assumption that the AM peak period produces approximately the same impact as the PM peak period. No benefits were assumed to be gained during off-peak conditions.
3. Daily benefits were then converted into annual benefits by multiplying times 260 workdays. This is a conservative estimate because transportation corridors can experience significant congestion on weekends and holidays.

Benefits were monetized through the following methods:

ICM Performance Measurement Areas



- **Travel Time Savings.** The reduction in PHT from the pre-ICM to the post-ICM simulations for the same operational condition was taken as the travel time savings to be gained from ICM deployment under those conditions. Multiplying the total hours saved by an estimated average value of travel time per hour (based on data from local MPOs) yielded the estimated monetary benefit of saved travel times. Trucks were also assigned a conservative same per-hour value of travel time.
- **Travel Time Reliability**. Following research on the subject, the monetary benefits for changes in travel-time reliability were estimated by the change in the standard deviation (or square root of variance) of the trip travel times. The value of travel-time reliability was assumed to be equal to the average value to travel time per hour. This is a conservative value of reliability time – typically, travel-time reliability is valued at 2.5 to 3 times the average value of travel time.
- **Fuel consumption**. Travel speeds on links in the system were examined in multiple time intervals throughout the analysis peak period and summarized in the amount of VMT occurring at various speeds and used to estimate the fuel consumption of the modeled vehicles in each scenario. This method is an approximation of fuel consumption and does not include the acceleration and deceleration effects and idle time of queued traffic. Fuel consumption rates were based on EMFAC 2007 and MOBILE6, and an average cost of $4.00 per gallon of fuel was assumed.
- **Emissions**. An estimate was made of reduced emissions from the pre-ICM to the post-ICM condition based on the number of VMT occurring in each scenario at varying speeds. Emissions rates and costs used in the analysis were based on MOBILE6 and EMFAC 2007, which are used by the Environmental Protection Agency and the California Air Resources Board, respectively.

Additional information on the specific approach used for each site is provided in each site’s ICM Experimental Plan and AMS Results Summary and the ICM AMS Guide. These and other references that may be of interest to readers are provided under “Additional Resources.”

Summary of Results

The ICM AMS effort resulted in findings in four main areas: 1) ICM effects on corridor performance, 2) benefit-cost of investment in ICM, 3) improved modeling approaches, and 4) value of ICM AMS to stakeholder agencies. Results at all three sites indicate that ICM brings mobility, reliability, energy, and environmental benefits to metropolitan corridors. Benefit-cost analysis at all three locations also suggest that ICM is an overwhelmingly cost-beneficial investment. Finally, by integrating aspects of three levels of modeling (macro-, meso-, and micro-), the AMS effort helped to further current approaches, enabling a truly comprehensive picture of corridor operations and performance. High-level findings in these four areas are reviewed below. Corridor profiles follow this discussion and provide more detail regarding each site's analysis goals and results.

1. ICM Benefits Overall Corridor Performance

The ICM strategies and scenarios evaluated at all three sites showed benefits in areas of travel time, reliability, decreased congestion, and reduced fuel consumption and environmental toxic emissions. An important finding of this analysis is that ICM strategies produce more benefits at higher levels of travel demand and during nonrecurrent congestion. Specifically, ICM AMS results across all three corridors suggest that:

- **ICM improves mobility.** ICM consistently, if moderately, improved overall travel times in all three Pioneer Site corridors, with improvements increasing nearly tenfold under conditions of high demand and severe traffic incident. The value of even a few minutes saved per trip is especially significant to highly time-sensitive freight and emergency management operations communities, where minutes correlate directly with economic and healthcare costs, respectively.
- **ICM improves the reliability** of transportation corridors, with improvements ranging from 2 percent to 23 percent under all operational scenarios evaluated. Corridors with relatively stable congestion levels saw lower improvements, whereas corridors with more volatile congestion saw higher improvements in reliability as ICM helped to smooth congestion "hot spots."
- **ICM may offer more extensive use of excess transit capacity.** At the two sites that have planned to expand transit parking, AMS indicates the possibility for increasing transit utilization, particularly under incident conditions, by drawing additional travelers to the transit facilities without overwhelming them. Parking expansion to accommodate this additional utilization appears to be a critical enabler of this benefit.
- **ICM reduced toxic emissions and fuel consumption** in all three Pioneer Site corridors. Dallas estimated the greatest savings in tons of mobile emissions annually (9,400) due to its extensive transit options, followed by San Diego, which estimated savings of approximately 3,100 tons of mobile emissions annually.

Table 5 summarizes the expected annual benefits of ICM based on the analysis completed at each of the three Pioneer Sites.[3] The benefits of ICM varied, sometimes widely, by site due to a host of variables, including different size travel sheds and corridor lengths, different implementations of different ICM strategies, differing baseline, and anticipated congestion levels within the corridors. However, all three sites experienced corridor-level benefits with implementation of ICM across all primary measure areas of interest.

Table 5. Expected Annual ICM Benefits of Pioneer Sites on Corridor Performance

PERFORMANCE MEASURE AREAS	San Diego	Dallas	Minneapolis
Annual Travel Time Savings (Person-Hours)	246,000	740,000	132,000
Improvement in Travel-Time Reliability (Reduction in Travel-Time Variance)	10.6%	3%	4.4%
Fuel Saved Annually (in Gallons)	323,000	981,000	17,600
Tons of Mobile Emissions Saved Annually (in Tons)	3,100	9,400	175

Specific results for each of the Pioneer Sites are highlighted in the next section and in detail in each site's Summary of Results documents.

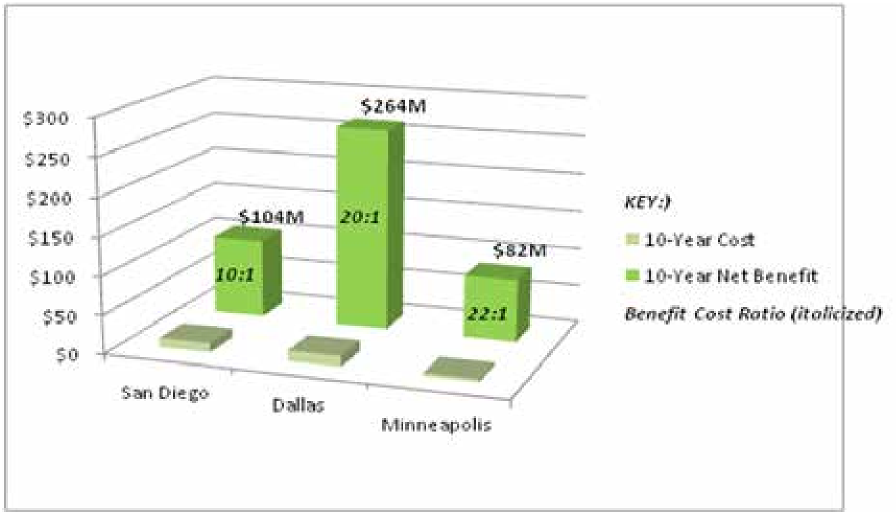
2. ICM Generates Substantially Positive Net Fiscal Benefits

In all three corridors, benefits accrued from implementing ICM more than outweighed the costs associated with implementing ICM within the first year. The benefit-to-cost ratio only grows as operations benefits continue to accrue and relatively modest operations and maintenance costs level out over the life of the ICM system: Net monetized benefit of ICM, calculated by total benefit minus total cost, ranged from $82 million to $264 million, depending on levels of congestion and planned capacity investments over a 10-year life cycle. When compared to rail, bus rapid transit (BRT), and highway lane addition projects (i.e., capacity addition projects), ICM proves to be the best value-for-the-money alternative in improving traffic conditions. Figure 4 depicts the expected annualized benefits of ICM, relative to cost, across the three Pioneer Sites.

Results suggest that ICM becomes even more valuable as demand grows and may become even more important during major traffic incidents.[4]

[3] These benefits were calculated over all trips made in each of the three corridors.
[4] Figures reflect annualized monetized benefits that can be attributed to ICM associated with improved mobility (reduced travel time), reduced emissions and fuel costs, and improved reliability of the roadway.

Figure 4. Expected 10-Year Annualized Monetized Benefits of ICM Relative to Cost



[Source: Cambridge Systematics, Inc., October 2010.]

3. ICM AMS Generated Improved Analysis Tools and Methods

Each existing tool type has different advantages and limitations and has advantages over other tool types at some specific analysis capabilities. No single type at this point in time can successfully address the analysis capabilities required to fully assess ICM. New methods that facilitate use of the tools in combination were developed to obtain a fuller picture of the complete "travel shed"[5] while maintaining the consistency across analytical approaches in the different tools and maintaining the consistency of performance measures used in the different tool types. New capabilities and tools were also developed for analyzing transit and, in particular, mode-shift, congestion pricing, high-occupancy toll (HOT) lanes, ramp metering, and active traffic management (these are documented in the site-specific Analysis Plans and results summaries, all available on the ICM Knowledgebase at www.its.dot.gov/icms/knowledgebase.htm).

4. Conducting ICM AMS Positions Corridors for Continuous Improvement and Provides a Platform for Longer Term Decision Support Systems

The Pioneer Sites found that the process of collaboratively developing the Analysis Plan, the challenge of undertaking alternatives analysis, and exploring results helped to improve their ICM concepts and design

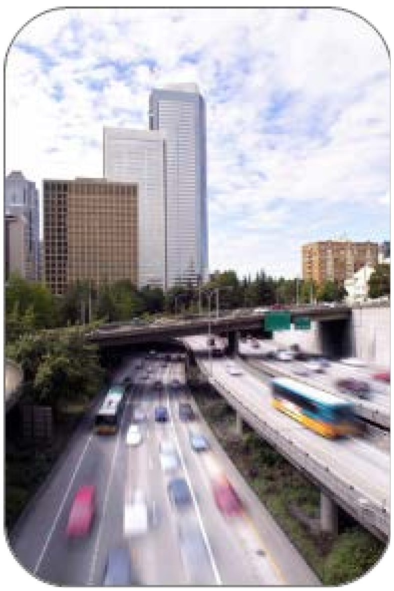
[5] Defined as the area including the feeder routes linking to the trunk lines that carry longer distance trips within the linear clusterings of travel along a corridor, as published in the Transportation Research Board, National Research Council: "NCHRP Report 435, Guidebook for Transportation Corridor Studies: A Process for Effective Decision-Making," Washington, D.C., 1999.

specifications. All three of the sites ultimately refined their original ICM concepts of operations and requirements documents through the iterative development of detailed analysis plans. The more in-depth examination of existing corridor conditions revealed sometimes mistaken assumptions about various corridor challenges (e.g., some observed bottlenecks that were believed to be major problems were revealed to be less of a problem than believed, whereas analysis of data showed other corridor segments to be greater impediments to corridor throughput). In several cases, the sites realized through the meticulous process of model calibration that more detail was needed in their ICMS requirements specifications in order to ensure system designs that would ultimately satisfy the requirements when implemented. By combining the three classes of models and collaborating closely with multimodal partner agencies, all three of the sites were able to validate which ICM strategies were likely to deliver the greatest value to overall corridor performance in a more robust manner than using any single model alone. The AMS effort of at least one Pioneer Site (San Diego) strengthened the analytic foundation for a planned decision support system. The effort provided all three sites with a foundation for continuous improvement, a cornerstone of ICM.

Conclusions

Results from the ICM AMS effort indicate that corridors that implement ICM can expect greater travel-time reliability and corridor network productivity along with reduced emissions. Travelers can expect improved predictability of their travel within the corridor and lower fuel consumption. By enabling truly integrated operations along a transportation corridor, ICM can help facilitate the more efficient flow of the more than $80 billion in goods transiting our Nation's busiest transportation corridors every month.

Because the benefits of ICM strategies scale with congestion levels, they are most beneficial to highly congested areas; i.e., any metro area in the United States that experiences a combination of mobility, safety, and environmental problems – characteristics often associated with our Nation's most important economic corridors. Since traffic congestion is associated with economically thriving regions, the importance of ICM as a congestion management tool can be expected to grow.



[Source: Source: Research and Innovative Technologies Administration, ITS JPO.]

The analysis demonstrated that the benefits of ICM become even more important under conditions of severe traffic incidents, which account for up to a quarter of stop-and-go gridlock. Every minute of unexpected delay from traffic incidents hurts the mobility, reliability, safety, and the environmental impacts of the corridor.[6] States experience between 100,000 and 200,000 reported traffic incidents per year in busy metropolitan regions, costing commuter, freight, and leisure travelers thousands of hours per year in traffic jams. ICM may be especially important in corridors with frequent or severe incidents as a means to absorb and more quickly mitigate the effects of incidents on corridor performance.

ICM is a highly cost-beneficial investment. This is because by truly integrating operations, ICM helps regions gain more value from existing ITS investments in their transportation infrastructure. These technologies are already gathering data every day, and operators are already working daily to manage the network. With ICM, this data is fused to provide managers with insight on conditions across the full travel shed of the corridor. Operators use this data and work together to implement predefined strategies and coordinate operations to manage the multimodal network more efficiently and are able to provide truly "actionable" information to travelers such that they alter travel times, route choices, and mode choices on a sufficient scale to "soften" congestion hotspots, spreading demand more evenly across the network.

[6] Indiana State Police responded to 198,000 traffic incidents in 2010. Georgia's Highway Emergency Response Operations (HERO) full function freeway service patrol program responded to 115,000 in 2010. These figures do not include unreported incidents which can also snarl traffic. Sources: Major Douglas E. Shelton Commander, Records, Division, Indiana State Police and Gary Millsaps, Former Director of the HERO Program.

Conducting ICM AMS offers the following benefits:

- **Invest in the right strategies.** The analysis offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions.
- **Invest with confidence.** The analysis allows corridor managers to "see around the corner" and discover optimum combinations of strategies as well as conflicts or unintended consequences that would otherwise be unknowable before implementation.
- **Improve the effectiveness/success of implementation.** With this analysis, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.
- The analysis provides a long-term capacity for corridor managers to **continually improve implementation** of ICM strategies based on experience.

Additional Resources

The following documents provide additional information regarding the ICM AMS methodology used at the three Pioneer Sites and detailed results of the analysis at each site:

[Source: Research and Innovative Technologies Administration, ITS JPO.]

- **ICM AMS Guide:** Provides step-by-step guidance to transportation managers interested in implementing the ICM AMS Methodology used at the ICM Pioneer Sites.
- **ICM AMS Methodology:** Provides an overview of potential ICM analytical approaches that can be used to assess transportation corridor operations and that was used at the three Pioneer Sites.
- **Experimental Plans for each Pioneer Site** (U.S. 75 [Dallas, TX]; I-394 [Minneapolis, MN]; I-15 [San Diego, CA])**:** Summarizes objectives, performance measures, detailed parameters, assumptions, and calibration criteria governing the AMS conducted at each of the three Pioneer Sites.
- **Model Validation and Calibration Reports for each Pioneer Site** (U.S. 75 [Dallas, TX]; I-394 [Minneapolis, MN]; I-15 [San Diego, CA]): Summarizes model calibration settings and validation approaches and results for each of the Pioneer Sites.
- **AMS Results for each Pioneer Site** (U.S. 75 [Dallas, TX]; I-394 [Minneapolis, MN]; I-15 [San Diego, CA]): Provides a detailed summary of the AMS approach used for each of the Pioneer Sites, operational conditions and specific ICM scenarios analyzed, and results, including estimated benefits of ICM for the Pioneer Site corridors.

Visit the ICM Knowledgebase at www.its.dot.gov/icms/knowledgebase.htm to download these and more knowledge and technology transfer resources.

APPENDIX A. Corridor Profiles

The following pages summarize the three AMS Pioneer Sites Corridors: Dallas, TX; Minneapolis, MN; and San Diego, CA. Each summary includes a corridor profile (including a map of the corridor), summary of the site's ICM AMS goals and scope of analysis, and summary of findings.

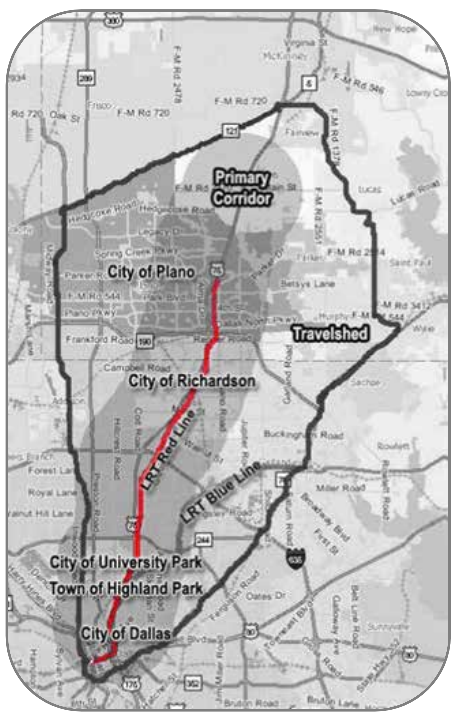
[Source: Source: Research and Innovative Technologies Administration, ITS JPO.]

U.S. 75 Corridor in Dallas, Texas

Corridor Profile

The U.S. 75 Corridor is a major north-south radial corridor connecting downtown Dallas with many of the suburbs and cities north of Dallas. Figure A-1 depicts the U.S. 75 corridor study area. The immediate corridor that was studied (see shaded area) consists of the freeway, a light-rail line, and arterial streets within approximately 2 miles of the freeway. In addition, a full travel shed influence area (see dark outline) has been defined that includes additional alternate modes and routes that may be affected by a major incident or event. The travel shed area is generally bound by downtown Dallas to the south, the Dallas North Tollway to the west, SH 121 to the north, and a combination of arterials streets and the Dallas Area Rapid Transit (DART) Blue Line to the east.

Figure A-1. U.S. 75 ICM Corridor, Dallas, TX



[Source: Cambridge Systematics, Inc., November 2009.]

U.S. 75 currently has a minimum of eight general-purpose lanes that carry over 250,000 vehicles a day, with another 20,000 to 30,000 on the frontage roads. The corridor study area also contains the first light-rail line, the Red Line. The Red Line expands into the Cities of Richardson and Plano and passes next to the Cities of Highland Park and University Park. In addition, the Blue Line operates near downtown Dallas and extends along the eastern edge of the corridor boundary. Finally, in downtown Dallas, light-rail lines connect to the regional commuter-rail line. There are three major freeway interchanges in the corridor study area—one in the southern area (the downtown freeway network connecting to I-45 and I-35E), one at the midpoint (I-635), and one in the northern area with President George Bush Turnpike (PGBT).

The corridor study area serves: a) commuting trips into downtown Dallas via the freeway, bus routes, LRT, and arterial streets; b) a significant number of reverse commuters traveling to commercial and retail developments in the northern cities and neighborhoods; c) regional traffic during off-peak periods; and d) interstate traffic into Oklahoma. Finally, the corridor also is a major evacuation route.[7]

ICM AMS Goals

The goals of the US-75 ICM initiative are to 1) increase corridor throughput, 2) improve travel time reliability, 3) improve incident management, and 4) enable intermodal travel decisions. Stakeholders defined performance measures to support analysis in areas of mobility, travel time reliability, and emissions and fuel consumption.

Dallas stakeholders were specifically interested in assessing:

- The benefits of ICM strategies (such as enhanced traveler information and "flush" signal timing plans that increase effective arterial capacity by 15 percent during an incident) during traffic incidents; during periods of high, medium, and low demand; and during special situations such as weather or special events;
- Potential effects of a new data sharing tool that will allow for real-time dissemination of incident information and comparative travel time information for freeways, arterials, and LRT lines as well as park-and-ride availability;
- The potential for increased capacity on the Red Line to facilitate mode-shift by travelers and for smart parking and expanded parking options to attract more drivers to transit;
- The fiscal benefits of ICM relative to cost.


Koorosh Olyai, DART

Scope of Analysis

The analysis assessed the application of ICM strategies during the morning peak hours of 5:30 a.m. – 11:00 a.m., determined to be the time of day with the highest probability for a traffic incident, plus the average time to return to normal operating conditions. It focused on major and minor freeway incidents[8] during conditions of high, medium, and low travel demand.[9] ICM strategies analyzed included comparative travel time information (pretrip and en-route), incident signal retiming plans for arterials and

[7] Source: Concept of Operations for the U.S. 75 Integrated Corridor, Dallas, Texas, March 2008.
[8] "Major" incidents were defined as affecting two or more general purpose lanes affected. "Minor" incidents affected one general purpose lane (or one general purpose lane plus shoulder).
[9] "High" demand was defined as greater than 7,500 vehicles per hour (vph). "Medium" demand included 6,900–7,500 vph, and "low" demand included less than 6,900 vph.

frontage roads, a light-rail transit (LRT) smart parking system, an LRT capacity increase, and LRT station parking expansion. Table A-1 presents a summary of ICM strategies and operational conditions analyzed.

Table A-1. ICM Strategies and Operational Conditions Analyzed for U.S. 75 AMS

Scenario	Daily Operations – No Incident			Minor Incident			Major Incident		
Demand	L	M	H	L	M	H	L	M	H
Traveler Information									
Comparative, multimodal travel time information (pretrip and en-route)	●	●	●	●	●	●	●	●	●
Decision Support System	●	●	●	●	●	●	●	●	●
Traffic Management									
Incident signal retiming plans for frontage roads[1]					●	●	●	●	●
Incident signal retiming plans for arterials[2]					●	●	●	●	●
Multi-Agency Data Exchange					●	●	●	●	●
Managed Lanes									
HOV lane[3]	-	-	-	-	-	-	-	-	-
Light-Rail Transit Management[4]									
Smart parking system								●	●
Red line capacity increase								●	●
Station parking expansion (private parking)								●	●

Notes:

1 The frontage road retiming plan was run as an individual traffic management strategy for minor incidents.

2 The traffic management strategies (frontage road timing and arterial timing) are combined and were not run as separate strategies for a major incident.

3 HOV lane 2+ currently is in operation, thus is not considered an ICM strategy, but was part of all scenarios.

4 The LRT Smart Parking System strategy was analyzed with the other three transit management strategies.

L = Low; M = Medium; and H = High.

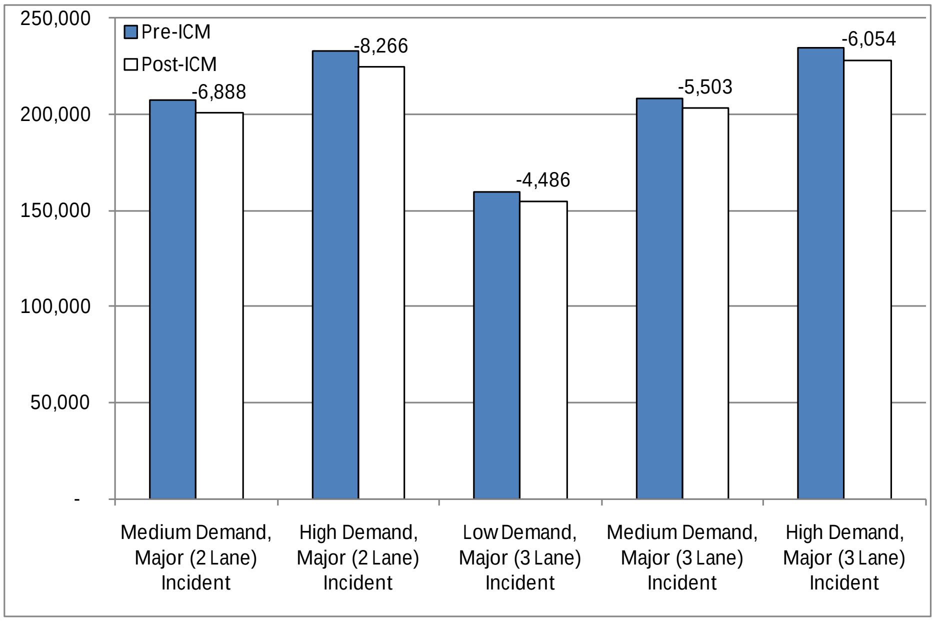
Findings

The U.S. 75 corridor AMS results show significant benefits resulting from the deployment of ICM strategies. Both the benefit-cost ratio and 10-year net benefits are positive and significant:

- Improved travel time reliability is the largest expected benefit of ICM – it accounts for about one-half of the total benefit. Travel time reliability captures the relative predictability of the public's travel time. Reduced travel time is the second largest benefit, followed by fuel consumption and emissions benefits.
- Overall, deployment of ICM on the U.S. 75 corridor produces $16.5 million in traveler benefits per year. The 10-year life cycle of the ICM systems yields a total benefit of $278.8 million.

- Costs to deploy ICM on the U.S. 75 corridor are estimated at $1.62 million per year. The 10-year life-cycle cost to deploy the ICM system is estimated at $13.6 million.
- The estimated benefit/cost ratio for the ICM deployment over the 10-year life cycle of the project is 20.4:1, demonstrating that an ICM implementation has an incremental but highly cost-beneficial impact.
- These benefits are attributable to reduced travel times, improved travel time reliability, reduced fuel consumption, and reduced mobile emissions. Expected annual savings include 740,000 person-hours of travel, a decrease in fuel consumption by 981,000 gallons, and a reduction of 9,400 tons of vehicular emissions.
- Corridor throughput also improves across all operating conditions. ICM helps reduce the duration of extreme travel times, particularly on trips using the freeway in the peak direction of travel (e.g., U.S. 75 southbound in the AM peak). An important finding of this analysis is that ICM strategies produce more benefits at higher levels of travel demand and during nonrecurrent congestion. For example, ICM-produced travel-time savings under minor and major incident conditions are shown to be 50 and 75 times higher, respectively, than under no incident conditions (see Figure A-2, where the Y axis is person-hours of delay). Travel time savings under medium- and high-demand conditions are shown to be 24 and 54 percent higher, respectively, than under the low demand condition.
- For individual travelers who primarily rely on the U.S. 75 southbound facility, the majority of benefits accrue under conditions of high travel demand and high numbers of incidents. Other corridor-wide travelers see smoothed benefit over most travel days as the system reacts more intelligently and more rapidly to variations in congestion conditions. These travelers experience small benefits accrued over many days rather than on particular days. Benefits from ICM are related to a ripple effect from better addressing the impacts of major disruptions.
- Lastly, transit excess capacity is better utilized overall, and particularly under incident conditions, drawing additional travelers to the LRT facility without overwhelming the LRT. Parking expansion to accommodate this additional utilization appears to be a critical enabler of this benefit.

Figure A-2. Delay Comparison of Major Incident Scenarios During Periods of Varying Demand, All Trips (Trips Starting 5:30 to 11:00 AM)



[Source: Cambridge Systematics, Inc., June 2010.]

[Source: Source: Research and Innovative Technologies Administration, ITS JPO.]

I-15 Corridor in San Diego, California

Corridor Profile

The I-15 corridor is an 8- to 10-lane freeway, providing an important multimodal connection between San Diego, CA, and destinations to the northeast. It is one of three primary north-south transportation corridors in San Diego County and is the primary north-south highway in inland San Diego County, serving local, regional, and interregional travel. The corridor is a heavily utilized regional commuter route, connecting communities with major regional employment centers. It is situated within a major interregional goods movement corridor, connecting Mexico, counties in California, and Las Vegas, Nevada.

The corridor study area, shown in Figure A-3, consists of the freeway, including managed/HOT lanes and general purpose lanes, frontage roads, bus rapid transit (BRT), park-and-ride lots, and regional arterial streets. The current operations on I-15 include two center-median lanes that run along 8 miles of I-15 between SR 163 in the south and Ted William Pkwy (SR 56) in the north. These center-median lanes are reversible High-Occupancy Vehicle (HOV) lanes that operate in the southbound direction in the AM peak period and in the northbound direction during the PM peak period. The current operations also allow Single Occupancy Vehicles (SOV) to utilize the roadway for a price, thereby operating as High-Occupancy Toll (HOT) lanes.

Current weekday traffic volumes range from 170,000 to 290,000 vehicles on the general purpose lanes of I-15; approximately 20,000 vehicles use the I-15 Express Lanes during weekdays. Analysis of corridor conditions showed that typical weekday demand along this linear corridor is high, largely due to the limited number of freeway alternatives. Analysis of historical data on this corridor shows that 10 percent of the days in the year experience major incidents under conditions of high demand.

ICM AMS Goals

The goals of the I-15 ICM initiative are to 1) increase corridor throughput, 2) improve travel time reliability, 3) improve incident management, and 4) enable intermodal travel decisions. Stakeholders defined performance measures to support analysis in areas of mobility, travel time reliability, and emissions and fuel consumption.

The San Diego region has made significant investments in transit, highway, and arterial systems along this corridor to derive maximum intelligent transportation system (ITS) benefits while focusing on data sharing. ICM stakeholders are seeking to optimize operational coordination of multiple transportation networks and cross-network connections to improve corridor mobility within the region. Because the frequency of traffic incidents increases during periods of high demand, the impacts of these incidents are more widespread (i.e., more travelers affected, increased environmental impacts associated with more travelers idling).

Figure A-3. I-15 ICM Corridor, San Diego, CA

[Source: SANDAG: AV Graphics, September 2009.]

San Diego stakeholders were specifically interested in assessing:

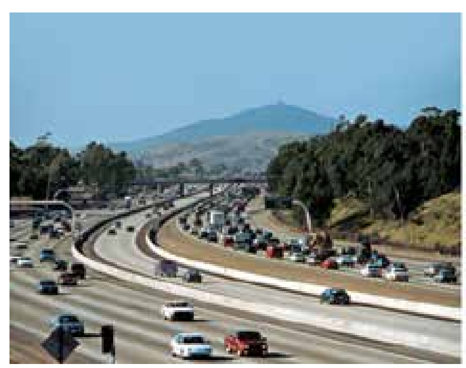


Photo: Alex Estrella, SANDAG.

- The potential for the region's new decision support system (DSS),[10] including implications from using centrally controlled measures like ramp metering, signal optimization, and en-route diversion information in a specific sequence;
- The benefits and effects of ICM strategies (such as the activation of ramp metering in combination with arterial signal timing plans), particularly in response to conditions of high demand and decreases of capacity;

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[10] The Intermodal Transportation Management System (ITMS) became operational in the region in 2007, with a modular, standards-based web service architecture that collects information from a variety of modal management systems.

- Potential opportunities associated with dynamic pricing and the implementation of reversible HOT lanes and corridor-wide Bus Rapid Transit (BRT) service that will connect to the HOT and general purpose lanes within the corridor study area.

Scope of Analysis

The I-15 ICM AMS investigated various operating conditions on the corridor, including high, medium, and low travel demand;[11] daily operations; and freeway and arterial incidents. A primary emphasis of the analysis was focused on implications of implementing the different ICM strategies in an uncoordinated manner versus a coordinated manner with the DSS. Stakeholders were particularly interested in examining the implications of ICM strategies under conditions of increased demand and decreased capacity, either due to incidents or to the extensive construction occurring and expected to continue along the corridor over the next decade. ICM strategies analyzed include pretrip and en-route traveler information, mode shift to transit, freeway ramp metering, signal coordination on arterials with freeway ramp metering, physical bus priority, and congestion pricing on managed lanes. Table A-2 presents a summary of operational conditions analyzed for the I-15 corridor AMS.

Table A-2. ICM Strategies and Operational Conditions Analyzed for I-15

Scenario	Daily Operations – No Incident			Minor Incident			Major Incident		
Demand	L	M	H	L	M	H	L	M	H
Traveler Information									
Comparative, multimodal travel time information (pretrip and en-route)	●	●	●	●	●	●	●	●	●
Decision Support System	●	●	●	●	●	●	●	●	●
Traffic Management									
Signal timing optimization	●	●	●	●	●	●	●	●	●
Freeway ramp metering	●	●	●	●	●	●	●	●	●
Multi-Agency Data Exchange	●	●	●	●	●	●	●	●	●
Managed Lanes									
Congestion pricing			●						●
Transit Management									
Bus priority		●	●		●				

The analysis assumed that travelers would have access to enhanced traveler information delivered through variable message signs (VMS) on roadways (in addition to 511 and internet-based traveler

[11] For purposes of analysis, high demand was defined as greater than 102 percent than median vehicle miles traveled (VMT), medium demand greater than 75 percent and less than 102 percent of median VMT, and low demand less than 75 percent of VMT) during the AM peak period.

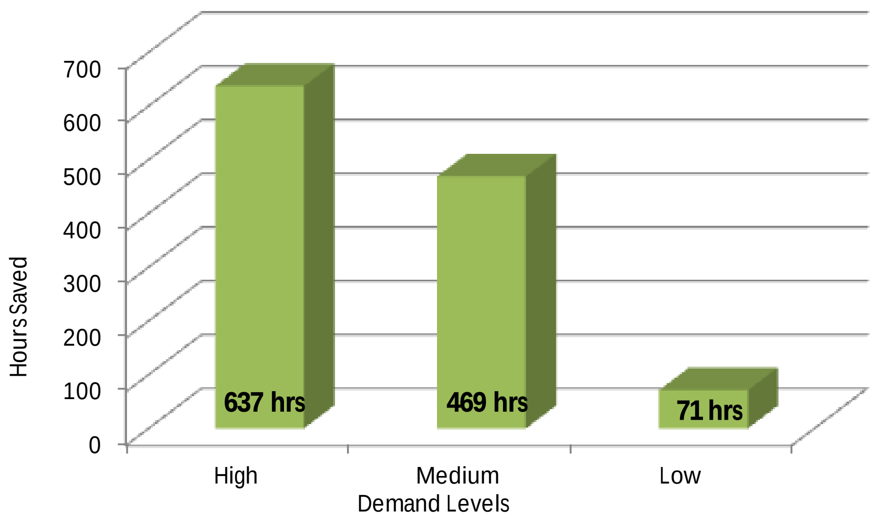
information).[12] The analysis examined effects of ICM strategies under major and minor incidents.[13] The simulation period covered AM peak hours of 6:00 a.m. to 11:00 a.m. based on analysis of the time of day with the highest probability for an incident to occur and the average time it took to return to normal operating conditions.[14] The approach examined implications of route, mode, and time-of-day shift in response to traveler information.

Summary of Findings

The I-15 corridor AMS results suggest considerable benefits resulting from the deployment of ICM strategies. Analysis results validate the ICM concept: dynamically applying ICM strategies in combination across a corridor is shown to reduce congestion and improve the overall productivity of the transportation system. Both the benefit-cost ratio and 10-year net benefits are positive and significant:

- An important finding of this analysis is that ICM strategies produce more benefits at higher levels of travel demand and during nonrecurrent congestion. Approximately 93 percent of the total ICM benefits result from the high- and medium-demand scenarios (representing 69 percent of commute days). Also, two-thirds of the total benefit is attributed to high- and medium-demand scenarios with an incident. ICM saved travelers time along the I-15 corridor during the AM peak period across all conditions, with the greatest travel time savings increasing during periods of higher demand, as shown in Figure A-4.

Figure A-4. Daily Aggregate AM Peak Travel Time Savings With ICM

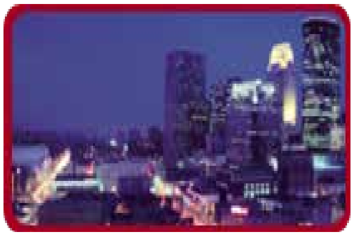


[Source: Cambridge Systematics, Inc., June 2010.]

[12] For example, the analysis assumed that the percentage of drivers with real-time information would increase from 5 percent without ICM to 30 percent with ICM and that they would receive updated travel time information every 15 minutes with ICM, compared to every 20 minutes without ICM.
[13] A freeway incident was defined as "major" if incident duration exceeded 20 minutes. All other freeway incidents were classified as minor for purposes of analysis.
[14] The simulation period encompassed not only the time that it took to reopen the lanes after an incident (incident clearance time) but the time that it took to return to normal operations.

- For individual travelers who primarily rely on the I-15 southbound facility, the majority of benefits accrue under particular operational conditions associated with high travel demand and incidents. This finding validates the hypothesis that ICM is most effective under the worst operational conditions, including heavy demand and major incidents.
- ICM reduced incident-related traveler delay on freeways with ICM compared to scenarios run without ICM, again with benefits increasing with increased demand and incident severity.
- Other corridor-wide travelers see smoothed benefit over most travel days as the system reacts more intelligently and more rapidly to variations in congestion conditions. These travelers experience small benefits accrued over many days rather than on particular days. Benefits from ICM are related to a ripple effect from better addressing the impacts of major disruptions. Benefits that accrue from multiple, distant ripples are smoothed over travel time, reliability, and fuel consumption. Those that are close to the source of disruption experience more reliability benefits.
- Overall, deployment of ICM on the I-15 Corridor produces $13.7 million in user benefits per year. Over the 10-year life cycle of the ICM systems, benefits produced a total benefit of $115.9 million. Costs to deploy ICM on the I-15 Corridor are estimated to be $1.42 million annualized over the 10-year life cycle of the project. The total life-cycle cost to deploy the ICM system is estimated at $12.0 million. The estimated benefit/cost ratio for the ICM deployment over the 10-year life cycle of the project is approximated at 9.7:1.

  The benefits from ICM are attributable to reduced travel times, improved travel time reliability, reduced fuel consumption, and reduced mobile emissions. Expected annual savings include 245,594 hours of vehicle-hours of travel, a reduction of fuel consumption by 322,767 gallons of fuel, and an annual reduction of 3,057 tons of vehicular emissions.
- Across all operational conditions, most of the ICM benefit is attributed to the travel time, travel time reliability, and fuel savings on the southbound freeway and arterials. With improved traveler information, more arterial travelers are attracted to the freeway, thus improving arterial performance and overall system performance.
- Managed lanes show some disbenefits as a result of opening these lanes to all traffic during major freeway incidents. However, vehicles using the open managed lane are not in the adjacent general purpose lane and arterials, thus improving overall corridor performance. Arterials show a considerable amount of travel time and travel time reliability benefits owing mostly to arterial signal optimization.
- Because of more comprehensive, multimodal traveler information and the availability of parking at BRT stations, transit excess capacity is better utilized overall, and particularly under incident conditions, drawing additional travelers to the BRT facility without overwhelming the BRT.
- For example, the I-15 AMS helped identify a potential unintended consequence resulting from opening the managed lanes to all traffic during major incidents on the freeway; this policy would have resulted in Bus Rapid Transit (BRT) losing mode share because the managed lanes would be slower than before, thus providing less incentive to travelers to shift to BRT. A policy solution tested and proven beneficial in the model involves making BRT free during major incidents.



[Source: Source: Research and Innovative Technologies Administration, ITS JPO.]

I-394 Corridor in Minneapolis, Minnesota

Corridor Profile

The I-394 corridor in the Twin Cities region of Minnesota is an east-west multimodal connecting the Minneapolis Central Business District with the western suburbs. With nearly 151,000 vehicles per day near the business district, the freeway is a primarily commuter route characterized by low heavy-truck use (4 percent) and the distinct directional peaks in congestion.

The corridor study area, shown in Figure A-5, consisted of the I-394 freeway (running east/west), including a HOT lane and general purpose lanes, frontage roads, express and local buses, transit stations, and park-and-ride lots. In addition to I-394, the roadway network in the study area included three north-south freeways (I-494, TH 169, and TH 100) as well as a number of arterials, which provide east-west alternative routes to I-394. The main freeway, I-394, was host to one of the first HOT lane deployments in the United States, the first in Minnesota, and dynamically adjusted pricing levels in response to varying traffic conditions. Unique within the Twin Cities region, I-394 also has two reversible, barrier-separated, high-occupancy vehicle (HOV) lanes.

Figure A-5. I-394 Corridor, Minneapolis, MN

[Source: MnDOT, September 2009.]

AMS Goals

The goals of the I-394 ICM initiative are to 1) maintain mobility and reliability of travel on a corridor basis; 2) maximize use of any spare capacity; 3) minimize impacts of incidents on travelers; and 4) provide travelers with “holistic,” timely, accurate, and reliable multimodal traveler information.[15] Stakeholders defined performance measures to support analysis in areas of mobility, travel time reliability, and emissions and fuel consumption. With the corridor experiencing a lane-blocking traffic incident on 25

[15] ICM AMS Results for the I-394 Corridor in Minneapolis, MN.

percent of all weekdays on the eastbound I-394 freeway, Minneapolis stakeholders were specifically interested in assessing:

- Effects of adding effective capacity with the reversible lanes, especially in relieving incident-related congestion;
- Effects of opening HOV lanes to all vehicles as a means to generate additional capacity;
- Possibilities associated with strategies to effect mode-shift to transit (i.e., enhanced traveler information at key decision points along the corridor where travelers could divert to transit); and
- Opportunities to facilitate increased mode-shift through enhanced messaging on new DMS signs, comparative travel times, and parking lot space availability information.

Scope of Analysis

Photo: Minnesota Department of Transportation

ICM strategies analyzed include earlier dissemination of pretrip and en-route traveler information, providing comparative travel times, mode shift to transit, parking availability at park-and-ride lots, incident signal retiming plans for arterials, predefined freeway closure points, opening the HOT lanes to all traffic during incidents, and transit signal priority. Table A-3 presents a summary of ICM strategies and operational conditions analyzed for the I-394 corridor AMS. Because of the frequency and severity of incidents on the corridor, the Minneapolis AMS effort focused on the effects of the application of ICM strategies along the I-394 corridor, both with and without traffic incidents.[16]

Analysts selected the morning peak as the focus because they felt it offered more likely options for travelers to mode shift. Also, relatively stable increases in demand during the AM rush hour provided the opportunity to experiment with more sensitive analysis on the incident severity and impacts.[17,18] Because current conditions analysis showed that approximately 40 percent of crashes occurred on two of the parallel arterials, one major arterial incident was included in the modeling.[19]

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[16] Analysis of historic corridor conditions showed that roughly 60 percent of all incidents occur in the eastbound direction of I-394. More than 75 percent of incidents occur during the morning rush hour.
[17] Demand patterns were estimated to be: 7,000 vehicles per hour (vph) at 7:00 a.m.; 8,000 vph at 8:00 a.m.; 9,000 vph at 7:45 a.m.; and 10,000 vph at 8:15 a.m.
[18] For purposes of analysis, “major” incidents were defined as incidents with a clearance time greater than 60 minutes, with “minor” incidents including any incident with a clearance time of less than 60 minutes.
[19] Weather and special events scenarios were considered for analysis but ultimately dropped. While the region experiences disruptive weather, especially in the winter, stakeholders felt the benefits of ICM would be more muted because travelers typically have warning about these disruptions. The corridor is a throughway for many special events; however, most of these occur in the evening rather than the morning.

Table A-3. ICM Strategies and Operational Conditions for I-394 AMS

Scenario	Minor Incident			Major Incident				
	Freeway			Freeway: Full Segment Closed[20]			Freeway:1-lane blocked	Arterial[21]
Demand	L	M	H	L	M	H	H	H
Traveler Information								
Earlier dissemination of information	●	●	●	●	●	●	●	●
Comparative, multimodal travel time information (pretrip and en-route)	●	●	●	●	●	●	●	●
Parking availability at park and ride lots	●	●	●	●	●	●	●	●
Decision Support System	●	●	●	●	●	●	●	●
Traffic Management								
Signal timing optimization				●	●	●	●	●
Freeway ramp metering[22]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Predefined Freeway Closure Points				●	●	●		●
Multi-Agency Data Exchange				●	●	●		●
Managed Lanes								
HOT Lanes (open to all traffic during an incident)[23]				●	●	●		
Transit Management[4]								
Transit signal priority	●	●	●	●	●	●		●

Summary of Findings

The I-394 corridor AMS results suggest considerable benefits resulting from the deployment of ICM strategies:

- Overall, deployment of ICM on the I-394 corridor produces $10.2 million in traveler benefits per year. Over the 10-year life cycle of the ICM systems, the benefits produced total $85.9 million. Costs to deploy ICM on the I-394 corridor are estimated to be $0.47 million annualized over the 10-year life cycle of the project. The total life-cycle costs to deploy the ICM system are estimated at $3.96 million. The estimated benefit/cost ratio for the ICM deployment over the 10-year life cycle of the project is approximated at 21.7:1.

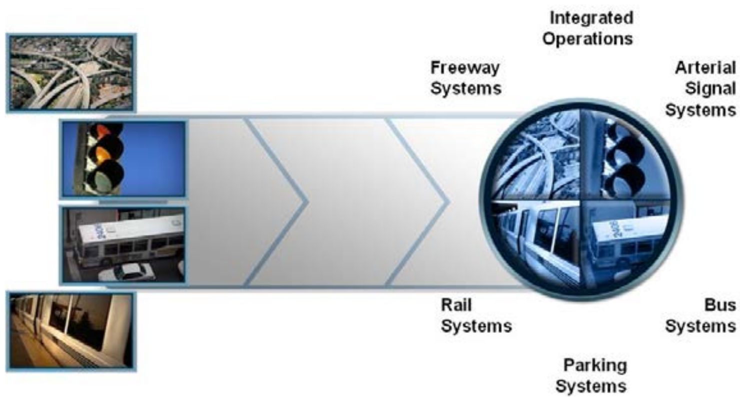
[20] Major incident scenarios examined both full closures of freeway segments and blocking of one freeway general purpose and auxiliary lane for 80 minutes. Minor incident scenarios examined blocking of one freeway general purpose and auxiliary lane for 30 and 45 minutes.
[21] The major arterial incident scenario assumed closure of an arterial segment for 65 minutes.
[22] Ramp metering was in place before ICM, was not funded by ICM, and will continue to be there after ICM deployment. Ramp metering, therefore, was analyzed but only as part of baseline – not as part of ICM improvements.
[23] The HOT Lane (congestion pricing) is currently in operation and thus is not considered an ICM strategy; however, opening the HOT lane to all traffic during an incident was included in the analysis as an ICM strategy.

- The benefits from ICM are attributable to reduced travel times, improved reliability of travel times, reduced fuel consumption, and reduced mobile emissions. Expected annual savings include 132,000 person-hours of travel; a decrease in fuel consumption of 17,600 gallons; and a reduction in vehicular emissions of 175 tons.
- Corridor throughput also improves across all operating conditions: ICM helped reduce the length of the extreme travel times in the corridor, especially on trips using I-394 eastbound and especially under incident conditions.
- Across all operational conditions, most of the ICM benefit is attributed to the travel time reliability and travel time savings on the eastbound freeway and other roads in the corridor. Other roads show a considerable amount of travel time and travel time reliability benefits owing mostly to better traveler diversion due to better traveler information and arterial signal optimization. This can be attributed to a combination of the improved dissemination of traveler information to advise travelers to seek alternative paths, opening the HOT lane to all travelers without tolling during major incidents, and transit signal priority. The parallel arterials did see some disbenefits, which can be attributed to the additional diverted traffic from I-394.

APPENDIX B. About ICM

ICM is a promising tool in the congestion management toolbox[24] that leverages existing intelligent transportation systems (ITS) investments along a corridor. With ICM, transportation agencies along a corridor manage the transportation assets as an integrated system, rather than as individual assets (see Figure B-1). They proactively coordinate transportation operations to efficiently manage multimodal demand across the corridor. Dynamically applying strategies such as enhanced traveler information, ramp metering, and smart parking to facilitate transit in a truly integrated manner across a corridor in response to varying conditions is expected to improve the overall productivity of the system. By helping to more evenly balance available supply relative to demand, ICM can help reduce congestion "hot spots" in the system. Furthermore, providing travelers actionable information on alternatives (such as opportunities to park their car and switch to transit, postpone their time of travel, and/or change their route) is expected to mitigate bottlenecks, reduce congestion, and empower travelers to make more informed travel choices.

Figure B-1. ICM Integrated System

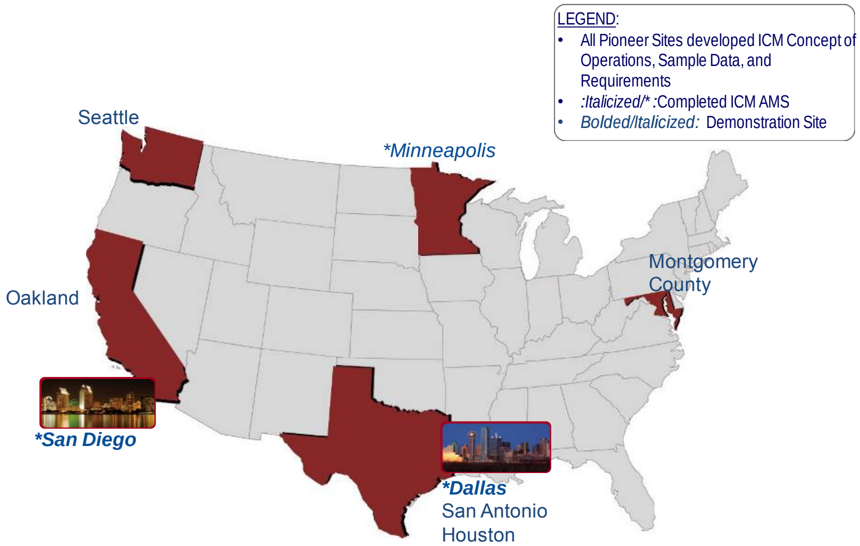


[Source: Research and Innovative Technologies Administration, ITS JPO.]

Eight ICM pioneer sites developed concepts of operations and requirements for ICM systems in 2009. In 2011, three of the sites (Dallas, TX; Minneapolis, MN; and San Diego, CA) conducted analysis, modeling, and simulation (AMS) to estimate the benefits of implementing ICM. Dallas and San Diego will demonstrate ICM in 2013. Figure B-2 depicts the ICM Pioneer Sites.

[24] ICM is a component of active transportation and demand management technologies.

Figure B-2. ICM Pioneer Sites



[Source: Research and Innovative Technologies Administration, ITS JPO.]

ANNEX 1.
Integrated Corridor Management

Analysis, Modeling, and Simulation Results for the U.S. 75 Corridor in Dallas, Texas

www.its.dot.gov/index.htm

Final Report – September 2010

U.S. Department of Transportation

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The COTM for FHWA is Dale Thompson

16. Abstract

This report documents the analysis methodologies, tools and performance measures used to analyze Integrated Corridor Management (ICM) strategies for the U.S. 75 Corridor, and presents high-level results and lessons-learned for the successful implementation of ICM. The U.S. 75 Corridor is a major north-south radial corridor connecting downtown Dallas with many of the suburbs and cities north of Dallas. The Corridor study area includes the freeway, continuous frontage roads, a light-rail line, transit bus service, park-and-ride lots, major regional arterial streets, toll roads, bike trails, and intelligent transportation systems.

The analysis investigated various operating conditions on the U.S. 75 Corridor, including high, medium, and low travel demand; daily operations; and major and minor freeway incidents. ICM strategies analyzed include comparative travel time information (pretrip and en-route); incident signal retiming plans for arterials and frontage roads; managed lanes, Light-Rail Transit (LRT) smart parking system; LRT capacity increase; and LRT station parking expansion.

17. Key Words	18. Distribution Statement
Integrated corridor management, ICM, mesoscopic models, cluster analysis, incident, strategies, traveler information, analysis, modeling, simulation, AMS, performance measures, Dallas, TX, US 75, light-rail transit, arterials, DART	No Restrictions.

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Executive Summary

This report documents the analysis methodologies, tools, and performance measures used to analyze Integrated Corridor Management (ICM) strategies for the U.S. 75 Corridor, and presents high-level results and lessons-learned for the successful implementation of ICM. The U.S. 75 Corridor is a major north-south radial corridor connecting downtown Dallas with many of the suburbs and cities north of Dallas. The Corridor study area includes the freeway, continuous frontage roads, a light-rail line, transit bus service, park-and-ride lots, major regional arterial streets, toll roads, bike trails, and intelligent transportation systems.

The analysis investigated various operating conditions on the U.S. 75 Corridor, including high, medium, and low travel demand; daily operations; and major and minor freeway incidents. ICM strategies analyzed include comparative travel time information (pretrip and en-route); incident signal retiming plans for arterials and frontage roads; managed lanes, Light-Rail Transit (LRT) smart parking system; LRT capacity increase; and LRT station parking expansion.

The U.S. 75 Corridor AMS results show significant benefits, resulting from the deployment of ICM strategies:

- Overall, deployment of ICM on the U.S. 75 Corridor produces $16.5 million in user benefits per year. The 10-year life cycle of the ICM systems yields a total benefit of $278.8 million.
- Costs to deploy ICM on the U.S. 75 Corridor are estimated at $1.62 million per year. The 10-year life-cycle cost to deploy the ICM system is estimated at $13.6 million.
- The estimated benefit/cost ratio for the ICM deployment over the 10-year life cycle of the project is 20.4:1.
- These benefits are attributable to reduced travel times, improved travel time reliability, reduced fuel consumption, and reduced mobile emissions. Expected annual savings include 740,000 hours of person-hours of travel, a reduction of fuel consumption by 981,000 gallons of fuel, and a reduction of 9,400 tons of vehicular emissions. Corridor throughput also improves across all operating conditions: ICM helps reduce the length of the extreme travel times, and is more pronounced on trips using U.S. 75 Southbound.

This analysis offers the following benefits:

- Invest in the right strategies. The analysis offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions.
- Invest with confidence. The analysis allows corridor managers to “see around the corner” and discover optimum combinations of strategies, as well as conflicts or unintended consequences that would otherwise be unknowable before implementation.
- Improve the effectiveness/success of implementation. With this analysis, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.
- The analysis provides a long-term capability to corridor managers to continually improve implementation of ICM strategies based on experience.

Chapter 1 Introduction and Background

The objective of the Integrated Corridor Management (ICM) initiative is to demonstrate how Intelligent Transportation Systems (ITS) technologies can efficiently and proactively manage the movement of people and goods in major transportation corridors. The ICM initiative aims to pioneer innovative multimodal and multi-jurisdictional strategies – and combinations of strategies – that optimize existing infrastructure to help manage congestion in our nation's corridors. There are an estimated 300 corridors in the country with under-utilized capacity (in the form of parallel transit capacity (bus, rail, Bus Rapid Transit(BRT), etc.) and/or arterials and under-utilized travel lanes) that could benefit from ICM.

The maturation of ITS technologies, availability of supporting data, and emerging multi-agency institutional frameworks make ICM practical and feasible. There are a large number of freeway, arterial, and transit optimization strategies available today and in widespread use across the U.S. Most of these strategies are managed locally by individual agencies on an asset-by-asset basis. Even those managed regionally are often managed in a stove-piped manner (asset-by-asset) rather than in an "integrated" fashion across a transportation corridor. Dynamically applying these strategies in combination across a corridor in response to varying conditions is expected to reduce congestion "hot spots" in the system and improve the overall productivity of the system. Furthermore, providing travelers with actionable information on alternatives (such as mode shift, time of travel shift, and/or route shift) is expected to mitigate bottlenecks, reduce congestion, and empower travelers to make more informed travel choices.

The objectives of the "ICM – Tools, Strategies and Deployment Support" project are to refine Analysis Modeling and Simulation (AMS) tools and strategies, assess Pioneer Site data capabilities, conduct AMS for three Stage 2 ICM Pioneer Sites, and conduct AMS tools post-demonstration evaluations. Current efforts under this project focus on analyzing the ICM systems proposed by the Stage 2 Pioneer AMS Sites and evaluating the expected benefits to be derived from implementing those ICM systems.

The overall benefits of this effort include:

- Help decision-makers identify gaps, evaluate ICM strategies, and invest in the best combination of strategies that would minimize congestion; comprehensive modeling increases the likelihood of ICM success, and helps minimize unintended consequences of applying ICM strategies to a corridor.
- Help estimate the benefit resulting from ICM across different transportation modes and traffic control systems; without being able to predict the effects of ICM strategies corridor transportation agencies may not take the risk of making the institutional and operational changes needed to optimize corridor operations.
- Transfer knowledge about analysis methodologies, tools, and possible benefits of ICM strategies to the Pioneer Sites and to the entire transportation community.

This report, ***Analysis Simulation and Modeling Results for the U.S. 75 Corridor in Dallas, Texas*** documents the ICM AMS tools and strategies for the U.S. 75 Corridor, presents high-level AMS results for the Corridor and lessons-learned, and documents the benefit-cost assessment for the successful implementation of ICM.

The remainder of this document is organized as follows:

- Chapter 2.0 provides a brief description of the U.S. 75 Corridor in Dallas, Texas, and the methodology used for the AMS;
- Chapter 3.0 summarizes the ICM strategies that will be tested and provides a list of the AMS scenarios;
- Chapter 4.0 defines performance measures that will be utilized in the analysis of the ICM strategies in the U.S. 75 Corridor;
- Chapter 5.0 summarizes the simulation model calibration approach, methodology, and results;
- Chapter 6.0 presents the results and benefit-cost analysis of the ICM alternatives tested as part of the AMS effort for the U.S. 75 Corridor;
- Appendix A presents a summary of the ICM strategies for the U.S. 75 Corridor; and
- Appendix B presents the Performance Measure calculation procedures from the simulation output for the U.S. 75 Corridor.

Chapter 2 U.S. 75 Corridor Site and AMS Methodology

The U.S. 75 Corridor is a major north-south radial corridor connecting downtown Dallas with many of the suburbs and cities north of Dallas. The U.S. 75 Corridor has been defined at two levels. The immediate corridor consists of the freeway, a light-rail line, and arterial streets within approximately two miles of the freeway. In addition, a full “travel shed” influence area has been defined that includes additional alternate modes and routes that may be affected by a major incident or event. The travel shed area is generally bound by downtown Dallas to the south, the Dallas North Tollway to the west, SH 121 to the north, and a combination of arterials streets and the Dallas Area Rapid Transit (DART) Blue Line to the east. The following sections provide a detailed overview of the study corridor.[1]

U.S. 75 Corridor Description

U.S. 75 is Dallas’ first major freeway, completed around 1950, and fully reconstructed with cantilevered frontage roads over the depressed freeway section and reopened in 1999 with a minimum of eight general-purpose lanes. The freeway mainlines carry over 250,000 vehicles a day, with another 20,000 to 30,000 on the frontage roads.

The U.S. 75 Corridor study area includes the freeway, continuous frontage roads, light-rail line, transit bus service, park-and-ride lots, major regional arterial streets, toll roads, bike trails, and intelligent transportation systems. A concurrent-flow, high-occupancy vehicle (HOV) lane in the corridor opened in December 2007.

The corridor study area also contains the first light-rail line, the Red Line, constructed in Dallas, part of the 20-mile DART starter system, opened in 1996. The Red Line now expands into the Cities of Richardson and Plano, and passes next to the Cities of Highland Park and University Park. This facility operates partially at-grade and partially grade-separated through deep-bored tunnels under U.S. 75. In addition, the Blue Line operates near downtown Dallas, and extends along the eastern edge of the corridor boundary. Finally, in downtown Dallas, the light-rail lines connect to the regional commuter-rail line, the Trinity Express.

The U.S. 75 Corridor study area serves: a) commuting trips into downtown Dallas, via the freeway, bus routes, light-rail line, and arterial streets; b) a significant number of reverse commuters traveling to commercial and retail developments in the northern cities and neighborhoods; c) regional traffic during off-peak periods; and d) interstate traffic into Oklahoma, since the freeway is a continuation of Interstate 45. Finally, the corridor also is a major evacuation route and experienced significant volumes during the Hurricane Rita evacuation in 2005.

There are three major freeway interchanges in the corridor study area. In the southern section, U.S. 75 has an interchange with the downtown freeway network connecting to Interstate 45 and

[1] Source: Concept of Operations for the U.S. 75 Integrated Corridor, Dallas, Texas, March 2008.

Interstate 35E. At midpoint there is a newly constructed interchange with Interstate 635, while in the northern section, there is an interchange with the President George Bush Turnpike (PGBT). Figure 2-1 illustrates the U.S. 75 Corridor, with the primary corridor study area highlighted, and the roadways included in the study area.

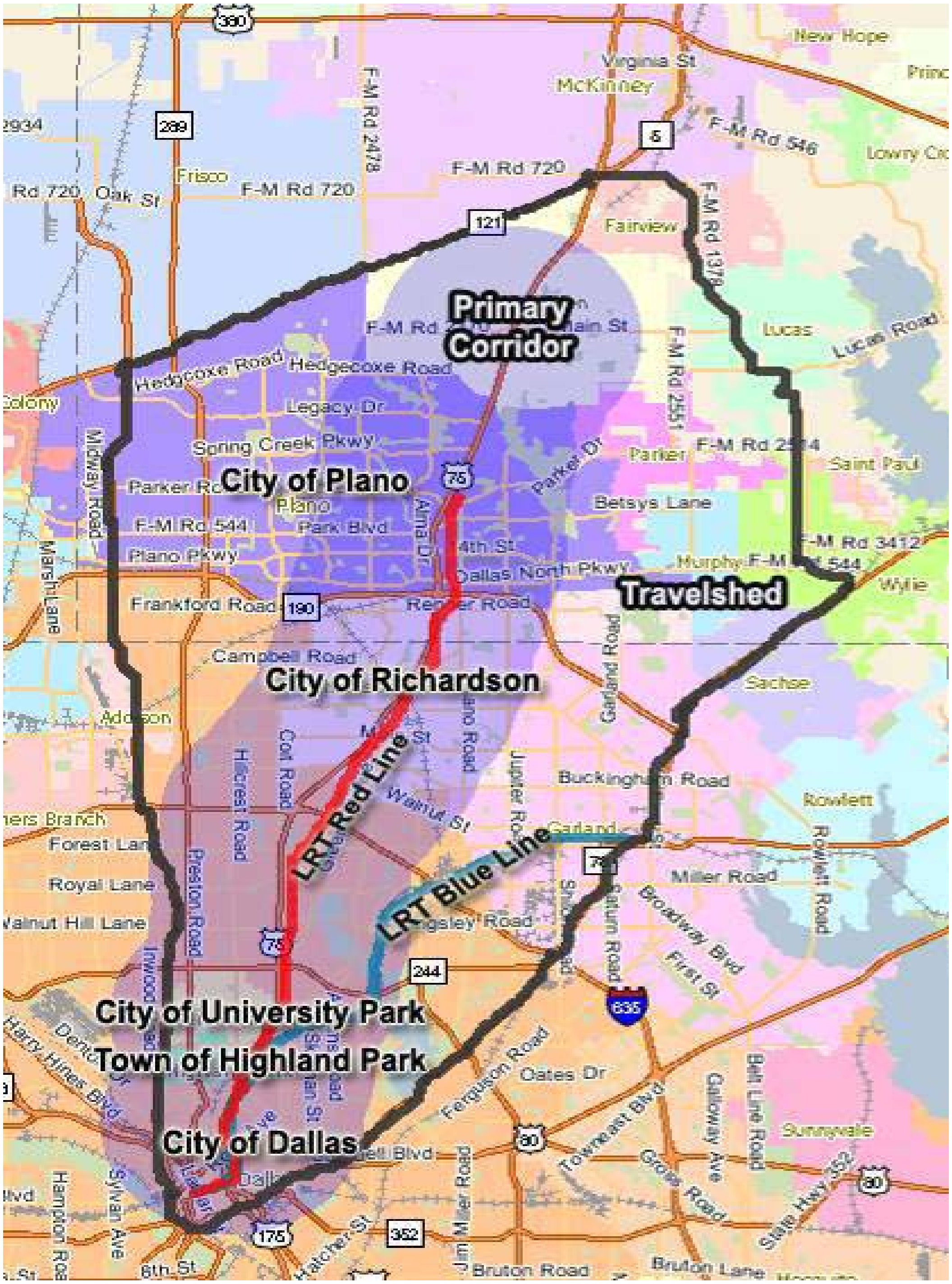
Modeling Approach

The modeling approach that emerged from the analysis of capabilities found in existing AMS tools as well as from the ICM Test Corridor project, was an ***integrated platform that can support corridor management planning, design, and operations by combining the capabilities of existing tools***. The integrated approach is based on ***interfacing travel demand models, mesoscopic simulation models, and microscopic simulation models***. The ICM AMS approach encompasses tools with different traffic analysis resolutions. All three classes of simulation modeling approaches – macroscopic, mesoscopic, and microscopic – may be applied for evaluating ICM strategies.

Within the U.S. 75 corridor, the AMS methodology applied included the macroscopic trip table manipulation for the determination of overall trip patterns and mesoscopic analysis of the impact of driver behavior in reaction to ICM strategies (both within and between modes). The use of microsimulation modeling was initially considered for assessing arterial traffic signal coordination, but due to the lack of comprehensive existing microscopic simulation networks, it was decided to use DIRECT, a mesoscopic traffic simulation model developed by Southern Methodist University (SMU). DIRECT has the ability to reflect signal timings.

In order to estimate the full benefits of the ICM strategies for the U.S. 75 Corridor, the simulation period for the mesoscopic model encompassed not only the time that it took to reopen the lane(s) after an incident (incident clearance time), but the time that it took to return to normal operations. Based on an analysis of U.S. 75 incidents, the time of day with the highest probability for an incident to occur and the average time it took to return to normal operating conditions were assessed. As such, the Dallas AMS team decided to use a simulation period covering the hours of 5:30 AM to 11:00 AM. It also was determined that the AM peak would allow the testing of a greater number of strategies than the PM peak, including strategies that support mode shift.

Figure 2-1. Location and Geographic Boundaries of Corridor



Source: DART.

The following paragraphs provide an overview of the various modeling components utilized in the AMS modeling framework for the U.S. 75 Corridor. Additional details are available in the separate report titled *AMS Analysis Plan for U.S. 75 in Dallas, Texas*.

Travel Demand Forecasting Model

Travel demand models estimate demand based on projections of household and employment characteristics and predict preferences in activity location, time-of-day, mode, and route choice. The North Central Texas Council of Governments (NCTCOG), Dallas' metropolitan planning organization (MPO), maintains the regional travel demand model in TransCAD, with 1999 being the most recent validation year. NCTCOG's model was being revalidated for 2004, but it was not be available for use in this study. The static nature of NCTCOG's travel demand model is not entirely compatible with the dynamic nature of travel choices during an incident situation. DIRECT, the selected mesoscopic model for the U.S. 75 Corridor study area, models the diversion to different routes or modes during simulation run time, thus circumventing the need to feed back to the travel demand model and providing a more realistic view of the traveler decisions and their impact to network conditions.

Therefore, the NCTCOG model was used as the primary source for the vehicular trip tables and networks utilized by DIRECT. NCTCOG had trip tables and networks available for 2007, and it was agreed that the base year for the U.S. 75 Corridor study area will be 2007. In addition, available coefficients (e.g., value of time, operating cost per mile, etc.) and variables from the travel demand model were reviewed and adjusted for incorporation into the to the generalized cost equation within DIRECT. While travel demand subarea procedures allowed for the extraction of the vehicular demand for the U.S. 75 Corridor study area, similar procedures were not available for the transit component. Therefore, the Dallas AMS team utilized the DART on-board survey to develop an estimate of the transit origin-destination (OD) trip table.

Mesoscopic Simulation Model

Mesoscopic models combine properties of both microscopic and macroscopic simulation models. Similar to microscopic models, the mesoscopic model's unit of traffic flow is the individual vehicle. The movements in a mesoscopic model, however, follow the approach of macroscopic models and are generally governed by the average speed on the travel link. Mesoscopic models provide less fidelity than microsimulation models, but are superior to travel demand models, in that they can evaluate dynamic traveler diversions in large-scale networks.

For the analysis of the U.S. 75 Corridor, the mesoscopic model DIRECT developed by the Southern Methodist University (SMU) was used. DIRECT supports the analysis of the dynamic impact of ICM strategies, such as HOT lanes, route shifts, mode shifts, and corridor-specific traveler information (pretrip and en route).

In DIRECT, the traveler's mode and route are generated so that each traveler is assigned to a route-mode option that: a) minimizes the traveler's generalized cost; and b) matches the traveler's mode preference options which are influenced by the willingness to car pool and to use transit.

As part of the model input, each origin-destination pair is assigned a value to represent the percentage of travelers who are willing to use transit (i.e., considering transit in their mode choice set either as pure mode or combined with private car) or carpool. An estimate of the willingness to use transit was obtained as the ratio between the number of transit travelers recorded in the DART on-board transit survey and the total number of travelers estimated for each origin-destination pair. During the scenario analysis, this methodology was deemed to be too conservative and did not allow travelers to consider transit during the unusual incident conditions with very long auto travel times. As such, the willingness to use transit was set to 100 percent to ensure that travelers that would benefit from shifting to transit would be able to.

Each origin-destination pair is also assigned a value to represent the percentage of travelers who are willing to car pool. The regional demand model provides information on the number of carpooling travelers who use the HOV facility, and number of carpooling travelers who do not use any HOV facility. As an estimate of the willingness to carpool, for an origin-destination pair, the sum of HOV and non-HOV users was first multiplied by the average car occupancy, and then divided by the total number of travelers for this pair. An average car occupancy of two persons per vehicle was assumed. Based on the DART survey, the average willingness to use transit was estimated at 44 percent. For origin-destination pairs that the DART survey did not provide estimates for, the willingness to use transit was set at 4 percent.[2] Based on these estimates and the regional model data, the average transit and carpool willingness were 5.8 and 21.5 percent, respectively.

Based on the willingness to use transit or carpool of a traveler, the following four sets of mode-route options are evaluated at five-minute intervals:

- **Set I –** Routes for SOVs (drive-alone);
- **Set II –** Routes for HOVs (carpool);
- **Set III –** Routes for park-and-ride (excluding carpool); and
- **Set IV –** Routes for transit (pure transit).

For example, if the traveler is not willing to use transit and not willing to carpool, then the traveler will choose a route from Set I. On the other hand, if the traveler is willing to use transit and not willing to carpool, then the traveler will choose from Sets I, III, or IV. Another case could be that the traveler is not willing to use transit but is willing to carpool, then the traveler will choose from Sets I or II.

For each traveler willing to carpool, a search for another traveler is made. This other traveler must satisfy the following conditions:

- Departing from the same origin zone;
- Departing within a given time window (10 minutes);
- Going to the same destination zone; and
- Willing to car pool.

This search is repeated until a maximum of four travelers is reached (i.e., capacity of the private car). If a match is found, this vehicle is marked as HOV, and the route set that includes the HOV facilities is made available as part of the choice set (Sets I and II). If a match is not found, the HOV route options are excluded and the other options are made available (Sets I, III, and IV). Currently, DIRECT does not model a drive-carpool option. As such, all travelers that are eligible to carpool are starting from the same origin node.

The travelers' mode and route choice is done simultaneously and is a function of the congestion evolution in the network. DIRECT utilizes a multiobjective shortest path algorithm coupled with an incremental all-or-nothing, rather than a dynamic user equilibrium (DUE), assignment. Travel times along a route are reflective of the link travel times when the traveler is generated (instantaneous travel

[2] The study area is subdivided in 235 zones and the DART survey provided information only for 4.5 percent out of the potential 55,225 OD pairs in the trip table.

times), rather than the link travel times at the time the traveler enters the link (experienced travel times). DIRECT loads each traveler to the shortest vehicular, transit, or park-and-ride path, calculated every five minutes according to the generalized cost function shown in Equation 1.\

$$Generalized\,Cost = Travel\,Time \times Value\ of\ Time + Travel\,Cost + Transit\,Cost \qquad \text{(Equation 1)}$$

Where:

Travel Time = The sum of in-vehicle time and out-of-vehicle time, where in-vehicle time is estimated from the simulation[3] and out-of-vehicle time (for transit users only) is a function of the transit service headway[4];

Value of Time = $12 per hour (cars) and $12 per hour (trucks);

Travel Cost = Sum of operating cost and toll (if any), where operating cost is $0.25 per mile, toll is $0.10 per mile; and

Transit Cost = $1 per ride.

The value of time and the travel and transit costs reflect global values based on NCTCOG's travel demand model documentation (1999 dollars) and were adjusted during the calibration of the DIRECT model to reflect the nature of travel within the U.S. 75 Corridor study area.

Based on this process, the actual number of travelers that use transit or carpool depends on the relative value of the generalized cost of the four potential mode-route options: drive alone (single-occupancy vehicle (SOV)), carpool (HOV), park-and-ride, and pure transit (with and without transfers). As such, in a scenario where the transit and carpool willingness may remain the same, the number of travelers that uses transit or carpool could also change.

At the end of the process, information on each generated traveler is saved in a text file (called the travelers file) describing the trip start time (loading time in the simulation) and the chosen mode and route. These mode-route choices reflect choices established over the long-term under normal (including recurring congestion) traffic conditions and are identified as "historical routes."

Figure 2-2 illustrates the modeling framework and the different components of DIRECT. Initial runs in DIRECT were completed for each demand conditions to establish a static population of travelers from the demand inputs from the NCTCOG demand model which were then used for each of the scenario runs. Each generated traveler is assigned a set of attributes, which includes his/her trip starting time, generation link, final destination, and a distinct identification number. In parallel, transit vehicles are generated according to a predetermined timetable and follow predetermined routes. Prevailing travel times on each link are estimated using the vehicle simulation component, which moves vehicles while capturing the interaction between autos and transit vehicles. DIRECT also utilizes other measures that may be used by travelers as criteria to evaluate the different mode-route options, including highway tolls, private car operation cost, transit fares, and out of vehicle time.

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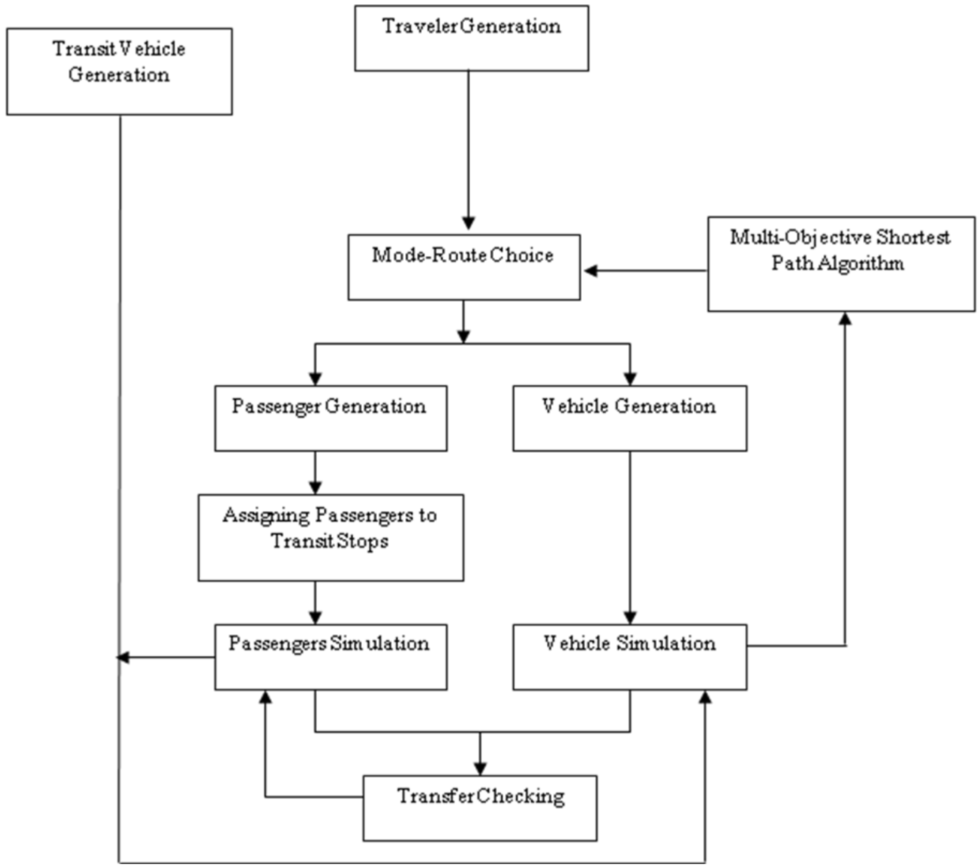
[3] Highway travel times reflect instantaneous travel times. Transit travel times are calculated by network segment and at key decision points in the corridor.

[4] Light rail runs on 10 minutes headway, while buses run on 30 minutes plus headways. Based on general modeling practices, the wait time for light-rail users was assumed to be 50 percent of the headway (i.e.; 5 minutes). For bus users though, a 15-minute wait time (50 percent of 30 minutes) was considered excessive, given that bus users in the Dallas area are aware of the schedules, especially commutes. As such, a wait time of 6 minutes was assumed for all bus users.

Figure 2-2. DIRECT Modeling Framework



Source: Southern Methodist University Transportation Research Laboratory, DIRECT Brochure (http://lyle.smu.edu/~khaled/DIRECT_bro.pdf) accessed 9/6/11.

These measures, along with travel time, are combined in a generalized cost formula utilized in a mode-route decision module activated at fixed intervals to provide travelers with a set of mode-route options. Travelers evaluate the different mode-route options and choose a preferred one. Based on the available options, a traveler may choose a “pure” mode or a combination of modes to reach his/her final destination.

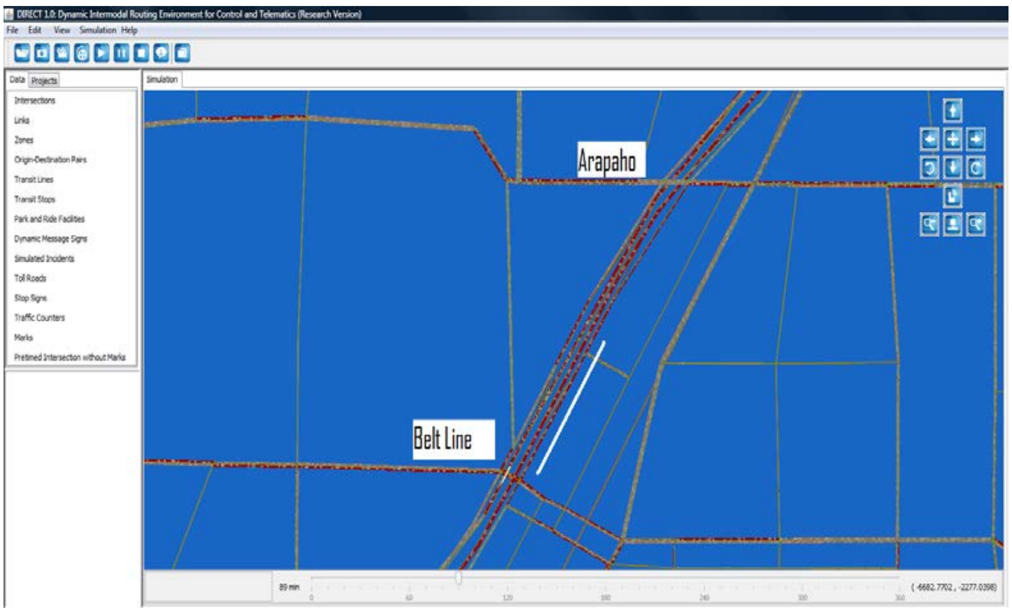
If a traveler chooses private car for the whole trip or part of it, a car is generated and moved into the network with a starting time equal to its driver starting time. Each newly generated vehicle is assigned an ID number that is unique to this vehicle. Vehicles are then moved in the network subject to the prevailing traffic conditions until they reach their final destinations or the next transfer node along the prespecified route (in the case of an intermodal trip).

If a traveler chooses a transit mode, he/she is assigned to a transit line such that the destination of this traveler is a node along the route followed by the bus line. If no single line is found or if the traveler is not satisfied with the available single line, the traveler is assigned to a path composed of two lines with one transfer node, such that the destination of the traveler is a node along the route followed by the second bus. When a transit vehicle arrives at a certain stop, all travelers waiting for a vehicle serving this specific line board this vehicle and head towards either their final destination or the next transfer node along their route.

Upon the arrival of a vehicle (private car or transit vehicle) to a certain destination node, this destination is compared to the final destinations of the travelers on board. If it matches the final destination of a traveler, the current time is recorded for this traveler as his/her arrival time. If they are different, the traveler transfers to the next transit line in his/her plan. The nearest stop is again determined and the traveler waits for his/her next transit vehicle. This process is continued until all vehicles reach their final respective destinations.

Figure 2-3 illustrates a sample of the DIRECT animation for the U.S. 75 Corridor study area.

Figure 2-3. Extracted DIRECT Subarea Network for ICM Corridor



Source: Screen capture of DIRECT software, Southern Methodist University, September 2008.

DIRECT uses the Greenshields flow model to relate speed, density, and flow on all links as shown in Equation 2. This formula generally describes traffic behavior, and is widely accepted and used in comparable traffic models.

$$V = \begin{cases} V_f * (1 - \frac{k}{K_{jam}})^{\alpha} & \text{if } k < K_{jam} \\ V_{\min} & \text{if } k \geq K_{jam} \end{cases}$$

Equation 2

Where:

V_f = Free-flow speed;

V_{min} = Minimum link speed;

K = Link density;

K_{jam} = Jam density; and

α = Speed-density curve shape term.

To better reflect operating conditions on freeways, the Dallas AMS team utilized research undertaken by Professors Sia Ardekani and Shiva Nepal of the Department of Civil Engineering at the University of Texas at Arlington.[5] This research, in conjunction with the Dallas AMS' team local traffic operations knowledge, provided the initial values indicated in Table 2-1 for the Greenshields model. Some of these values were adjusted during the calibration of the DIRECT model to reflect the nature of travel within the U.S. 75 Corridor study area.

Table 2-1. Initial Greenshields' Model Parameters

Parameter	Value
V_{min}	15 mph
V_f	62.8 to 76.6 mph
K_{jam}	120.8 to 137.7 veh/mile/lane

Analysis of Route and Mode Shift

Route and mode choices in the U.S. 75 Corridor are influenced by adverse traffic conditions (e.g., incidents or heavy demand) or ICM strategies (such as traveler information systems). The integrated mode-route choice in DIRECT utilizes the generalized cost function described in Equation 1 above to support comparison of multimodal alternatives. For example, travelers may choose to use transit instead of their vehicle, if they receive information before their departure from home and the transit option is more attractive (i.e., the generalized cost is lower). Alternatively, if they receive en-route information of an incident, they may decide to park their car at the nearest park-and-ride lot and switch to transit. Finally, they may choose to continue driving if they receive en-route information of an incident, and they are either close to their destination or it is determined that driving to the nearest park-and-ride lot would significantly increase their generalized cost.

During an incident, travelers follow their long-term established mode-route choices *("historical routes")* unless they encounter freeway/arterial congestion or receive and consider pretrip or en-route information that may identify a more attractive mode-route option compared to the *"historical route."* Pretrip information could be in the form of a TV announcement, an e-mail alert, or information provided by a web site. En-route information could be in the form of a radio announcement, a dynamic message sign (DMS), or live traffic updates via a Global Positioning System (GPS) receiver. Since the ICM strategies were assessed for future year (2011) conditions, the validated DIRECT model was run with an adjusted demand trip table reflecting anticipated background growth to identify established mode-route choices based on these future conditions. The mode-route choices resulting from this future run were identified as the *"historic routes"* for further evaluation of the ICM strategies. Since three future demand levels (low, medium and high) were tested, a traveler from a specific origin to a specific destination could potentially be associated with three "*historical routes.*" This approach reflects the notion that travelers are qualitatively associating weekdays with a certain demand level, therefore, establishing a long-term mode-route choice set that includes more than one option.

[5] Nepal, S. M., and S. A. Ardekani, "Traffic Flow Models for Freeway Operation," University of Texas at Arlington, October 2008.

During an ICM strategy assessment, travelers are loaded from the pertinent traveler file, which includes information related to the trip start time (loading time in the simulation) and their "*historical route.*" In addition, as part of the model input, travelers are associated with three mutually exclusive groups based on their degree of access to information: 1) no information (Group A); 2) pretrip information (Group B); and 3) en-route information (Group C).

Travelers with no-information follow their "*historical routes.*" Travelers with pretrip information have the option to update their routes and/or mode of transportation at the origin of their trips. Travelers with access to en-route information could receive updates through their devices at any node along their routes, including their trip origin. Therefore, a portion of them could be considered travelers with access to pretrip information as well. As such, for modeling purposes, Group B consider travelers with access to pretrip information ONLY, while Group C consider travelers that have access to pretrip, as well as en-route information.

In addition to the above, travelers on a freeway or arterial link consider changing their route if they perceive that they have encountered severe congestion, where severe congestion is defined as the density of either of the two links downstream of the vehicle's current position exceeding 80 percent of the link's jam density. These travelers are picked randomly among Groups A, B, and C and constitute Group R.

Finally, any traveler associated with Groups A, B, or C could pass a DMS and be eligible to respond to the available information. As such, travelers passing a DMS sign are picked randomly among Groups A, B, and C and constitute Group DMS.

The following paragraphs provide an overview of the diversion rules for each traveler group. It should be noted that travel times associated with "*nonhistorical routes*" are based on instantaneous travel times – these are travel times at the instance that travel time information is provided to travelers.

- **DMS Diversion –** This type of diversion is only applicable to travelers in Group DMS. Travelers responding to a DMS compare the generalized cost of the updated route, from the downstream node of the current link to the final destination, with the generalized cost of the corresponding section of the originally assigned route. Diversion occurs only if the generalized cost savings between the updated and originally assigned route, compared to the generalized cost of the originally assigned route, is more than 10 percent.
- **Pretrip Diversion –** This type of diversion is applicable to travelers in Group B. Travelers with access to pretrip information at their origin, compare the generalized cost of the suggested mode-route option to their destination with the generalized cost of their "*historical route.*" Diversion occurs only if the generalized costs savings between the updated and originally assigned route, compared to the generalized cost of the originally assigned route, is more than 10 percent.
- **En-Route Diversion –** This type of diversion is applicable to travelers in Group C. Travelers equipped to receive en-route information compare the generalized cost of the updated route, from the downstream node of the current link to the final destination, with the generalized cost of the corresponding section of the originally assigned route. Diversion occurs only if the generalized costs savings between the updated and originally assigned route, compared to the generalized cost of the originally assigned route, is more than 10 percent.
- **Congestion Diversion –** This type of diversion is only applicable to travelers in Group R. When the congestion diversion is triggered, the shortest freeway or arterial path (based on travel time and the current interval shortest path calculation) initiating from the first

downstream exit (ramp or intersection) is assigned to the traveler. As such, Group R travelers' decisions are neither multimodal nor comparative.

The priority of compliance for route diversion is as follows: 1) DMS, then 2) en-route, and 3) congestion. For example, at a DMS location, if a traveler belongs to Group C, Group R, and Group DMS, it is assumed that the traveler will follow the DMS diversion rule.

In order for DIRECT to account for traveler information and model the above diversion rules correctly, each traveler with pretrip or en-route information is associated with two parameters: awareness and use. *Awareness* indicates that a traveler has access to the information (pretrip or en-route), while *use* indicates that a traveler is willing to act based on the information. Willingness does not necessarily result in an action, unless the proposed mode-route option is more attractive than the *"historical route,"* based on the diversion rules discussed above. Therefore, *use* reflects an upper bound on the percent of travelers who might divert as a response to the information, with the actual percentage dependant on the attractiveness of the new route and referred to as compliance. As an example, if 20 percent of travelers have access to pretrip information (*awareness*) and of that subgroup, 15 percent are willing to act on that information (*use*), then the maximum compliance would be 3 percent of the total traveler population.

While DMS is a form of en-route information, it presents a special case in the current version of DIRECT, where *awareness* and *use* are collapsed under the *use* parameter (i.e., it is assumed that 100 percent of the travelers have access to the information presented in the DMS).

Chapter 3 Analysis Scenarios and ICM Strategies

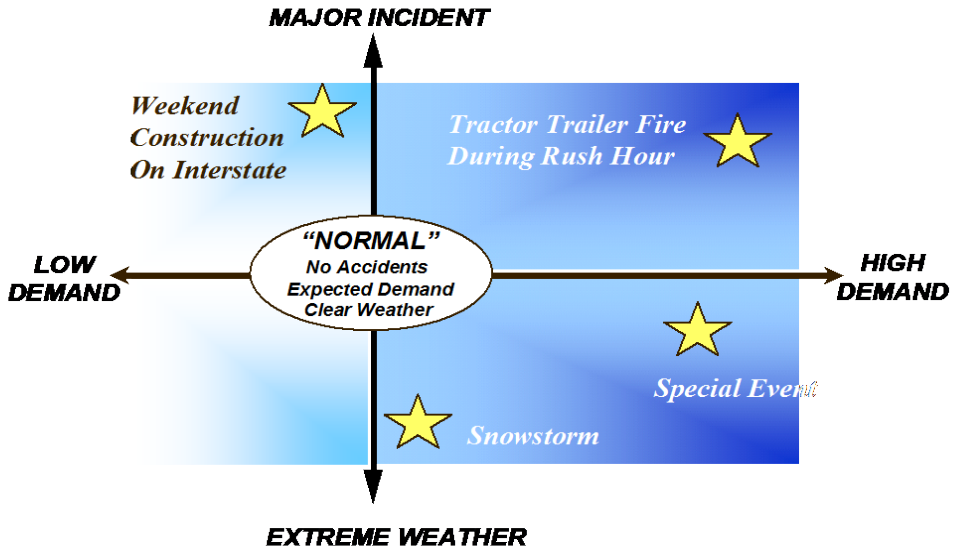
This section provides an overview of priority ICM strategies for the U.S. 75 Corridor, and the scenarios that were studied to analyze the impacts of these strategies. The analysis will assist local agencies to:

- **Invest in the right strategies –** The analysis offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions;
- **Invest with confidence –** AMS will allow corridor managers to "see around the corner" and discover optimum combinations of strategies, as well as conflicts or unintended consequences inherent in certain combinations of strategies that would otherwise be unknowable before implementation;
- **Improve the effectiveness/success of implementation –** With AMS, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful; and
- AMS provides a long-term capability to corridor managers to **continually improve implementation** of ICM strategies based on experience.

Analysis Scenarios

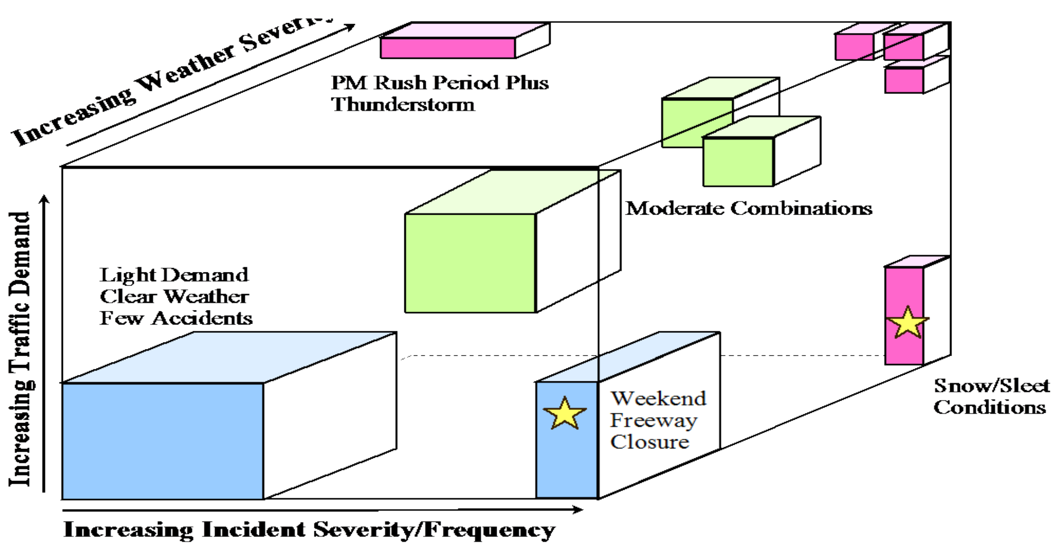
The U.S. 75 Corridor's nonrecurrent congestion scenarios entail combinations of increases of demand and decreases of capacity. Figure 3-1 depicts how key ICM impacts may be lost if only "normal" travel conditions are considered; the proposed scenarios take into account both average and high travel demand, with and without incidents. The relative frequency of nonrecurrent conditions also is important to estimate in this process – based on archived traffic conditions, as shown in Figure 3-2.

Figure 3-1. Key ICM Impacts May be Lost if Only "Normal" Conditions are Considered



Source: Wunderlich, Karl E., Incorporating Intelligent Transportation Systems into Planning Analysis: Summary of Key Findings From a 2020 Case Study - Improving Travel Time Reliability With ITS. This document is available at the RITA NTL (http://ntl.bts.gov/lib/jpodocs/repts_te/13605.html), May 2002.

Figure 3-2. Sources of System Variation – Classifying Frequency and Intensity



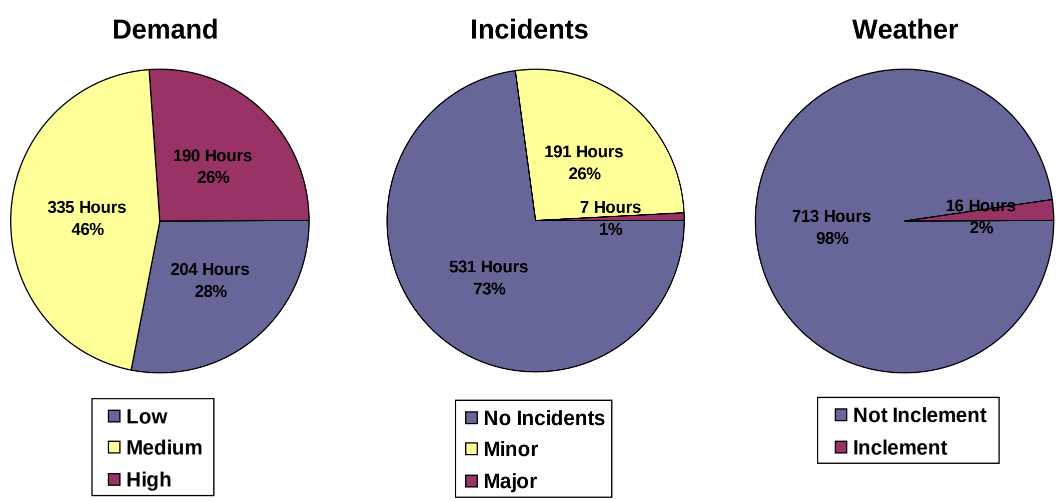
Source: Wunderlich, Karl E., Incorporating Intelligent Transportation Systems into Planning Analysis: Summary of Key Findings From a 2020 Case Study - Improving Travel Time Reliability With ITS. This document is available at the RITA NTL (http://ntl.bts.gov/lib/jpodocs/repts_te/13605.html), May 2002.

The Dallas AMS team conducted a cluster analysis to examine the impacts of demand, incidents, and weather conditions on travel, with an overall objective of determining the percent of "normal" days. The analysis focused on the AM peak period because ICM strategies are likely to be more effective during the AM peak, and limited resources prevented the analysis of both AM and PM peak periods. The analysis examined year 2007, weekday hourly travel data from 6:00 AM to 9:00 AM, on southbound U.S. 75 excluding days where detectors produced incomplete or insufficient data (e.g., the detector was malfunctioning or data was not available for all hours working, etc.). The following definitions were established for the basis of conducting the cluster analysis:

- **Travel Demand –** High demand is defined as greater than 7,500 vph; medium demand is between 6,900 and 7,500 vph; and low demand is less than 6,900 vph.
- **Incidents –** A major incident is defined as two or more general-purpose lanes affected, while a minor incident is defined as one general-purpose lane (or one general-purpose lane and shoulder) affected.
- **Weather –** Inclement weather is defined as raining more than 0.1 inch per hour, or having conditions of ice or snow.

The results of the cluster analysis are shown in Figure 3-3 and Table 3-1. Figure 3-3 illustrates the individual impacts of demand, incidents, and weather conditions on weekday morning peak-period travel on southbound U.S. 75, while Table 3-1 shows the cumulative impacts of these conditions.

Figure 3-3. Cluster Analysis for U.S. 75 Dallas – Southbound Direction



NOTES
Cluster analysis conducted for Year 2007, Weekday, 6:00-9:00 am, Southbound direction only
Historical weather data obtained from www.weatherunderground.com
Incident and demand data obtained from DalTrans Traffic Management Center
Incident data includes accidents, minor breakdowns, debris, etc.

Source: DalTrans Traffic Management Center, July 2010.

Table 3-1. Distribution of Operating Conditions in U.S. 75 Dallas

Demand	Incident	Inclement Weather	Number of Hours	Percent
Med	No	No	247	33.9%
Low	No	No	136	18.7%
High	No	No	134	18.4%
Med	Minor	No	79	10.8%
High	Minor	No	55	7.5%
Low	Minor	No	55	7.5%
Low	No	Yes	9	1.2%
Med	No	Yes	5	0.7%
Med	Major	No	4	0.5%
Low	Major	No	2	0.3%
Low	Minor	Yes	2	0.3%
High	Major	No	1	0.1%
Med	Minor	Yes	0	0.0%
High	No	Yes	0	0.0%
High	Minor	Yes	0	0.0%
High	Major	Yes	0	0.0%
Med	Major	Yes	0	0.0%
Low	Major	Yes	0	0.0%

In the ICM Concept of Operations (ConOps) report, the Dallas AMS team identified a variety of scenarios to illustrate the impacts of full ICM implementation. The scenarios reflect major or minor incidents on the freeway and arterial network within the ICM Corridor study, as well as special situations such as a special event (e.g., Texas State Fair) and an inclement weather event. Modeling the AM inbound peak period is not conducive to modeling special event scenarios, since the special events that attract large volumes of traffic arriving at a fixed start time are almost always in the evening or afternoon (with some rare exceptions). Furthermore, travel demand patterns during special events could be drastically different compared to normal weekday peak-period patterns, and currently there is no such data available for special events.

In addition, in terms of weather events, the year 2007 cluster analysis undertaken for the morning peak period for U.S. 75 found that very few days included inclement weather (i.e., approximately two percent). Therefore, in the interest of dedicating modeling time where it would be most efficient, the Dallas AMS team decided to exclude special event and weather-related scenarios from the AMS efforts. Table 3-2 summarizes the revised cluster analysis.

Table 3-2. Revised Distribution of Operating Conditions in U.S. 75 Dallas

Demand	Incident	Number of Hours	Percent
Med	No	252	34.6%
Low	No	145	19.9%
High	No	134	18.4%
Med	Minor	79	10.8%
Low	Minor	57	7.8%
High	Minor	55	7.5%
Med	Major	4	0.5%
Low	Major	2	0.3%
High	Major	1	0.1%

During a meeting of the U.S. Department of Transportation (DOT) and the Dallas AMS team, it was requested for the purposes of the study, that the remaining scenarios and their associated strategies be ranked from low to high priority. Based on this exercise, the following scenarios and their associated probability of occurrence were identified for analysis:

- **Daily Operations (No Incident) – High Demand –** This scenario with good weather and no incidents represented approximately 18.4 percent of the morning peak-period hours of year 2007. High demand was defined as a volume of greater than 7,500 vehicles per hour in the peak direction (four lanes of capacity in the peak direction).
- **Daily Operation (No Incident) – Medium Demand –** This scenario represented 34.6 percent of the morning peak-period hours of year 2007.
- **Daily Operation (No Incident) – Low Demand –** This scenario represented 19.9 percent of the morning peak-period hours of year 2007.
- **Minor Freeway Traffic Incident – High Demand –** This scenario represented 7.5 percent of the morning peak-period hours of year 2007. A minor incident was defined as an incident that closed one freeway lane, and impacted traffic operations for less than one hour.
- **Minor Freeway Incident – Medium Demand –** This scenario represented 10.8 percent of the morning peak-period hours of year 2007. A minor incident was defined as an incident that closed one freeway lane, and impacted traffic operations for less than one hour.
- **Minor Freeway Incident – Low Demand –** This scenario represented 7.8 percent of the morning peak-period hours of year 2007. A minor incident was defined as an incident that closed one freeway lane, and impacted traffic operations for less than one hour
- **Major Freeway Traffic Incident – High Demand –** This scenario represented less than 1 percent of the morning peak-period hours of year 2007. A major incident was defined as an incident that closed two or more freeway lanes, and impacted traffic operations for an hour or more.
- **Major Freeway Incident – Medium Demand –** This scenario represented less than 1 percent of the morning peak-period hours of year 2007. A minor incident was defined as an incident that closed one freeway lane, and impacted traffic operations for less than one hour.

- **Major Freeway Incident – Low Demand –** This scenario represented less than 1 percent of the morning peak-period hours of year 2007. A major incident was defined as an incident that closed two or more freeway lanes, and impacted traffic operations for an hour or more.

In addition, the Dallas AMS team was interested in examining two different incident locations under the minor incident scenario and two different incident severities (i.e., number of lanes blocked) under the major incident scenario. Incident locations were selected based on highest occurrence of actual incidents on U.S. 75. The matrix shown in Table 3-3 summarizes the freeway operating scenarios modeled, along with their characteristics and associated probabilities. The sum of the freeway operating scenario probabilities is 100 percent, and it was assumed that the probability for a minor incident with medium or high demand is the sum of the probabilities for this type of incident at two locations. Similarly, the probability for a major incident with medium or high demand is the sum of the probabilities for this type for two operating conditions (i.e., two lanes versus three lanes blocked).

Table 3-3. Revised Distribution of Operating Conditions in U.S. 75 Dallas

	No Incident			Minor Incident					Major Incident				
Demand	**Low**	**Med**	**High**	**Low**	**Med**	**Med**	**High**	**High**	**Low**	**Med**	**Med**	**High**	**High**
Scenario No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Incident Duration	NA	NA	NA	45 min	45 min	45 min	45 min	45 min	1 hour	1 hour	1 hour	1 hour	1 hour
No. of Lanes Blocked	NA	NA	NA	1	1	1	1	1	3	2	3	2	3
Incident Location	NA	NA	NA	Belt Line Road	Belt Line Road	Forest Lane	Belt Line Road	Forest Lane	Belt Line Road	Belt Line Road	Belt Line Road	Belt Line Road	Belt Line Road
Incident Start Time	NA	NA	NA	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM
Probability	19.9%	34.6%	18.4%	7.8%	5.4%	5.4%	3.75%	3.75%	0.3%	0.25%	0.25%	0.05%	0.05%

ICM Strategies

Travelers have multiple possible responses to congestion and mitigating ICM strategies: route diversion, temporal diversion, mode change, changing travel destination, or canceling their trip are some of these traveler responses. The U.S. 75 Corridor will have a number of ICM strategies in operation in the near future, and the Analysis Plan took that into account. The base year for model development reflected year 2007 operating conditions (which did not include HOV operations). All ICM scenarios modeled used information for year 2011, and included the HOV lane as part of the pre-ICM conditions.

The following list identifies the strategies associated with the high-priority scenarios, while Table 3-4 identifies their applicability with each of the abovementioned scenarios:

- Comparative travel time information (pretrip and en-route);
- Incident signal retiming plans for arterials;
- Incident signal retiming plans for frontage roads;
- Light-Rail Transit (LRT) smart parking system;
- Red Line capacity increase;
- LRT station parking expansion (private parking); and
- LRT station parking expansion (valet parking).

A key in implementing any ICM strategy is disseminating good quality, comparative travel time data to each of the ICM partner agencies. The stakeholders in the ICM Corridor are implementing a data sharing tool that will allow for real-time dissemination of incident information and comparative travel time information for freeways, frontage roads, arterials, and LRT lines. This will initially be deployed as a stand-alone application that each transportation management center will run.

The strategies listed above are discussed in more detail in the ensuing sections. Appendix A provides additional details reflecting pre- and post-ICM implementation for each ICM strategy.

Table 3-4. Summary ICM High Priority Strategies for U.S. 75

Scenario	Daily Operations – No Incident			Minor Incident			Major Incident		
Demand	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**
Traveler Information									
Comparative, multimodal travel time information (pretrip and en-route)	●	●	●	●	●	●	●	●	●
Traffic Management									
Incident signal retiming plans for frontage roads[1]					●	●	●	●	●
Incident signal retiming plans for arterials[2]					●	●	●	●	●
Managed Lanes									
HOV lane[3]	○	○	○	○	○	○	○	○	○
Light-Rail Transit Management[4]									
Smart parking system								●	●
Red line capacity increase								●	●
Station parking expansion (private parking)								●	●
Station parking expansion (valet parking)								●	●

Notes:
[1] The frontage road retiming plan was run as an individual traffic management strategy for minor incidents.
[2] The traffic management strategies (frontage road timing and arterial timing) are combined and were not run as separate strategies for a major incident.
[3] HOV lane 2+ currently is in operation, thus is not considered an ICM strategy, but was part of all scenarios.
[4] The LRT Smart Parking System strategy was always conducted with the other three transit management strategies. Private and valet parking expansion were not implemented as a combined strategy.
L = Low; M = Medium; and H = High.

Traveler Information

Comparative Travel Times (Mode and Route)

Multimodal information dissemination included travel time comparisons for freeway, arterial, and transit to provide travelers with information on the best routes and modes. The information also included park-and-ride availability. As a result, more travelers were able to choose the best option (alter route, mode, and departure time) that reflected the optimal path. The comparative travel time information was distributed pretrip and en-route.

Pretrip Traveler Information

Pretrip information includes any traveler information accessible to the public that could be used in planning trip routes, estimating departure times, and/or choosing a travel mode. Such information can be available through the agency web sites, a 511 system, public access television (TV), local radio, and other media. The analysis captured the impacts of such information on traveler's route choice, departure times, and/or choice of travel mode.

Based on the 2005 Perception Tracking survey conducted in Minneapolis, 61 percent of travelers were aware of pretrip information and 15 percent made use of it. Given that limited data exist on the percentage of U.S. 75 travelers who access such information and are willing to act on it (i.e., divert from their "historical routes") prior to making their trips, the Dallas AMS team utilized awareness and use values similar to the Minneapolis study. The ITS system in the U.S. 75 corridor is still in development, thus the Dallas AMS team used 60 percent *awareness* and 10 percent *use* of pretrip information for the pre-ICM scenarios. In the future, the Dallas AMS team expects *awareness* to increase as 511 and more valuable traveler information is deployed (i.e., comparative travel times). Therefore, the Dallas AMS team used 80 percent *awareness* and 20 percent *use* of pretrip information for post-ICM scenarios. Travelers with pretrip information had the capability to update their routes only at the origin of their trips. As such, the generalized cost of the available mode-route options was calculated at the beginning of their trip, and if an option was more attractive compared to the "historical route," that option was selected.

Given the relationship in DIRECT of travelers with access to pretrip and en-route information (previously discussed), 10 percent (out of the 60 percent) in the pre-ICM scenario were considered travelers with access to pretrip information ONLY (Group B). The remaining 50 percent reflected travelers that have access to en-route information also (Group C). For the post-ICM scenario, the corresponding percentages were 20 and 60 percent for Groups B and C, respectively.

En-Route Traveler Information

One of the ICM strategies is to proactively disseminate en-route information via 511, radio/TV, agency Internet sites, smart phones, etc. Discussions with U.S. DOT and the Dallas AMS team revealed a need to model the impact of en-route information available to drivers to assess two major issues:

- **Change in Route Choice –** This relates to real-time change in route choice of drivers based on travel time or congestion updates they receive via radio, 511, GPS devices or information provided by a DMS sign.
- **Change in Mode En-Route –** The possibility of changing mode while en-route has potential on the U.S. 75 Corridor, considering that there are a number of park-and-ride facilities. An SOV traveler may receive en-route traveler information of congested conditions on U.S. 75 and park-and-ride availability at the stations along the DART Red line. DMS message information may be simple with incident information and which park-and-ride station to use, while other media may provide more detail about the incident, actual number of park-and-ride lots spaces available, and comparative travel time information.

En-route information is provided by either a DMS sign or traveler information media that can range from radio to GPS devices. The 2005 Minneapolis Perception Tracking survey indicated that 72 percent of the drivers have seen a sign (awareness), but only 29 percent alter their route based on the available information (use). For DMS analysis, the Dallas AMS team utilized 60 and 75 percent awareness and a use of 20 and 30 percent for the pre-ICM and post-ICM scenarios, respectively. Since there was no data related to en-route traveler information media, the Dallas team utilized 50-percent awareness and 20-percent use for the pre-ICM scenarios. For the post-ICM scenarios, awareness increased to 60 percent and use to 30 percent. These awareness percentages are consistent with the discussion above related to travelers with pretrip information.

Incident Signal Retiming

As part of the ICM deployment, the various stakeholders will develop ‘flush’ signal timing plans to increase arterial capacity by approximately 15 percent and decrease arterial travel time during an incident. The approximate 15 percent increase in capacity was reflected in DIRECT in the form of signal retiming. Southbound phases had the green time phases increased to allow for more capacity along those routes.

Frontage Road Signal Retiming

For a minor incident, signal retiming adjustments may suffice on the frontage roads only. By giving more green time to the southbound movements on the frontage road, freeway travelers can detour to the frontage road upstream of an incident and return to the freeway downstream of the incident. As such, the retiming of the frontage road signals was considered by itself without the retiming of the arterial streets.

Arterial Street Signal Retiming/Coordination

In addition to the frontage road signal retiming, signal retiming and signal coordination to a strategic arterial may increase corridor capacity. The stakeholders identified Greenville Avenue as the primary arterial for diverted freeway traffic, since it runs parallel to U.S. 75 for nearly the entire length of the freeway corridor and it is also the closest major arterial with available capacity. This strategy was always run in combination with the frontage road signal retiming, and included increasing green time to the southbound movements along Greenville Avenue. Signal offsets were also adjusted, as needed and where warranted.

Managed Lanes

As outlined in the U.S. 75 Analysis Plan, there was interest in examining the role of managed lanes in the corridor. These included examination of operating the current HOV 2+ operation on U.S. 75 under a congestion pricing HOT/HOV scheme with either static or dynamic tolling and under an express toll operation, in which HOV 2 vehicles pay one-half of the toll paid by the SOVs, and HOV 3+ travel in the managed lane for free.

Since the managed lanes operations are not considered an ICM strategy, they were excluded from the analysis presented in Chapter 6. As such, all pre- and post-ICM scenarios considered only the current HOV 2+ operation.

Parking Availability at Red Line Park-and-Ride Lots

For the mode shift strategies, parking at the Red Line Light Rail (LRT) park-and-ride lots is critical to encourage changes in travelers’ behavior. The DART park-and-ride lots toward the north end of the Red Line have been in past years at capacity, with station parking often taking place on adjacent city streets. However, DART recently expanded the Parker Road and the President George Bush Turnpike (PGBT) stations, which will provide needed capacity for future ICM strategies. There were three strategies implemented related to parking at these park-and-ride lots.

Smart Parking

The first parking strategy was to implement Smart Parking systems at each of the DART park-and-ride lots on the Red Line along U.S. 75. This is a basic system that continuously collects vehicle counts entering and leaving the lot, and records the number of parking spots available. By disseminating information regarding park-and-ride lot availability, traveler's confidence in transit is expected to increase, and potential modal shifts may occur during incidents. DMS message information will indicate which park-and-ride station to use. Internet, TV, and radio information may include more detail about the actual number of park-and-ride lots spaces available at each station. In DIRECT, the parking lot capacity was kept at five percent below the actual lot capacity in the pre-ICM scenarios, since currently, lot operators try to keep a buffer of spaces to make sure everyone has enough spaces. When the lot reaches this threshold, paths with park-and-ride are not allowed. With ICM and Smart Parking, DIRECT allows the lot to reach full capacity before the park-and-ride lot paths are excluded from the route and mode selection. Since this strategy augments the other parking strategies, it was always used in combination with one of the other two parking strategies.

Private Parking

The second strategy was to implement station parking expansion by forming public-private partnerships with parking owners near DART LRT stations. Under this scenario, DART will establish agreements with these private parking owners for use of their parking facilities, either on a daily basis or during peak parking times. By utilizing this private overflow parking, more transit passengers can be accommodated at the stations. DART will need to provide shuttle service from these private lots to the LRT stations. Modeling of this strategy consisted of an additional 250 parking spaces in the post-ICM scenario at the PGBT park-and-ride lot, including a 10-minute time penalty for those 250 additional spaces to account for the transfer time from the expansion lot to the LRT station.

Valet Parking

The third strategy was to implement station parking expansion with valet service for parking. This is a service that has been introduced at the DFW International Airport. Within the U.S. 75 Corridor, the plan consists of implementing the service at one of the strategic park-and-ride lots (i.e., PGBT Station). Valet parking service would reduce the transfer time at the station, and increase the utility of using LRT transit for mode-shift strategies. As modeled in the post-ICM scenarios, an additional 250 spaces were provided at the PGBT park-and-ride lot, without any additional transfer penalty as seen in the private parking strategy.

Red Line Capacity Increase

DART has the capability of adding capacity to the Red Line through additional train cars or through decreased headways. Under major corridor incidents, it may be beneficial to decrease headways of the Red Line to increase the person carrying capacity of the LRT system. Modeling of this ICM strategy consisted of decreasing headways on the Red Line from 10 minutes (pre-ICM) to 7.5 minutes (post-ICM).

Summary of Analysis Settings

The goal of the ICM alternatives analysis for the U.S. 75 Site was to determine under which incident and demand conditions a given strategy has the potential to benefit the corridor. Thus, the analysis settings revolved around severity and location of an incident under various demand settings. The number of ICM strategies and scenarios involved in the Analysis Plan made it imperative to analyze only one peak period in order to stay within the schedule and budget constraints. Based on discussions between the U.S. DOT AMS team and the Dallas team, the AM peak period was selected for analysis.

The Dallas AMS team considered how the strategies should be coordinated to provide the greatest impact on the U.S. 75 corridor. Under traveler information strategies, there is only one strategy of offering comparative travel times. The comparative travel time strategy was run isolated and in conjunction with other traffic management and transit management strategies.

Under the traffic management strategies, alternate timing plans were investigated for both the U.S. 75 frontage roads and Greenville Avenue, which is a strategic arterial. Under a minor incident, the stakeholders were interested in how a strategy with just frontage roads compares to a strategy with both frontage roads and Greenville Avenue to improve corridor operations. For a major incident, it was assumed that both strategies are needed; and thus, the traffic management scenarios always included both frontages roads and Greenville Avenue.

Under transit management strategies, there were four strategies. The LRT Smart Parking System strategy is a foundational element that provides information on parking availability; and thus always was paired with the other three transit management strategies. The Dallas AMS team was interested in the benefits of adding LRT capacity, private parking, and valet parking. Each of these three strategies was tested individually in conjunction with the Smart Parking System. One combined transit management strategy included adding LRT capacity and private parking along with the Smart Parking System. The private parking was selected over the valet, because it is perceived to have lower operation and maintenance costs to the transit agency. Private and valet parking expansion are considered mutually exclusive, and were not implemented as a combined strategy.

Chapter 4 Performance Measures

This section provides an overview of the performance measures used in the evaluation of ICM strategies for the U.S. 75 Corridor. To be able to compare different investments within a corridor, a consistent set of performance measures were applied. These performance measures:

- Provide an understanding of traffic conditions in the study area;
- Demonstrate the ability of ICM strategies to improve corridor mobility, throughput, and reliability, based on current and future conditions; and
- Help prioritize individual investments or investment packages within the U.S. 75 Corridor for short- and long-term implementation.

In the Concept of Operations, the Dallas AMS team defined four overall goals for the U.S. 75 ICM initiative, as summarized below.

- **Goal 1. Increase corridor throughput –** The U.S. 75 ICM initiative will optimize the overall throughput of the corridor by managing delays on a corridor basis, utilizing any spare capacity within the corridor, and coordinating the junctions and interfaces between networks.
- **Goal 2. Improve travel time reliability –** The transportation agencies within the corridor will provide a multimodal transportation system that adequately meets customer expectations for travel time predictability.
- **Goal 3. Improve incident management –** Provide a corridor-wide and integrated approach to the management of incidents, events, and emergencies that occur within the corridor; or that otherwise impact the operation of the corridor, including planning, detection and verification, response, and information sharing, such that the corridor returns back to "normal."
- **Goal 4. Enable intermodal travel decisions –** Travelers must be provided with a holistic view of the corridor and its operation through the delivery of timely, accurate, and reliability multimodal information, which then allows travelers to make informed choices regarding departure time, mode, and route of travel.

Based on the goals identified by the Dallas AMS team and the objectives of the U.S. DOT ICM project, a set of performance measures were developed to assess the various scenarios and strategies. The performance measures focus on the following four key areas:

- **Mobility –** Describes how well the corridor moves people and freight;
- **Reliability and Variability –** Captures the relative predictability of the public's travel time; and,
- **Emissions and Fuel Consumption –** Captures the impact on emissions and fuel consumption.

U.S. DOT, in collaboration with the Pioneer sites and Cambridge Systematics, developed guidance for mobility and reliability performance measures utilizing outputs from the simulation models. The following sections provide an overview of the areas the selected performance measures will address, while Appendix B provides the U.S. DOT guidance.

Mobility

Mobility describes how well the corridor moves people and freight. The mobility performance measures are readily forecast. Three primary types of measures were used to quantify mobility in the U.S. 75 Corridor, including the following:

- **Travel time –** This is defined as the average travel time for the entire length of the corridor or segment within a study corridor by facility type (e.g., general purpose lanes, HOV lanes, local streets, and transit) and by direction of travel. Travel times are computed for the peak period. Travel time is reported both in terms of vehicle-hours and person-hours of travel.
- **Delay –** This is defined as the total observed travel time less the travel time under uncongested conditions, and is reported both in terms of vehicle-hours and person-hours of delay. Delays are calculated for freeway mainline and HOV facilities, transit, and surface streets.
- **Throughput** – This is defined as both vehicle and person per hour by direction. The measure is reported for both the freeway (general-purpose lanes, HOV, and frontage roads) and for the entire corridor (general-purpose lanes, HOV, frontage roads, strategic arterials, and LRT line).

Reliability and Variability of Travel Time

Reliability and variability capture the relative predictability of the public's travel time. Unlike mobility, which measures how many people are moving at what rate, the reliability/variability measures focus on how mobility varies from day to day. For the U.S. 75 Corridor, travel time reliability/variability was calculated using the simulation models by performing multiple model runs for all scenarios. Appendix B describes the methodology used in calculating reliability and variability impacts. Travel time reliability/variability is reported in terms of changes in the Planning Index and changes in the standard deviation of travel time. Both performance measures are defined and explained in the U.S. 75 Analysis Plan.

Emissions and Fuel Consumption

The U.S. 75 Corridor AMS also produced estimates of emissions and fuel consumption associated with the deployment of ICM strategies. This was done by utilizing IDAS methodology, which incorporates reference values to identify the emissions and fuel consumption rates based on variables such as facility type, vehicle mix, and travel speed. The emissions and fuel consumption rates were based on the California Air Resources Board's EMFAC 2007. Emissions and fuel consumption was then monetized using costs per ton of pollutants released and the purchase price of fuel for use in the benefit/cost analysis. These costs are defined and explained in the U.S. 75 Analysis Plan.

Safety

While the Analysis Plan identifies safety as one of the performance measures to be produced by the analysis, it has become apparent that available safety analysis methodologies are not sensitive to ICM strategies. The best available safety analysis methods rely on crude measures such as V/C and cannot take into account ICM effects on smoothing traffic flow. Clearly, this is an area deserving new research. As such, the analysis results presented in this report do not include safety as one of the performance measures.

Cost Estimation

For the identified ICM strategies, planning-level cost estimates were prepared, including life-cycle costs (capital, operating, and maintenance costs). Costs were expressed in terms of the net present value of various components and are defined as follows:

- **Capital Costs –** Includes up-front costs necessary to procure and install ITS equipment. These costs are shown as a total (one-time) expenditure, and include the capital equipment costs, as well as the soft costs required for design and installation of the equipment.
- **Operations and Maintenance (O&M) Costs –** Includes those continuing costs necessary to operate and maintain the deployed equipment, including labor costs. While these costs do contain provisions for upkeep and replacement of minor components of the system, they do not contain provisions for wholesale replacement of the equipment when it reaches the end of its useful life. These O&M costs are presented as annual estimates.
- **Annualized Costs –** Represent the average annual expenditure that is expected in order to deploy, operate, and maintain the ICM improvement; and replace (or redeploy) the equipment as they reach the end of their useful life. Within this cost figure, the capital cost of the equipment is amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual O&M cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of the ICM deployments.

Local Measures

The Dallas AMS team was interested in estimating the increase in transit ridership on the Red Line in scenarios where mode shift is promoted. The Red Line LRT transit is the only viable option for carrying the growth in travel in the U.S. 75 Corridor. The additional ridership was calculated as the difference in ridership between the pre-ICM run and the corresponding post-ICM run.

Lastly, the stakeholders were interested in the parking utilization at Red Line stations. However, there were three strategies that will affect parking: 1) comparative traveler information with available parking from the smart parking system; 2) station parking expansion with private lots; and 3) station parking expansion with valet parking. The stakeholders were interested in the impacts on parking for each of these different strategies. Similar to ridership, the additional parking utilization was calculated as the difference in utilization between the pre-ICM run and the corresponding post-ICM run.

Chapter 5 Model Calibration

Accurate calibration is a necessary step for proper simulation modeling. Before modeling ICM strategies, model calibration ensures that base scenarios represent reality, creating confidence in the scenario comparison. Before ICM strategies were analyzed, the U.S. 75 team, U.S. DOT, and Cambridge Systematics agreed upon the validation/calibration criteria that should be met in the modeling effort. The highway model validation/calibration criteria are shown in Table 5-1.

Table 5-1. Highway Model Validation and Calibration Criteria for the ICM Corridor AMS

Validation Criteria and Measures	Acceptance Targets
Traffic flows within 15% of observed volumes for links with peak-period volumes greater than 2,000 vph	For 85% of cases for links with peak-period volumes greater than 2,000 vph
Sum of all link flows	Within 5% of sum of all link counts
Travel times within 15%	>85% of cases
Visual Audits *Individual Link Speeds: Visually Acceptable Speed-Flow Relationship*	To analyst's satisfaction
Visual Audits *Bottlenecks: Visually Acceptable Queuing*	To analyst's satisfaction

Because of the strong transit presence in the U.S. 75 corridor and DIRECT's multimodal modeling capability, a set of validation and calibration criteria was established for the transit component of the analysis and modeling. These criteria are shown in Table 5-2.

Table 5-2. Transit Model Validation and Calibration Criteria for U.S. 75 ICM Dallas

Validation Criteria and Measures	Acceptance Targets
Light-rail station volumes within 20% of observed volumes	For 85% of cases
Light-rail park-and-ride lots	
Parked cars in each lot	Within 30%
Total parked cars for all lots combined	Within 20%

The following section summarizes the model calibration and validation approach and results. Details of the model calibration are available in the separate report titled *Integrated Corridor Management U.S. 75 Dallas, Texas, Model Validation and Calibration Report*.

Simulation Model Calibration

Each simulation software program has a set of user-adjustable parameters that enable the practitioner to calibrate the software to better match specific local conditions. These parameter adjustments are necessary because no simulation model can include all of the possible factors (both on- and off-street) that might affect capacity and traffic operations. The calibration process accounts for the impact of these “unmodeled” site-specific factors through the adjustment of the calibration parameters included in the software for this specific purpose. Therefore, model calibration involves the selection of a few parameters for calibration and the repeated operation of the model to identify the best values for those parameters. Calibration improves the ability of the model to accurately reproduce local traffic conditions. The key issues in calibration are the following:

- Identification of necessary model calibration targets;
- Selection of the appropriate calibration parameter values to best match locally measured street, highway, freeway, and intersection capacities;
- Selection of the calibration parameter values that best reproduce current route and mode choice patterns; and
- Validation of the overall model against overall system performance measures, such as travel time, delay, and queues.

Calibration Approach

The U.S. 75 team followed the approach outlined below to validate and calibrate the DIRECT model for the U.S. 75 corridor. Selected steps are described in more detail in later sections. Some steps were performed simultaneously, while others were performed iteratively until the best results were achieved.

- The first step was to import the roadway network from the regional macroscopic travel demand model. A geometry check was performed to ensure correct lane configurations and traffic signal locations.
- The AM peak-period, origin-destination trip table (6:30-9:00 AM Peak) was extracted from the regional travel demand model for the U.S. 75 Corridor study area. For modeling purposes, this trip table was expanded to reflect the desired 5:30-11:00 AM simulation period.
- After development of the trip tables and networks, the validation and calibration process was initiated. Several metrics were used to evaluate the model’s performance, including screenline volumes, speed and flow rate profiles, and congestion patterns and bottleneck locations.
- In addition to the year 2007 baseline model calibration, a “known incident” scenario was evaluated to test the sensitivity of the DIRECT model to a major incident along U.S. 75.

The model validation and calibration was performed with the year 2007 network, which did not include the U.S. 75 high-occupancy vehicle (HOV) lanes that opened in 2008. An additional test was performed that included the HOV lanes with the previously calibrated network to validate how DIRECT handles mode choice and assignment with an HOV lane. Slight increases in demand were made to the travel demand to account for growth between years 2007 and 2008.

Model Calibration Results

This section summarizes the model validation and calibration results of the ICM analysis, modeling, and simulation for the U.S. 75 Corridor in Dallas, Texas. A complete presentation of the model calibration methods and validation results are presented in a separate report titled *Integrated Corridor Management U.S. 75 Dallas, Texas, Model Validation and Calibration Report*.

The base year for the U.S. 75 corridor modeling was 2007. The U.S. 75 team used the DIRECT traffic model developed by Southern Methodist University (SMU) as the mesoscopic model for this analysis.

Before ICM strategies were analyzed, the U.S. 75 team, U.S. DOT, and Cambridge Systematics Inc. (CS) agreed upon the validation/calibration criteria that should be met in the modeling effort. Because of the strong transit presence in the U.S. 75 corridor and DIRECT's multimodal modeling capability, a set of validation and calibration criteria was established for the transit component of the analysis and modeling.

The model validation and calibration methodology used a diversified set of data, including the following:

- Traffic flows at individual links, as well as on screenlines across the arterial, freeway, and transit components of the ICM Corridor;
- Travel times along critical segments of the ICM Corridor freeway and arterial components;
- Origin-destination surveys, identifying travel patterns along the freeway and arterial components of the ICM Corridor; and
- Queue observations along critical segments of the ICM Corridor freeway and arterial components.

Highway Validation/Calibration

The first step in the validation and calibration process was to develop and check the roadway network to make sure year 2007 conditions were accurately reflected in the model. With some small adjustments, the U.S. 75 team felt the model network was acceptable. The next step was to ensure that the OD trip table reflected the demand and the general travel patterns within the U.S. 75 Corridor. To accomplish that, model-estimated traffic volumes were compared against observed traffic volumes at a number of internal and external screenlines. After the validation of the screenlines was completed, the calibration of the model at individual links was initiated. Finally, comparison of travel times on selected routes was performed, and additional model calibration was performed to more closely match the travel time data. Figure 5-1 illustrates the validation results comparing link flows to observed volumes for the 5:30 to 11:00 AM simulation. Within the figure, the initial NCTCOG subarea trip table is shown (Ite 0) along with the final trip table developed from the calibration process (Ite 45). Lines represent a 45-degree perfect match, and the 15-percent error range.

Figure 5-1. Link Volume Comparison for the U.S. 75 Model

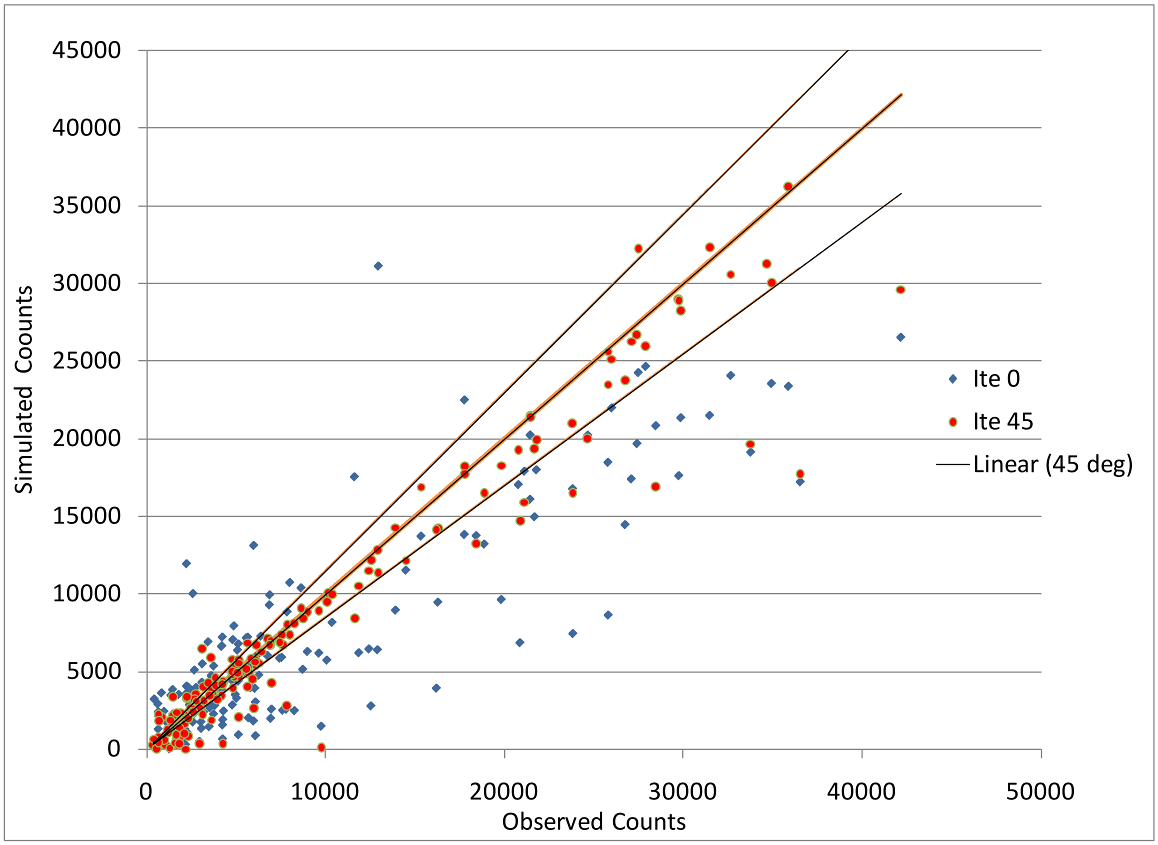


Table 5-3 summarizes the modeled travel times as compared to observed travel times as measured on U.S. 75 and other key roadways in the corridor.

Table 5-3. Travel Time Calibration Results, 6:30 to 9:00 AM (in Minutes)

ROUTE	6:30	7:00	7:30	8:00	8:30	Average	DIRECT	% DIFF
Abrams_NB_AM	27.63	26.74	28.51	27.31		27.55	25.24	-8%
Abrams_SB_AM	21.30	25.33	28.44	25.88		25.24	24.70	-2%
Arapaho_EB_AM	17.99	20.63	21.87	23.59	18.37	20.95	24.59	17%
Arapaho_WB_AM	17.64	21.30	27.02	27.04	21.56	22.91	24.56	7%
Coit_NB_AM	23.96	27.80	33.28	30.45		28.87	26.07	-10%
Coit_SB_AM	25.18	23.47	35.49	34.02		29.54	32.16	9%
Greenville_N_NB_AM	17.51	18.82	19.43	16.91		18.17	17.08	-6%
Greenville_N_SB_AM	19.41	19.19	21.92	18.29		19.70	17.57	-11%
Greenville_S_NB_AM			24.97	23.84	23.16	23.99	26.12	9%
Greenville_S_SB_AM		21.90	23.77	24.65	25.52	23.96	26.18	9%
NW_HWY_EB_AM		14.64	14.67	15.94	17.50	15.68	18.11	15%
NW_HWY_WB_AM	16.50	25.24	22.67	17.86		20.57	19.16	-7%
Parker_EB_AM		32.59		28.34		30.46	32.03	5%
Parker_WB_AM		31.21	38.57	27.72		32.50	32.68	1%
Plano_NB_AM	25.04	23.91	26.89	24.41	24.32	24.92	24.19	-3%
Plano_SB_AM	21.39	26.96	30.57	40.13	24.67	28.74	26.12	-9%
US75_FR_NB_AM_NWHWtoI635	9.08	9.41		9.51	7.92	8.98	9.54	6%
US75_FR_NB_AM_I635_PGPT	13.46	15.48		17.36	14.21	15.13	15.33	1%
US75_FR_SB_AM_PGPT_I635		15.72		16.96	13.66	15.45	19.90	29%
US75_FR_SB_AM_I635toNWHW		8.87		9.40	10.22	9.50	10.31	9%
US75_NB_AM_I635_to_Galatyn	5.30	5.18	5.02	5.06		5.14	6.15	20%
US75_NB_AM_Galatyn_to_Parker_Rd	3.63	3.77	3.50	3.73		3.66	4.11	12%
US75_NB_AM_Parker_Rd_to_MCDERMOTT	4.84	4.68	4.34	4.64		4.62	6.03	30%
US75_SB_AM_MCDERMOTT_to_Parker_Rd	6.23	7.93	9.06	8.59	5.20	7.40	7.14	-4%
US75_SB_AM_Parker_Rd_to_Galatyn	4.22	4.95	5.43	4.71	3.72	4.61	5.58	21%
US75_SB_AM_Galatyn_to_I635	5.40	6.98	8.83	10.24	6.76	7.64	6.90	-10%

Visual Audits

The model validation criteria require visual audits of the speed-flow relationships and queuing. The U.S. 75 team relied on detector data from the Dallas ITS systems, as well as the expertise of the stakeholders to generate comparison data. Visual audits were performed for individual link speed-flow relationships and queue patterns, as well as the adjustments made in the calibration process.

Transit Validation

Mode choice in DIRECT is governed by modeling logic related to the variables “willingness to use transit” and “willingness to carpool.” Using shortest path algorithms updated for each time interval (i.e., 5 minutes) to reflect the latest network conditions, travelers select the best path (lowest generalized cost from minimizing travel time and travel costs) from among their available travel options. The transit components within the model were calibrated to consider LRT person volumes, bus person volumes, and LRT parking lot utilization. The resulting 5:30 to 11:00 AM ridership validation results for the baseline model for the Red and Blue Lines are shown in Table 5-4. Similarly, the validation results for the Red Line park-and-ride lot utilization are shown in Table 5-5.

Table 5-4. LRT Station Volumes, 5:30 to 11:00 AM

Red	Northbound						Southbound				
Stop	DART 5-11	DIRECT	DIFF	%DIFF		Stop	Stop	DART 5-11	DIRECT	DIFF	%DIFF
Mockingbird	2140	2141	1	0%		326	Parker	1953	1973	20	1%
Lovers	2120	2007	-113	-5%		353	Dtn Plano	2195	2045	-150	-7%
Park Ln	2029	1862	-167	-8%		330	Bush Tpk	2807	2786	-21	-1%
Walnut Hill	1864	1626	-238	-13%		401	Galatyn	2839	2756	-83	-3%
Forest Ln	1689	1252	-437	-26%		462	Arapaho	3300	2995	-305	-9%
LBJ/Central	1555	1445	-110	-7%		521	Spring Valley	3588	3073	-515	-14%
Spring Valley	1431	1273	-158	-11%		2003	LBJ/Central	3595	4176	581	16%
Arapaho	987	1035	48	5%		640	Forest Ln	3882	3987	105	3%
Galatyn	864	609	-255	-30%		758	Walnut Hill	3924	4144	220	6%
Bush Tpk	710	410	-300	-42%		688	Park Ln	4124	4031	-93	-2%
Dtn Plano	579	401	-178	-31%		762	Lovers	4180	3782	-398	-10%
						856	Mockingbird	4135	3677	-458	-11%
Blue	Northbound						Southbound				
Stop	DART 5-11	DIRECT	DIFF	%DIFF		Stop	Stop	DART 5-11	DIRECT	DIFF	%DIFF
Mockingbird	880	921	41	5%		81	Dtn Garl	1244	922	-322	-26%
White Rock	792	843	51	6%		217	Forest/Jupiter	1594	1480	-114	-7%
LBJ/Skillman	612	763	151	25%		395	LBJ/Skillman	2126	2048	-78	-4%
Forest/Jupiter	442	519	77	17%		520	White Rock	2387	2511	124	5%
						856	Mockingbird	2425	2592	167	7%

Note: Stations south of Mockingbird are not included as they are in the tunnel section going into downtown with no parking available.

HOV Validation

A sensitivity test was conducted to assess how DIRECT modeled the HOV lanes on U.S. 75 that were opened in 2008. The DIRECT model volumes were compared favorably to the observed HOV volumes collected by TTI in 2008.

Known Incident Validation

A known incident along southbound U.S. 75, approximately one-quarter mile south of Belt Line (approximately midpoint of corridor), was modeled and compared to the observed traffic conditions during the actual incident. The two inside lanes (closest to median) were closed as a result of the incident. It was inferred from the police report that four cars were involved, thus the incident occupied approximately 200 linear feet of roadway. Results from the modeled incident were validated against the observed or anticipated incident related congestion duration, extent of the queue propagation, and traffic flow diversions resulting from the incident.

Table 5-5. LRT Parking Lot Utilization, 5:30 to 11:00 AM

Location	DART						DIRECT				
	Parked Cars in Lot	Lot Capacity	Lot Percent Occupied	Ancillary On-street Capacity	Total Station Parking Capacity	Total Parking Percent Occupied	Parked Cars	Lot Percent Occupied	Total Parking Percent Occupied	Difference Parked Cars	Percent Difference
Parker Road	1,954	1,566	125%	420	1,986	98%	1,996	127%	101%	42	2%
Bush Turnpike	800	778	103%	0	778	103%	776	100%	100%	-24	-3%
Arapaho Center	513	1,105	46%	35	1140	45%	511	46%	45%	-2	0%
Spring Valley	306	403	76%	40	443	69%	309	77%	70%	3	1%
LBJ/Central*	142	553	26%	83	636	22%	429	78%	67%	288	203%
Forest Lane*	126	271	46%	30	301	42%	233	86%	77%	108	86%
Walnut Hill*	76	215	35%	240	455	17%	144	67%	32%	69	91%
Park Lane*	163	346	47%	0	346	47%	194	56%	56%	32	19%
Mockingbird	542	735	74%	0	735	74%	737	100%	100%	195	36%
Total	**4,621**						**5,329**			**708**	**15%**

*TTI counts from 11/11/08 to 11/18/08 and does not include on-street and retail parking lots.

Note: Highlight represents the stations impacted by ICM strategies.

Chapter 6 Analysis Results

The AMS results for the U.S. 75 corridor model in Dallas are presented in this chapter. Results are presented for different operational conditions, ICM strategies, and performance measures employed in the analysis, including the following:

- ***Thirteen operational conditions*** represented by combinations of low, medium, and high demand conditions under no incident and different severity of freeway incidents on U.S. 75 SB at either Beltline Road or Forest Lane.
- ***ICM strategy alternatives***, including comparative travel times for both mode and route, pre-trip and en-route traveler information, traffic signal retiming and coordination on frontage roads and arterials, increased park-and-ride lot capacity, decreased transit headways, and combinations of these strategies.

The analysis produced performance measures for all operational conditions and for all ICM strategies tested. Performance measures include mobility, reliability, fuel consumption, and emissions reported across different transportation modes and facility types.

Sections 6.1, 6.2, and 6.3 present the results by incident scenario using the performance measures described in Appendix B. To clarify, all measures listed in these sections are calculated on an origin-destination basis and are aggregated based on which corridors the travelers use, namely the U.S. 75 SB or U.S. 75 NB facilities. For example, if a traveler uses a section of U.S. 75 SB, that traveler's entire trip is included in the U.S. 75 SB trip set, and the entire trip travel distance and time is included in the person-miles traveled (PMT) and person-hours traveled (PHT) measures. This produces PMT and PHT that are greater than those values actually using the facilities, but represents the PMT and PHT for traveler's that are influenced by the ICM strategies and operations on U.S. 75. All travelers starting their trips between 5:30 to 11:00 AM are included in the analysis, including those travelers whose trips are incomplete at 11:00 AM. Estimations are made for the completed trip travel distance and time for these incomplete trips and are included in the analysis.

Section 6.4 presents and discusses the aggregated pre-ICM and post-ICM performance measures, as averaged over all operating conditions. As with results in the previous sections, performance measures discussed here are all OD based as opposed to facility based.

Section 6.5 outlines the benefits that are seen from ICM implementation. In order to locate which facilities see improvements and which see worsening condition, the benefits calculations are based on facility specific performance measures. The one exception is travel time reliability, which is only definable at the OD level. For reliability measures, reliability costs are included for those facilities for which traveler data was tracked through the model, namely U.S. 75 SB and U.S. 75 NB facilities. Reliability benefits attributed to U.S. 75 SB were calculated from the change in the travel time variance for any trip using U.S. 75 in the SB direction. Similarly, U.S. 75 NB reliability benefits were calculated from the NB direction trips. The total corridor-wide benefits were calculated from the change in variance for all trips in the system. The U.S. 75 SB and NB benefits were then subtracted from the entire network benefits, and the remaining reliability benefits were distributed amongst the non-U.S. 75 facilities based on the share of person hours of travel.

Section 6.6 outlines the costs associated with deploying the tested ICM system.

Section 6.7 outlines the conclusions and lessons learned from the ICM analysis of the U.S. 75 corridor.

No Incident Scenarios

Peak-period volumes on roadways fluctuate throughout the year due to variations in travel demand by day of the week, time of the year, or other conditions. ICM strategies need to be evaluated under all the conditions throughout the year, not just the normal or average conditions. As such, no incident conditions are simulated as occurring in three different demand conditions: low, medium, and high demand. Demand was stratified based on the vehicles per hour in the AM peak direction on U.S. 75; high demand conditions are defined as greater than 7,500 vph; medium demand is between 6,900 and 7,500 vph; and low demand is less than 6,900 vph. Based on 2007 volume data, these conditions represent 19.9 percent, 34.7 percent, and 18.4 percent, respectively, of work days during a typical year. Collectively, they account for 72.9 percent of all work days.

The no incident scenarios under pre-ICM strategies were also used as the definition of the baseline conditions to determine the threshold for delay, the zero-delay travel time, for the model. The minimum travel time for each origin, destination, and mode combination in the model in any of the three no incident pre-ICM scenarios was used to establish the zero delay travel time for that pairing. This benchmark travel time was used later in the ICM performance measure calculations as defined later in this document. Further details of the use of the zero delay travel time in the performance measures are contained in Appendix B.

ICM Strategies in No Incident Conditions

During the no incident conditions, there is limited deployment of ICM strategies, but there are some elements at work. Through the use of ATIS systems and DMS on roadways, the traveling population has an increased awareness of the roadway conditions. The following parameters were adjusted in the no incident scenarios to model the pre- and post-ICM conditions:

- Congestion Diversion activated in DIRECT;
- Awareness and use of pre-trip information from 60 percent awareness and 10 percent use pre-ICM to 80 percent awareness and 20 percent use post-ICM;
- Awareness and use of en-route information from 50 percent awareness and 20 percent use pre-ICM to 60 percent awareness and 30 percent use post-ICM; and
- Use of DMS information from 60 percent pre-ICM to 75 percent post-ICM.

Performance Measures in No Incident Conditions

Results reported in this section are associated with a typical weekday AM peak period, during which no incidents occur. Performance measures reported include person-miles traveled (an indication of the amount of tripmaking), person-hours of travel, and delay in person hours.

Table 6-1 lists the person miles traveled, person hours traveled, and delay (in person hours) that are experienced by the different traveler trip sets during low volume, no incident conditions. Travelers are classified into a traveler set if they use a link on the either the U.S. 75 southbound or northbound facilities. The values listed, however, include the total performance measures for the entire trip, from origin to destination, including some travel on facilities other than U.S. 75.

Table 6-2 similarly lists the performance measures experienced by travelers under medium demand, no incident conditions. Compared to Table 6-1, values in person miles traveled have increased between 8 and 13 percent, while person hours traveled increase 14 to 22 percent and delays increase between 28 and 40 percent.

Table 6-3 lists the performance measures as seen under the high demand conditions. As expected, person hours traveled (10 to 13 percent) and delay (15 to 25 percent) far exceed the increases in person miles traveled (7 to 8 percent) when compared to the medium demand conditions of Table 6-2. Comparing the performance measures for scenarios pre- and post-ICM, the deployment is seen to reduce the delay hours by 0.2 to 1.7 percent, depending on the traveler set.

Table 6-4 summarizes the average travel time by mode for all travelers across the system. Only minor differences are seen in the average travel time by mode.

Table 6-1. No Incident Pre- and Post-ICM Performance Measures, Low Demand
Trips Starting 5:30 to 11:00 AM

Trips Using:	Pre-ICM			Post-ICM			Pre- to Post-Change		
	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)
U.S. 75 SB	1,945,750	59,415	22,734	1,946,547	59,538	22,858	798	122	124
U.S. 75 NB	1,671,340	44,723	12,573	1,670,756	44,763	12,634	-584	40	61
Entire Network	**13,391,671**	**428,941**	**169,773**	**13,391,800**	**428,973**	**169,838**	**130**	**32**	**66**

Table 6-2. No Incident Pre- and Post-ICM Performance Measures, Medium Demand
Trips Starting 5:30 to 11:00 AM

Trips Using:	Pre-ICM			Post-ICM			Pre- to Post-Change		
	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)
U.S. 75 SB	2,091,932	67,976	29,060	2,092,196	67,713	28,688	264	-263	-372
U.S. 75 NB	1,839,201	52,724	17,643	1,837,199	52,619	17,482	-2,002	-105	-161
Entire Network	**15,166,490**	**522,755**	**234,250**	**15,166,694**	**523,053**	**234,679**	**204**	**298**	**429**

Table 6-3. No Incident Pre- and Post-ICM Performance Measures, High Demand
Trips Starting 5:30 to 11:00 AM

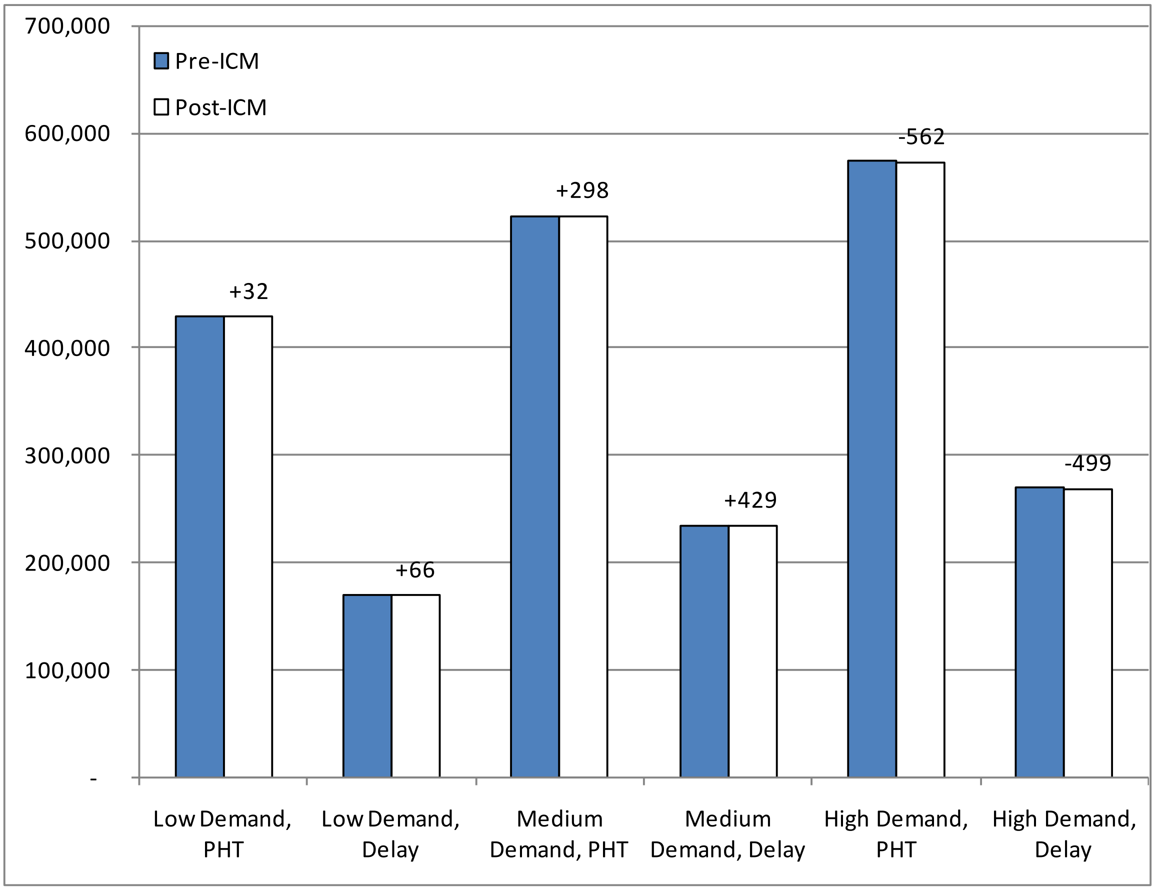
	Pre-ICM			Post-ICM			Pre- to Post-Change		
Trips Using:	**Person Miles Traveled**	**Person Hours Traveled**	**Delay (Person Hours)**	**Person Miles Traveled**	**Person Hours Traveled**	**Delay (Person Hours)**	**Person Miles Traveled**	**Person Hours Traveled**	**Delay (Person Hours)**
U.S. 75 SB	2,230,368	75,159	33,720	2,229,890	75,054	33,395	-478	-104	-325
U.S. 75 NB	1,983,645	59,607	21,985	1,980,958	59,314	21,611	-2,687	-293	-374
Entire Network	**16,173,588**	**573,612**	**269,588**	**16,173,884**	**573,050**	**269,089**	**296**	**-562**	**-499**

Table 6-4. No Incident Pre- and Post-ICM Average Travel Time by Mode
Trips Starting 5:30 to 11:00 AM (in Minutes)

	Pre-ICM				Post-ICM				Pre- to Post-Change			
Demand Level	**Auto (SOV)**	**Auto (HOV)**	**Transit Only**	**Park-and-Ride Transit**	**Auto (SOV)**	**Auto (HOV)**	**Transit Only**	**Park-and-Ride Transit**	**Auto (SOV)**	**Auto (HOV)**	**Transit Only**	**Park-and-Ride Transit**
Low	17.2	13.6	21.3	31.6	17.2	13.6	21.5	31.6	0.00	-0.01	0.20	-0.02
Medium	18.7	14.8	21.3	32.3	18.8	14.8	21.4	32.6	0.03	-0.02	0.02	0.29
High	19.4	15.3	21.1	33.0	19.4	15.3	21.1	33.0	-0.01	-0.03	-0.02	0.01

Figure 6-1 compares the total person hours traveled and the total delay in hours due to the ICM deployment.

Figure 6-1. PHT and Delay Comparison No Incident Scenarios, All Trips
Trips Starting 5:30 to 11:00 AM



As anticipated, very small changes were seen in the PMT, PHT, and total delay values between the pre-ICM and post-ICM no incident scenarios under any demand levels. While the differences are small within a single AM peak period, the savings could accumulate across all non-incident work days and become meaningful savings.

Minor Incident Scenarios

Results reported in this section are associated with a typical weekday AM peak period, during which minor incidents occur. Performance measures reported include person-miles traveled (an indication of the amount of tripmaking), person-hours of travel, and delay in person hours.

Occurring on over one quarter of the commute days in a typical year in Dallas, minor incidents on the network have the opportunity to cause significant delays over the course of a year. In order to estimate the impact that the ICM deployment would have during minor incident scenarios, five different minor incident scenarios were tested. Three of the scenarios consisted of a minor incident with 45-minute clearance blocking one general purpose lane on U.S. 75 southbound near Belt Line Rd under low, medium, and high demand conditions. Another two scenarios consisted of a similar minor incident near Forest Lane under medium and high demand conditions.

ICM Strategies in Minor Incident Conditions

As with no incident scenarios, minor incident scenarios would see deployment of ICM strategies that improve traveler information in the form of pre-trip information, en-route information, and comparative travel times for modes and routes are available to help travelers avoid congestion within the network. Additionally, signal retiming on both the frontage roads and arterials in the system to help to alleviate congestion caused by traffic diverting from U.S. 75 southbound and incident generated delays. Specific parameters adjusted from pre-ICM conditions in the model for all ICM strategies deployed in minor incident scenarios include:

- Congestion Diversion activated in DIRECT;
- Awareness and use of pre-trip information from 60 percent awareness and 10 percent use pre-ICM to 80 percent awareness and 20 percent use post-ICM;
- Awareness and use of en-route information from 50 percent awareness and 20 percent use pre-ICM to 60 percent awareness and 30 percent use post-ICM;
- Use of DMS information from 60 percent pre-ICM to 75 percent post-ICM; and
- Signal retiming on the U.S. 75 frontage road and Greenville Avenue to increase capacity by approximately 15 percent to help reduce travel times on roads carrying travelers diverting off U.S. 75.

Performance Measures in Minor Incident Conditions

Tables 6-5, 6-6, and 6-7 list the performance measures as modeled for the minor incident scenarios under low, medium, and high demand conditions. These results are for U.S. 75 northbound and southbound for both general purpose lanes and HOV lanes. Table 6-8 lists the average travel time by mode (in minutes) for the trips under minor incident conditions.

Figures 6.2 and 6.3 illustrate the differences in PHT and total delay, respectively, for the entire network pre- and post-ICM strategies deployed during minor incident scenarios. Figures 6.4 and 6.5 compare the PHT and delay experienced only by trips that use U.S. 75 Southbound during the minor incident scenarios.

Table 6-5. Minor Incident Pre- and Post-ICM Performance Measures, Low Demand
Trips Starting 5:30 to 11:00 AM

	Pre-ICM			Post-ICM			Pre- to Post-Change		
Trips Using:	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)
Minor Incident on U.S. 75 Southbound at Belt Line Rd									
U.S. 75 SB	1,933,755	58,655	22,101	1,930,782	57,970	21,428	-2,974	-685	-673
U.S. 75 NB	1,662,997	43,260	11,301	1,661,826	43,052	11,121	-1,171	-207	-179
Entire Network	**13,398,989**	**414,912**	**155,203**	**13,397,149**	**411,502**	**151,699**	**-1,840**	**-3,411**	**-3,504**

Table 6-6. Minor Incident Pre- and Post-ICM Performance Measures, Medium Demand
Trips Starting 5:30 to 11:00 AM

	Pre-ICM			Post-ICM			Pre- to Post-Change		
Trips Using:	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)
Minor Incident on U.S. 75 Southbound at Belt Line Rd									
U.S. 75 SB	2,088,492	66,544	27,504	2,088,501	65,911	26,823	8	-632	-681
U.S. 75 NB	1,836,993	49,824	14,593	1,832,509	49,478	14,297	-4,484	-346	-296
Entire Network	**15,178,960**	**494,313**	**203,947**	**15,176,735**	**490,431**	**200,007**	**-2,224**	**-3,882**	**-3,940**
Minor Incident on U.S. 75 Southbound at Forest Lane									
U.S. 75 SB	2,101,104	65,343	25,969	2,106,030	64,916	25,381	4,926	-427	-589
U.S. 75 NB	1,829,671	49,670	14,567	1,831,002	49,358	14,214	1,331	-312	-354
Entire Network	**15,177,751**	**491,861**	**201,405**	**15,175,901**	**488,117**	**197,593**	**-1,850**	**-3,744**	**-3,812**

Table 6-7. Minor Incident Pre- and Post-ICM Performance Measures, High Demand
Trips Starting 5:30 to 11:00 AM

	Pre-ICM			Post-ICM			Pre- to Post-Change		
Trips Using:	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)
Minor Incident on U.S. 75 Southbound at Belt Line Rd									
U.S. 75 SB	**2,211,562**	**72,102**	**30,564**	**2,200,280**	**70,783**	**29,441**	**-11,282**	**-1,319**	**-1,123**
U.S. 75 NB	1,974,958	55,729	18,137	1,972,236	55,215	17,626	-2,722	-514	-511
Entire Network	**16,189,662**	**535,926**	**228,581**	**16,184,301**	**530,336**	**222,726**	**-5,361**	**-5,590**	**-5,854**
Minor Incident on U.S. 75 Southbound at Forest Lane									
U.S. 75 SB	2,223,330	70,761	28,873	2,217,215	69,919	28,141	-6,115	-842	-732
U.S. 75 NB	1,976,921	55,908	18,252	1,972,657	55,087	17,522	-4,264	-821	-730
Entire Network	**16,185,703**	**532,272**	**224,740**	**16,182,508**	**529,087**	**221,482**	**-3,195**	**-3,185**	**-3,258**

Table 6-8. Minor Incident Pre- and Post-ICM Average Travel Time by Mode

Trips Starting 5:30 to 11:00 AM (in Minutes)

		Pre-ICM				Post-ICM				Pre- to Post-Change			
Demand Level	Incident Location	Auto (SOV)	Auto (HOV)	Transit Only	Park-and-Ride Transit	Auto (SOV)	Auto (HOV)	Transit Only	Park-and-Ride Transit	Auto (SOV)	Auto (HOV)	Transit Only	Park-and-Ride Transit
Low	Belt Line	16.7	13.2	21.2	31.2	16.5	13.1	21.2	31.2	-0.14	-0.12	-0.04	0.02
Medium	Belt Line	17.6	14.1	21.3	31.6	17.5	13.9	21.3	31.8	-0.14	-0.11	0.00	0.13
High	Belt Line	18.0	14.3	21.0	32.0	17.8	14.2	21.0	32.0	-0.21	-0.13	-0.03	-0.05
Medium	Forest	17.5	14.0	21.2	31.7	17.4	13.9	21.3	31.6	-0.14	-0.10	0.06	-0.09
High	Forest	17.8	14.2	20.9	32.0	17.7	14.2	20.9	32.0	-0.12	-0.06	-0.01	0.02

Figure 6-2. PHT Comparison of Minor Incident Scenarios, All Trips
Trips Starting 5:30 to 11:00 AM

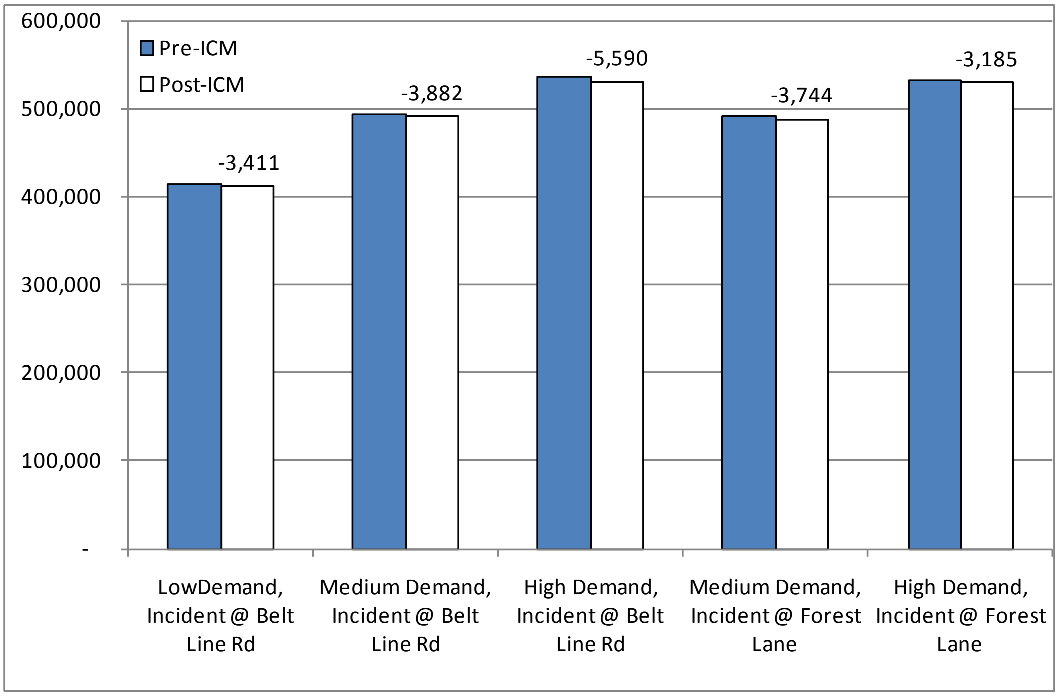


Figure 6-3. Delay Comparison of Minor Incident Scenarios, All Trips
Person-Hours of Delay for Trips Starting 5:30 to 11:00 AM

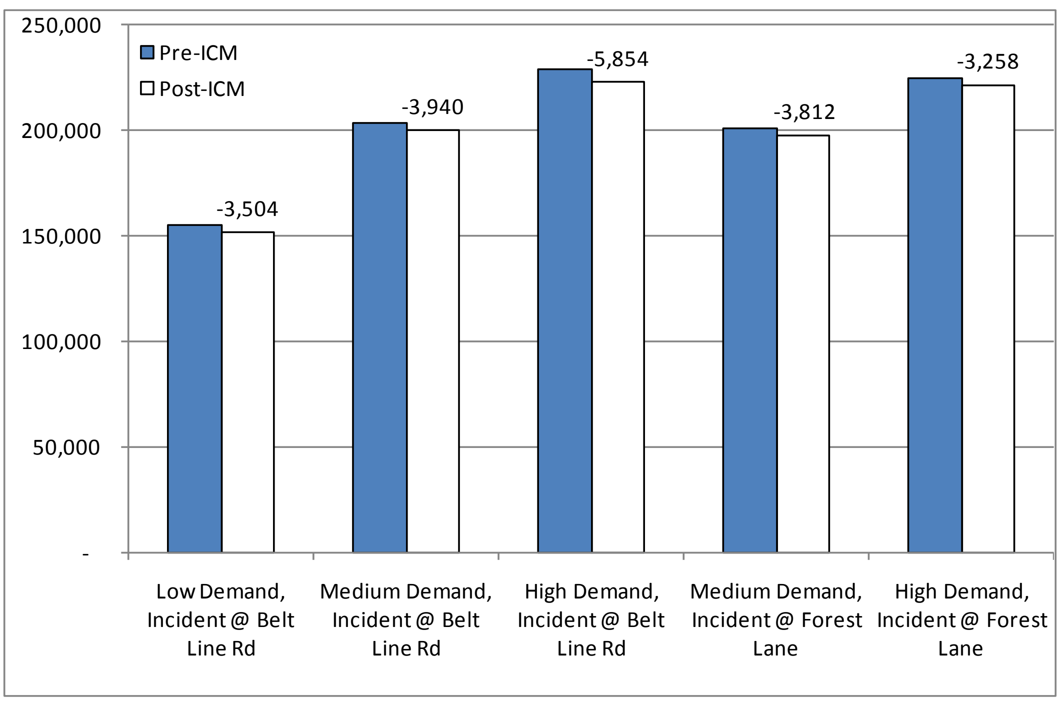


Figure 6-4. PHT Comparison of Minor Incident Scenarios, U.S. 75 SB Trips
Trips Starting 5:30 to 11:00 AM

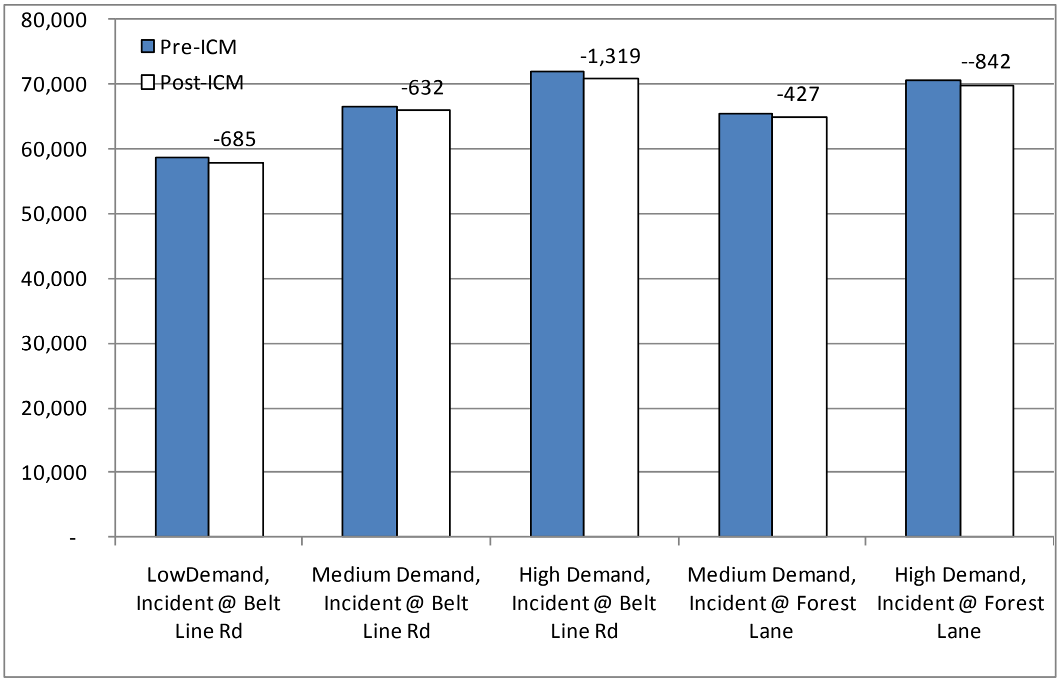
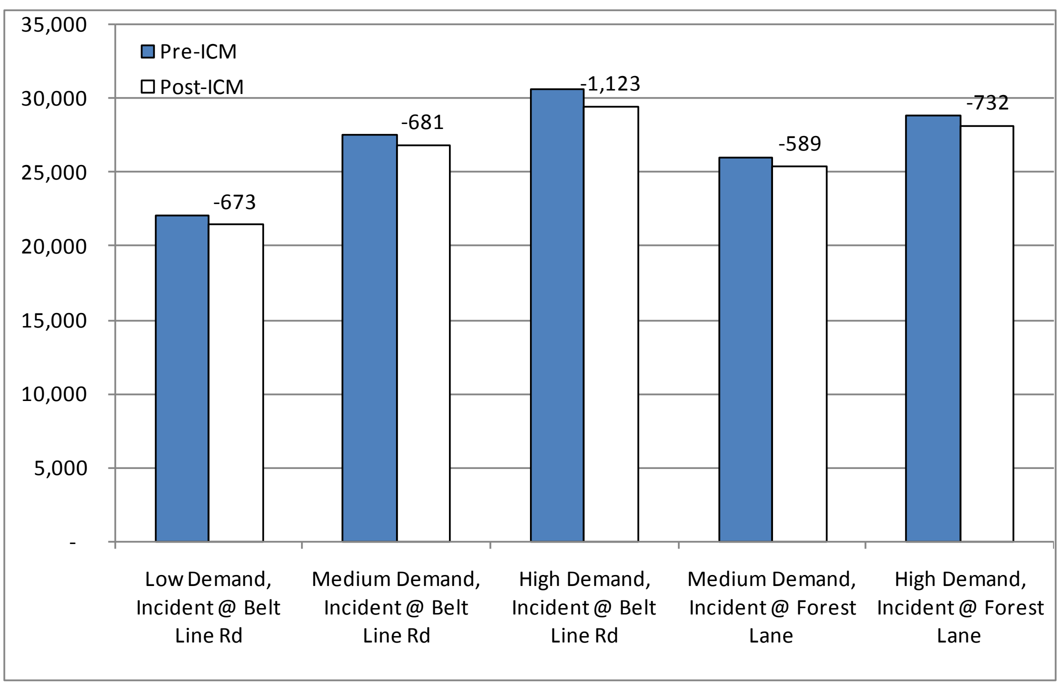


Figure 6-5. Delay Comparison of Minor Incident Scenarios, U.S. 75 SB Trips
Trips Starting 5:30 to 11:00 AM



Comparing the scenarios pre- and post-ICM strategies in place, all minor incident scenarios see reduced person hours traveled by 0.5 to 1.8 percent, while a 1.4 to 4 percent reduction in person hours of delay. Across the entire network (U.S. 75 corridor travel shed represented in the simulation model), the delay reduction from the ICM deployment ranges from 3,500 to 5,900 person hours of delay. These findings confirm the assumption that ICM strategies deployed during minor incident scenarios can provide significant amounts of travel timesavings.

Major Incident Scenarios

Results reported in this section are associated with a typical weekday AM peak period, during which major incidents occur. Performance measures reported include person-miles traveled (an indication of the amount of tripmaking), person-hours of travel, and delay in person hours.

While occurring on less than one percent of commute days in Dallas, a major incident can disrupt a network to the point where significant delays are created. In order to estimate the impact the ICM deployment would have during major incident scenarios, five different major incident scenarios were tested. All five of the scenarios consisted of an incident with a 60-minute clearance on U.S. 75 southbound near Belt Line Road. Two of the scenarios blocked two general purpose lanes under medium and high demand conditions, while the other three scenarios were for an incident blocked three general purpose lanes under low, medium and high demand conditions.

ICM Strategies in Major Incident Conditions

Building on the traveler information systems and signal retiming ICM strategies deployed during minor incident scenarios, the major incident scenarios see additional ICM deployments to encourage mode shifts to transit, and in particular the Red Line LRT paralleling U.S. 75. This would be accomplished by increasing awareness of en-route mode shifts to the Red Line as a travel option, increasing park-and-ride capacity, and increasing capacity on the LRT itself. The increased awareness of en-route mode shifts to the LRT would entail deploying Smart Parking systems at park-and-ride lots along U.S. 75 and disseminating information about available spaces to travelers on U.S. 75. Increase lot capacity would be accomplished through adding valet service and through public-private partnerships to temporarily use nearby private lots and shuttle passengers to the LRT station. Additionally, capacity increases on the LRT Red Line would be accomplished by reducing headways. Specific parameters adjusted from pre-ICM conditions in the model for all ICM strategies deployed in major incident scenarios include:

- Congestion Diversion activated in DIRECT;
- Awareness and use of pre-trip information from 60 percent awareness and 10 percent use pre-ICM to 80 percent awareness and 20 percent use post-ICM;
- Awareness and use of en-route information from 50 percent awareness and 20 percent use pre-ICM to 60 percent awareness and 30 percent use post-ICM;
- Use of DMS information from 60 percent pre-ICM to 75 percent pre-ICM;
- Signal retiming on the U.S. 75 frontage road and Greenville Avenue to increase capacity by approximately 15 percent to help reduce travel times on roads carrying travelers diverting off U.S. 75;
- Deployment of the Smart Parking system will increase the utilization rate from the pre-ICM 95 percent cap to allow 100 percent utilization of park-and-ride lots;

- Increase capacity by 250 spaces (to a total of 1,443) at the President George Bush Turnpike (PGBT) park-and-ride lot as a result of either travelers parking at a nearby private parking lot and being shuttled to the station or a valet parking service being deployed at the station; and
- Reduced headways on the Red Line LRT from 10 to 7.5 minutes.

Performance Measures in Major Incident Conditions

Tables 6-9, 6-10, and 6-11 list the performance measures as modeled for the major incident scenarios under low, medium, and high demand conditions. Table 6-12 lists the average travel time by mode under major incident conditions. Figures 6-6 and 6-7 illustrate the differences in PHT and total delay, respectively, for the entire network pre- and post-ICM strategies deployed during major incident scenarios. Figures 6-8 and 6-9 compare the PHT and delay experienced only by trips that use U.S. 75 Southbound during the major incident scenarios, across both general purpose lanes and HOV lanes.

Comparing the performance measures of the major incident scenarios, the ICM deployments can be seen to have significant impact on reducing total PHT and delay, both systemwide and for U.S. 75 Southbound travelers. For all travelers, the PHT is reduced between 1.0 and 1.5 percent, depending on the incident scenario, while the PHT reductions for trips using U.S. 75 Southbound ranges from 2.0 to 2.6 percent. Total systemwide delays are reduced between 2.6 and 3.6 percent, while delays experienced by trips using U.S. 75 Southbound are reduced by between 4.5 and 5.6 percent. As expected, results show that under the major incident conditions, the ICM strategies prove to help reduce the total travel times not only on the corridor affected by the incident but also systemwide. Under the major incident scenarios, the effects of reducing the headways on the Red Line LRT can be seen to reduce the average travel time for transit and park-and-ride transit users by nearly a minute per trip.

Table 6-9. Major Incident Pre- and Post-ICM Performance Measures, Low Demand
Trips Starting 5:30 to 11:00 AM

	Pre-ICM			Post-ICM			Pre- to Post-Change		
Trips Using:	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)
Major (3-Lane) Incident on U.S. 75 Southbound at Belt Line Rd									
U.S. 75 SB	1,925,876	61,888	25,696	1,916,450	60,315	24,246	-9,426	-1,573	-1,450
U.S. 75 NB	1,669,711	43,467	11,367	1,668,221	43,265	11,204	-1,490	-202	-163
Entire Network	**13,401,213**	**418,856**	**159,263**	**13,400,101**	**414,504**	**154,777**	**-1,112**	**-4,353**	**-4,486**

Table 6-10. Major Incident Pre- and Post-ICM Performance Measures, Medium Demand
Trips Starting 5:30 to 11:00 AM

	Pre-ICM			Post-ICM			Pre- to Post-Change		
Trips Using:	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)
Major (2-Lane) Incident on U.S. 75 Southbound at Belt Line Rd									
U.S. 75 SB	2,074,274	68,448	29,828	2,070,083	67,072	28,254	-4,191	-1,376	-1,573
U.S. 75 NB	1,838,351	49,888	14,609	1,835,850	49,577	14,334	-2,501	-312	-275
Entire Network	**15,181,082**	**497,763**	**207,522**	**15,166,239**	**490,987**	**200,633**	**-14,843**	**-6,776**	**-6,888**
Major (3-Lane) Incident on U.S. 75 Southbound at Belt Line Rd									
U.S. 75 SB	2,069,531	69,830	31,442	2,058,769	68,144	29,646	-10,762	-1,686	-1,796
U.S. 75 NB	1,836,836	49,768	14,516	1,837,674	49,574	14,290	838	-193	-226
Entire Network	**15,181,037**	**498,752**	**208,631**	**15,167,569**	**493,416**	**203,128**	**-13,468**	**-5,336**	**-5,503**

Table 6-11. Major Incident Pre- and Post-ICM Performance Measures, High Demand
Trips Starting 5:30 to 11:00 AM

	Pre-ICM			Post-ICM			Pre- to Post-Change		
Trips Using:	**Person Miles Traveled**	**Person Hours Traveled**	**Delay (Person Hours)**	**Person Miles Traveled**	**Person Hours Traveled**	**Delay (Person Hours)**	**Person Miles Traveled**	**Person Hours Traveled**	**Delay (Person Hours)**
Major (2-Lane) Incident on U.S. 75 Southbound at Belt Line Rd									
U.S. 75 SB	2,197,401	73,944	32,915	2,170,068	72,012	31,145	-27,333	-1,932	-1,770
U.S. 75 NB	1,977,243	56,147	18,507	1,974,280	55,239	17,591	-2,963	-907	-916
Entire Network	**16,190,859**	**539,932**	**232,826**	**16,173,303**	**531,893**	**224,560**	**-17,556**	**-8,039**	**-8,266**
Major (3-Lane) Incident on U.S. 75 Southbound at Belt Line Rd									
U.S. 75 SB	2,193,892	75,171	34,293	2,171,360	73,548	32,763	-22,532	-1,623	-1,530
U.S. 75 NB	1,978,941	56,121	18,455	1,970,689	55,042	17,508	-8,252	-1,079	-948
Entire Network	**16,192,929**	**541,352**	**234,213**	**16,177,081**	**535,458**	**228,159**	**-15,848**	**-5,894**	**-6,054**

Table 6-12. Major Incident Pre- and Post-ICM Average Travel Time by Mode
Trips Starting 5:30 to 11:00 AM (in Minutes)

		Pre-ICM				Post-ICM				Pre- to Post-Change			
Demand Level	Lanes Blocked	Auto (SOV)	Auto (HOV)	Transit Only	Park-and-Ride Transit	Auto (SOV)	Auto (HOV)	Transit Only	Park-and-Ride Transit	Auto (SOV)	Auto (HOV)	Transit Only	Park-and-Ride Transit
Low	3 Lanes	16.8	13.3	21.2	31.3	16.7	13.1	21.2	31.3	-0.17	-0.15	0.00	-0.07
Medium	2 Lanes	17.8	14.1	21.3	31.7	17.5	13.9	20.5	31.0	-0.24	-0.19	-0.85	-0.68
Medium	3 Lanes	17.8	14.1	21.2	31.7	17.6	14.0	20.5	31.0	-0.21	-0.12	-0.75	-0.74
High	2 Lanes	18.1	14.4	21.0	32.1	17.9	14.2	20.1	31.3	-0.28	-0.19	-0.92	-0.75
High	3 Lanes	18.2	14.4	21.0	32.2	18.0	14.3	20.2	31.5	-0.21	-0.13	-0.85	-0.70

Figure 6-6. PHT Comparison of Major Incident Scenarios, All Trips
Trips Starting 5:30 to 11:00 AM

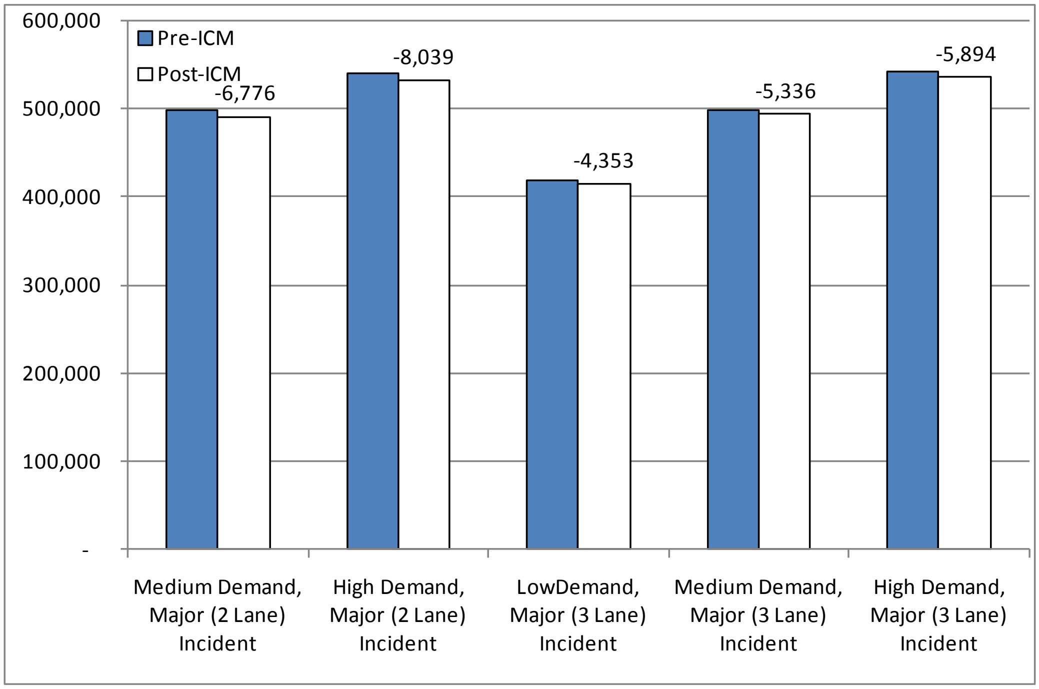


Figure 6-7. Delay Comparison of Major Incident Scenarios, All Trips
Trips Starting 5:30 to 11:00 AM

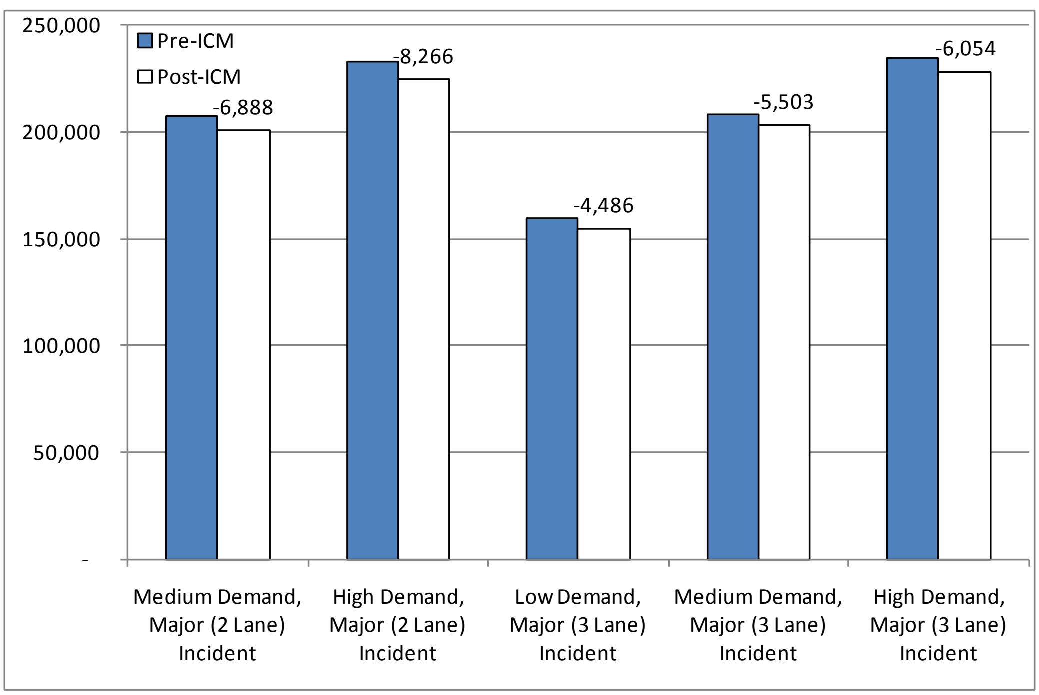


Figure 6-8. PHT Comparison of Major Incident Scenarios, U.S. 75 SB Trips
Trips Starting 5:30 to 11:00 AM

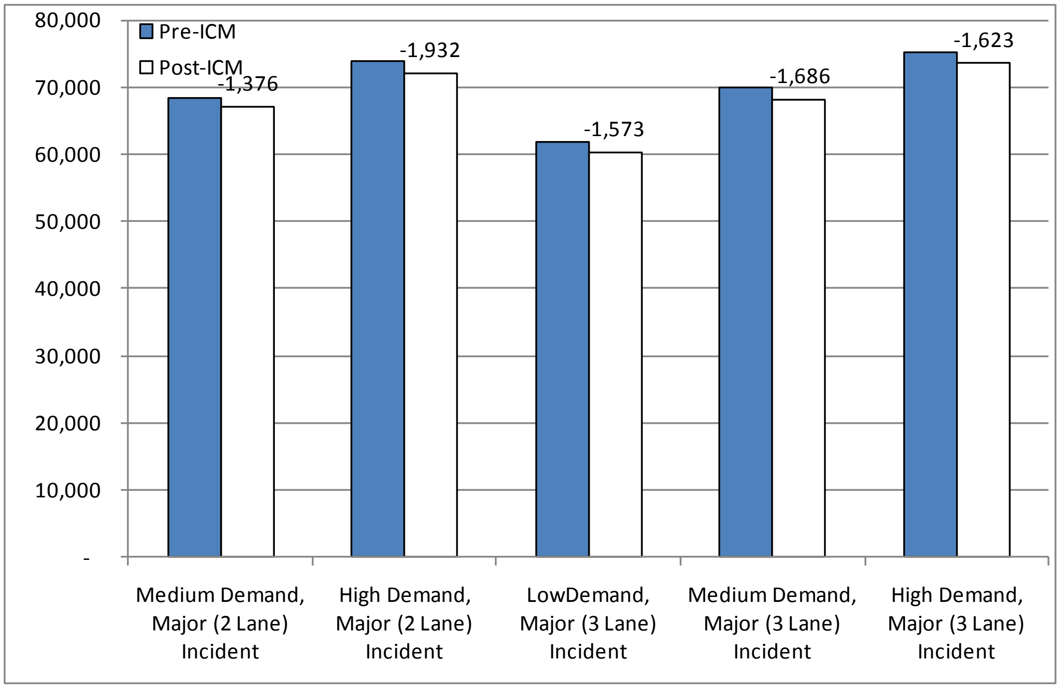
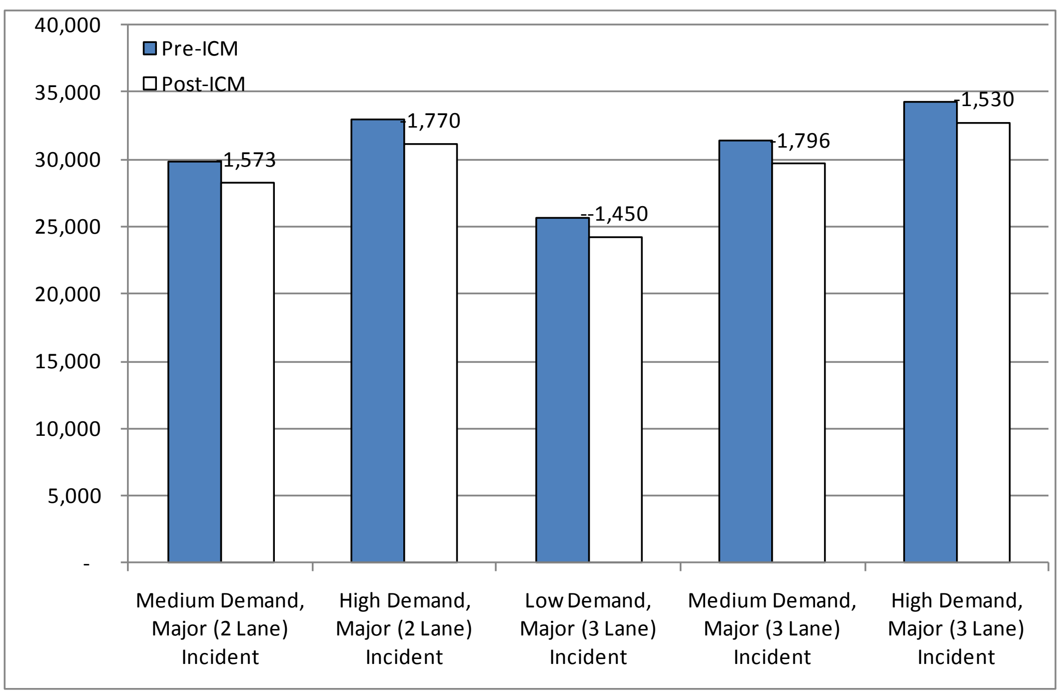


Figure 6-9. Delay Comparison of Major Incident Scenarios, U.S. 75 SB Trips
Trips Starting 5:30 to 11:00 AM



ICM strategies deployed under the major incident scenario aim to increase the corridor capacity by better utilizing the Red Line LRT. Modeled Red Line LRT ridership and parking activity at the five northern park-and-ride locations north of the incident location (Parker, PGBT, Arapaho, Spring Valley, and LBJ) are listed in Table 6-13 for medium and high demand conditions with a major incident blocking three general purpose lanes. Results show that the ICM strategies do indeed help shift travelers to transit, with an additional 525 to 568 additional park-and-ride lot users and another 530 to 588 riders on the Red Line.

Table 6-13. Red Line LRT Modeled Performance Measures
Medium and High Demand, Major (Three-Lane) Incident

	Pre-ICM Medium Demand	Post-ICM Medium Demand	Pre-ICM High Demand	Post-ICM High Demand
Ridership	3,718	4,248	4,018	4,606
Transit Capacity	8,250			
% Utilization	45%	51%	49%	56%
Parking Lot Users	3,616	4,141	3,939	4,507
Park-and-Ride Capacity*	5,552	5,802	5,552	5,802
% Utilization	65%	71%	71%	78%

* Both pre- and post-ICM scenarios include additional parking lot capacity added since the year of the 2007 baseline validated model. Post-ICM includes an additional 250 spaces at the PGBT station.

ICM Performance Measures

Key performance measures were presented in the US 75 AMS Analysis Plan, and were used in the benefit-cost analysis presented in this chapter. In this methodology, the analyzed scenarios representing different operating conditions are combined together weighted by the probability of occurrence to arrive at a total annual benefit, net annual benefit, and benefit-cost.

Table 6-14 lists the aggregated performance measures for the pre-ICM and post-ICM scenarios. The detailed methodology used for generating these performance measures is outlined in Appendix B.

Deploying ICM strategies as analyzed can reduce the total average daily person hours of delay both systemwide (over the U.S. 75 corridor travelshed analyzed) and for trips using the U.S. 75 freeway. Improvements to the planning index (a measure of the reliability of travel times) can be seen as well, showing that the travel time of the extremely long travel times are reduced. Total person-miles traveled and total person-miles delivered are insignificantly affected. The aggregated performance measures show that the ICM strategies improve the operating conditions on the network.

Table 6-14. Performance Measures Aggregated over all Scenarios

Performance Measure Trip Selection Set	Pre-ICM	Post-ICM	Change	Percent Change
Average Travel Time (Minutes/Traveler)				
All Routes	17.59	17.56	-0.03	-0.2%
Trips Using U.S. 75 SB	28.65	28.49	-0.15	-0.5%
Trips Using U.S. 75 NB	25.49	25.33	-0.16	-0.6%
Average Delay (Minutes/Traveler)				
All Routes	6.93	6.90	-0.03	-0.4%
Trips Using U.S. 75 SB	10.66	10.51	-0.15	-1.4%
Trips Using U.S. 75 NB	7.81	7.67	-0.15	-1.9%
Total Delay (Person-Hours)				
All Routes	235,106	234,145	-960	-0.4%
Trips Using U.S. 75 SB	33,713	33,310	-403	-1.2%
Trips Using U.S. 75 NB	23,220	22,758	-462	-2.0%
Planning Index				
All Routes	4.59	4.54	-0.05	-1.0%
Trips Using U.S. 75 SB	1.93	1.91	-0.01	-0.6%
Trips Using U.S. 75 NB	1.70	1.69	-0.01	-0.5%
Variance in Travel Time (Minutes^2)				
All Routes	15.29	14.83	-0.46	-3.0%
Trips Using U.S. 75 SB	21.35	19.91	-1.44	-6.7%
Trips Using U.S. 75 NB	8.16	7.81	-0.35	-4.3%
Passenger Hours Traveled				
All Routes	596,737	595,687	-1,049	-0.2%
Trips Using U.S. 75 SB	90,605	90,300	-304	-0.3%
Trips Using U.S. 75 NB	75,734	75,194	-540	-0.7%
Passenger Miles Traveled				
All Routes	17,393,765	17,394,135	370	0.0%
Trips Using U.S. 75 SB	2,740,343	2,745,828	5,485	0.2%
Trips Using U.S. 75 NB	2,562,483	2,558,385	-4,098	-0.2%
Passenger Miles Delivered (by 11:00 AM)				
All Routes	16,456,147	16,456,721	574	0.0%
Trips Using U.S. 75 SB	2,595,363	2,601,746	6,383	0.2%
Trips Using U.S. 75 NB	2,456,693	2,454,593	-2,100	-0.1%

Throughput Measures

In order to estimate the degree to which ICM affects the network throughput and duration of trips with longer travel times, the travel times under the incident scenarios can be compared to those under the no incident of the same demand level. By comparing the percentage of trips under the same threshold travel time in both the pre- and post-ICM scenarios, the relative influence of ICM on reducing extreme travel times can be estimated.

Table 6-15 lists the percentage of trip travel times in the incident scenarios that are less than the 90th percentile travel time in the no incident scenario for all trips in the modeled network. This is an indication of improvements to corridor throughput. Similarly, Table 6-16 lists the same only for trips that use U.S. 75 Southbound. In both cases, only the trips with start times between 6:30 and 8:30 AM were included in the analysis, so the analysis could focus on trips that would most likely be affected by the simulated incident.

Table 6-15 shows a small post-ICM improvement for all operating conditions. Table 6-16 shows more significant and consistent post-ICM improvements in reducing the length of extreme travel times for trips using U.S. 75 Southbound, since these trips are more heavily impacted by the incident. This shows that ICM strategies are effective at reducing the longer travel times in the corridor under incident conditions.

Table 6-15. Percentage of Travel Times Less than the 90th Percentile Travel Time in the No Incident Scenario, All Trips
Trips Starting 6:30 to 8:30 AM

Operating Conditions	Pre-ICM	Post-ICM	Change
Minor Incident Scenarios			
Low Demand, Incident @ Belt Line Rd	91.4	91.8	0.39
Medium Demand, Incident @ Belt Line Rd	91.3	91.7	0.38
High Demand, Incident @ Belt Line Rd	91.7	92.1	0.38
Medium Demand, Incident @ Forest Lane	91.7	92.0	0.35
High Demand, Incident @ Forest Lane	92.1	92.4	0.24
Major Incident Scenarios			
Low Demand, Incident @ Belt Line Rd (3 lanes blocked)	90.9	91.3	0.41
Medium Demand, Incident @ Belt Line Rd (3 lanes blocked)	90.9	91.5	0.60
High Demand, Incident @ Belt Line Rd (3 lanes blocked)	91.4	91.9	0.51
Medium Demand, Incident @ Belt Line Rd (2 lanes blocked)	90.8	91.3	0.45
High Demand, Incident @ Belt Line Rd (2 lanes blocked)	91.2	91.6	0.37

Table 6-16. Percentage of Travel Times Less than the 90th Percentile Travel Time in the No Incident Scenario, U.S. 75 SB Trips
Trips Starting 6:30 to 8:30 AM

Operating Conditions	Pre-ICM	Post-ICM	Change
Minor Incident Scenarios			
Low Demand, Incident @ Belt Line Rd	91.4	92.5	1.02
Medium Demand, Incident @ Belt Line Rd	89.9	90.4	0.45
High Demand, Incident @ Belt Line Rd	89.8	90.4	0.59
Medium Demand, Incident @ Forest Lane	92.1	92.3	0.27
High Demand, Incident @ Forest Lane	91.8	92.1	0.25
Major Incident Scenarios			
Low Demand, Incident @ Belt Line Rd (3 lanes blocked)	84.1	85.9	1.87
Medium Demand, Incident @ Belt Line Rd (3 lanes blocked)	85.4	87.4	1.99
High Demand, Incident @ Belt Line Rd (3 lanes blocked)	85.6	87.1	1.42
Medium Demand, Incident @ Belt Line Rd (2 lanes blocked)	82.3	84.6	2.30
High Demand, Incident @ Belt Line Rd (2 lanes blocked)	83.1	84.3	1.23

ICM Benefits

Benefits considered from the ICM system deployment included saved travel time, increased travel time reliability, reduced fuel consumption, and reduced emissions production. All benefits are monetized to allow for the direct comparison to the costs to install and operate the ICM system.

These benefits were calculated on a facility basis by summarizing the PMT and PHT on individual links in the network to determine which roadways and roadway types in the system see benefits from ICM deployment and which see conditions worsen. This is in contrast to all previous reported performance measures, which were all based on origin-destination travel times. The exception is in travel time variance, which as defined as the total trip time variance, cannot be calculated at the facility level.

Specific steps involved in annualizing these benefits include the following:

- Using AMS tools the analysis produced performance measures associated with the pre-ICM and post-ICM alternatives for the AM peak period. The differences in performance measures between the post-ICM and pre-ICM conditions are deemed the improvement in AM peak period performance due to the introduction of ICM.
- The resulting benefits for the AM peak period are then doubled to approximate the daily benefits under the assumption that the AM peak period produces approximately the same impact as the PM peak period. No benefits were assumed to be gained during off-peak conditions.
- Daily benefits were then converted into annual benefits by multiplying times 260 workdays.

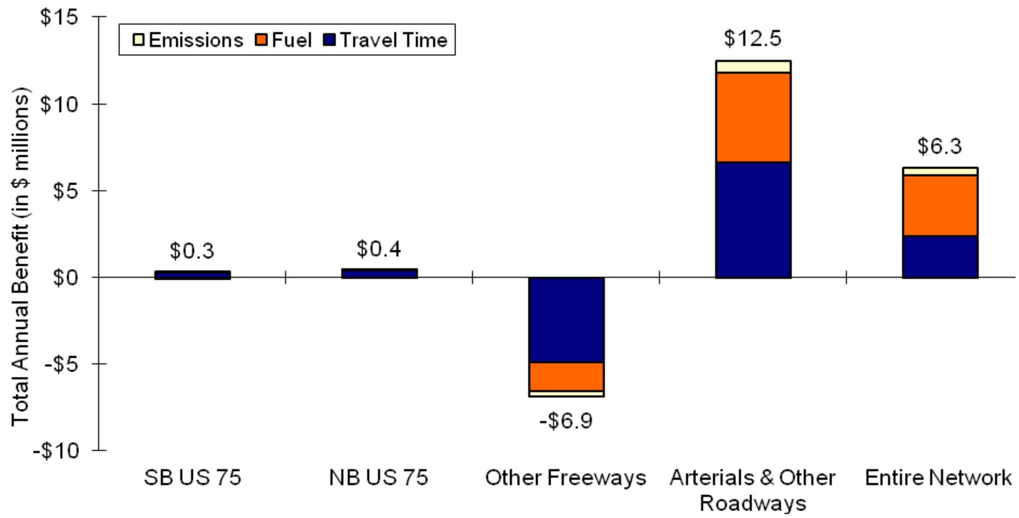
Benefits were monetized through the following methods:

- **Travel Time Savings.** The reduction in PHT from the pre-ICM to the post-ICM simulations for the same operation condition was taken as the travel timesavings to be gained from ICM deployment under those conditions. By multiplying by the total hours saved by an estimated average value of travel time of $16.01 per hour yielded the estimated monetary benefit of saved travel times. Trucks were also assigned a conservative $16.01 per hour value of travel time.
- **Travel Time Reliability.** Following research on the subject, the monetary benefits for changes in travel time reliability were estimated by the change in the standard deviation (or square root of variance) of the trip travel times. The value of travel time reliability was assumed to be equal to the value to travel time, $16.01 per hour. This is a conservative value of reliability time – typically travel time reliability is valued at 2.5 to 3 times the average value of travel time.
- **Fuel Consumption.** Travel speeds on link in the system were examined in multiple time intervals throughout the morning peak period and summarized in the amount of VMT occurring at various speeds and used to estimate the fuel consumption of the modeled vehicles in each scenario. This method is an approximation of fuel consumption and does not include the acceleration and deceleration effects and idle time of queued traffic. Fuel consumption rates were based on EMFAC 2007 and MOBILE6 and an average cost of $4.00 per gallon of fuel was assumed.
- **Emissions.** An estimate was made of reduced emissions from the pre-ICM to the post-ICM based on the amount of VMT occurring in each scenario at varying speeds. Emissions rates and costs used in the analysis were based on MOBILE6 and EMFAC 2007.

Summary of Net Annual Benefits

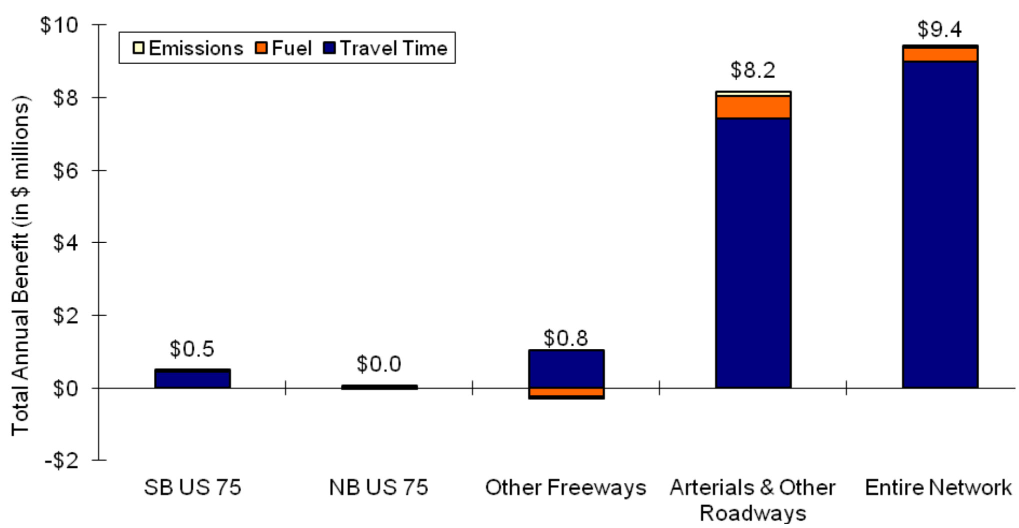
Figures 6-10, 6-11, and 6-12 present summaries of monetized annual benefits achieved under the combined ICM strategies for the no incident, minor incident, and major incident scenarios, respectively, for the U.S. 75 Corridor. Travel time reliability benefits are not included in the individual operating condition analyses since it is derived from the average travel time variance overall operating conditions.

Figure 6-10. Total Estimated Annual Benefits from ICM Deployment
No Incident Operation Conditions



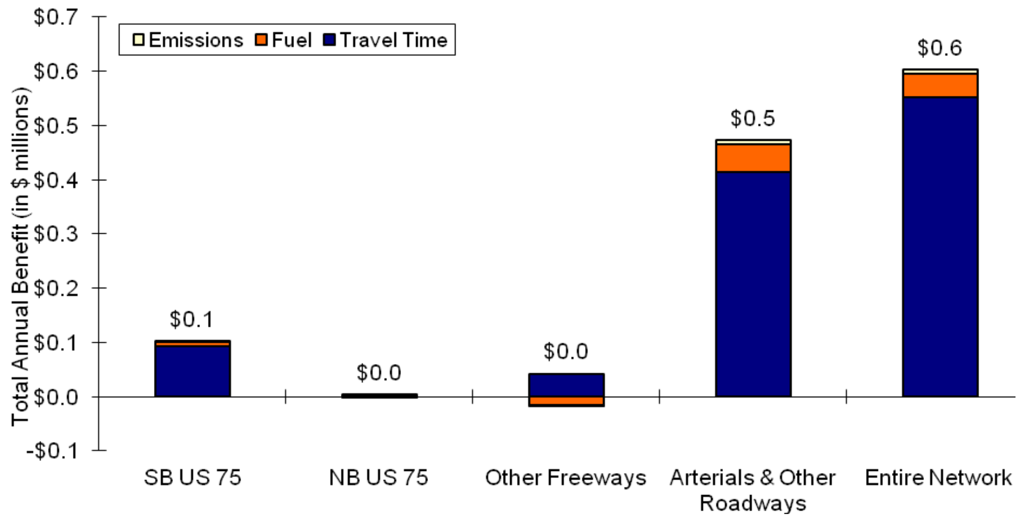
U.S. 75 no-incident operations see very small improvements from ICM, with the total systemwide benefits largely split between savings in travel time and fuel consumption. Freeways other than U.S. 75 see disbenefits from the ICM deployment, while arterials see improvements. This could be attributed to the improved traveler information, which may result to some travelers diverting from the arterial system onto freeways other than U.S. 75. The overall performance of the system sees annualized user benefits of $6.3 million.

Figure 6-11. Total Estimated Annual Benefits from ICM Deployment,
Minor Incident Operating Conditions



Under all minor incident scenarios, the benefits are mostly attributable to travel timesavings. Many of the benefits to the arterial street system can be attributed to the improved traveler information and the deployment of better coordinated signal timing plans. A total of $9.4 million in annual user benefits systemwide is estimated during the minor incident scenarios.

Figure 6-12. Total Estimated Annual Benefits from ICM Deployment,
Major Incident Operating Conditions



Major incident scenarios again see benefits that are mostly attributable to travel timesavings. Many of the benefits to the arterial street system can be attributed to the improved traveler information, the deployment of better coordinated signal timing plans, and headway and park-and-ride capacity improvements related to the Red Line. Due to the limited number of times during a year that the system operates under major incident condition, a $0.6 million in annual user benefits are estimated.

Figures 6-13, 6-14, and 6-15 present the summaries of monetized annual benefits for the varying ICM strategy alternatives under low, medium, and high demand scenarios, respectively.

Low demand conditions see benefits largely in the form of saved fuel consumption on the arterial street system. These benefits can be largely attributed to the deployment of improved signal timing plans during incident conditions. Total benefits occurring during low demand conditions are estimated to reach $8.0 million over the course of the year.

Figure 6-13. Total Estimated Annual Benefits from ICM Deployment,
Low Demand Conditions

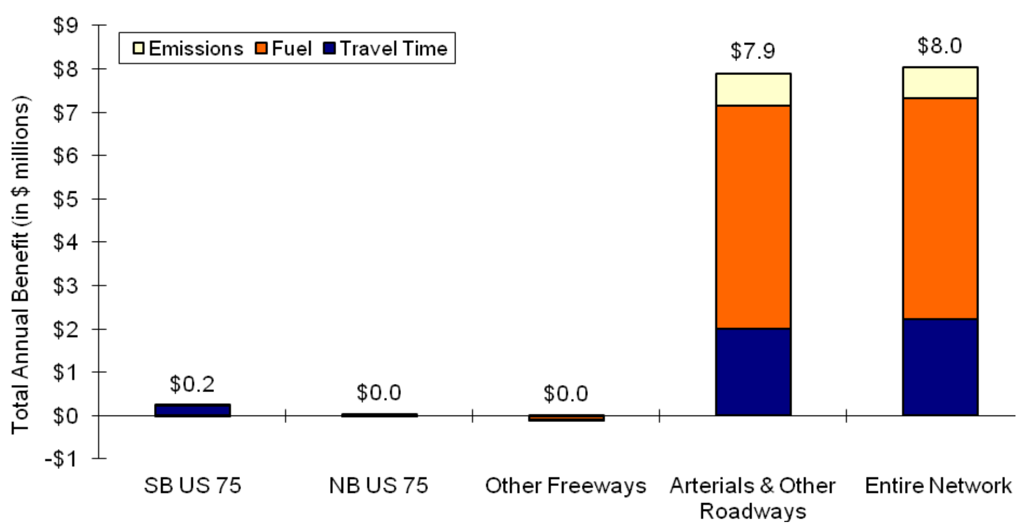
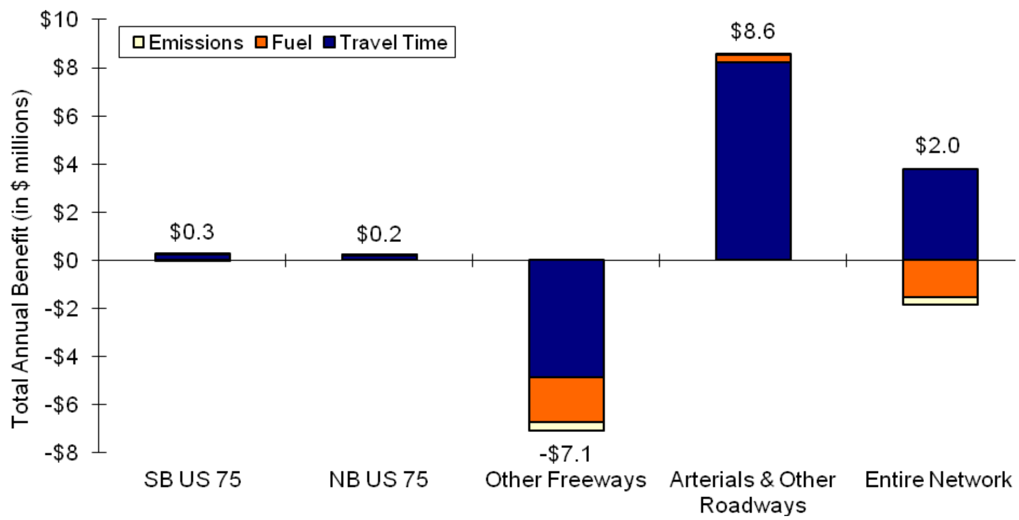
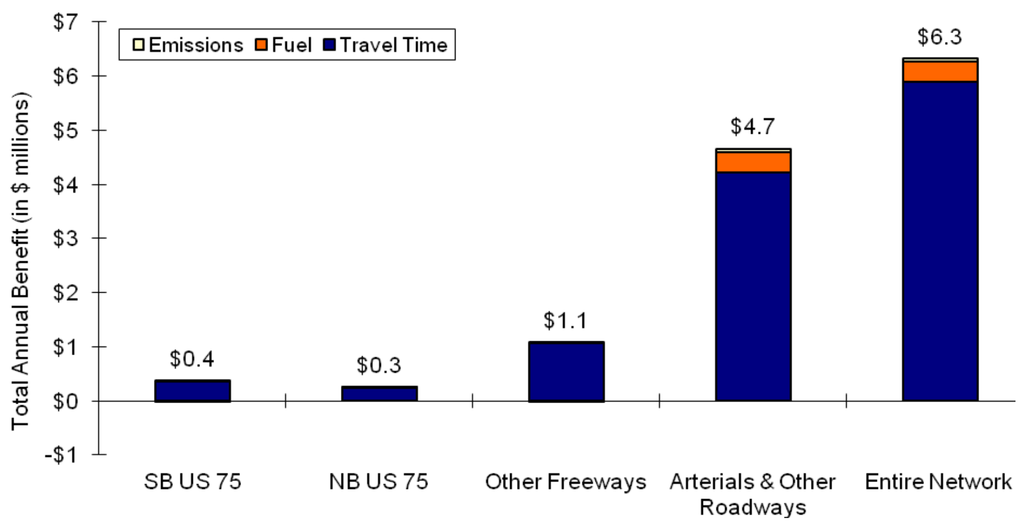


Figure 6-14. Total Estimated Annual Benefits from ICM Deployment,
Medium Demand Conditions



Medium demand conditions see mixed benefits across the system. Disbenefits on the freeways other than U.S. 75 and positive offsets on the arterial system are seen as a result of diverting traffic from the arterial system onto the freeway system, however, the net benefit to the system is still positive. Total benefits occurring during medium demand conditions are estimated to total $2.0 million throughout the year.

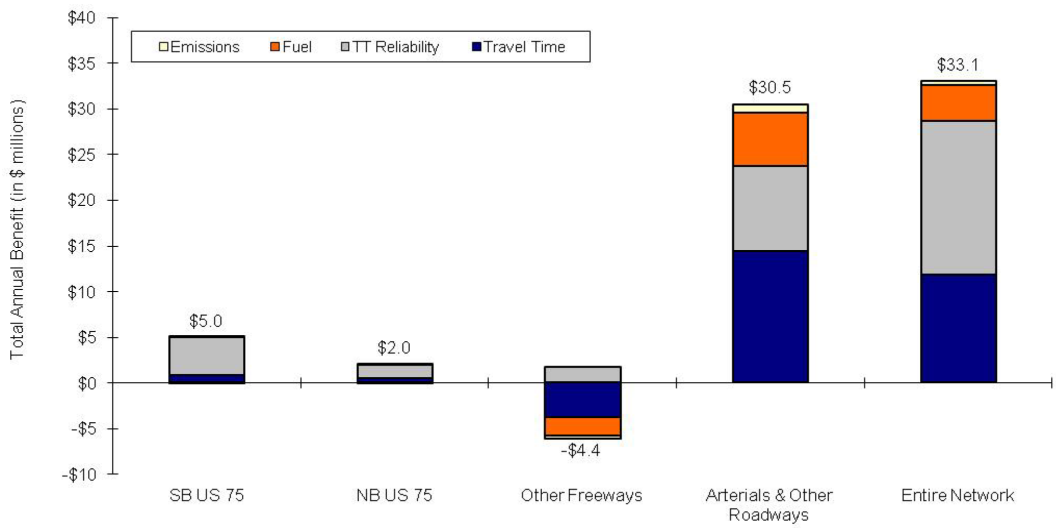
Figure 6-15. Total Estimated Annual Benefits from ICM Deployment,
High Demand Conditions



As expected, ICM strategies deployed during high demand conditions see significant improvements on all parts of the system, largely in the form of travel timesavings. The significant savings seen on the arterial system are due to traveler diversions onto the freeway system and improved arterial signal timing plans during the incident conditions. Total benefits occurring during high demand conditions are estimated to reach $6.3 million throughout a typical year.

Finally, Figure 6-16 presents the average monetized annual benefits for the ICM deployment for all operating conditions occurring during a typical year.

Figure 6-16. Total Estimated Annual Benefits from ICM Deployment,
During All Operating Conditions



While the percentage change in Person Hours Traveled (PHT) between the individual pre- and post-ICM scenarios is in the order of one to five percent, monetized benefits accumulated over the varying operating conditions in a typical year are significant.

Reliability benefits (measured by the standard deviation of travel times) are also significant, and actually larger than the benefits seen from reduced travel times. The reliability benefits are seen across the corridor study area. The majority of the reliability benefits are from a systemwide 1.5 percent decrease in the standard deviation of travel time for all travelers. Trips using U.S. 75 SB, however, see a larger 3.4 percent decrease in the standard deviation of travel time and account for approximately one quarter of the systemwide reliability benefits.

Total estimated benefits for other freeways are negative, and that could be attributed to better operating conditions downstream associated with the metering effect of an incident. Given the improved traveler information, combined with the deployment of better coordinated signal plans, travelers are aware of the improved operating conditions of the freeways affected by the incident on U.S. 75, and consider them as a better route to their destination (fill the gap effect).

Finally, the increased benefits seen on the arterials can be attributed to the improvements in the arterial signal timing plans put in place during an incident.

The deployment of ICM in the U.S. 75 corridor has net positive and significant benefits over a typical year. As analyzed, the average annual benefits are estimated to be $33.1 million per year. Extended over the 10-year life cycle, a total benefit of $278.8 million is estimated.

ICM Costs

The costs presented in this section provide an estimate of the costs for various components needed for the development and operation of the ICM on the U.S. 75 Corridor. The cost analysis methodology is presented in more detail in the U.S. 75 Analysis Plan. The costs presented in this section are defined as follows:

- **Capital Costs –** Includes up-front costs necessary to procure and install equipment. These costs are shown as a total (one-time) expenditure, and they include the capital equipment costs as well as the soft costs required for design and installation of the equipment.
- **Operations and Maintenance (O&M) Costs –** Includes those continuing costs necessary to operate and maintain the deployed equipment, including labor costs. While these costs do contain provisions for upkeep and replacement of minor components of the system, they do not contain provisions for wholesale replacement of the equipment when it reaches the end of its useful life. These O&M costs are presented as annual estimates.
- **Annualized Costs –** Represents the average annual expenditure that would be expected in order to deploy, operate, and maintain the ICM improvement, and replace (or re-deploy) the equipment as they reach the end of their useful life. Within this cost figure, the capital cost of the equipment is amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual O&M cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of Test Corridor ICM deployments.

Total Cost Estimates

The initial capital costs for the ICM deployments in the U.S. 75 corridor is estimated at $4.38 million, with an additional $1.10 million per annum in operating and maintenance costs.

Assuming a 10-year life cycle for all components, the total annualized cost for all ICM deployments for the U.S. 75 corridor is $1.61 million, which translates to $13.6 million in total life-cycle costs.

Conclusions and Lessons-Learned

The ICM AMS methodology offers the following benefits to corridor managers across the country:

- **Invest in the right strategies –** The methodology offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions.
- **Invest with confidence –** AMS allows corridor managers to “see around the corner” and discover optimum combinations of strategies as well as conflicts or unintended consequences inherent in certain combinations of strategies that would otherwise be unknowable before implementation.
- **Improve the effectiveness/success of implementation –** With AMS, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.
- AMS provides a long-term capability to corridor managers to **continually improve implementation** of ICM strategies based on experience.

The U.S. 75 Corridor AMS results show significant benefit/cost ratios and net annual benefits, resulting from the deployment of ICM strategies.

- Overall, deployment of ICM on the U.S. 75 Corridor produces $16.5 million in user benefits per year. Over the 10-year life cycle of the ICM systems, benefits produced a total benefit of **$278.8 million**.
- Costs to deploy ICM on the U.S. 75 Corridor are estimated to be $1.62 million annualized over the 10-year life cycle of the project. The total life-cycle cost to deploy the ICM system is estimated at **$13.6 million**.
- The estimated benefit/cost ratio for the ICM deployment over the 10 life cycle of the project is approximated at **20.4:1**.
- The benefits from ICM are attributable to reduced travel times, improved reliability of travel times, reduced fuel consumption, and reduced mobile emissions. Expected annual savings include 740,000 hours of person-hours of travel, a reduction of fuel consumption by 981,000 gallons of fuel, and an annual reduction of 9,400 tons of vehicular emissions.
- Corridor throughput also improves across all operating conditions: ICM helps reduce the length of the extreme travel times is continued, and is more pronounced on trips using U.S. 75 Southbound. The percent improvement of these trips completed under the 90th percentile travel time ranges from 0.25 to 2.3 percent.

A comparison of benefits across operational conditions reveals that the effectiveness of ICM strategies varies under different prevailing conditions. An ICM strategy, which produces positive overall benefits under high travel demand, may produce small system disbenefits under low travel demand. This validates the hypothesis that implementation of ICM is not “one size fits all”; effective real-time corridor management requires selective implementation of different ICM strategies, depending on the extent of underlying nonrecurrent congestion (due to incidents, weather and other unexpected events) and on the severity of prevailing travel demand.

Appendix A Summary of Dallas U.S. 75 ICM Strategies

The following table summarizes the ICM strategies for the Dallas U.S. 75 ICM Stage II (AMS) Project.

Table A-1. Dallas U.S. 75 ICM – Table Outlining Assumptions of Outcomes and Effects and Model Inputs

		Model Assumptions/Inputs	
Strategy	**Expected Outcome/Effect**	**Pre-ICM (2011)**	**Post-ICM (2011)**
Traveler Information			
Comparative, multimodal travel time information (pretrip and en-route)	Pretrip and en-route traveler information will be disseminated, including incidents, freeway travel time, arterial travel time, Red Line travel time to major destinations, and park-and-ride lot availability via radio, TV, GPS, DMS, and the Internet. The strategy will result in a more reliable information dissemination and potential route and mode diversions.	Pretrip awareness: 10%; En-route awareness: 50%; Pretrip use: 10%; and En-route use: 20%.	Pretrip awareness: 20%; En-route awareness: 60%; Pretrip use: 20%; and En-route use: 30%.
Traffic Management			
Incident signal retiming plans for frontage roads	Cities of Dallas, Plano, and Richardson will implement signal timing plans to increase green time on southbound through movements at frontage road diamond interchanges.	No coordination.	Modify frontage road DIRECT signal timings to achieve 15% increase in throughput.
Incident signal retiming plans for arterials and frontage roads	Cities of Dallas, Plano, and Richardson will implement coordinated plan on Greenville Ave in north-south direction in addition to frontage road retiming as described above.	No coordination.	Modify Greenville DIRECT signal timings to achieve 15% increase in throughput.

Table A-1. Dallas ICM – Table Outlining Assumptions of Outcomes and Effects (continued)

		Model Assumptions/Inputs	
Strategy	**Expected Outcome/Effect**	**Pre-ICM (2011)**	**Post-ICM (2011)**
Transit Management			
LRT smart parking system	Parking systems at LRT stations allow for real-time counts of parking availability for all 8 lots along DART Red Line. Throughout day, the parking availability information will be disseminated by radio, TV, DMS, and the Internet. Availability of Red Line station parking is available pretrip and en-route. During major incident scenarios, Red Line ridership and station parking north of incident increase cumulatively by 10%.	Station parking availability is not known to travelers. Red Line Parker and PGBT stations reach capacity each day.	In DIRECT, the parking lot capacity will be kept at 5% below the actual lot capacity in the pre-ICM scenario. When the lot reaches this threshold, paths with park-and-ride will not be allowed.
Red Line Capacity Increase	DART decreases headways to Red Line to increase capacity on days with higher expected demand due to mode shifts during major traffic accidents. Red Line ridership increases cumulatively by 10%.	Red Line operating below capacity.	Decrease Red Line headways from 10 minutes to 7.5 minutes.
Station parking expanded with private parking	DART adds shuttle bus service from private parking lots to Red Line PGBT station to handle increase in transit demand. Red Line ridership increases cumulatively by 10%.	1,193 spaces at PGBT station.	In DIRECT, the PGBT nominal lot capacity (1,193 vehicles) will be increased by 250 spaces to reflect the available private parking. As soon as the PGBT nominal lot capacity is reached, each additional traveler utilizing the overflow capacity will be assessed with a time penalty to represent the time to “go to” the nearby private lot and for the shuttle service back to the PGBT station.
Station parking expanded with valet parking	DART runs valet parking service from the Red Line PGBT station. Transit riders can drop car off at station and not search for parking spot. Valet will retrieve car upon transit riders return to station. Increased parking at the Red Line PGBT station Red Line ridership increases cumulatively by 10%.	1,193 spaces at PGBT station.	Similar to the private parking, but no penalty will be assessed.

Appendix B Performance Measure Calculation Using Simulation

This appendix describes the methodology used in calculating various performance measures for the ICM AMS as summarized in this report.

Calculation Procedures for Key Integrated Corridor Performance Measures from Simulation Outputs

A core element of the Integrated Corridor Management (ICM) initiative is the identification and refinement of a set of key performance measures. These measures represent both the bottom-line for ICM strategy evaluation and define what “good” looks like among key corridor stakeholders. To date, the emphasis on performance-driven corridor management among the participating Pioneer sites has been on measures derived from observed data. In the Analysis, Modeling and Simulation (AMS) phase of the effort, however, attention has turned to producing comparable measures derived from simulation outputs. This document provides a detailed process by which a set of key national measures of corridor performance can be calculated. It is the intent of the ICM program, and this document, that these processes will be implemented consistently in the three participating AMS sites applying the ICM AMS methodology.

This document provides a detailed description of how measures of ***delay***, ***travel time reliability*** and ***throughput*** are calculated from simulation outputs. A brief discussion of travel time variance is also provided given that travel time variance measures are used in ICM-related benefit-cost calculations. The algorithmic approaches defined here are software independent, that is, this process can be implemented with outputs from any of the time-variant simulation tools utilized in the three participating ICM AMS sites. The document begins with a discussion of the calculation of travel time, which informs both a calculation of delay as well as travel time reliability. Next, we provide a discussion of how corridor throughput is defined and measured. The document concludes with a discussion of how these measures are used to make comparisons between system performance in the pre-ICM case and in one or more distinct post-ICM cases.

Travel Time

Our basic unit of observation in calculating ICM-related performance measures is a trip i made between an origin o, finishing at a destination d, starting within a particular time interval τ using mode m.

We record travel time from a single run of the simulation under operational conditions k for this unit

of observation as $t_i^k = t_{o,d,\tau',m}^k$. [6] *Operational conditions* here refer to a specific set of simulation settings reflecting a specific travel demand pattern and collection of incidents derived from a cluster analysis of observed traffic count data and incident data. An example of an operational condition would be an AM peak analysis with 5 percent higher than normal demand and a major arterial incident. Let k be a specific operational condition and the set of all conditions K. Note that each condition has a probability of occurrence p_k and $\sum_k p_k = 1$.

First, for this particular run(s) representing a specific operational condition, we calculate an average travel time for trips between the same o-d pair that begin in a particular time window. Let τ represent this interval, e.g., an interval between 6:30 AM and 6:45 AM and $\mathbf{I}_{o,d,\tau,m}^k$ the set of $n_{o,d,\tau,m}^k$ trips from o to d starting in interval τ under operational condition k using mode m. Note that $\mathbf{I}_{o,d,\tau,m}^k$ is a collection of trips and $n_{o,d,\tau,m}^k$ the scalar value indicating the number of trips contained in $\mathbf{I}_{o,d,\tau,m}^k$. The set of all τ of interest is the set T. For example, we may be interested in consistently calculating performance measures over all trips that begin in the 12 quarter-hour intervals between 6:00 AM and 9:00 AM.

The classification of travel mode may be determined independently at each site, but the breakdown should capture the combination of all modes utilized in making the trip. For example, one may choose to classify non-HOV-auto trips as a mode separately from non-HOV-auto/HOV/walk trips to track the performance of travelers utilizing park-and-ride facilities. However, any classification of modes must be mutually exclusive and collectively exhaustive, that is, $\bigcup_m \mathbf{I}_{o,d,\tau,m}^k = \mathbf{I}_{o,d,\tau}^k$ and $\sum_m n_{o,d,\tau,m}^k = n_{o,d,\tau}^k$.

The average travel time of trips with origin and destination by mode staring in this time interval is:

$$T_{o,d,\tau,m}^k = \frac{\sum_{i \in \mathbf{I}_{o,d,\tau}^k} t_i^k}{n_{o,d,\tau,m}^k} \qquad (1)$$

where $n_{o,d,\tau,m}^k > 0$. Let $T_{o,d,\tau,m}^k = 0$ when $n_{o,d,\tau,m}^k = 0$.

The calculation of Equation 1 must also include some estimated travel time for trips that cannot reach their destinations by the end of the simulation period. Later in this document, we will discuss the method for estimating travel times for these trips still underway when the simulation ends.

Next, we calculate the average travel time for this same set of trips across all operational conditions, that is, $\forall k \in K$. Note that it is possible that we may have trips for some o, d, τ, m under some

6 In the case where multiple random seeds are varied, but the operational conditions are identical, this travel time represents an average for a single trip across the multiple runs. Also, note that this discussion of measures assumes that we are calculating measures for a single case (e.g., pre-ICM); later we will address comparisons between cases.

conditions and no trips for the same o, d, τ, m under other conditions. Let $K'_{o,d,\tau,m}$, $K'_{o,d,\tau,m} \subseteq K$ be the subset of conditions where $n^k_{o,d,\tau,m} > 0$.

Equation 2 finds the average travel time by mode for all trips from o to d starting in interval τ over all conditions where at least one trip is made, $k \in K'_{o,d,\tau,m}$:

$$T_{o,d,\tau,m} = \frac{\sum_{k \in K'_{o,d,\tau,m}} T^k_{o,d,\tau,m} p_k}{\sum_{k \in K'_{o,d,\tau,m}} p_k} \tag{2}$$

The average number of trips by mode from o to d starting in interval τ over all conditions $k \in K$:

$$n_{o,d,\tau,m} = \sum_{k \in K} n^k_{o,d,\tau,m} p_k \tag{2a}$$

Combining across modes, the average travel time of trips from o to d starting in interval τ under operational condition k:

$$T^k_{o,d,\tau} = \frac{\sum_{m} T^k_{o,d,\tau,m} n^k_{o,d,\tau,m}}{n^k_{o,d,\tau}} \tag{3}$$

where $n^k_{o,d,\tau} > 0$. Let $T^k_{o,d,\tau} = 0$ when $n^k_{o,d,\tau} = 0$.

The average travel time for all trips from o to d starting in interval τ under $K'_{o,d,\tau}$ the subset of conditions where $n^k_{o,d,\tau} > 0$, $K'_{o,d,\tau} \subseteq K$:

$$T_{o,d,\tau} = \frac{\sum_{k \in K'_{o,d,\tau}} T^k_{o,d,\tau} p_k}{\sum_{k \in K'_{o,d,\tau}} p_k} \tag{4}$$

The average number of trips from o to d starting in interval τ over all conditions $k \in K$:

$$n_{o,d,\tau} = \sum_{k \in K} n^k_{o,d,\tau} p_k \tag{4a}$$

Equation 5 defines the trip-weighted average travel time of the system across all o, d, τ :

$$\overline{T} = \frac{\sum_{\forall o,d,\tau} T_{o,d,\tau}\, n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \tag{5}$$

Delay

Delay can be broadly defined as travel time in excess of some *subjective minimum* travel time threshold. Often, discussions of delay focus solely on roadway-only travel focus on either travel time at posted speeds or 85th percentile speeds. Delay for ICM must be defined differently since ICM explicitly includes multimodal corridor performance. Instead, we directly identify delay at the o, d, m level by deriving a zero-delay threshold $T^{0}_{o,d,m}$, considering travel times observed across all operating conditions $\forall k \in K$ and all time intervals $\forall \tau \in T$.

The zero-delay threshold for each o-d pair by mode is calculated looking across all operating conditions and all time intervals:

$$T^{0}_{o,d,m} = \min_{k \in K, \tau \in T} \left\{ T^{k}_{o,d,\tau,m} \right. \tag{6}$$

In some cases, the cluster analysis will group low-demand, non-incident conditions into a large, high-probability operational condition. In this case, it is possible that a notionally “low” demand pattern will still produce significant congestion in the corridor, particularly in a peak-period analysis.

For this reason, the minimum threshold may also be calculated as the travel time derived in the pre-ICM case under a substantially reduced demand pattern with no incidents or weather impacts. The reduced demand pattern should produce enough trips to generate travel time statistics by mode for every set of trips from o to d starting in interval τ (i.e., $n^{0}_{o,d,\tau,m} > 0 \;\forall\, o, d, \tau, m$). At the same time, the reduced demand should generate no volume-related congestion in the network.

Alternatively, $T^{0}_{o,d,m}$ may be estimated directly from model inputs. For consistency, however, the travel time associated with these thresholds should include expected transfer time between modes and unsaturated signal delay as in the case where a low-demand pattern is used to drive a zero-delay model run.

From our previous calculation of travel time in Equation 1, recall the average travel time of all trips traversing the network from origin o to destination d starting in time interval τ using mode m under operational condition k , $T^{k}_{o,d,\tau,m}$

Using zero-delay thresholds $T^{0}_{o,d,\tau,m}$, calculate average trip delay under condition k for each o,d,τ,m:

$$D^{k}_{o,d,\tau,m} = max\left[T^{k}_{o,d,\tau,m} - T^{0}_{o,d,\tau,m}, 0\right] \quad (7)$$

Combining across all operational conditions, calculate the average delay for each o,d,τ,m over $K'_{o,d,\tau,m}$, the subset of conditions where $n^{k}_{o,d,\tau,m} > 0$.

$$D_{o,d,\tau,m} = \frac{\sum_{k \in K'_{o,d,\tau,m}} D^{k}_{o,d,\tau,m} p_k}{\sum_{k \in K'_{o,d,\tau,m}} p_k} \quad (7a)$$

Combining across modes, the average delay for trips from o to d starting in interval τ :

$$D_{o,d,\tau} = \frac{\sum_{m} D_{o,d,\tau,m}\, n_{o,d,\tau,m}}{n_{o,d,\tau}} \quad (8)$$

where $n_{o,d,\tau} > 0$. Let $D_{o,d,\tau} = 0$ when $n_{o,d,\tau} = 0$.

Systemwide average trip delay (Equation 9):

$$D = \frac{\sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \quad (9)$$

Aggregating this average delay over all trips produces total system delay (Equation 10):

$$\hat{D} = \sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau} \quad (10)$$

Travel Time Reliability

Corridor reliability measures are inherently measures of outlier travel times experienced by a traveler making the same (or similar) trip over many days and operational conditions. We have already defined and organized travel time measures from the simulation with respect to trips from o to d starting in interval τ over using mode m for all conditions $k \in K$. Just as in the case of the subjective notion of delay as travel time in excess of some minimum threshold, the notion of what reliable travel is depends on a *relative maximum* acceptable travel time threshold. For the ICM AMS effort, as in many studies with a travel reliability measure, a threshold based on the 95th percentile travel time is selected. Note that this percentile is calculated considering travel times for similar trips (i.e.,

o,d,τ,m) with respect to travel time variation induced by changes in operational conditions $k \in K$.

To identify the 95th percentile travel time, first we generate an ordered list of travel times for each o,d,τ,m across all operating conditions:

$$\mathrm{T}_{o,d,\tau,m} = \left[T^{1}_{o,d,\tau,m}, T^{2}_{o,d,\tau,m}, \cdots, T^{J}_{o,d,\tau,m}\right] \quad (11)$$

where $T^{j}_{o,d,\tau,m} \leq T^{j+1}_{o,d,\tau,m}$ for all $j = 1 \cdots J$.

The 95th percentile travel time from this list is identified using the probabilities associated with each operational condition.

$$T^{[95]}_{o,d,\tau,m} = T^{j}_{o,d,\tau,m} \quad (11a)$$

where $\sum_{k=1}^{j} p_k = 0.95$.

Note the array of travel times $\mathbf{T}_{o,d,\tau,m}$ represents levels on a linear step-function. This implies that if 17.4 minutes is the travel time associated with an operational condition occupying the 92nd through 98th travel time percentile, we simply use the 17.4-minute travel time as the 95th percentile value. Also note that the specific operational conditions under which the 95th percentile travel time is found will vary among o,d,τ,m. For example, a major freeway incident creates congestion and high travel times for trips that originate upstream of the incident location, but creates free-flowing and uncongested conditions for trips that originate downstream of the incident location.

Equation 12 defines planning time index for each o,d,τ,m, the ratio of the 95th percentile travel time to the zero-delay travel time for trips from o to d starting in interval τ using mode m over all conditions $k \in K$:

$$\rho_{o,d,\tau,m} = \frac{T^{[95]}_{o,d,\tau,m}}{T^{0}_{o,d,\tau,m}} \quad (12)$$

Equation 12a defines planning time index by o,d,τ across all modes:

$$\rho_{o,d,\tau} = \frac{\sum_{m} \rho_{o,d,\tau,m} n_{o,d,\tau,m}}{n_{o,d,\tau}} \quad (12a)$$

Average systemwide planning time index considers all o, d, τ, weighted average by trip volume:

$$\rho = \frac{\sum_{\forall o,d,\tau} \rho_{o,d,\tau}\, n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \tag{13}$$

We may also be interested in trip-weighted planning time index within a mode across all o, d, τ:

$$\rho_m = \frac{\sum_{\forall o,d,\tau} \rho_{o,d,\tau}\, n_{o,d,\tau,m}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \tag{13a}$$

Variance in Travel Time

Variance in travel time can be calculated in a variety of ways. The key here is that some care must be taken to isolate the specific variation of interest. Additionally, as variance is strongly influenced by outliers, in order to eliminate any potential bias introduced into the variance of travel times resulting from the estimation of a fulfilled travel time for incomplete travelers at the end of the simulation period, the variance calculation should be restricted to completed travelers defined as set $\ddot{\mathbf{I}}^{k}_{o,d,\tau}$ consisting of $\ddot{n}^{k}_{o,d,\tau}$ trips. While the inclusion of the fulfilled incomplete travelers' travel times in the other performance measures may be influenced by the same bias, the nature of the variance calculation magnifies the effects of that potential bias. This effect may be more significant in larger models where the calibration and validation efforts must be focused on the primary corridor or study area.

Given this, the variance in travel time among members of the same origin, destination, and time interval in a single run is:

$$V^{k}_{o,d,\tau} = \frac{\sum_{i \in \ddot{\mathbf{I}}^{k}_{o,d,\tau}} \left(\ddot{t}^{k}_{i} - \ddot{T}^{k}_{o,d,\tau}\right)^2}{\ddot{n}^{k}_{o,d,\tau} - 1} \tag{14}$$

Recall $K'_{o,d,\tau}$, $K'_{o,d,\tau} \subseteq K$ as the subset of conditions where $\ddot{n}^{k}_{o,d,\tau} > 0$. The variance of travel time for each o, d, τ under all operation conditions is then defined as:

$$V_{o,d,\tau} = \frac{\sum_{k \in K'_{o,d,\tau}} V^{k}_{o,d,\tau}\, p_k}{\sum_{k \in K'_{o,d,\tau}} p_k} \tag{14a}$$

The average variance among all o, d, τ is a weighted average of the variances:

$$V = \frac{\sum_{\forall o,d,\tau} V_{o,d,\tau} \ddot{n}_{o,d,\tau}}{\sum_{\forall o,d,\tau} \ddot{n}_{o,d,\tau}} \tag{14b}$$

Throughput

The role of a throughput measure in ICM is to capture the primary product of the transportation system: travel. Particularly in peak periods, the capability of the transportation infrastructure to operate at a high level of efficiency is reduced. One of the goals of ICM is to manage the various networks (freeway, arterial, transit) cooperatively to deliver a higher level of realized system capacity in peak periods. While throughput (e.g., vehicles per lane per hour) is a well-established traffic engineering point measure (that is, in a single location), there is no consensus on a systemwide analog measure. In the ICM AMS effort, we use the term *corridor throughput* to describe a class of measures used to characterize the capability of the integrated transportation system to efficiently and effectively transport travelers. We do not consider freight throughput in these calculations, although this could be revisited at a later date.

In order to support throughput measures, additional trip data need to be generated as simulation outputs. For each trip i made between an origin o, finishing at a destination d, starting at a particular time τ' we obtain from the simulation the travel time $t^k_{o,d,\tau'}$ and a distance traveled $s^k_{o,d,\tau'}$. In some cases, trip-level outputs from the simulation are only available at a vehicle level, so some trips may have multiple passengers associated with that trip (e.g., in the case of carpool travel). Let $x^k_{o,d,\tau'}$ represent the number of travelers associated with a particular trip record.

Passenger-miles traveled (PMT) are accumulated using a process similar to travel time. First, we convert individual trip PMT into an average PMT for trips from origin o to destination d with a trip start in time interval τ.

$$X^k_{o,d,\tau} = \frac{\sum_{i \in I^k_{o,d,\tau}} s^k_i x^k_i}{n^k_{o,d,\tau}} \tag{15}$$

For trips that cannot be completed before the end of the simulation, see the following section for the estimation of total trip distance.

Equation 16 finds the average PMT for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$X_{o,d,\tau} = \sum_{k \in K} X^k_{o,d,\tau} p_k \tag{16}$$

Equation 17 defines the aggregate PMT across all o, d, τ:

$$X = \sum_{\forall o,d,\tau} X_{o,d,\tau}\, n_{o,d,\tau} \tag{17}$$

Passenger-miles delivered (PMD) and Passenger-trips delivered (PTD) are measures that introduce notions of travel quality into throughput. Simple PMT measures often cannot differentiate between a well-managed system and a poorly managed system because passenger-trip distances are counted equally regardless of trip duration. In other words, a five-mile trip completed in 15 minutes counts equally with the same five-mile trip completed in two hours. Here, we restrict the accounting of passenger-miles traveled (or passenger-trips delivered) to trips that successfully complete their trips prior to the end of the simulation (or some other logical time-point). Let $\dot{\mathbf{I}}^k_{o,d,\tau}$ be the set of $\dot{n}^k_{o,d,\tau}$ trips from o to d starting in interval τ under operational condition k that complete their trip before the simulation ends (or some other logical time-cutoff).

Equation 18 shows passenger-trips delivered (PTD) calculated at the o, d, τ level.

$$Y^k_{o,d,\tau} = \frac{\sum_{i \in \dot{\mathbf{I}}^k_{o,d,\tau}} x^k_i}{\dot{n}^k_{o,d,\tau}} \tag{18}$$

Equation 19 finds the average PTD for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$Y_{o,d,\tau} = \sum_{k \in K} Y^k_{o,d,\tau}\, p_k \tag{19}$$

Equation 19b finds the average number of completed trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$\dot{n}_{o,d,\tau} = \sum_{k \in K} \dot{n}^k{}_{o,d,\tau}\, p_k \tag{19b}$$

Equation 20 defines the aggregate PTD across all o, d, τ:

$$Y = \sum_{\forall o,d,\tau} Y_{o,d,\tau}\, \dot{n}_{o,d,\tau} \tag{20}$$

Passenger-miles delivered (PMD) is a distance-weighted measure of throughput based on PTD:

$$Z^k_{o,d,\tau} = \frac{\sum_{i \in \dot{\mathbf{I}}^k_{o,d,\tau}} s^k_i x^k_i}{\dot{n}^k_{o,d,\tau}} \tag{21}$$

Equation 22 finds the average PMD for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$Z_{o,d,\tau} = \sum_{k \in K} Z^{k}_{o,d,\tau} p_k \tag{22}$$

Equation 23 defines the aggregate PMD across all o, d, τ :

$$Z = \sum_{\forall o,d,\tau} Z_{o,d,\tau}\, \dot{n}_{o,d,\tau} \tag{23}$$

For example, in the Dallas ICM Corridor, the simulation period is from 5:30 AM to 11:00 AM, while the peak hours are from 6:30 AM to 9:00 AM. It is anticipated that with or without an ICM strategy in place, all trips that begin in the peak period should be completed before the simulation ends at 11:00 AM. In this case, there may be little difference in PMT or PMD when 11:00 AM is used as the logical time cutoff. In order to measure the peak capability of the system to deliver trips, the set of trips counting towards PMD could potentially be restricted to those trips that can both begin and complete their trips in the peak period (6:30-9:00 AM). At this point, it is premature to define a specific time cut-off for PMD to be applied in all three sites.

Restricting the calculation of measures to selected cohorts is also relevant to the calculation of delay and travel time reliability measures. Although peak periods vary among the AMS sites in terms of the onset and duration of congestion, a consistent set of trips that contribute to measure calculation (others simply run interference) should be identified. As in the case of the throughput time cut-off point, U.S. DOT may wish to prescribe specific times in the future.

At this time, it is unclear whether PMT, PMD, or PTD will be the selected performance measure for corridor throughput, pending clarification that all ICM models can support these measures.

Estimation of Travel Times and Travel Distance for Incomplete Trips

Trips that cannot complete their trips by the time that the simulation ends are still included in the calculation of all delay and travel time calculations. Our approach is to estimate total travel time including any additional time that would be required to complete the trip given the average speed of travel.

First, let $\ddot{\mathbf{I}}^{0}_{o,d,\tau}$ be the set of $\ddot{n}^{0}_{o,d,\tau}$ trips from origin o , destination d starting a trip in time interval τ that can be completed under the low-demand operational condition used to identify the zero-delay travel times.

The average distance traveled over these trips is:

$$\ddot{X}^{0}_{o,d,\tau} = \frac{\sum_{i \in \ddot{\mathbf{I}}^{0}_{o,d,\tau}} s_i}{\ddot{n}^{0}_{o,d,\tau}} \tag{24}$$

Note: If $\ddot{n}^{0}_{o,d,\tau} = 0$ then $\ddot{X}^{0}_{o,d,\tau}$ is indeterminate. In this case, find τ', the closest time interval such that $\underset{\tau'}{\arg\min} |\tau' - \tau|$ where $n^{0}_{o,d,\tau'} > 0$. Approximate $\ddot{X}^{0}_{o,d,\tau}$ using $\ddot{X}^{0}_{o,d,\tau'}$.

Next, let $\overleftarrow{\mathbf{I}}^{k}_{o,d,\tau}$ be the set trips from origin o, destination d starting a trip in time interval τ that *cannot* be completed under operational condition k. For all $i \in \overleftarrow{\mathbf{I}}^{k}_{o,d,\tau}$, let $\overleftarrow{x}^{k}_{i}$ be the distance traveled on the trip i up to the point where the simulation ends, and let $\overleftarrow{t}^{k}_{i}$ the travel time on trip i up to the point where the simulation ends. Average travel speed for a trip that cannot be completed is expressed in Equation 25:

$$\overleftarrow{v}^{k}_{i} = \frac{\overleftarrow{x}^{k}_{i}}{\overleftarrow{t}^{k}_{i}} \tag{25}$$

Estimated total trip travel time for a trip that cannot be completed before the simulation ends is the accumulated travel time plus the time to travel the remaining distance at average trip speed:

$$t^{k}_{i} = \overleftarrow{t}^{k}_{i} + max\left\{ \frac{\left(\ddot{X}^{0}_{o,d,\tau} - \overleftarrow{x}^{k}_{i}\right)}{\overleftarrow{v}^{k}_{i}}, 0 \right\} \tag{26}$$

$$x^{k}_{i} = max\left\{\ddot{X}^{0}_{o,d,\tau}, \overleftarrow{x}^{k}_{i}\right\} \tag{27}$$

Comparing Pre-ICM and Post-ICM Cases

All of the travel time and throughput measure calculation procedures defined above are conducted under a single set of simulation settings reflecting a specific set of corridor management policies, technologies and strategies (here referred to as a *case*, but often called an *alternative*). The complete suite of delay, travel time reliability and throughput measures are calculated independently for each case (e.g., Pre-ICM). Comparisons of the resulting measures are then made to characterize corridor performance under each case.

Comparing Observed and Simulated Performance Measures

These few key measures have been defined in detail for national consistency across all AMS sites. Sites have also identified measures. This document has dealt in detail with the calculation of measures from simulation outputs. However, the calculation of comparable measures using observed data demands an equivalent level of detailed attention. These observed measures will be critical in the AMS effort to validate modeling accuracy and in performance measurement in the demonstration phase. Because of the nature of the simulation output, the modeling analyst is able to resolve and track performance at a level of detail that is not available to an analyst working with field counts, speeds and transit passenger-counter outputs. However, it is the responsibility of the site and the AMS contractor to ensure that these measures are similar in intent, if not in precise calculation. In many cases, the simulation tools or their basic outputs can be manipulated to produce measures quite comparable with field data. An example of this is in throughput calculation, where a site may wish to pursue a screenline passenger throughput measure from field data. In addition to the system-level throughput measures detailed above, the simulation model can be configured to produce passenger-weighted counts across the same screenline to match the field throughput measure.

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ANNEX 2.
Integrated Corridor Management

Analysis, Modeling, and Simulation Results for the I-394 Corridor in Minneapolis, Minnesota

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Final Report – November 2010

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This report documents the analysis methodologies, tools and performance measures used to analyze Integrated Corridor Management (ICM) strategies for the I 394 corridor, and presents high-level results and lessons-learned for the successful implementation of ICM. The I 394 corridor is an east-west, commuter route connecting the Minneapolis Central Business District (CBD) with the western suburbs. The corridor study area consists of the I 394 freeway, including a high-occupancy toll (HOT) lane and general purpose lanes, intersecting freeways, frontage roads, express and local buses, transit stations, park-and-ride lots, regional arterial streets, and ABC garages located at the western edge of the CBD.

The analysis investigated various operating conditions on the I 394 corridor, including daily nonincident operations, major and minor freeway and arterial incidents, special events, and adverse weather events. ICM strategies analyzed include earlier dissemination of pretrip and en-route traveler information, provision of comparative travel times, mode shift to transit, parking availability at park-and-ride lots, incident signal retiming plans for arterials, predefined freeway closure points, opening the HOT lanes to all traffic during incidents, and transit signal priority.</td></tr>
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Executive Summary

This report documents the analysis methodologies, tools and performance measures used to analyze Integrated Corridor Management (ICM) strategies for the I-394 corridor, and presents high-level results and lessons-learned for the successful implementation of ICM. The I-394 corridor is an east-west, commuter route connecting the Minneapolis Central Business District (CBD) with the western suburbs. The corridor study area consists of the I-394 freeway, including a high-occupancy toll (HOT) lane and general purpose lanes, intersecting freeways, frontage roads, express and local buses, transit stations, park-and-ride lots, regional arterial streets, and ABC garages located at the western edge of the CBD.

The analysis investigated various operating conditions on the I-394 corridor, including daily nonincident operations, major and minor freeway and arterial incidents, special events, and adverse weather events. ICM strategies analyzed include earlier dissemination of pretrip and en-route traveler information, provision of comparative travel times, mode shift to transit, parking availability at park-and-ride lots, incident signal retiming plans for arterials, predefined freeway closure points, opening the HOT lanes to all traffic during incidents, and transit signal priority.

The I-394 corridor AMS results show significant benefits, resulting from the deployment of ICM strategies:

- Overall, deployment of ICM on the I-394 corridor produces $10.2 million in user benefits per year. Over the 10-year life cycle of the ICM systems, benefits produced total **$85.9 million**.
- Costs to deploy ICM on the I-394 corridor are estimated to be $0.47 million annualized over the 10-year life cycle of the project. The total life-cycle costs to deploy the ICM system is estimated at **$3.96 million**.
- The estimated benefit/cost ratio for the ICM deployment over the 10-year life cycle of the project is approximated at **22:1**.
- The benefits from ICM are attributable to reduced travel times, improved reliability of travel times, reduced fuel consumption, and reduced mobile emissions. Expected annual savings include 132,000 hours of person-hours of travel; a reduction of fuel consumption by 17,600 gallons of fuel; and a reduction of 175 tons of vehicular emissions. Corridor throughput also improves across all operating conditions: ICM helps reduce the length of the extreme travel times in the corridor, and this effect is more pronounced on trips using I-394 eastbound.
- Across all operational conditions, most of the ICM benefit is attributed to the travel time reliability and travel time savings on the eastbound freeway and other roads in the corridor. Other roads show travel time and travel time reliability benefits owing mostly to better traveler diversion due to better traveler information and arterial signal optimization. This can be attributed to a combination of the improved dissemination of traveler information to advise travelers to seek alternative paths, opening the HOT lane to all travelers without tolling during major incidents, and transit signal priority. The parallel arterials do see disbenefits during major incidents, which can be attributed to the additional diverted traffic from I-394. Arterial disbenefits notwithstanding, the overall I-394 corridor experiences positive benefits.

- An important finding of this analysis is that ICM strategies produce more benefits during nonrecurrent congestion. For individual travelers who primarily rely on the I-394 eastbound facility, the majority of benefits accrue under particular operational conditions associated with incidents. This finding validates the hypothesis that ICM is most effective under the worst operational conditions including incidents.
- The I-394 corridor AMS validates the ICM concept: dynamically applying ICM strategies in combination across a corridor is shown to reduce congestion and improve the overall productivity of the transportation system.

This analysis offers the following benefits:

- **Invest in the right strategies –** The analysis offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions.
- **Invest with confidence –** The analysis allows corridor managers to "see around the corner" and discover optimum combinations of strategies, as well as conflicts or unintended consequences that would otherwise be unknowable before implementation.
- **Improve the effectiveness/success of implementation –** With this analysis, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.
- The analysis provides a long-term capability to corridor managers to **continually improve implementation** of ICM strategies based on experience.

Chapter 1 Introduction and Background

The objective of the ***Integrated Corridor Management (ICM)*** initiative is to demonstrate how Intelligent Transportation Systems (ITS) technologies can efficiently and proactively manage the movement of people and goods in major transportation corridors. The ICM initiative aims to pioneer innovative multimodal and multi-jurisdictional strategies – and combinations of strategies – that optimize existing infrastructure to help manage congestion in our nation's corridors. There are many corridors in the country with under-utilized capacity (in the form of parallel transit capacity (bus, rail, etc.) and/or arterials and under-utilized travel lanes) that could benefit from ICM.

The maturation of ITS technologies, availability of supporting data, and emerging multiagency institutional frameworks make ICM practical and feasible. There is a large number of freeway, arterial, and transit optimization strategies available today and in widespread use across the U.S. Most of these strategies are managed locally by individual agencies on an asset-by-asset basis. Even those managed regionally are often managed in a stove-piped manner (asset-by-asset) rather than in an integrated fashion across a transportation corridor. Dynamically applying these strategies in combination across a corridor in response to varying conditions is expected to reduce congestion "hot spots" in the system, and improve the overall productivity of the system. Furthermore, providing travelers with actionable information on alternatives (such as mode shift, time of travel shift, and/or route shift) is expected to mitigate bottlenecks, reduce congestion, and empower travelers to make more informed travel choices.

The objectives of the ***"ICM – Tools, Strategies and Deployment Support"*** project are to refine Analysis Modeling and Simulation (AMS) tools and strategies, assess Pioneer Site data capabilities, conduct AMS for three Stage 2 ICM Pioneer Sites, and conduct AMS tools post-demonstration evaluations. Current efforts under this project focus on analyzing the ICM systems proposed by the Stage 2 Pioneer AMS Sites, and evaluating the expected benefits to be derived from implementing those ICM systems.

The overall benefits of this effort include:

- Help decision-makers identify gaps, evaluate ICM strategies, and invest in the best combination of strategies that would minimize congestion; comprehensive modeling increases the likelihood of ICM success, and helps minimize unintended consequences of applying ICM strategies to a corridor.
- Help estimate the benefit resulting from ICM across different transportation modes and traffic control systems; without being able to predict the effects of ICM strategies corridor transportation agencies may not take the risk of making the institutional and operational changes needed to optimize corridor operations.
- Transfer knowledge about analysis methodologies, tools, and possible benefits of ICM strategies to the Pioneer Sites and to the entire transportation community.

This report, ***Analysis Simulation and Modeling Results for the I-394 corridor in Minneapolis, Minnesota***, documents the ICM AMS tools and strategies for the I-394 corridor, presents high-level AMS results and lessons-learned, and documents the benefit-cost assessment for the successful implementation of ICM.

The remainder of this document is organized as follows:

- **Chapter 2.0** provides a brief description of the I-394 corridor in Minneapolis, Minnesota, and the methodology used for the AMS;
- **Chapter 3.0** summarizes the ICM strategies tested and provides a list of the AMS scenarios;
- **Chapter 4.0** defines performance measures that utilized in the analysis of the ICM strategies in the I-394 corridor;
- **Chapter 5.0** summarizes the simulation model calibration approach, methodology, and results;
- **Chapter 6.0** presents the results and benefit-cost analysis of the ICM alternatives tested as part of the AMS effort for the I-394 corridor;
- **Appendix A** presents a summary of the ICM strategies for the I-394 corridor; and
- **Appendix B** presents the Performance Measure calculation procedures from the simulation output for the I-394 corridor.

Chapter 2 I-394 Corridor Site and AMS Methodology

The I-394 corridor is an east-west route connecting the Minneapolis Central Business District (CBD) with the western suburbs. This is a primarily commuter route as evidenced by the relatively low heavy-truck percentage of four percent, and the distinct directional peaks in congestion. The corridor's study area extends from the Minneapolis CBD to the Hennepin County border to the west, TH 55 to the north, TH 7 to the south, and Hennepin Avenue/7th Street to the east. Traffic on I-394 reaches 151,000 vehicles per day near the CBD.

In addition to I-394, the roadway network in the study area includes three north-south freeways, I-494, TH 169, and TH 100, as well as a number of arterials, including TH 7 and TH 55, which provide east-west alternative routes to I-394. Express and local buses run along the corridor with transit stations at Louisiana and Plymouth Avenues. Finally, I-394 provides direct access to the ABC garages (three garages totaling 6,755 spaces) located at the western edge of the CBD.

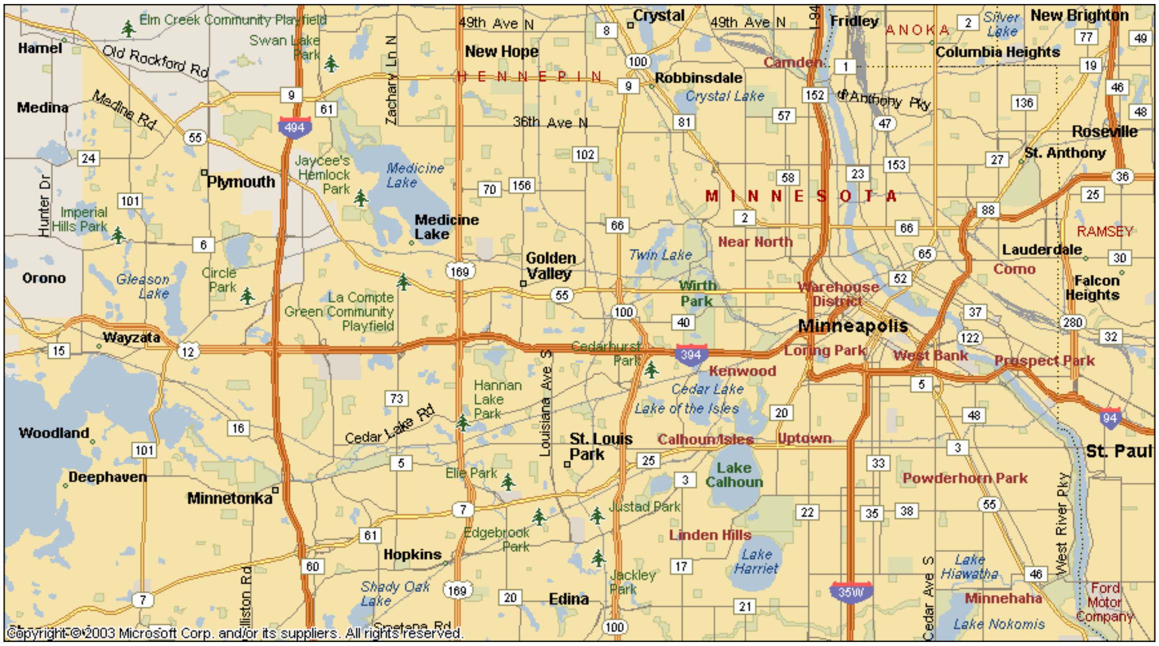
Figure 2-1 illustrates the I-394 corridor and the roadways included in the study area, while the following sections provide an overview of the study corridor.

I-394 Corridor Description

On May 16, 2005, the Minnesota Department of Transportation (Mn/DOT) started operation of the State's first application of high-occupancy toll (HOT) lanes on a segment of the I-394 corridor in the Minneapolis/St. Paul region. This system, known locally as MnPASS, represents the first deployment of HOT lane strategies in Minnesota and one of the first in the United States that dynamically adjusts pricing levels in response to varying traffic conditions.

Unique within the Twin Cities region, I-394 also has two reversible, barrier-separated high-occupancy vehicle (HOV) lanes located in the center median between I-94 and TH 100. Historically, these lanes were open to buses and carpools only with two or more passengers in the inbound (eastbound) direction from 6:00 AM to 1:00 PM, and open in the outbound (westbound) direction from 2:00 PM to midnight on weekdays. These lanes also were opened to buses and HOV traffic on a limited basis on weekends, usually in support of special event traffic. The lanes were closed at all other times. This portion of the I-394 HOV corridor is referenced as the ***"reversible lane"*** section.

Figure 2-1. Location and Geographic Boundaries of the I-394 Corridor



Source: MnDOT.

West of TH 100, the facility was built with a single, nonbarrier-separated HOV lane in each direction. Prior to the introduction of MnPASS, the HOV lanes were designated for use by carpools and transit vehicles during the morning commute period (6:00 AM to 9:00 AM) for the inbound direction, and during the afternoon commute period (3:00 PM to 6:00 PM) for the outbound direction. The HOV restrictions on this section of the corridor were only applied on weekdays, and the lane was available for use by all traffic for the remaining hours of the day. This portion of the I-394 HOV corridor is referenced as the ***"diamond lane"*** section.

The I-394 freeway historically has been well utilized and often experienced congestion, particularly during the commute hours. While HOV demand in the corridor had been robust, it was often less than the available capacity, resulting in the perception among some residents that the HOV lanes were underutilized. As a result of this perception, Mn/DOT was directed by the Legislature in 2000 to evaluate various options for increasing the utilization of the HOV facilities, including opening the HOV lane to all vehicles and the conversion to a HOT lane operation.

The MnPASS system, made operational on May 16, 2005, allowed single-occupancy vehicles (SOV) to use the HOV (MnPASS) lanes by electing to pay a toll. The actual price of the toll (ranging from $0.25 to $8.00) varies with the current congestion levels and with the distance traveled – a different toll is paid whether the MnPASS subscriber chooses to travel on the reversible section, the diamond lane section, or both. The price of the toll is advertised through the use of Dynamic Message Signs (DMS) placed at strategic locations throughout the corridor, and the toll is paid electronically through a user-obtained transponder positioned within the vehicle.

All vehicles previously eligible to use the HOV lanes, including public transit vehicles, carpools, and motorcycles, are still able to use the MnPASS lanes free of charge; however, access and egress to and from the MnPASS lane in the diamond lane section are now limited to specific entry and exit merge areas. As originally developed and implemented, the MnPASS system was intended to operate

24 hours a day, 7 days a week (24/7); however, due to some residents' concerns regarding new restrictions on SOV use of the lanes during nonpeak hours and in the nonpeak direction, operational hours were modified to a slightly expanded approximation of the previous operational hours and direction of HOV lane restrictions. The current operational hours for the MnPASS lane in the diamond section are 6:00 AM to 10:00 AM for the inbound direction (an addition of 1 hour of morning commute period HOV restrictions compared with historical hours), and 2:00 PM to 7:00 PM for the outbound direction (an addition of 2 hours of afternoon commute period HOV restrictions compared with historical hours). These operational hour modifications were implemented approximately one month after the opening of the MnPASS system.

Modeling Approach

The modeling approach that emerged from the analysis of capabilities found in existing AMS tools, as well as from the ICM Test Corridor project, is an ***integrated platform that can support corridor management planning, design, and operations by combining the capabilities of existing tools***. The integrated approach is based on ***interfacing travel demand models, mesoscopic simulation models, and microscopic simulation models***. The ICM AMS approach encompasses tools with different traffic analysis resolutions. All three classes of simulation modeling approaches – macroscopic, mesoscopic, and microscopic – may be utilized for evaluating ICM strategies.

In modeling the I-394 corridor, macroscopic and mesoscopic approaches were utilized. Microscopic tools were considered, but were not used since the selected mesoscopic tools allow for the modeling of all required ICM strategies on the large scale required. The following sections provide an overview of the various modeling components utilized in the AMS modeling framework for the I-394 corridor. Additional details are available in the separate report titled *Integrated Corridor Management - I-394 Minneapolis, Minnesota - Analysis Plan - Final Report* ***EDL#: 14944.***

Travel Demand Forecasting Model

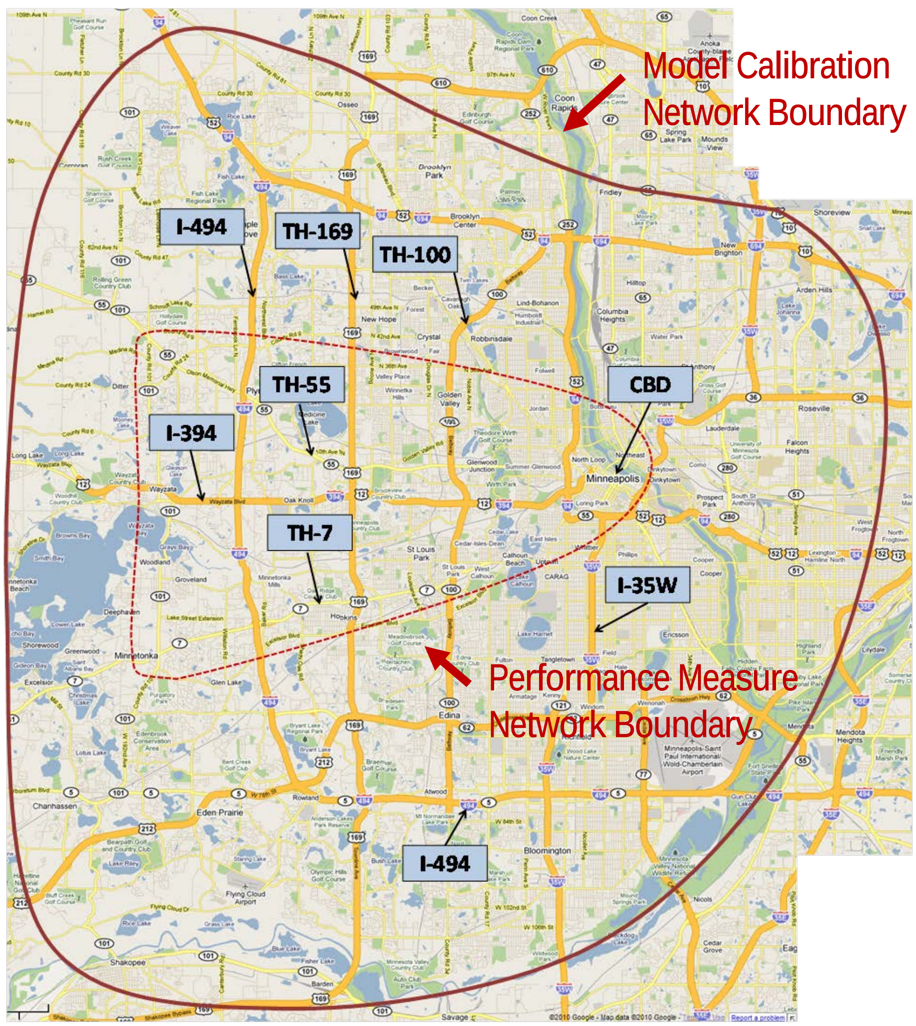
The Minneapolis Metropolitan Planning Organization (MPO) travel demand model is developed in TP+, and covers an area larger than the I-394 corridor study area. Travel demand models estimate travel demand based on projections of household and employment characteristics, and predict travel preferences in activity location, time of day, mode, and route choice. The static nature of the travel demand models is not entirely compatible with the dynamic nature of travel choices during an incident situation. DynusT, the selected mesoscopic model for the I-394 corridor study area, models the diversion to different routes and/or to different modes during simulation run time, thus circumventing the need to feed back to the travel demand model and providing a more realistic view of the decisions and their impact to network condition. During analyses conducted after the I-35W bridge collapse, the University of Arizona migrated the MPO's travel demand model to DynusT and, therefore, no interaction with the TP+ travel demand model was needed.

Mesoscopic Simulation Model

Mesoscopic models combine properties of both microscopic and macroscopic simulation models. The mesoscopic models' unit of traffic flow is the individual vehicle, and the model assigns vehicle types and driver behavior. It also takes into account their relationships with the roadway characteristics. The movements in a mesoscopic model, however, follow the approach of macroscopic models and are generally governed by the average speed on the travel link. Mesoscopic models provide less fidelity than microsimulation tools, but are superior to travel demand models in that, mesoscopic models can evaluate dynamic traveler diversions in large-scale networks. DynusT employs a vehicle speed calculation based on the notion that a vehicle's prevailing speed is affected by vehicles in front and ahead of it, no matter if they are in the same lane or not.

DynusT has the capability to perform "select link" analysis, in which the origins and destinations of the traffic traversing the main corridors (e.g., I-394, TH 55, TH 7, I-494) within the I-394 corridor study area are captured. Utilizing this feature, the limits/boundaries of the I-394 corridor study area were determined. An initial subarea was extracted from the larger DynusT model created from the regional demand model and used as the future year model calibration network. Following the development of that future model calibration network and trip tables, another subarea was created to define the performance measure network. The performance measure network was created to allow a more focused analysis of the ICM strategies within the I-394 corridor. Figure 2-2 illustrates boundaries of both of the model calibration and the performance measure networks.

Figure 2-2. I-394 Corridor Subarea Network Boundaries

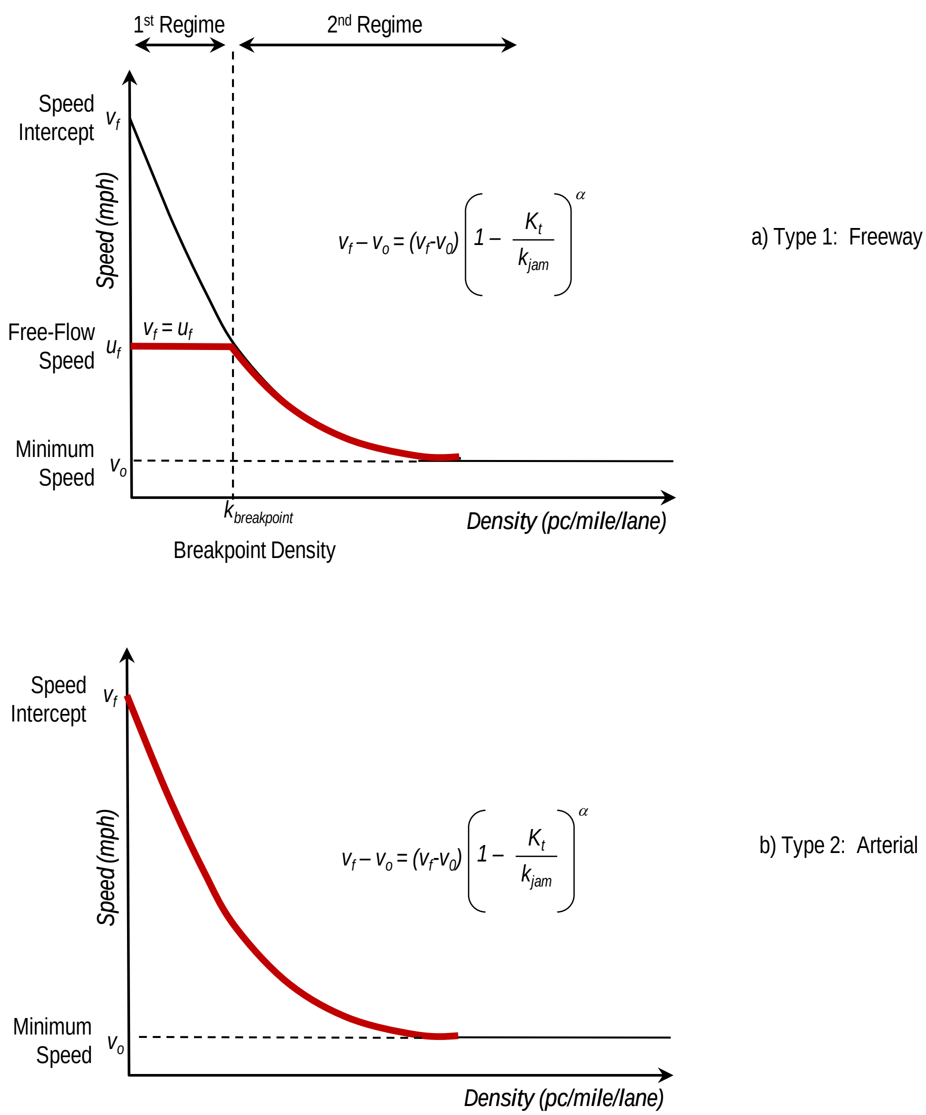


Source: MnDOT, September 2009.

For the analysis of the I-394 corridor, DynusT 2.0 was used. The flow model utilized in DynusT is based on the modified Greenshields' model as shown in Equation 1, which follows the basic traffic engineering principles and relationships of speed, density, and flow. There are two types of traffic flow models identified in DynusT. Type 1 is better suited for freeway traffic flow, because freeway links have greater capacity than arterials, and can hold larger densities near free-flow speeds. Type 2 is better suited for interrupted flow roadways (arterials, ramps), reflecting their lower capacity and their sensitivity to density changes. Both flow model types are shown in Figure 2-3.

$$v_i - v_0 = \left(v_f - v_0\right)\left(1 - \frac{\kappa_1}{\kappa_{jam}}\right)^{\alpha} \qquad \text{(Equation 1)}$$

Figure 2-3. Modified Greenshields' Model



Source: University of Arizona, September 2009.

Free-flow speed v_f, minimum speed v_0, density breakpoint $k_{breakpoint}$, and jam$k_{breakpoint}$ density k_{jam} are estimated based on field data. The unknown variable α is the shape term that gives the curvature of the speed-density curve as the density increases.

DynusT is a User Equilibrium (UE) Dynamic Traffic Assignment (DTA) model incorporating algorithms that adjust the path assignment using an iterative solution procedure. The procedure is said to have converged, or reached an acceptable approximation to a UE solution, when there is no incentive for a user to shift paths (i.e., a traveler will not improve his/her travel time by selecting another alternate path). This translates to no significant changes in flow pattern, or experienced travel time $\{ XE\ \text{"experienced travel time"} \}$ after multiple iterations.

DynusT utilizes a convergence criterion based on path travel times, termed the *relative gap*, and is a commonly-used iteration stopping criterion used by static traffic assignment models. The typical definition of the total relative gap is:

$$rel_{gap} = \frac{\sum_t \sum_{i \in I} \sum_{\kappa \in K_i} f_\kappa^t \tau_\kappa^t - \sum_t \sum_{i \in I} d_i^t u_i^t}{\sum_t \sum_{i \in I} d_i^t u_i^t}$$

(Equation 2)

Where t is an index for an assignment interval $\{ XE\ \text{"experienced travel time"} \}$ or a departure time interval, i is an index for an origin-destination (O-D) pair, and k is an index for a path. Index i represents the set of O-D pairs, and k_i denotes the set of paths connecting the O-D pair i. f_κ^t represents the flow on path k, departing at assignment interval t, τ_κ^t is the travel time on path k for assignment interval t. $d_\kappa^t d_i^t$ denotes the demand (total flow) for O-D pair i at time interval t, and u_i^t is the shortest path travel time for O-D pair i i and departure time interval t. For the I-394 corridor, the *relative gap* was set to 5 percent.

From a behavioral standpoint, routes resulting from a Dynamic User Equilibrium (DUE) application could be viewed as a representation of the travelers' established long-term routes (habitual paths). In contrast, routes resulting from an incremental assignment could be viewed as a representation of the travelers' routes resulting from pretrip information about the optimal routes at the time of departure. During the simulation, if the travelers do not update their path en-route, it is assumed they are invariably staying with the path given by the pretrip information. They either do not have en-route information or they choose not to divert regardless of the en-route traffic condition. If the travelers update their path en-route, it is assumed that they access en-route information along the journey and are willing to consider diversion.

In reality, the traveler population is composed of a mix of the above route choice habitual behavior and traveler information accessibility and usage. In evaluating the scenarios, one needs to carefully specify adequate market shares of different behavior classes. DynusT allows the modeler to specify percentage of travelers following the habitual paths or accessing pretrip and/or en-route information. In DynusT, there are five classes comprising the traveler population – habitual path, system optimal, user equilibrium, en-route information, and pretrip information. Furthermore, DynusT allows the modeler to assess either the short- or long-term impact of a scenario. The following describes the applied methodology for the scenarios and strategies modeled for the I-394 corridor in Minneapolis.

- **Baseline Scenario (Future scenario *without* Incident) –** Travelers are generated from O-D matrices, with a certain percentage assumed to have access to pretrip information (incremental assignment) and the remaining to follow habitual paths. DynusT runs to DUE and the vehicles and their associated paths are saved. The vehicle file contains all vehicle attributes, including user class ID, departure time, arrival time, etc.

- **ICM Scenarios (Future scenarios *with* Incident) –** Travelers are loaded to the network through the vehicle file following habitual paths. Percentages of travelers are specified to access pretrip or en-route information to seek improved routes around incident generated congestion.

Analysis of Mode Shift and Transit

Mode shift can be influenced by adverse traffic conditions (incidents or heavy demand) and by ICM strategies (such as traveler information systems). Modeling of mode shift requires input of transit travel times, which are calculated by network segment and at key decision points in the corridor. This can support comparison of network and modal alternatives, and facilitate the analysis of traveler shifts among different transportation modes.

The application of a full scale mode choice model for the I-394 corridor study area though requires modeling transit and vehicular travelers at the trip origin. As was indicated in the "I-394 Corridor Model Validation and Calibration Report," the vehicular trip table for the study area was extracted from a DynusT application previously developed for the I-35 Bridge, but transit demand trip tables were available only through the regional travel demand model, which represents an area significantly larger than the I-394 corridor study area. While the Minneapolis metropolitan planning organization's (MPO) subarea modeling procedures allow for the extraction of vehicular demand trip tables, similar procedures are not available for the transit component of the travel demand model. In addition, on-board surveys that could have been used to develop the transit trip table for the I-394 corridor study area were not available.

Prior to this project, DynusT did not have any capabilities for modeling mode shift, and transit modeling was limited primarily to transit vehicles assigned on prespecified paths (i.e., on fixed routes) with predetermined dwell times at stops along each route. Through this effort, an approach was developed to enhance transit modeling in DynusT, and provide the means to broadly establish transit baseline data for the corridor that could be used to: 1) model mode choice between auto and transit using time-dependent travel times, costs, and other factors affecting the utility of auto and transit; and 2) model transit vehicle loading and the usage of park-and-ride lots.

One important element is the consideration of distance from the destination, since traveler information could entice travelers to change their mode. For example, travelers may take transit instead of their vehicle, if they receive the information before their departure from home. Alternatively, they may decide to park their car at the nearest park-and-ride lot and switch to transit, if they receive en-route information of an incident. Finally, they may choose to continue driving if they receive en-route information of an incident, and they are either close to their destination or driving to the nearest park-and-ride lot significantly increases their time.

The approach developed is summarized as follows. Modal alternatives are represented by utility functions with three variables measured during simulation, including travel time, fare, and accessibility.

- The travel time attribute applies to both existing and alternate routes and is primarily assessed based on prior model experience (e.g., prior DUE run), but can account for available traveler information.
- Fare is represented as cents per mile, but the methodology can accommodate more complicated fare structures.
- The accessibility measure is measured by two attributes: distance to park-and-ride facility and distance to final destination. The distance to nearby park-and-ride facility is determined by

querying the shortest path algorithm that is regularly executed. In this case, the origin is the location of the vehicle (could be en-route or pretrip), and the destination is the park-and-ride facility. Similarly, the distance to the final destination is calculated by querying the distance label from the shortest path for candidate locations.

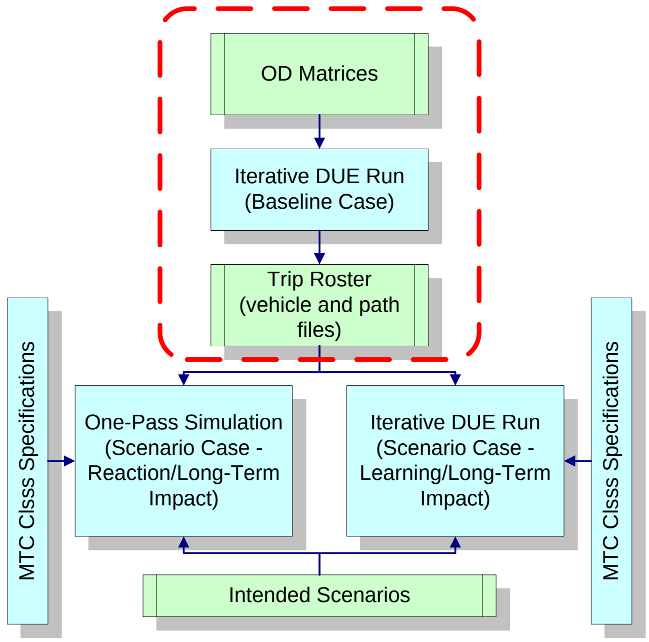
Incident Scenario Modeling

A key issue in the analysis of traveler response to incidents relates to how a traveler may react to the incident. The reaction to an incident may take the form of a short-term response or a long-term learning/adaptation, depending on the characteristics of the incident. For an unexpected short-duration incident, a traveler may change route and/or mode, and/or departure time at the instance of perceiving the incident either through experiencing delay or through available information sources. If nonrecurrent congestion persists for several weeks or months, then travelers will learn from the situation and may be willing to make a route, mode and/or departure time change after days of learning and adjustment. Although travelers may adjust their behavior in both short-term and long-term scenarios, the underlying mechanisms governing such decisions are rather distinct. In the short term, if travelers do not have access to pretrip or en-route information they may not be aware of the incident until they begin experiencing congestion. Those who have access to pretrip information and/or en-route information and find that their path is directly impacted by the incident, may choose to take a different route even before encountering the incident-induced congestion. Those who become aware of the incident via DMSs may also choose to alter their routes, but this diversion would occur at the DMS location.

These travel decision choices need to be carefully modeled in order to properly evaluate the impact and benefit of the ICM strategies. DynusT models various travel decisions by incorporating multiple traveler classes (MTC). Four traveler classes are used in the I-394 corridor modeling, including 1) historical or habitual, 2) dynamic user equilibrium, 3) en-route information, and 4) pretrip information.

The overall modeling procedure for DynusT is presented below. The highlighted section in Figure 2-4 illustrates the process for modeling the baseline case (i.e., the no-incident scenario). Since this scenario reflects long-term established patterns, potentially only adjusted for congestion due to background growth, the process starts from estimating the demand for the future year and completing the iterative Dynamic User Equilibrium (DUE) assignment. In this model run, all travelers are specified as the Dynamic UE class; meaning that they reach a habitual route choice through a sufficient period of learning about network conditions. At the end of this model run, each traveler’s information and personal attributes are recorded in a trip roster, including the generation link, start time, arrival time at each route node and final destination, node sequence of the route, etc. The routes resulted by the DUE are referred to as “habitual” routes. The arrival time at each route node is considered to be the “experienced” reference time, to which the arrival time at the same route node during an incident scenario is compared.

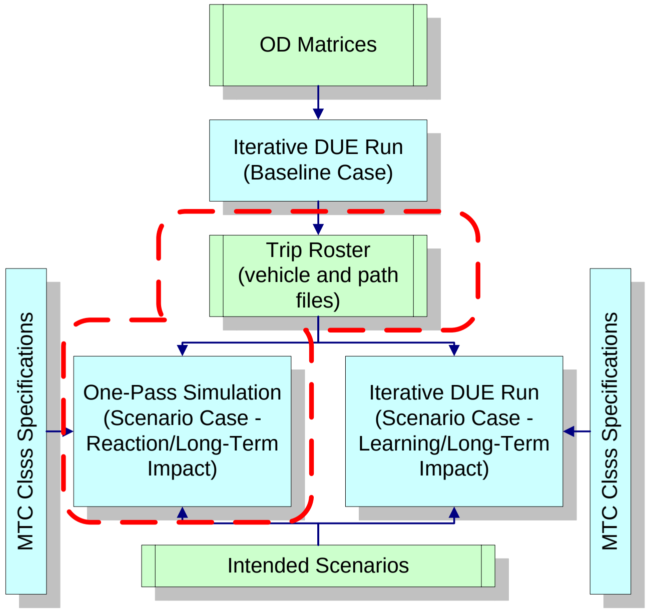
Figure 2-4. DynusT Incident Modeling Framework – Baseline Case



Source: University of Arizona, September 2008.

For incident scenarios, the same trip roster produced by the baseline case is used. This ensures that the same population with the same origins and destinations is applied across all analysis scenarios. Furthermore, for each scenario, the One-Pass Simulation mode is conducted due to the fact that the driving public can not anticipate the occurrence of the incident, but can only react to it through experiencing delay or receiving information. In other words, in each of the incident simulation runs, travelers will start by taking their habitual paths. Those who become aware that their habitual paths are subject to the incident impact (either through experiencing delay en-route and/or through en-route or pretrip information) will consider various diversion options. The highlighted section of Figure 2-5 illustrates the simulation elements for the incident scenario.

Figure 2-5. DynusT Incident Modeling Framework – Scenario Case



Source: University of Arizona, September 2008.

Rerouting Rules

Modeling of traveler reaction to the incident considers two aspects: 1) reaction to prevailing congestion and 2) reaction to information describing congestion. The first aspect is based on the premise that a traveler may consider to commence diversion during the journey when, upon arrival at an intersection, his/her current travel time exceeds the historical travel time by a certain tolerance threshold. This decision process is called the “congestion responsive rerouting (CRR)” behavior rule. The second aspect is addressed in DynusT via the provision of pretrip and en-route information. The incident information triggers a traveler to consider an alternative route when the information indicates that the traveler’s current route may be disrupted by the incident. This rerouting decision can be commenced either when the traveler departs from the origin and/or mid-journey to the destination, depending on the spatial and temporal availability of the information. For example, pretrip information such as Internet or TV news may influence a certain percentage of the travelers seeking pretrip information. En-route information such as radio, DMS, or mobile device, affects travelers’ rerouting decisions in different temporal and spatial manners. Radio or mobile device information may reach a certain percent of travelers on the entire network, but DMS has limited spatial coverage, reaching only those traversing the DMS location.

Moreover, the priority of compliance for route diversion generally follows the principle that the latest information accessed by the user takes priority. For example, a traveler can make a decision to re-route or not at departure. However, he/she can engage in another re-route decision at later time when passing through a DMS location.

The paragraphs below provide additional details for rerouting rules and mechanisms in DynusT.

Congestion Responsive Rerouting (CRR)

The CRR rule consists of two decision processes:

- **Decision to Divert.** It is postulated that travelers will continue to use their "habitual" routes, if the perceived delay does not exceed their personal tolerance thresholds. In DynusT, this threshold ($\bar{\varepsilon}_n$) is randomly generated from an analyst-specified normal distribution function $N(\mu, \sigma^2)$ with a set minimal threshold value (e.g., no negative value). For the I-394 corridor, the normal distribution function parameters are set to $N(15,2)$; meaning that the mean value and standard deviation of the normal distribution is 15 and 2, respectively. For an incident scenario, the analyst specifies DynusT to read the "experienced" arrival times for all nodes in the "habitual" path of a traveler, which are then compared with the current arrival times recorded during the incident simulation. The delay (ε_n^p) for a traveler n at current node p is calculated as the difference in perceived arrival time between the baseline and scenario cases. Those who experience delays will then select alternative paths[1] if a) this traveler has not diverted before, b) the delay exceeds the threshold (i.e., $\varepsilon_n^p \geq \bar{\varepsilon}_n$), and c) the immediate downstream link is congested (90 percent of the jam density).

  This diversion rule realistically represents the diversion decision-making mechanism, but also captures the complex interactions between diverted travelers, including those who are directly impacted by the incident (if their original path traverses the incident location) and those who are impacted by the diverted vehicles. The diversion timing and location are not hard-wired, but intuitively induced by delay that is exceedingly lengthy compared to the "experienced" travel time.

- **Selection of an alternative route.** When a traveler decides to choose an alternative route, he/she contemplates a) auto mode-only routes, and b) multimodal routes. The traveler will make the final route selection based on the generalized-cost assessment of both types of routes. The auto-mode-only route starts from the diversion decision location to the traveler's destination. The path is then computed using travel times calculated from the baseline case updated with incident location information. The monetary cost associated with the path is also included if the vehicle is an SOV vehicle and a HOT lane is present in the network. This realistically considers the situation in which travelers may not know the instantaneous shortest path at the time of decision, but they will try to use the prior knowledge to select a good diversion path. The multimodal route searching algorithm seeks for a multimodal route with the minimal generalized cost, which includes travel time and bus fare. The travel time includes the time driving from the current diversion location to the boarding bus stop, waiting time and line-haul time for the bus, and walk time from the alighting bus stop to the final destination. A traveler is assumed to be aware of the line-haul time based on prior experience and/or bus schedule. The fare is assumed to be a fixed value for a bus trip. Once the generalized cost for both auto-mode-only route and multimodal route are computed, the driver then selects the route with a lower generalized cost.

[1] $\varepsilon_n^p = max\{0.0, t_n^{p,s} - t_n^{p,b} + \epsilon_n^{p,s} - \epsilon_n^{p,b}\}\ \forall\, p \in \{1,2,\ldots,P\}$, where $t_n^{p,s}$ is the arrival time at node p for traveler n in the scenario case and $t_n^{p,b}$ is for the same traveler n the "experienced" arrival time at node p, $\epsilon_n^{p,s}$ is the perception error for traveler n at node p in the scenario case, $\epsilon_n^{p,b}$ is the perception error for traveler n at node p in the baseline case, and P is the maximum number of nodes in the "habitual" path.

The following summarize the characteristics and applicability of the CRR mechanism:

- Applicable to. All travelers.
- **Baseline-No Incident.** Not applicable since the baseline case reflects established patterns (including recurring delays), and provides the reference point for “habitual” paths.
- Incident Scenario. Applicable.
    - Each traveler starts on a “habitual” path, unless he/she have pretrip information and the pretrip information indicates that the intended path is impacted by an incident.
    - Each traveler is assigned with a delay threshold from the truncated Normal Distribution (i.e., $N(0, undefined, 15{,}2)$ where 0 and undefined are the truncation parameters, 15 is the mean, and 2 is the variance).
    - At the analyst-defined traffic information update interval (5 min), if the traveler has not diverted before and the “current minus experienced” arrival time exceeds the delay threshold, and the immediate downstream link is congested (90 percent of the jam density), then a new route is chosen from the current location to the traveler’s destination. The new route is retrieved from the computed shortest path (SP) using “experienced” travel time.
    - If the HOT/HOV lane is open to all traffic, then there is no cost in the alternative path travel time estimation. Otherwise, the alternative path travel time includes the price implemented at time of diversion decision.

Pretrip Information Responsive Rerouting (PIRR)

Pretrip information includes any travel information accessible to the public that can be used in planning trip routes, estimating departure times, and/or choosing travel modes. Such information can be available through the 511 system, public access television (TV), and other media. The anticipated increased use of 511, combined with potential e-mail and text alerts (travelers who do not turn on and log in to their computer could receive text messages to their telephones and be informed about conditions) is expected to increase the number of travelers utilizing available information in the future.

It is postulated that travelers with pretrip information will utilize the proposed route by the media, if 1) their “habitual” route is impacted by the incident; and 2) the perceived delay to reach their destination, along their “habitual’ route, exceeds their personal tolerance thresholds. The analyst specifies DynusT to read the “experienced” arrival time for a traveler’s destination utilizing the “habitual” path, which is then compared with the arrival time utilizing the shortest path available to the traveler’s destination during departure time. The delay (ε_n^p) for a traveler is calculated as the difference in perceived arrival time between the baseline and scenario cases. When travelers decide to choose an alternative route, they select a path starting from their origin location to their destination.

The following summarize the characteristics and applicability of the PIRR mechanism:

- **Applicable to.** Travelers with pretrip information:
    - Pre-ICM. 10 percent of travelers have access to pretrip information; and
    - Post-ICM. 12 percent of travelers have access to pretrip information.
- **Baseline-No Incident.** Not applicable since the baseline case reflects established patterns (including recurring delays) and provides the reference point for “habitual” paths.

- Incident Scenario. Applicable.
  - Each traveler is assigned with a delay threshold from the truncated Normal Distribution (i.e., $N(0, undefined, 15,2)$).
  - Each traveler initially selects his/her “habitual” path.
  - An analyst-specified percentage of travelers always check the prevailing network conditions at time of departure.
  - The traveler selects the best available path to his/hers destination, at departure, if the “habitual” path is found to be impacted by an incident and the “current time – experienced time” arrival time at the destination exceeds the delay threshold.
  - During the traveler’s journey the route could be further updated by a DMS.
  - If the HOT/HOV lane is open to all traffic, then there is no cost in the alternative path travel time estimation. Otherwise, the alternative path travel time includes the price implemented at time of departure.

En-route Information Responsive Rerouting (EIRR)

En-route information pertains to travel information accessible to the public via 1) an in-vehicle device (such as radio or smart phone) equipped to receive real-time updates; or 2) DMS. Travelers utilize this information to access travel time for the remaining length of their journey. The mechanism associated with a DMS is detailed in the Comparative Travel Time Information Rerouting section.

It is postulated that travelers with en-route information will utilize the shortest-time route for the remaining length of their trip if the time savings exceed a certain threshold. The analyst specifies DynusT to read the arrival time for a traveler’s destination utilizing the current (“habitual” or previously updated) path, which is then compared with the arrival time utilizing the shortest path available to the traveler’s destination at the predefined information update interval. If the time saving of the new alternative route exceeds the threshold (5 min), then the travelers would choose the alternate route, starting from their current location to their destination.

The following summarize the characteristics and applicability of the EIRR mechanism:

- **Applicable to.** Travelers with en-route information:
  - Pre-ICM. 5 percent of travelers have access to en-route information; and
  - Post-ICM. 10 percent of travelers have access to en-route information.
- **Baseline-No Incident.** Not applicable since the baseline case reflects established patterns (including recurring delays), and provides the reference point for “habitual” paths.
- Incident Scenario. Applicable.
  - At departure, the PIRR rule applies to each traveler;
  - At the predefined information update interval (5 min), the traveler compares the remaining travel time of the current route and the new route proposed by the in-vehicle device.
  - If the time savings from the new route exceed the threshold (5 min), the traveler will switch.
  - Multiple switches can take place at each information update instance.
  - En-route information rerouting supersedes the CRR rule.
  - If the HOT/HOV lane is open to all traffic, then, there is no cost in the alternative path travel time estimation. Otherwise, the alternative path travel time includes the price implemented at time of diversion decision.

Comparative Travel Time Information Rerouting (CTTIR)

Pretrip and en-route information dissemination includes travel time comparisons for freeway, arterial and transit. It is anticipated that more travelers will choose the best option (alter route or mode) to maintain consistent trip times. Furthermore, information regarding park-and-ride lot utilization is disseminated at selected locations via DMS, which is expected to potentially result in modal shifts during incidents. Three park-and-ride lots (Louisiana Avenue, Plymouth Avenue and County Road 73) are monitored for space availability. The two transit stations (Louisiana and Plymouth Avenues) and the multiple park-and-ride lots at various locations along I-394 present limited, but potential, opportunities for changing mode while en-route.

To model en-route CTTIR, two types of DMS signs are established; DMS-1 reflects information related to highway, arterial, and transit time, while DMS-2 reflects park-and-ride utilization and is posted at exits along I-394 that provide access to park-and-ride facilities.

It is postulated that travelers approaching a DMS-1 will utilize the proposed route or mode for the remaining length of their trip if the time savings exceed a certain threshold. For travelers not willing to switch to transit, the analyst specifies DynusT to read the arrival time for a traveler's destination utilizing the current ("habitual" or previously updated) path, which is then compared with the arrival time utilizing the path (i.e., the shortest path available to the traveler's destination at the predefined information update interval) proposed by DMS-1. For travelers willing to switch to transit, the analyst specifies DynusT to read the generalized cost for a traveler's destination utilizing the current ("habitual" or previously updated) path, which is then compared with the generalized cost utilizing transit. When travelers decide to choose an alternate route or mode, they select a path starting from their current location to their destination or to their closest park-and-ride facility.

The following summarize the characteristics and applicability of the CTTIR mechanism:

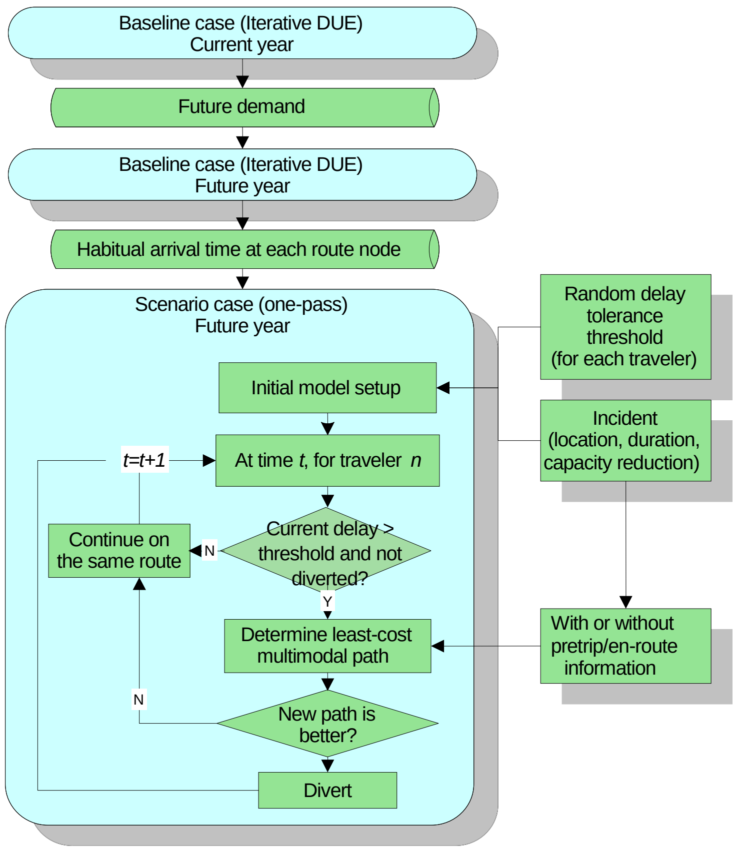
- **Applicable to.** Travelers approaching a DMS-1.
  - Pre-ICM. DMS-1 is not available. However, congestion warning type of messages are posted, and 72 percent of drivers are assumed to respond to the message sign;
  - Post-ICM: DMS-1 available with a use rate of 80 percent, and DMS traveler information available to 100 percent of all travelers.
- **Baseline-No Incident.** Not applicable since the baseline case reflects established patterns (including recurring delays), and provides the reference point for "habitual" paths.
- **Incident Scenario.** Applicable.
  - All travelers. Travelers willing to switch to transit, approaching a DMS-1 will compare the remaining travel time of the current route and the new route proposed by the DMS.
  - If the time savings from the new route exceed the threshold (5 min), the traveler will switch. Travelers in the TI group will consider transit as a potential alternative, by:
    - » Estimating the time to the closest boarding bus stop serving the same destination zone.
      - ✓ If the traveler is aware of the capacity (and capacity is zero), then this time is infinite; and
      - ✓ Otherwise, this time is estimated from the "actual" SP time.
    - » Estimating the walk time from the closest alighting bus stop to the destination.
    - » Estimating the line-haul time.

- » Adding the three travel times listed above to equal the total travel time.
- » Adding fare equivalent time by taking fare divided by the value of time (VOT).

- The traveler chooses the new route if the travel time of the new route is shorter than the remaining travel time by the threshold (5 min).
- Upon arriving at DMS-2:
  - » If the capacity is zero, then the traveler will take a new auto route based on instantaneous travel time to the destination; otherwise, he/she will take transit.

Figure 2-6 illustrates a flowchart of the various elements of modeling an incident.

Figure 2-6. Incident Modeling Process



Source: University of Arizona, September 2008.

Chapter 3 Analysis Scenarios and ICM Strategies

This section provides an overview of priority ICM strategies for this corridor, and the scenarios studied to analyze the impacts of these strategies. The analysis will assist local agencies to:

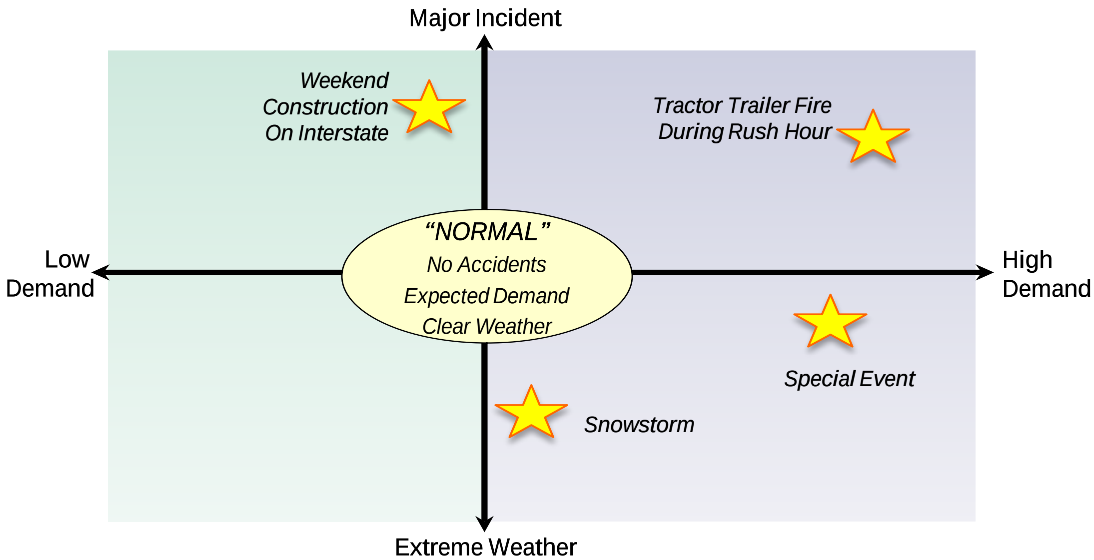
- **Invest in the Right Strategies.** The analysis offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions.
- **Invest with Confidence.** AMS will allow corridor managers to "see around the corner" and discover optimum combinations of strategies, as well as conflicts or unintended consequences inherent in certain combinations of strategies that would otherwise be unknowable before implementation.
- **Improve the Effectiveness/Success of Implementation.** With AMS, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.

  AMS provides a long-term capability to corridor managers to **continually improve implementation** of ICM strategies based on analysis supporting experience.

Analysis Scenarios

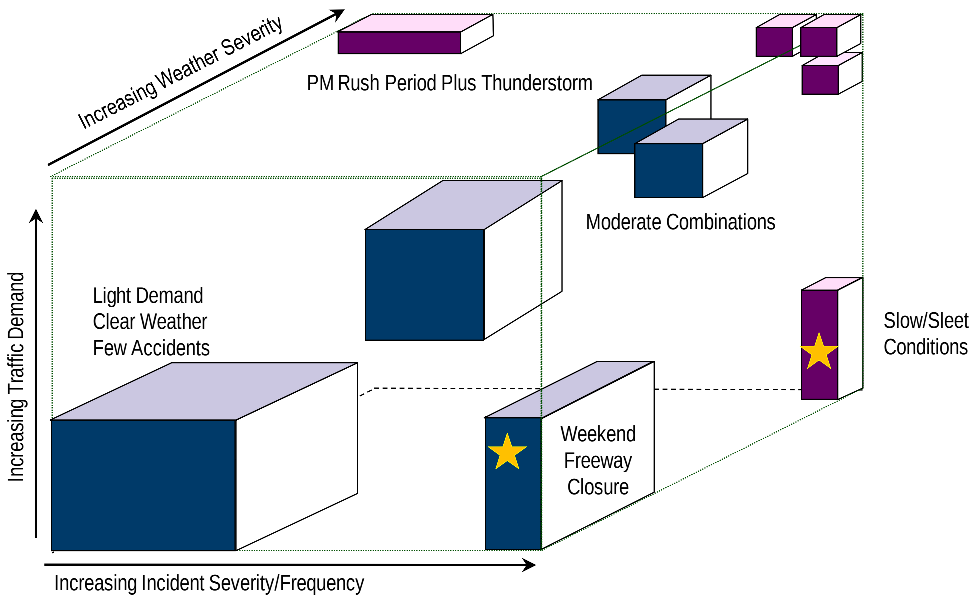
The I-394 AMS Analysis Plan describes tools and procedures capable of supporting the analysis of both recurrent and nonrecurrent congestion scenarios. The corridor's nonrecurrent congestion scenarios entail combinations of increases of demand and decreases of capacity. Figure 3-1 depicts how key ICM impacts may be lost if only "normal" travel conditions are considered; the proposed scenarios take into account both average- and high-travel demand, with and without incidents. The relative frequency of nonrecurrent conditions also is important to estimate in this process – based on archived traffic conditions, as shown in Figure 3-2.

Figure 3-1. Key ICM Impacts May Be Lost If Only "Normal" Conditions Are Considered



Source: Wunderlich, Karl E., Incorporating Intelligent Transportation Systems into Planning Analysis: Summary of Key Findings From a 2020 Case Study - Improving Travel Time Reliability With ITS. This document is available at the RITA NTL (http://ntl.bts.gov/lib/jpodocs/repts_te/13605.html), May 2002.

Figure 3-2. Sources of System Variation – Classifying Frequency and Intensity



Source: Wunderlich, Karl E., Incorporating Intelligent Transportation Systems into Planning Analysis: Summary of Key Findings From a 2020 Case Study - Improving Travel Time Reliability With ITS. This document is available at the RITA NTL (http://ntl.bts.gov/lib/jpodocs/repts_te/13605.html), May 2002.

The first step in the analysis was to determine the directional split of incidents on I-394. As Figure 3-3 shows, 62 percent of all incidents occur in the eastbound direction, with most of these incidents being congestion-related, as the eastbound direction experiences significant congestion during both the AM and PM peak periods. Next, the frequency of incidents during the AM peak period (Monday to Friday, 6:00 AM to 9:00 AM); the PM peak period (Monday to Friday, 2:00 PM to 7:00 PM); and the off-peak period (midday and weekends) was determined. The analysis indicates that, on average, 75 incidents occur during the AM peak period each year (roughly 10 percent of the total number of incidents on I-394 eastbound each year).

Figure 3-3. Classifying Incidents by Direction and Peak Period

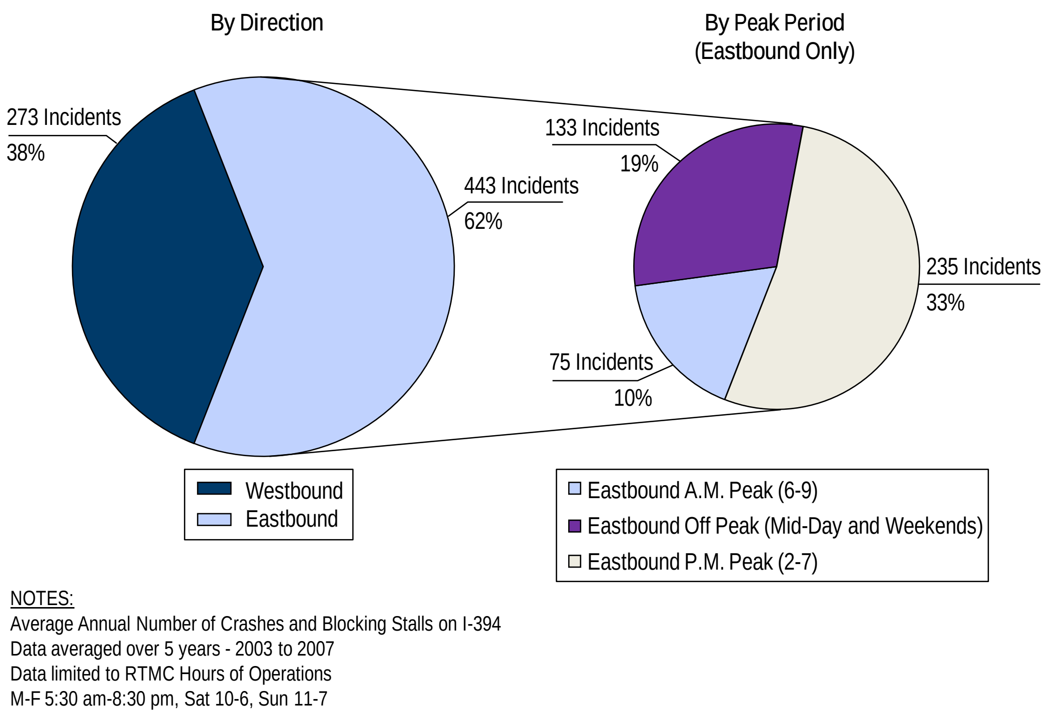


Figure 3-4 illustrates that 25 percent of all weekdays on I-394 eastbound experience at least one incident, defined as a crash or a blocking stall. The majority of weekdays, 75 percent, do not experience this type of incident.

Figure 3-5 illustrates the frequency distribution of incident clearance time on I-394 eastbound for the AM peak period (6:00 AM to 9:00 AM). Incident clearance time was measured from the Regional traffic Management Center (RTMC) 2003 to 2007 incident logs, and is defined as the time from when an incident is detected to the time the incident clears the freeway. Based on the clearance times, any incident with clearance time less or equal to 60 minutes is considered a minor incident, while incidents with clearance times greater than 60 minutes are considered major.

Figure 3-4. Incident versus Nonincident Days (I-394 EB)

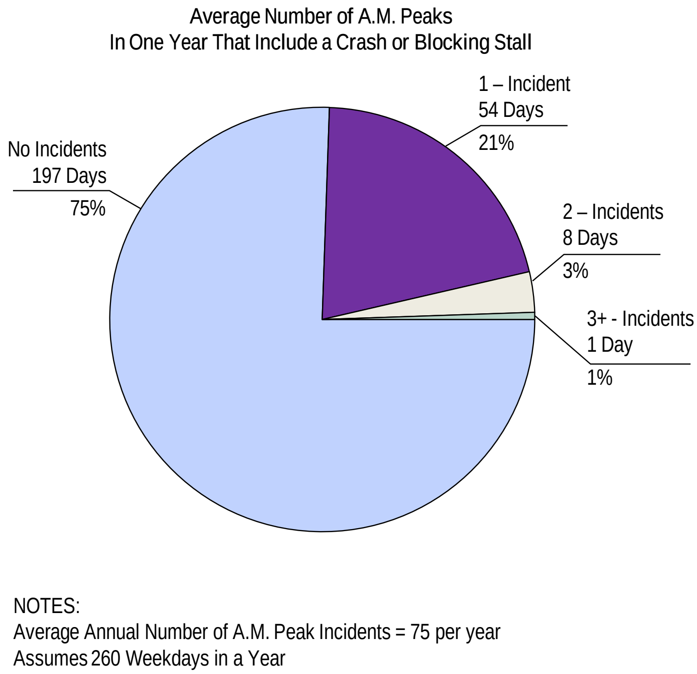
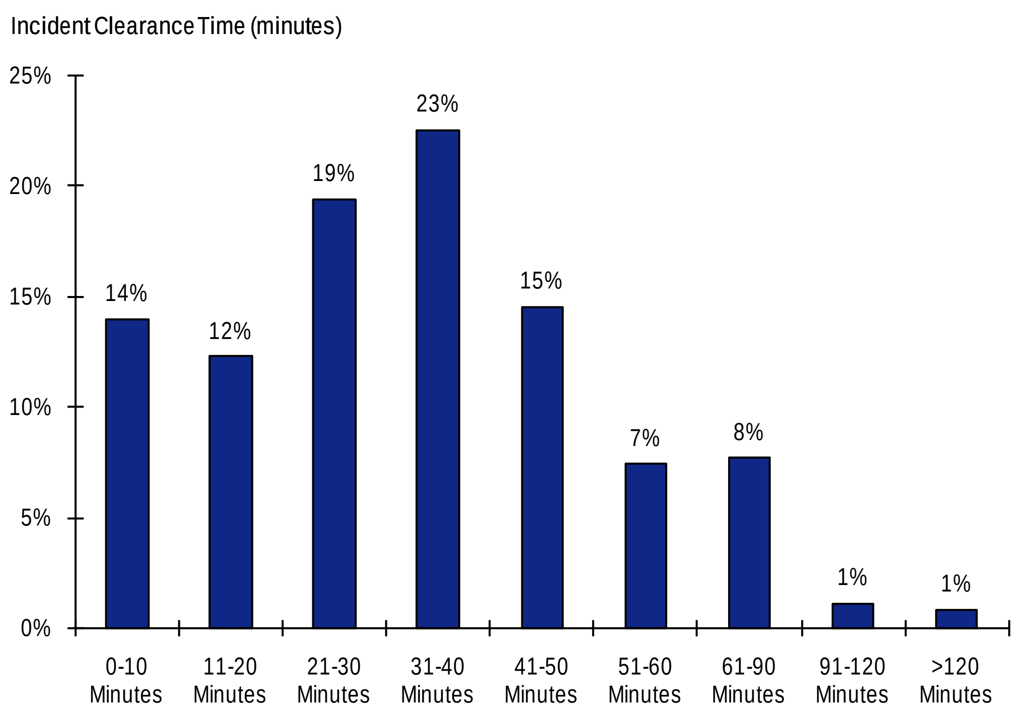


Figure 3-5. Distribution of Incidents by Clearance Time
AM Peak Period



Having identified the number of incidents that occur on I-394 eastbound during the AM peak period and their clearance time, the joint frequency of incident clearance time and hourly demand were determined. Hourly demand was calculated using entry ramp and upstream (western end of I-394) vehicle counts. Based on analysis and knowledge of the corridor, it was concluded that the AM peak-period demand does not vary appreciably from day to day. The I-394 corridor is a heavily traveled commuter corridor during the morning peak hours, with little fluctuation in demand. During the afternoon peak period, the demand is more variable due to events at stadiums and entertainment venues at the east end of the corridor. Figure 3-6 illustrates the hourly demand by day of the week. Incident clusters were then identified based on similar clearance times and hourly demand volumes. Figure 3-7 illustrates the joint frequency distribution of incident clearance time and demand.

Figure 3-6. Variation of Weekday Hourly Demand (I-394 EB)

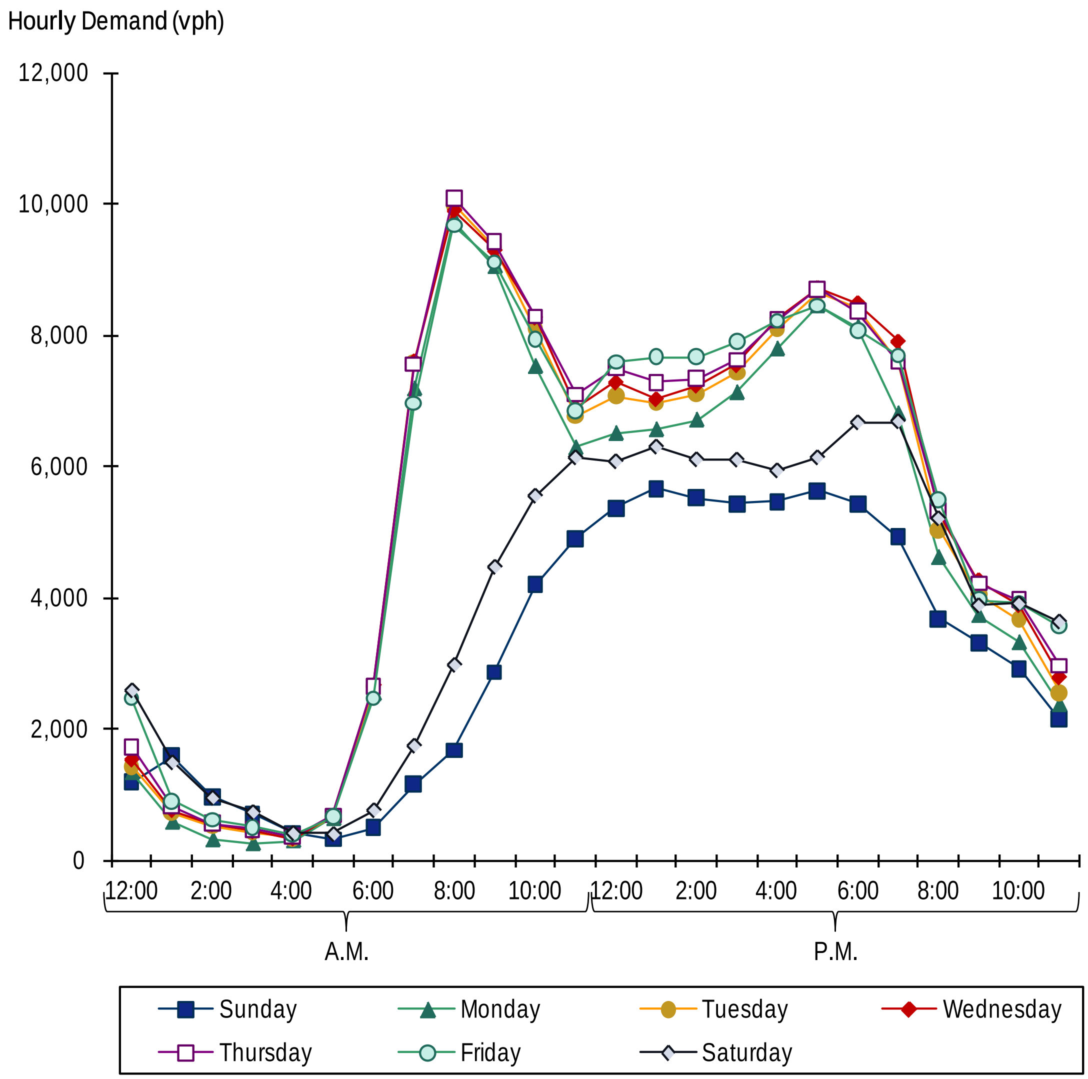
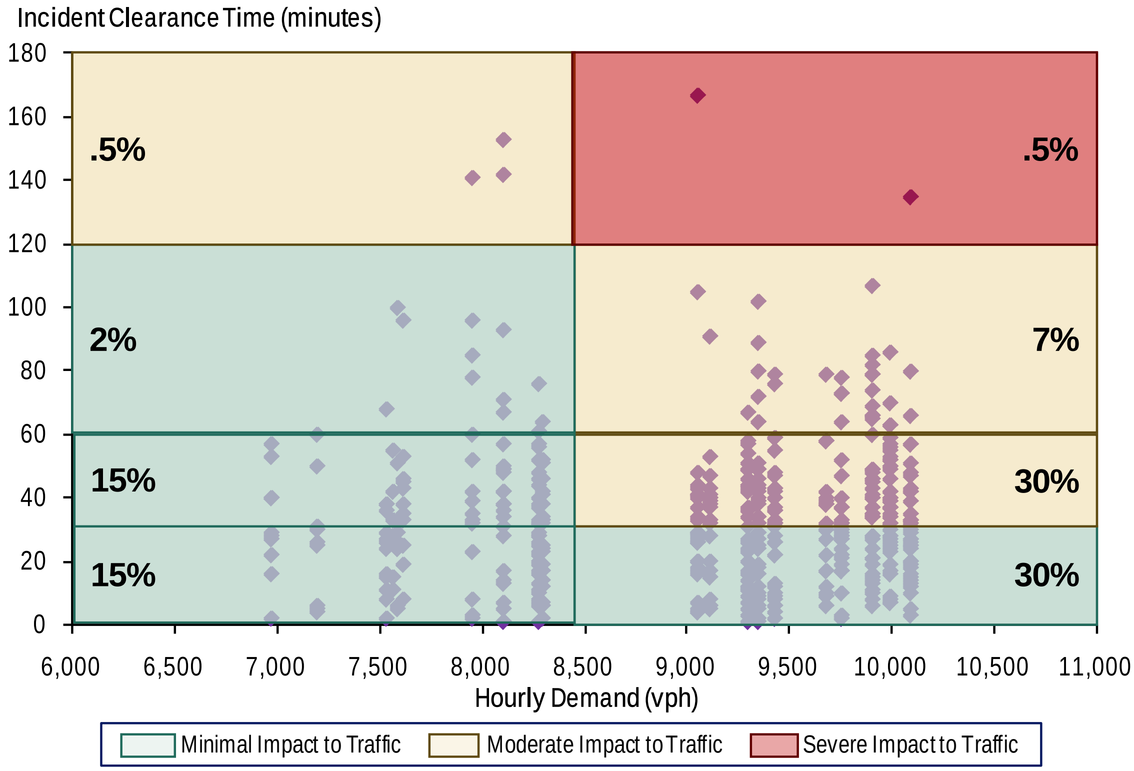


Figure 3-7. Distribution of Incidents by Clearance Time and Demand Level (I-394 EB)



In addition to the cluster analysis presented above, 10 analysis scenarios were developed that 'paint a picture' of activities to be performed by different stakeholders, the ICM strategies employed, and the likely impacts that would be experienced by travelers. These scenarios depict incidents as well as special situations such as a baseball game and a snow event; and are fully described in the I-394 Concept of Operations (ConOps) report. Incident scenarios are described as major or minor based on the severity and the clearance time of the incident. For the purpose of this study, the analysis scenarios were ranked from low to high importance, and the following scenarios were identified as priorities (in no particular order):

1. Major freeway traffic incident;
2. Major arterial traffic incident;
3. Minor freeway incident;
4. Minor arterial traffic incident;
5. Special event; and
6. Adverse weather event.

Weather events reflect situations where snow, ice, or heavy rain has caused travelers to alter their patterns; often choosing arterials over freeways in order to avoid inevitable congestion. Special events include sporting events at the baseball stadium, basketball stadium, and football stadium (all in close proximity to the eastern end of the corridor). While there are expected benefits from the ICM strategies during weather events, it is not anticipated that the selected strategies will have a major impact during weather events, when essentially all routes and modes of travel are slower due to hazardous conditions. In addition, the AM inbound peak period is not conducive to modeling special event scenarios since the special events that attract large volumes of traffic are almost always in the evening or afternoon. Furthermore, travel demand patterns during special events could be drastically different compared to normal weekday peak-period patterns. Therefore, it was decided that the special event and weather scenarios be removed from further consideration so that available resources could focus on the scenarios where the ICM strategies may have the most impact.

One of the key objectives of this project is the assessment of proposed ICM strategies under different operating scenarios. A key variable in defining an operating scenario is the pertinent demand level. Since the between-days demand variability for the I-394 corridor is not appreciable (as illustrated in Figure 3-6), it was decided to vary the incident starting time and benefit from the within-day demand variability. Based on Figure 3-6, the demand levels identified in the cluster analysis could be approximated with the following timeframe: the demand is estimated at 7,000 vph at 7:00 AM; 8,000 vph at 7:30 AM; 9,000 vph at 7:45 AM; and 10,000 vph at 8:15 AM.

Furthermore, the probability of each operating scenario will weigh in the effectiveness of a particular strategy; therefore, each operating condition is associated with a probability. These probabilities are calculated based on Figures 3-4 and 3-7. For example, the probability of not having an incident is 75 percent (see Figure 3-4), while the probability of an incident with an 80-minute clearance time is 25 percent (probability of an incident) times 2 percent (probability of an incident with 80 minutes clearance and hourly demand less than 8,500 vehicles – see Figure 3-7).

A matrix was developed identifying the freeway operating scenarios to be modeled. Since there will be no incident scenarios with clearance times of 120 minutes or more, the sum of the freeway operating scenario probabilities is 99.75 percent. A total of six freeway incident operating scenarios have been identified, as defined by severity, clearance time, and start time, along with the daily operations scenario.

Although complete incident log data for TH 55 and TH 7 were not available, there were data available on the number of crashes on each corridor. Data on the number of stalled vehicles and the duration of the incident were not available. Mn/DOT collected crash data from the Department of Public Safety's crash report database during the 2003 to 2007 five-year period. This analysis found that 59 percent of all crashes occurred on I-394, while 41 percent of the crashes occurred either on TH 55 or TH 7. Therefore, it was decided, in addition to the I-394 incidents, to analyze one major arterial incident. The incident was simulated on TH 55 at Glenwood Avenue and reflected a closure of the arterial with a clearance time of 65 minutes. For simplicity and practicality it was assumed that the probability of a major arterial incident is 0.25 percent; the balance of the freeway incident probabilities. Therefore, the freeway and arterial incidents analyzed represent 100 percent of the anticipated operating conditions in the corridor.

Table 3-1 summarizes the analyzed operating conditions.

Table 3-1. Analyzed Operating Conditions

Scenario	Daily Operations No Incident	Freeway Segment Closed	One Freeway General Purpose and Auxiliary Lane Blocked						Arterial Segment Closed
Incident Clearance Time (Minutes)	N/A	80	80	30	45	30	45	65
Severity	N/A	Major	Major	Minor	Minor	Minor	Minor	Major
Location	N/A	I-394 EB @ Louisiana Ave	I-394 EB @ Louisiana Ave	I-394 EB @ Louisiana Ave	I-394 EB @ Louisiana Ave	I-394 EB @ Louisiana Ave	I-394 EB @ Louisiana Ave	TH 55 @ Glenwood Ave
Incident Start Time	N/A	8:00 AM	7:30 AM	7:15 AM	7:30 AM	7:45 AM	8:15 AM	7:30 AM
Probability (Percent)	75	1.75	0.5	3.75	3.75	7.5	7.5	0.25

ICM Strategies

Travelers have multiple possible responses to congestion and mitigating ICM strategies, such as route diversion, temporal diversion, mode change, and destination change or trip cancellation. The I-394 corridor already has a number of ITS strategies in operation, and the analysis plan took that into account. The base year for analysis reflected 2008 travel demand to capture the operations of MnPASS. The future baseline scenario was modeled using information for year 2011, the anticipated year of implementation. The ensuing sections provide details of the following ICM strategies:

- Earlier Dissemination of Traveler Information;
- Comparative Travel Times;
- Parking Availability at Park-and-Ride Lots;
- Incident Signal Retiming Plans;
- Predefined Freeway Closure Points;
- HOT Lanes Open to All, and
- Transit Signal Priority.

Earlier Dissemination of Pretrip Traveler Information

Earlier dissemination includes any travel information accessible to the public that can be used in planning trip routes, estimating departure times, and/or choosing travel modes. Such information can be available through the 511 system, public access television (TV), and other media.

Annually since 1987, Mn/DOT has sought public opinion about transportation through a Transportation Omnibus survey. The last report was completed in 2006, and is now on a biannual schedule. In addition to the Omnibus survey, the Minneapolis AMS team had available the Perception Tracking survey. The survey measured and compared traffic management tools, based on a sample of 600 interviews conducted over the telephone to individuals that drive and/or commute. The first survey was undertaken in 1996 and the latest in 2005. The following are some of the key findings of the 2005 survey:

- Traffic Internet awareness and use were 61 and 15 percent, respectively;
- 511 awareness and use were 30 and 4 percent, respectively;
- KBEM radio awareness and use were 50 and 9 percent, respectively;
- The proportion of drivers that had seen a travel time sign was 72 percent; and
- The proportion of drivers that used an alternate route, based on the travel time sign information, was 29 percent.

With travel times available on the 511 telephone system (including freeway, arterials, and transit), it is anticipated that the 511 telephone system will become a more valuable tool for commuters (now that 511 is limited to incidents). Furthermore, with the push technologies planned (e-mail, text) travelers will be alerted to incidents and serious delays earlier than previously. The anticipated increased use of 511, combined with the planned e-mail and text alerts (travelers who do not log in to their computer could receive text messages to their telephones and be informed about traffic conditions) is expected to increase the number of travelers utilizing available information in the future. Based on the available data, it was assumed that the pretrip traveler information use rate was 10 percent for pre-ICM operating scenarios, and 12 percent for post-ICM.

Earlier Dissemination of En-Route Traveler Information

Discussions with U.S. DOT and Mn/DOT revealed the need to model the impact of en-route information available to drivers to assess two major issues:

1. **Change in Route Choice.** This relates to real-time change in route choice of drivers based on travel time or congestion updates they receive via radio or smart phone devices. Based on the Perception Tracking survey, 72 percent of the drivers have seen a Travel Time Sign, but only 29 percent alter their route based on the available information. The addition of new Dynamic Signs, as well as the enhanced information on these signs (current signs provide information for two points ahead in the pertinent corridor, while in the future, information also will be provided for alternate routes), is expected to increase both the percent of drivers aware of en-route traveler information, and the percent of drivers that alter their route based on the available information (compliance ratio). In the absence of any information related to other en-route traveler information media (e.g., radio, GPS, etc.), it was assumed the en-route use rate was 5 percent for pre-ICM operating scenarios, and 10 percent for post-ICM scenarios.
2. **Change in Mode En-Route.** The two transit stations (Louisiana and Plymouth Avenues) and the park-and-ride lots at various locations along I-394 present limited, but potential, opportunities for changing mode while en-route. Currently, travelers do not have access to comparable mode travel time or parking lot space availability information. This is expected to change, and it is anticipated that traveler awareness to be raised from 0 percent today to 100 percent in the future. Potential mode shift utilizing this information was evaluated using the mode choice model integrated with DynusT.

Comparative Travel Times (Mode and Route)

Information dissemination (pretrip and en-route) included travel time comparisons for freeway, arterial, and transit. As a result, more travelers were able to choose the best option (alter route, mode, and departure time) to minimize trip times.

Parking Availability at Park-and-Ride Lots

By disseminating information regarding park-and-ride lot availability, potential modal shifts during incidents may occur. This was modeled by providing travelers with parking availability at park-and-ride lots as simulated in the model.

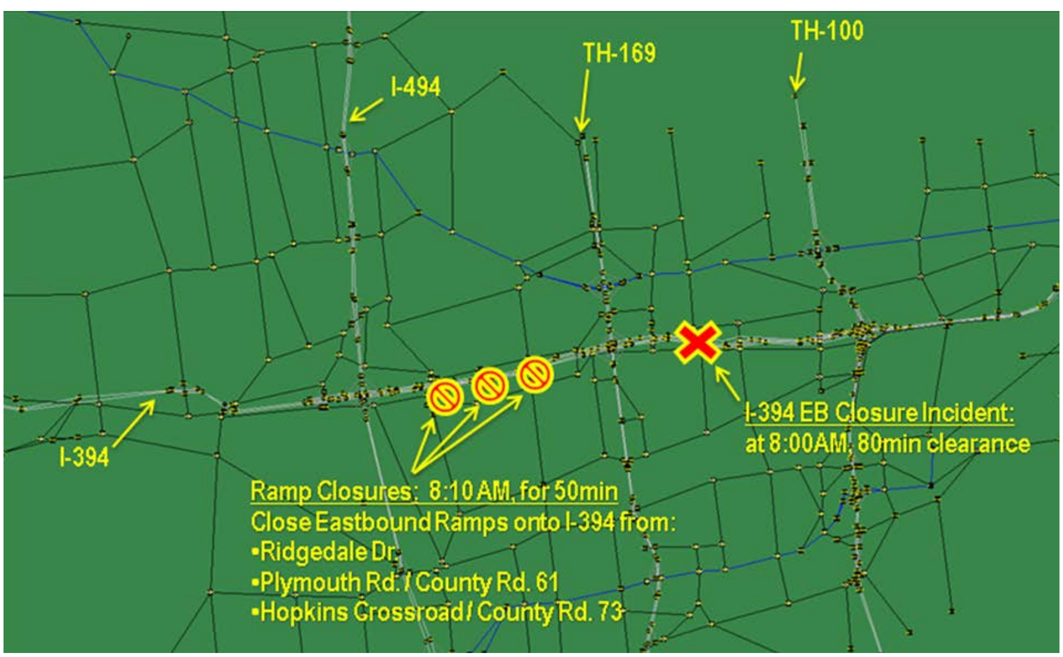
Incident Signal Retiming Plans

Under a major incident condition, “flush” signal timing plans (to increase eastbound green time and decrease arterial travel time during an incident) were assumed to be activated on the parallel arterials of TH 55 and TH 7. Estimates of those revised signal timings were incorporated directly into DynusT.

Predefined Freeway Closure Points

During major incidents on the freeway, using predesignated freeway closure points at on-ramps feeding the affected freeway sections is expected to prevent travelers causing more delay. As no plans currently exist, several different plans were devised and tested in the model. The selected plan closes on-ramps to I-394 eastbound from Ridgedale Drive, Plymouth Road/County Road 61, and Hopkins Crossroad/County Road 73 at 10 minutes after the incident starts and reopens them 50 minutes later. This plan is illustrated in Figure 3-8.

Figure 3-8. Modeled Predefined Freeway Closure Point Plan



Source: MnDOT, September 2009.

HOT Lanes

The I-394 corridor includes a High Occupancy Toll (HOT) facility along the I-394 freeway. As part of MnPass, the I-394 HOT facility allows HOVs with two passengers or more, including transit vehicles, to use the dedicated lane at no cost. The HOT facility also allows SOVs to use the lane by paying a toll. The price that SOVs pay varies according to congestion levels. The current pricing strategy was replicated in the model under both pre- and post-ICM scenarios.

One ICM strategy included an option to open the HOT lane to all traffic during major incidents. While the intent of the HOT lane is to maintain free-flow conditions for HOV and transit vehicles, there are some situations along I-394 that merit opening the HOT lane to all traffic to allow ‘flushing’ of congested traffic. The decision to open the HOT lane to all vehicles would be based upon the location, severity, and duration of the incident.

Transit Signal Priority

A key objective of this ICM strategy is to improve transit efficiency and service by giving priority to buses leaving park-and-ride lots to return to I-394. This strategy reduces the amount of time associated with the bus service, and potentially increases transit usage. Within the model, TSP is activated only when a bus approaches a signal and is behind schedule.

Table 3-2 cross-tabulates the scenarios and strategies, while Appendix A provides additional details reflecting pre- and post-ICM implementation.

Table 3-2. ICM Strategies and Scenarios Summary

Strategy/Scenario	Freeway Segment Closed	One Freeway General Purpose and Auxiliary Lane Blocked			Arterial Segment Closed
Incident Clearance Time (Minutes)	**80**	**80**	**30**	**45**	**65**
Incident Severity	Major	Major	Minor[1]	Minor[1]	Major
Traveler Information					
Earlier Dissemination	●	●	●	●	●
Comparative Travel Times (Mode and Route)	●	●	●	●	●
Parking Availability at Park-and-Ride Lots	●	●	●	●	●
Traffic/Incident Management					
Incident Signal Retiming Plans for Arterials	●	●			●
Predefined Freeway Closure Points	●				
HOT/HOV Lanes[2]					
HOT Lane Open to All Traffic		●			
Transit Management					
Transit Signal Priority[3]	●	●			

[1] Multiple minor freeway incident scenarios with the same incident severity and duration, but different start times are reflected once in the table.
[2] The HOT lane (congestion pricing) currently is in operation, thus is not considered an ICM strategy.
[3] Transit signal priority is available in all post-ICM scenarios.

Analysis Settings

The number of ICM strategies and scenarios involved in the analysis made it imperative to analyze only one peak period. While the AM peak period experiences higher median travel times, the PM peak period experiences higher maximum times. If only the PM peak were modeled, it would not have been possible to model and analyze the strategies that specifically target modal shift, since commuters who have driven to work are not likely to leave their vehicle at work and ride transit home. The only strategy that does not apply to the AM peak and could not be modeled was the ABC garage information dissemination (a strategy specifically targeting drivers of vehicles parked in the garage). Modeling the inbound direction during the AM peak period was the best option, since it allowed the modeling of transit decisions based on traveler information, as it is easier to influence modal choice when a commuter is traveling to work).

Chapter 4 Performance Measures

This section provides an overview of the performance measures used in the evaluation of ICM strategies for the I-394 corridor. To be able to compare different investments within a corridor, a consistent set of performance measures was applied. These performance measures:

- Provide an understanding of traffic conditions in the study area;
- Demonstrate the ability of ICM strategies to improve corridor mobility, throughput, and reliability based on current and future conditions; and
- Help prioritize individual investments or investment packages within the Pioneer Corridor for short- and long-term implementation.

In addition, four overall goals were defined during the Concept of Operations development. These goals, together with candidate performance measures, are summarized below.

- **Goal 1. Mobility and Reliability.** The I-394 corridor network of agencies, infrastructure, systems, and supporting personnel will work together to maintain mobility and reliability of travel on a corridor basis.
- **Goal 2. Corridor-wide Capacity Utilization.** Any spare capacity throughout the I-394 corridor will be used to the maximum extent possible.
- **Goal 3. Corridor Event and Incident Management.** Mostly, there will be only minor impacts of incidents on travel time throughout the corridor, both in the extent of impact and duration; and, incident management will preserve the safety of the travelers throughout the corridor.
- **Goal 4. Holistic Traveler Information Delivery.** To provide travelers and transportation professionals with a 'holistic' view of the corridor and its operations through the delivery of timely, accurate, and reliable multimodal travel information and data exchange.

Based on the goals and objectives, a set of national performance measures (see Appendix B) was developed to assess the various analysis scenarios and ICM strategies. While these measures are not defined to support the testing of site-specific hypotheses on ICM impacts, they could potentially be utilized to indirectly assess site-specific goals. For example, Goal 4 is associated with specific changes in drivers' behavior, which are not modeled by the AMS efforts. Nevertheless, Goal 4 could still be indirectly addressed through the national measures, since improving reliability (as defined by the Planning Index) could be viewed as an indicator of better dissemination of travel information.

The proposed performance measures will focus on the following four key areas:

1. **Mobility.** Describes how well the corridor moves people and freight;
2. **Reliability.** Captures the relative predictability of the public's travel time; and
3. **Emissions and Fuel Consumption.** Captures the impact on emissions and fuel consumption.

U.S. DOT, in collaboration with the Pioneer Sites and Cambridge Systematics, Inc., developed guidance for mobility and reliability performance measures utilizing outputs from simulation models.

The sections below provide an overview of the areas the selected performance measures address, while Appendix B provides the U.S. DOT guidance.

Mobility

Mobility describes how well the corridor moves people and freight. Three performance measures were utilized to quantify mobility in the I-394 corridor:

- **Travel Time.** This is defined as the average travel time of the system across all origins, destinations, scenarios, and modes. Travel times were computed for the peak period.
- **Delay.** This can be broadly defined as travel time in excess of a minimum travel time threshold. Often, discussions of delay focus solely on roadway-only travel, but delay for this project explicitly includes multimodal corridor performance. Specifically, delay is identified at the O-D level by deriving a zero-delay threshold by mode.
- **Throughput.** While throughput (e.g., vehicles per lane per hour) is a well-established traffic engineering point measure (that is, in a single location), there is no consensus on a systemwide analog measure. In this effort, we use the term corridor throughput to describe a class of measures used to characterize the capability of the integrated transportation system to efficiently and effectively transport travelers. Passenger-miles traveled (PMT), passenger-miles delivered (PMD), and passenger-trips delivered (PTD) are used as the throughput performance measures.

Reliability of Travel Time

Reliability and variability capture the relative predictability of the public's travel time. Unlike mobility, which measures how many people are moving at what rate, the reliability/variability measures focus on how much mobility varies from day to day. For the I-394 corridor, travel time reliability/variability is calculated by using the simulation models' output across different operational conditions. The planning index is also used as a measure of reliability, while the travel time variance is used as a measure of variability. Calculation details are provided in Appendix C.

Safety

While the Analysis Plan identifies safety as one of the performance measures to be produced by the analysis, it has become apparent that available safety analysis methodologies are not sensitive to ICM strategies. The best available safety analysis methods rely on crude measures such as V/C and cannot take into account ICM effects on smoothing traffic flow. Clearly, this is an area deserving new research. As such, the analysis results presented in this report do not include safety as one of the performance measures.

Emissions and Fuel Consumption

The I-394 corridor AMS also produced estimates of emissions and fuel consumption associated with the deployment of ICM strategies. This was done by utilizing the Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS) methodology, which incorporates reference values to identify the emissions and fuel consumption rates based on variables such as facility type, vehicle mix, and travel speed. The emissions and fuel consumption rates were based on the California Air Resources Board's EMission FACtors (EMFAC) 2007 and the EPA's MOBILE6. Emissions and fuel consumption impacts were then monetized using costs per ton of pollutants released and the purchase price of fuel for use in the benefit/cost analysis.

Cost Estimation

For the identified ICM strategies, planning-level cost estimates were prepared, including life-cycle costs (capital, operating, and maintenance costs). Costs were expressed in terms of the net present value of various components and are defined as follows:

- **Capital Costs.** Includes up-front costs necessary to procure and install ICM equipment. These costs are shown as a total (one-time) expenditure, and include capital equipment costs, as well as the soft costs required for design and installation of the equipment.
- **Operations and Maintenance (O&M) Costs.** Includes those continuing costs necessary to operate and maintain the deployed equipment, including labor costs. While these costs do contain provisions for upkeep and replacement of minor components of the system, they do not contain provisions for wholesale replacement of the equipment when it reaches the end of its useful life. These O&M costs are presented as annual estimates.
- **Annualized Costs.** Represent the average annual expenditure that would be expected in order to deploy, operate, and maintain the ICM improvement; and replace (or redeploy) the equipment as they reach the end of their useful life. Within this cost figure, the capital cost of the equipment is amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual O&M cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of Pioneer Corridor ICM deployments.

The complexity of these deployments warrants that these cost figures be further segmented to ensure their usefulness. Within each of the capital, O&M, and annualized cost estimates, the costs are further disaggregated to show the infrastructure and incremental costs. These are defined as follows:

- **Infrastructure Costs.** Include the basic “backbone” infrastructure equipment necessary to enable the system. For example, in order to deploy a camera (closed-circuit television (CCTV)) surveillance system, certain infrastructure equipment must first be deployed at the traffic management center to support the roadside ITS elements. This may include costs, such as computer hardware/software, video monitors, and the labor to operate the system. Once this equipment is in place, however, multiple roadside elements may be integrated and linked to this backbone infrastructure without experiencing significant incremental costs (i.e., the equipment does not need to be redeployed every time a new camera is added to the system). These infrastructure costs typically include equipment and resources installed at the traffic management center, but may include some shared roadside elements as well.
- **Incremental Costs.** Include the costs necessary to add one additional roadside element to the deployment. For example, the incremental costs for the camera surveillance example include the costs of purchasing and installing one additional camera. Other deployments may include incremental costs for multiple units. For instance, an emergency vehicle signal priority system would include incremental unit costs for each additional intersection and for each additional emergency vehicle that would be equipped as part of the deployment.

Structuring the cost data in this framework provides the ability to readily scale the cost estimates to the size of potential deployments. Infrastructure costs would be incurred for any new technology deployment. Incremental costs would be multiplied with the appropriate unit (e.g., number of intersections equipped, number of ramps equipped, number of variable message sign locations, etc.); and added to the infrastructure costs to determine the total estimated cost of the deployment.

Chapter 5 Model Calibration and Methodology

Accurate model calibration is a necessary step for proper simulation modeling. Before modeling ICM strategies, model calibration ensures that base scenarios represent reality, creating confidence in the scenario comparison. The following summarizes the model calibration approach and validation results. Complete model calibration results are available in a separate report titled *Integrated Corridor Management (ICM) Analysis, Modeling, and Simulation (AMS) for Minneapolis Site, Model Calibration and Validation Report*.

Simulation Model Calibration

Each simulation software program has a set of user-adjustable parameters that enable the practitioner to calibrate the software to better match specific local conditions. These parameter adjustments are necessary because no simulation model can include all of the possible factors (both on- and off-street) that might affect capacity and traffic operations. The calibration process accounts for the impact of these "unmodeled" site-specific factors through the adjustment of the calibration parameters included in the software for this specific purpose. Therefore, model calibration involves the selection of a few parameters for calibration and the repeated operation of the model to identify the best values for those parameters. Calibration improves the ability of the model to accurately reproduce local traffic conditions. The key issues in calibration are the following:

- Identification of necessary model calibration targets;
- Selection of the appropriate calibration parameter values to best match locally measured street, highway, freeway, and intersection capacities;
- Selection of the calibration parameter values that best reproduce current route and mode choice patterns; and
- Validation of the overall model against overall system performance measures, such as travel time, delay, and queues.

Before ICM strategies were analyzed, the I-394 team, U.S. DOT, and Cambridge Systematics agreed upon the validation/calibration criteria that should be met in the modeling effort. The highway model validation/calibration criteria are shown in Table 5-1.

Table 5-1. Highway Model Validation and Calibration Criteria for the ICM Corridor AMS

Validation Criteria and Measures	Acceptance Targets
Traffic flows within 15% of observed volumes for links with peak-period volumes greater than 2,000 vph	For 85% of cases for links with peak-period volumes greater than 2,000 vph
Sum of all link flows	Within 5% of sum of all link counts
Travel times within 15%	>85% of cases
Visual Audits *Individual Link Speeds: Visually Acceptable Speed-Flow Relationship*	To analyst's satisfaction
Visual Audits *Bottlenecks: Visually Acceptable Queuing*	To analyst's satisfaction

Calibration Approach

The setup of the baseline simulation model started with the conversion of the travel demand model (TDM), available in the Twin Cities region. After converting the existing TDM, additional data were acquired and entered into the model. These data included signal timing plans and intersection lane geometry configuration. The calibration of the regional model focused on both traffic flow models and Origin-Destination (OD) tables.

The calibration of the traffic flow model was aimed at matching the speed-density relationship exhibited in the collected field data. The calibration of the OD tables emphasized the matching of link counts by adjusting the OD tables, originally available in the TDM. Once the regional model was calibrated, a select-link analysis was performed to determine the limit/boundary of the I-394 network. The purpose of the select-link analysis was to understand the origin and destination for all the traffic traversing the I-394 corridor. With this step, the boundary determined for the I-394 network of interest retained most of the trips' lengths.

Given the extracted ICM network, a second round of OD calibration was performed. This step applied more detector data within the ICM network to further fine-tune and develop time-dependent OD tables. Validation was performed using collected travel time to ensure the validity of the calibrated model.

Once the I-394 network was calibrated, the performance measures network was extracted using a second round of select-link analysis for the links defining the boundary of the performance network. No additional calibration efforts were undertaken on the performance network. At this step, the baseline model was ready for scenario analysis.

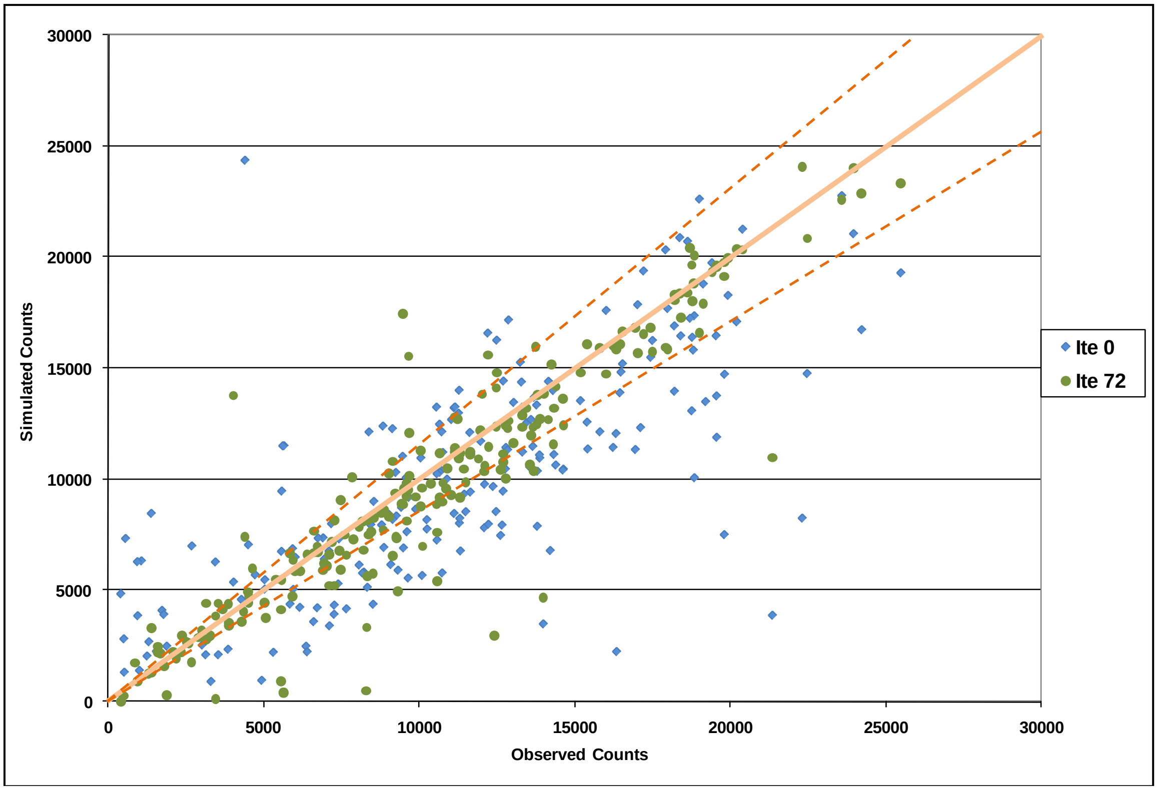
Model Calibration Results

After the I-394 network was calibrated, efforts were undertaken to validate the model.

Estimated Traffic Volumes vs. Observed Counts

Figure 5-1 shows validation results comparing observed and simulated counts on links. A 45-degree (solid) line represents a perfect match of observed versus simulated counts. The two dashed lines are the upper and lower bound for the 15 percent error band. It is evident from the figure that most of the link counts are within the 15 percent range. The calibration iterations improved the matching of the observed and simulated counts over the OD iterations. Shown in the figure are the comparisons of the assigned OD table from the regional model (Ite 0) and the assigned final OD table from the final iteration (Ite 72).

Figure 5-1. Link Volume Validation Results – 5:00 AM to 11:00 AM



Travel Times

Probe vehicles collected travel times on TH-55, TH-7, and I-394 in both the EB and WB directions from October 28, 2008 to October 30, 2008, for a total of 143 runs. To ensure consistent comparison, simulation probe vehicles following the same routes and departure times as the actual probe vehicles were inserted to the DynusT vehicle and path files generated from the last converged DUE iteration. Then, a one-shot simulation was performed using these vehicle and path files. After simulation, the experienced travel times (end time minus start time) for each inserted probe vehicle was extracted to compare with the experienced travel time for each actual probe vehicle. Table 5-2 lists the model validation results and the number of travel time observations per corridor that fall within different error ranges.

Table 5-2. Travel Time Validation Results

	TH-55 EB	TH-55 WB	TH-7 EB	TH-7 WB	I-394 EB	I-394 WB
Total Runs	**32**	**32**	**39**	**40**	**35**	**33**
Runs within 15% travel time	21 (66%)	24 (75%)	28 (72%)	29 (73%)	22 (62%)	30 (91%)
Runs within 20% travel time	28 (88%)	30 (94%)	30 (77%)	33 (83%)	28 (80%)	32 (97%)
Runs within 25% travel time	28 (88%)	32 (100%)	33 (85%)	36 (90%)	33 (94%)	33 (100%)
Runs within 30% travel time	32 (100%)	32 (100%)	34 (87%)	37 (93%)	33 (94%)	33 (100%)

Note: Number of runs within error range (percentage of runs).

Visual Audits

Visuals audits were conducted that compared individual link volumes and speeds. Selected sensor locations on I-394 were examined to understand how well modeled volumes and speeds matched observed values on key locations along the I-394 corridor. Overall, the simulated volumes and speeds satisfactorily replicated experienced volumes and speeds at most locations.

Visual audits were also conducted to compare bottleneck locations in the corridor. This was completed by comparing speed space-time contour data compiled from field sensors (averaged over three days) to modeled data for sensors in the same locations as the field sensors.

Transit and Park-and-Ride Utilization Validation

The DynusT version utilized during the initial validation stages did not have a transit component and therefore no attempt was made to validate the model for transit ridership. Nevertheless, a tool was needed to identify the current park-and-ride lot utilization and how it may change due to the deployment of ICM strategies. As such, the current transit demand was estimated for bus routes serving park-and-ride lots in the I-394 corridor utilizing Origin-Destination Matrix Estimation (ODME) techniques, and parking utilization was derived from the estimated alighting and boarding volumes. Available Automated Passenger Counter (APC) data and route ridership data was used to help build the transit OD tables. The resulting model, while not validated for ridership, can accurately model the potential for mode shifts from autos to park-and-ride transit trips.

Known Incident Validation

In order to ensure that the model could accurately predict the observed traffic conditions during an incident, a known incident was simulated in the model. The known incident occurred on I-394 just east of the I-494 interchange and blocked one lane. The same incident was simulated in the I-394 model, including starting at the same time, with the same clearance time. The pre-ICM conditions for pretrip and en-route information dissemination were assumed to be in place and messages on the model's DMS were posted as they were assumed to be during the incident.

Speed space-time contours and volumes as measured by field sensors during the incident were compared to modeled values. The simulated speed contour exhibited an analogous pattern compared to the actual field data, indicating that the DynusT simulation results properly reflect the incident situation on I-394 corridor. The flow profiles and volume comparisons in the vicinity of the incident location also indicate that the overall simulation results exhibit comparable patterns to the field data.

Chapter 6 Analysis Results

The AMS results for the I-394 corridor model in Minneapolis are presented in this chapter. Results are presented for different operational conditions, ICM strategies, and performance measures employed in the analysis, including the following:

- ***Seven operational conditions***, represented by varying severity of incidents occurring at different volume demand conditions through the morning peak period. All freeway incidents are simulated on I-394 EB in the vicinity of Louisiana Avenue, and the arterial incident is simulated on TH 55 eastbound at Glenwood Avenue.
- ***ICM strategy alternatives***, including earlier dissemination of pretrip and en-route traveler information, comparative travel times, dissemination of park-and-ride lot information, incident traffic signal plans on arterials, predefined highway closure plans, HOT lanes open to all, transit signal priority and combinations of these strategies.
- The analysis produced ***performance measures*** for all operational conditions and for all ICM strategies tested. Performance measures include mobility, reliability, fuel consumption, and emissions reported across different transportation modes and facility types. All measures presented were calculated based on performance measures network, as previously described in the modeling approach. Reporting measures as seen on this subarea network from the calibration network allows for a more focused analysis of the ICM strategies within the I-394 corridor.

This chapter is organized as follows:

- Section 6.1 presents the results of the individual simulated baseline and incident scenarios using the origin-destination-based performance measures described in Appendix B.
- Section 6.2 presents and discusses the aggregated pre-ICM and post-ICM performance measures, as averaged over all operating conditions. As with results in the previous section, performance measures discussed here are all OD based as opposed to facility based.
- Section 6.3 outlines the benefits that are seen from ICM implementation. In order to locate which facilities see improvements and which see worsening condition, the benefits calculations are based on facility-specific performance measures. The one exception is travel time reliability, which is only definable at the OD level. Reliability benefits attributed to I-394 EB were calculated from the change in the travel time variance for any trip using I-394 in the EB direction. Similarly, I-394 WB reliability benefits were calculated from the WB direction trips. The total systemwide benefits were calculated from the change in variance for all trips in the system. The I-394 EB and WB benefits were then subtracted from the entire network benefits, and the remaining reliability benefits were distributed amongst the non-I-394 facilities based on the share of vehicle hours of travel.
- Section 6.4 outlines the costs associated with deploying the ICM in the I-394 corridor as tested.
- Section 6.5 outlines the conclusions and lessons-learned from the ICM analysis of the I-394 corridor.

Individual Scenarios

This section presents the results of the individual baseline and incident scenarios using the performance measures described in Appendix B. To clarify, all measures listed in these sections are calculated on an origin-destination basis and are aggregated based on which corridors the travelers use, namely the I-394 EB or I-394 WB facilities. For example, if a traveler uses a section of I-394, that traveler's entire trip is included in the trip set, and the entire trip travel distance and time is included in the vehicle miles traveled (VMT) and person hours traveled (PHT) measures. This produces VMT and PHT that are greater than those values actually using the facilities, but represents the VMT and PHT for travelers that are influenced by the ICM strategies and operations on I-394. All travelers starting their trips between 5:00 AM and 11:00 AM are included in the analysis, including those travelers whose trips are incomplete at 11:00 AM Estimations are made for the completed trip travel distance and time for these incomplete trips and are included in the analysis.

Baseline (No Incident) Scenario

Comprising 75 percent of workdays in Minneapolis, the no incident scenario is the predominant condition. Under no incident conditions, travelers are subjected to normal recurring congestion that most drivers are familiar with from habitual use of the transportation network. This is simulated in DynusT through a Dynamic User Equilibrium (DUE) assignment, an iterative process in which travelers seek improved routes and modes based on knowledge of travel conditions across the network. As such, travelers in a DUE assignment have already routed themselves knowing what typical, no incident travel conditions entail. Increasing the availability of traveler information will not, therefore, improve routing.

The no incident scenario was also used to determine the threshold for delay, the zero-delay travel time, for the model. The minimum travel time for each origin, destination, and mode combination in the model in the baseline scenarios was used to establish the zero delay travel time for that pairing. This benchmark travel time was used later in the ICM performance measure calculations, as defined later in this document. Further details of the use of the zero delay travel time in the performance measures are contained in Appendix B.

Incident Scenarios

The transportation system on the remaining 25 percent of the workdays in a year is influenced by nonrecurring delay caused by incidents. Several incident scenarios were run to test the impacts of ICM deployment under varying combined demand levels and incident conditions.

Volume demand conditions do not vary much from day to day in the I-394 corridor. Different times within the AM peak period were selected to represent different demand levels on the corridor. By simulating the same incident at different times within the AM peak period, the effects of that incident occurring under different demand profiles can be determined. As determined by the cluster analysis of observed traffic data on I-394, the following relationship between time and demand was estimated:

- 7,000 vph at 7:00 AM;
- 8,000 vph at 7:30 AM;
- 9,000 vph at 7:45 AM; and
- 10,000 vph at 8:15 AM.

Seven different incident scenarios were considered and can be classified as major freeway incidents, minor freeway incidents, and major arterial incidents.

Major freeway incidents account for 2.25 percent of the workdays. Two different major freeway incidents were simulated:

- I-394 closure (all lanes blocked) at Louisiana Avenue starting at 8:00 AM with an 80-minute clearance time; and
- I-394 EB blocked for one general purpose lane and one auxiliary lane at Louisiana Avenue starting at 7:30 AM with an 80-minute clearance time.
- Minor freeway incidents are much more common and account for 22.5 percent of workdays. Four different minor freeway accidents were simulated:
- I-394 EB blocked for one general purpose lane and one auxiliary lane at Louisiana Avenue starting at 7:30 AM with a 45-minute clearance time;
- I-394 EB blocked for one general purpose lane and one auxiliary lane at Louisiana Avenue starting at 8:15 AM with a 45-minute clearance time;
- I-394 EB blocked for one general purpose lane and one auxiliary lane at Louisiana Avenue starting at 7:15 AM with a 30-minute clearance time; and
- I-394 EB blocked for one general purpose lane and one auxiliary lane at Louisiana Avenue starting at 7:45 AM with a 30-minute clearance time.
- Finally, one major arterial incident was included in the analysis, and assumed to occur for 0.25 percent of work days:
- TH 55 closure (all lanes blocked) at Glenwood Avenue starting at 7:30 AM with a 65-minute clearance time.

ICM Strategies

ICM strategies deployed vary depending on the severity and nature of the incident. The simulated incident conditions are classified as either minor or major. All minor incidents are treated with the same ICM strategies, while major incidents are considered individual cases, and are as such each treated with a different set of ICM strategies.

Minor incident scenarios would see deployment of ICM strategies that improve traveler information in the form of pretrip information, en-route information, and comparative travel times for modes and routes are available to help travelers avoid congestion within the network. Park-and-ride information would be distributed in order to encourage en-route mode shifts to transit. In addition, transit signal priority would be activated to allow buses to better adhere to schedules and minimize delays incurred by incident-related congestion. Specific parameters adjusted from pre-ICM conditions in the model for all ICM strategies deployed in minor incident scenarios include:

- Congestion Responsive Rerouting activated in DynusT, both pre- and post-ICM;
- Earlier dissemination (10 minutes pre-ICM to 2 minutes post-ICM) and increased use rate (10 percent pre-ICM to 12 percent post-ICM) of pretrip information related to incidents;
- Increased use rate of en-route traveler information from 5 percent pre-ICM to 10 percent post-ICM;
- Increased use rate of DMS information from 72 percent pre-ICM to 80 percent post-ICM;

- Park-and-ride information on DMS for passing travelers (100 percent awareness) for post-ICM only; and
- Transit Signal Priority activated when buses are behind schedule in the post-ICM case only.

Major incident scenarios are less frequent, but more impactful on the transportation network; and receive additional ICM strategies in attempts to reduce the incident-related congestion in the corridor. All strategies that are deployed under minor incident conditions were also deployed under major incident conditions, with additional ICM strategies deployed depending on the nature of the major incident.

During an incident where the freeway still has some residual capacity, but is of a long enough duration to have major impacts, the goal is to allow traffic to better use not only the I-394 freeway, but to allow for improved travel flows on the parallel arterials for those travelers who divert from the freeway. Specific parameters adjusted from pre-ICM conditions in the model for all ICM strategies deployed in the major incident scenario blocking one general purpose and one auxiliary lane on I-394:

- All minor incident ICM strategies;
- Implement Incident Signal Timing Plans on TH 55 and TH 7 to reduce travel times on the parallel arterials (post-ICM only); and
- HOT lane open to all, allows all traffic to use the HOT lane without incurring penalties or having to pay tolls (post-ICM only).

During a severely disruptive incident that blocks all lanes on the freeway, the goal is to prevent travelers from accessing the freeway where they would later be forced off onto local roadways just upstream of the incident, which may not have the capacity to handle significant volume exiting from the freeway. Specific parameters adjusted from pre-ICM conditions in the model for all ICM strategies deployed in the major incident scenario blocking all lanes (closure) on I-394:

- All minor incident ICM strategies;
- Implement Incident Signal Timing Plans on TH 55 and TH 7 to reduce travel times on the parallel arterials (post-ICM only); and
- Implement predesignated Freeway Closure Point Plan (post-ICM only).

During a major arterial incident, the focus is not on the freeway, but allowing the arterials as much peak direction capacity as possible to minimize the congestion surrounding the incident site. Specific parameters adjusted from pre-ICM conditions in the model for all ICM strategies deployed in the major incident scenario blocking all lanes (closure) on TH 55:

- All minor incident ICM strategies; and
- Implement Incident Signal Timing Plans on TH 55 and TH 7 to reduce travel times on the parallel arterials (post-ICM only).

Performance Measures

All operating conditions were simulated as outlined previously, and the OD-based performance measures of PMT, PHT, and total person hours of delay were calculated. Table 6-1 lists the performance measures for all trips simulated in the network. Table 6-2 lists the performance measures only for trips using any part of the I-394 eastbound roadway. As DynusT is a vehicle-based model, as opposed to a person- or traveler-based model, all model outputs were converted from vehicular units to person units by assuming an average vehicle occupancy of 1.1 persons per vehicle. Table 6-3 lists the average travel time by mode (in minutes) as simulated for all trips in the corridor. In this table, travel time listed for transit trips relates to bus travel time on the network.

Table 6-1. Pre- and Post-ICM Individual Scenario Performance Measures, All Trips, Daily AM Peak
Trips Starting 5:00 AM to 11:00 AM

		Pre-ICM			Post-ICM			Pre to Post Change		
Scenario	Incident Severity	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)
No incident	NA	2,564,320	100,373	70,793	2,564,320	100,373	70,793	0	0	0
Freeway closed for 80 min. at 8:00 AM	Major	2,562,702	102,529	73,003	2,562,610	99,843	70,322	-92	-2,686	-2,681
Freeway blocked (1 GP + 1 Aux Lane) for 80 min. at 7:30 AM	Major	2,562,749	97,638	68,112	2,561,950	95,866	66,353	-799	-1,772	-1,759
Freeway blocked (1 GP + 1 aux lane) for 45 min. at 7:30 AM	Minor	2,563,149	97,676	68,148	2,561,617	96,293	66,769	-1,532	-1,384	-1,379
Freeway blocked (1 GP + 1 aux lane) for 45 min. at 8:15 AM	Minor	2,563,955	98,893	69,357	2,562,372	97,662	68,138	-1,584	-1,230	-1,219
Freeway blocked (1 GP + 1 aux lane) for 30 min. at 7:15 AM	Minor	2,563,661	98,017	68,485	2,562,907	96,196	66,675	-754	-1,820	-1,810
Freeway blocked (1 GP + 1 aux lane) for 30 min. at 7:45 AM	Minor	2,563,552	97,159	67,629	2,562,134	96,374	66,851	-1,418	-785	-778
Arterial closed for 65 min. at 7:30 AM	Major	2,564,036	98,608	69,076	2,563,066	97,124	67,604	-971	-1,484	-1,472

Table 6-2. Pre- and Post-ICM Individual Scenario Performance Measures, I-394 EB Trips, Daily AM Peak
Trips Starting 5:00 AM to 11:00 AM

Scenario	Incident Severity	Pre-ICM			Post-ICM			Pre to Post Change		
		Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)	Person Miles Traveled	Person Hours Traveled	Delay (Person Hours)
No incident	NA	577,736	17,338	10,141	577,736	17,338	10,141	0	0	0
Freeway closed for 80 min. at 8:00 AM	Major	570,488	21,440	14,324	562,386	19,622	12,623	-8,102	-1,818	-1,701
Freeway blocked (1 GP + 1 aux lane) for 80 min. at 7:30 AM	Major	568,891	16,882	9,792	566,987	15,921	8,863	-1,904	-961	-929
Freeway blocked (1 GP + 1 aux lane) for 45 min. at 7:30 AM	Minor	573,339	16,949	9,813	570,833	16,680	9,570	-2,506	-270	-243
Freeway blocked (1 GP + 1 aux lane) for 45 min. at 8:15 AM	Minor	572,456	16,978	9,848	570,019	16,491	9,385	-2,437	-487	-462
Freeway blocked (1 GP + 1 aux lane) for 30 min. at 7:15 AM	Minor	575,468	16,893	9,727	573,880	16,654	9,507	-1,588	-239	-220
Freeway blocked (1 GP + 1 aux lane) for 30 min. at 7:45 AM	Minor	573,494	16,990	9,852	571,190	16,718	9,597	-2,303	-271	-255
Arterial closed for 65 min. at 7:30 AM	Major	577,056	16,935	9,754	579,170	16,833	9,624	2,114	-103	-130

Table 6-3. Pre- and Post-ICM Average Travel Time by Mode, All Trips, Daily AM Peak
Trips Starting 5:00 AM to 11:00 AM (in Minutes)

Scenario	Incident Severity	Pre-ICM			Post-ICM			Pre to Post Change		
		Auto (SOV)	Auto (HOV)	Transit (Bus)	Auto (SOV)	Auto (HOV)	Transit (Bus)	Auto (SOV)	Auto (HOV)	Transit (Bus)
No incident	NA	12.0	10.6	22.1	12.0	10.6	22.1	0.00	0.00	0.00
Freeway closed for 80 min. at 8:00 AM	Major	12.3	10.8	21.7	12.0	10.8	21.7	-0.33	-0.03	0.03
Freeway blocked (1 GP + 1 aux lane) for 80 min. at 7:30 AM	Major	11.7	10.4	21.6	11.5	10.5	20.8	-0.22	0.10	-0.82
Freeway blocked (1 GP + 1 aux lane) for 45 min. at 7:30 AM	Minor	11.7	10.4	21.9	11.5	10.3	21.6	-0.17	-0.07	-0.26
Freeway blocked (1 GP + 1 aux lane) for 45 min. at 8:15 AM	Minor	11.8	10.5	21.9	11.7	10.5	21.7	-0.15	-0.01	-0.25
Freeway blocked (1 GP + 1 aux lane) for 30 min. at 7:15 AM	Minor	11.7	10.4	22.0	11.5	10.3	21.6	-0.22	-0.10	-0.45
Freeway blocked (1 GP + 1 aux lane) for 30 min. at 7:45 AM	Minor	11.6	10.4	22.0	11.5	10.4	21.6	-0.10	0.00	-0.47
Arterial closed for 65 min. at 7:30 AM	Major	11.8	10.5	22.0	11.6	10.5	21.8	-0.18	-0.05	-0.12

Figures 6-1 and 6-2 illustrate the differences between pre- and post-ICM scenarios in PHT and total delay, respectively, for all trips on the network. Similarly, Figures 6-3 and 6-4 illustrate the differences in the measures only for trips using I-394 EB.

Comparing the performance measures of the different incident scenarios, the ICM deployments can be seen to have significant impact on reducing total PHT and delay, both systemwide and for travelers using I-394 EB. For all travelers, PHT is reduced between 1.0 and 2.5 percent, depending on the incident scenario, while PHT reductions for trips using I-394 EB range from 0.5 in the arterial closure scenario to 8.5 percent in the major freeway closure incident. Total systemwide delays are reduced between 1.1 and 3.7 percent, while delays experienced by trips using I-394 EB are reduced by between 1.3 and 11.9 percent. As expected, results show that under the major freeway incident conditions, the ICM strategies can greatly reduce the total travel times not only on I-394 but systemwide. While not as large, improvements from ICM deployments during minor freeway incidents are still significant. The arterial incident scenario sees the smallest benefits from ICM strategies, but still shows improvements.

Figure 6-1. Pre- and Post-ICM Comparison, PHT for All Trips, Daily AM Peak
Trips Starting 5:00 AM to 11:00 AM

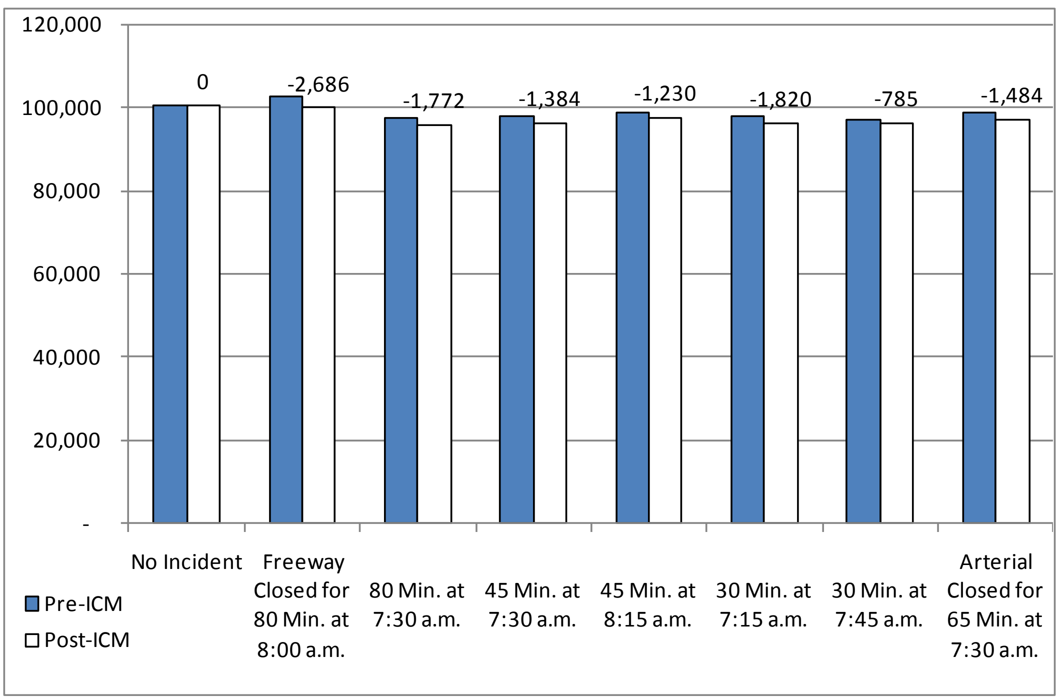


Figure 6-2. Pre- and Post-ICM Comparison, Delay for All Trips, Daily AM Peak
Trips Starting 5:00 AM to 11:00 AM

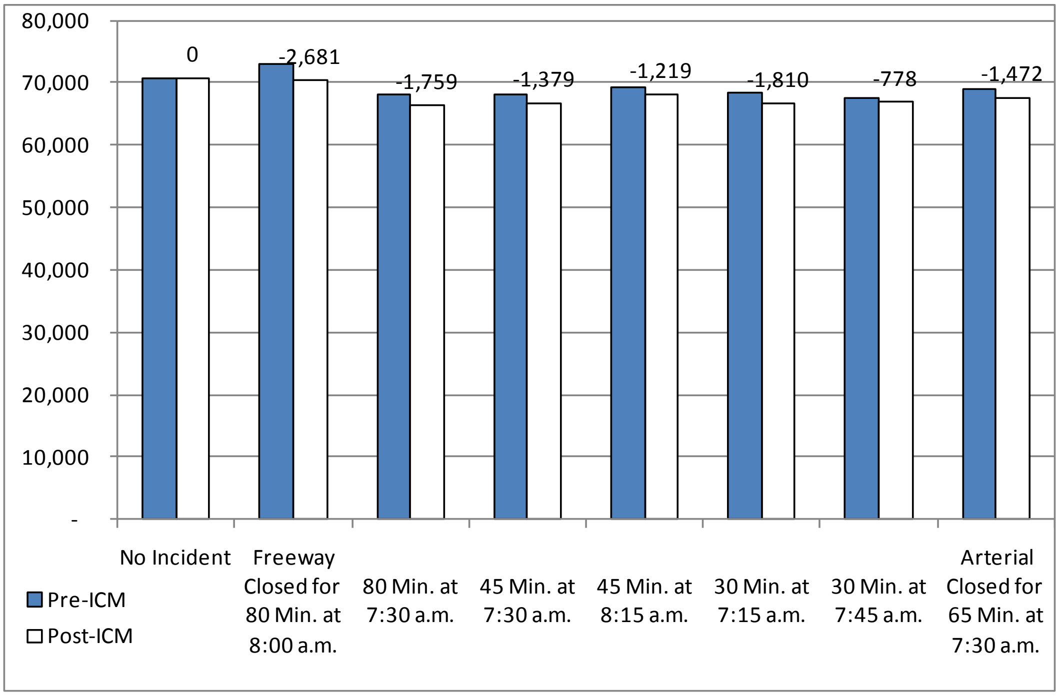


Figure 6-3. Pre- and Post-ICM Comparison, PHT for I-394 EB Trips, Daily AM Peak
Trips Starting 5:00 AM to 11:00 AM

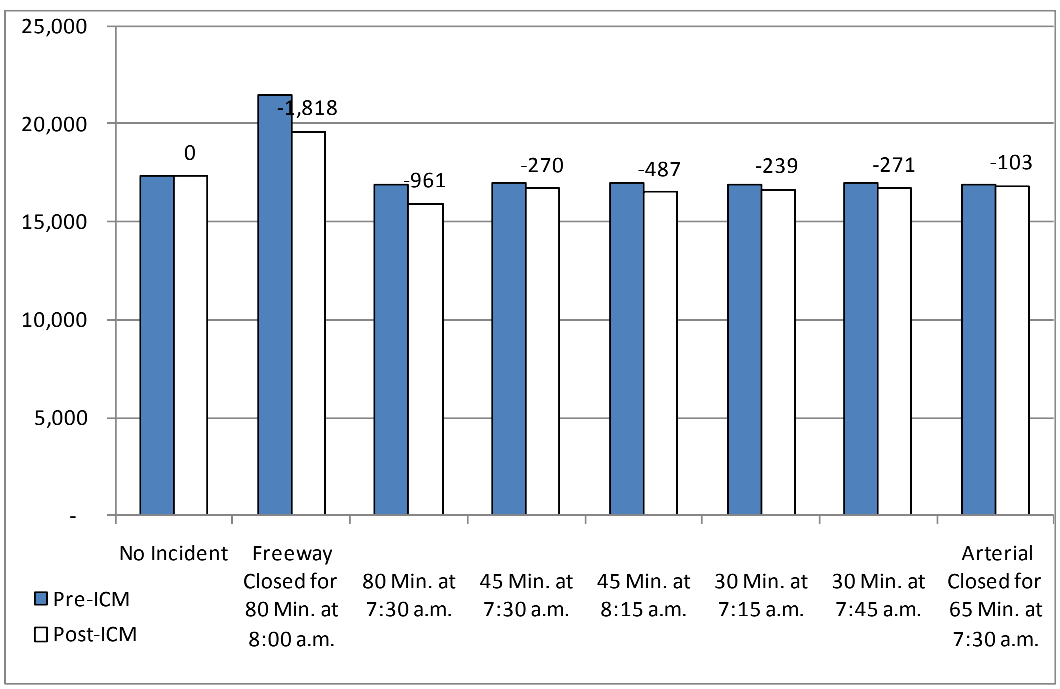
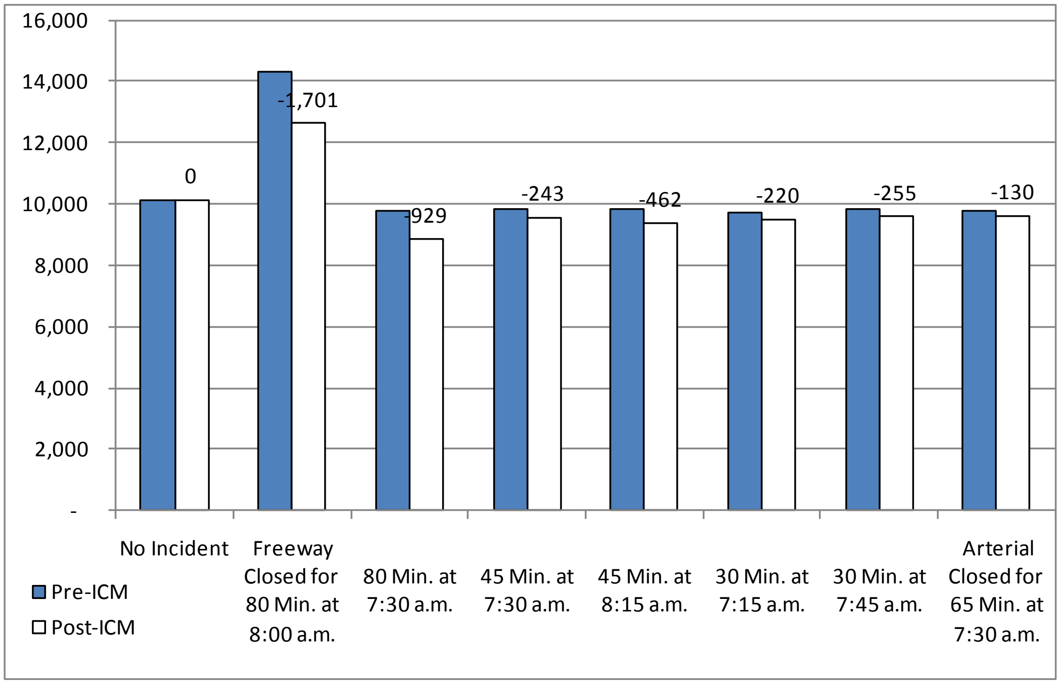


Figure 6-4. Pre- and Post-ICM Comparison, Delay for I-394 EB Trips, Daily AM Peak
Trips Starting 5:00 AM to 11:00 AM



ICM Performance Measures

A set of key performance measures was presented in the *I-394 ICM Analysis Plan.* These performance measures are used in the benefit-cost analysis presented later in this chapter. In this methodology, the analyzed scenarios representing different operating conditions are combined together weighted by the probability of occurrence to arrive at a total annual benefit, net annual benefit, and benefit-cost.

Table 6-4 lists the aggregated performance measures for the pre-ICM and post-ICM scenarios. The detailed methodology used for generating these performance measures is outlined in Appendix B. The analysis shows that deploying ICM strategies can reduce the total average daily person hours of delay and person hours traveled, both systemwide and for trips using I-394 eastbound. Morning peak-period delay savings account for 329 person-hours saved.

Table 6-4. Performance Measures Aggregated over all Scenarios, Daily AM Peak

Performance Measure Trip Selection Set	Pre-ICM	Post-ICM	Change	Percent Change
Average Travel Time (Minutes/Trip)				
All Routes	11.92	11.88	-0.04	-0.3%
Trips Using I-394 EB	19.93	19.82	-0.10	-0.5%
Trips Using I-394 WB	15.33	15.37	0.03	0.2%
Average Delay (Minutes/Trip)				
All Routes	8.39	8.35	-0.04	-0.5%
Trips Using I-394 EB	11.66	11.55	-0.10	-0.9%
Trips Using I-394 WB	7.52	7.56	0.05	0.6%
Total Delay (Person Hours)				
All Routes	70,283	69,955	-329	-0.5%
Trips Using I-394 EB	10,226	10,201	-25	-0.2%
Trips Using I-394 WB	4,478	4,537	59	1.3%
Planning Index				
All Routes	6.57	6.59	0.02	0.3%
Trips Using I-394 EB	4.52	4.51	-0.01	-0.2%
Trips Using I-394 WB	3.56	3.63	0.07	2.0%
Travel Time Variance (Minutes^2)				
All Routes	36.39	34.78	-1.61	-4.4%
Trips Using I-394 EB	37.60	35.25	-2.35	-6.3%
Trips Using I-394 WB	14.89	14.51	-0.38	-2.6%
Passenger Hours Traveled				
All Routes	99,851	99,520	-331	-0.3%
Trips Using I-394 EB	17,480	17,504	24	0.1%
Trips Using I-394 WB	9,133	9,218	85	0.9%
Passenger Miles Traveled				
All Routes	2,564,130	2,563,811	-319	0.0%
Trips Using I-394 EB	581,852	585,464	3,612	0.6%
Trips Using I-394 WB	329,103	331,326	2,223	0.7%
Passenger Miles Delivered (by 11:00 AM)				
All Routes	2,482,125	2,482,515	389	0.0%
Trips Using I-394 EB	571,971	575,597	3,626	0.6%
Trips Using I-394 WB	318,399	320,873	2,474	0.8%

Systemwide travel time, delay and travel time reliability benefits are significant – ICM is expected to improve travel conditions for I-394 corridor travelers. Changes in person-miles traveled and person-miles delivered by 11:00 AM are relatively insignificant. Overall, the aggregated performance measures show that the ICM strategies can improve the operating conditions on the network during incident conditions.

Throughput Measures

In order to estimate the degree to which ICM affects the network throughput and duration of trips with longer travel times, the travel times under the incident scenarios can be compared to those under the no incident of the same demand level. By comparing the percentage of trips under the same threshold travel time in both the scenarios pre- and post-ICM, the relative influence of ICM on reducing extreme travel times can be estimated.

Table 6-5 lists the percentage of trip travel times in the incident scenarios that are less than the 90th percentile travel time in the no incident scenario for all trips in the modeled system. Similarly, Table 6-6 lists the same only for trips that use I-394 EB. In both cases, only trips with start times between 7:00 and 9:00 AM were included so the analysis could focus on trips that would most likely be affected by the simulated incidents.

Table 6-5. Percentage of Travel Times Less than the 90th Percentile Travel Time of the No Incident Scenario, All Trips

Trips Starting 7:00 AM to 9:00 AM

Operating Conditions	Pre-ICM	Post-ICM	Change
Freeway closed for 80 min. at 8:00 AM	89.92	90.3	0.38
Freeway blocked (1 GP + 1 Aux Lane) for 80 min. at 7:30 AM	90.67	91.32	0.65
Freeway blocked (1 GP + 1 Aux Lane) for 45 min. at 7:30 AM	90.54	90.78	0.24
Freeway blocked (1 GP + 1 Aux Lane) for 45 min. at 8:15 AM	90.64	90.75	0.11
Freeway blocked (1 GP + 1 Aux Lane) for 30 min. at 7:15 AM	90.8	90.96	0.16
Freeway blocked (1 GP + 1 Aux Lane) for 30 min. at 7:45 AM	90.3	90.26	-0.04
Arterial closed for 65 min. at 7:30 AM	90.27	90.66	0.39

Table 6-6. Percentage of Travel Times Less than the 90th Percentile Travel Time of the No Incident Scenario, I-394 EB Trips
Trips Starting 7:00 AM to 9:00 AM

Operating Conditions	Pre-ICM	Post-ICM	Change
Freeway closed for 80 min. at 8:00 AM	78.18	80.7	2.52
Freeway blocked (1 GP + 1 Aux Lane) for 80 min. at 7:30 AM	89.45	92.93	3.48
Freeway blocked (1 GP + 1 Aux Lane) for 45 min. at 7:30 AM	90.94	91.31	0.37
Freeway blocked (1 GP + 1 Aux Lane) for 45 min. at 8:15 AM	90.05	90.61	0.56
Freeway blocked (1 GP + 1 Aux Lane) for 30 min. at 7:15 AM	90.05	90.44	0.39
Freeway blocked (1 GP + 1 Aux Lane) for 30 min. at 7:45 AM	89.76	90.83	1.07
Arterial closed for 65 min. at 7:30 AM	90.74	91.16	0.42

Table 6-5 shows a post-ICM improvement for all operating conditions, except for a slight decrease in one minor incident scenario. Table 6-6 shows more significant and consistent post-ICM improvements in reducing the length of extreme travel times for trips using I-394 eastbound, since these trips are more heavily impacted by the incident. This shows that ICM strategies are effective at reducing the longer travel times in the corridor under incident conditions.

ICM Benefits

Benefits considered include saved travel time, increased travel time reliability, reduced fuel consumption, and reduced emissions production. All benefits are monetized to allow for the direct comparison to the costs to install and operate the ICM system.

These benefits were calculated on a facility basis so as to determine which roadways and roadway types in the system see benefits from ICM deployment, and which see conditions worsen. This is in contrast to all previous reported performance measures, which were all based on origin-destination travel times. The exception is in travel time variance, which is defined as the total trip time variance.

Specific steps involved in annualizing these benefits include the following:

- Using AMS tools the analysis produced performance measures associated with the pre- and post-ICM alternatives for the AM peak period. The differences in performance measures between the pre- and post-ICM conditions are deemed the improvement in AM peak-period performance due to the introduction of ICM.
- The resulting benefits for the AM peak period are then doubled to approximate the daily benefits under the assumption that the AM peak period produces approximately the same impact as the PM peak period. No benefits were assumed to be gained during off-peak conditions.
- Daily benefits were then converted into annual benefits by multiplying times 260 workdays.

- Benefits were monetized through the following methods:
  - **Travel Timesavings.** The reduction in PHT from the pre-ICM to the post-ICM simulations for the same operating condition was taken as the travel time savings to be gained from ICM deployment under those conditions. By multiplying the person total hours saved by an estimated average value of travel time of $13.59 per passenger hour and $17.08 per truck hour yielded the estimated monetary benefit of saved travel times. Vehicles were assumed to have average vehicle occupancy of 1.1 passengers per vehicle.
  - **Travel Time Reliability.** Following research on the subject, the monetary benefits for changes in travel time reliability were estimated by the change in the standard deviation (or square root of variance) of the trip travel times. The value of travel time reliability was assumed to be equal to the value to travel time. This is a conservative value of reliability time – typically, travel time reliability is valued at 2.5 to 3 times the average value of travel time.
  - **Fuel consumption.** Travel speeds on link in the system were examined in multiple time intervals throughout the morning peak period and summarized in the amount of VMT occurring at various speeds and used to estimate the fuel consumption of the modeled vehicles in each scenario. This method is an approximation of fuel consumption and does not include the acceleration and deceleration effects and idle time of queued traffic. Fuel consumption rates were based on EMFAC 2007 and MOBILE6 and an average cost of $4.00 per gallon of fuel was assumed.
  - **Emissions.** An estimate was made of reduced emissions from the pre-ICM to the post-ICM based on the amount of VMT occurring in each scenario at varying speeds. Emissions rates and costs used in the analysis were based on MOBILE6 and EMFAC 2007.

Summary of Net Annual Benefits

During no incident traffic conditions, no benefits of ICM deployment were assumed to be gained. ICM strategies, such as improved traveler information disseminated during no incident conditions, may allow for travelers unfamiliar with the transportation network to seek better routes and avoid congestion, but it was conservatively assumed that the benefits from this would be small and were excluded from the benefits analysis.

Figures 6-5 through 6-11 present summaries of the monetized annual benefits produced by the varying ICM strategies deployed in each of the combined incident scenarios analysis throughout the year. Travel time reliability benefits are not included in the individual operating condition analyses since these were derived from the average travel time variance over all operating conditions.

Figure 6-5. Total Estimated Annual Benefits from ICM Deployment – Freeway Closure Incident (80 Minutes) at 8:00 AM

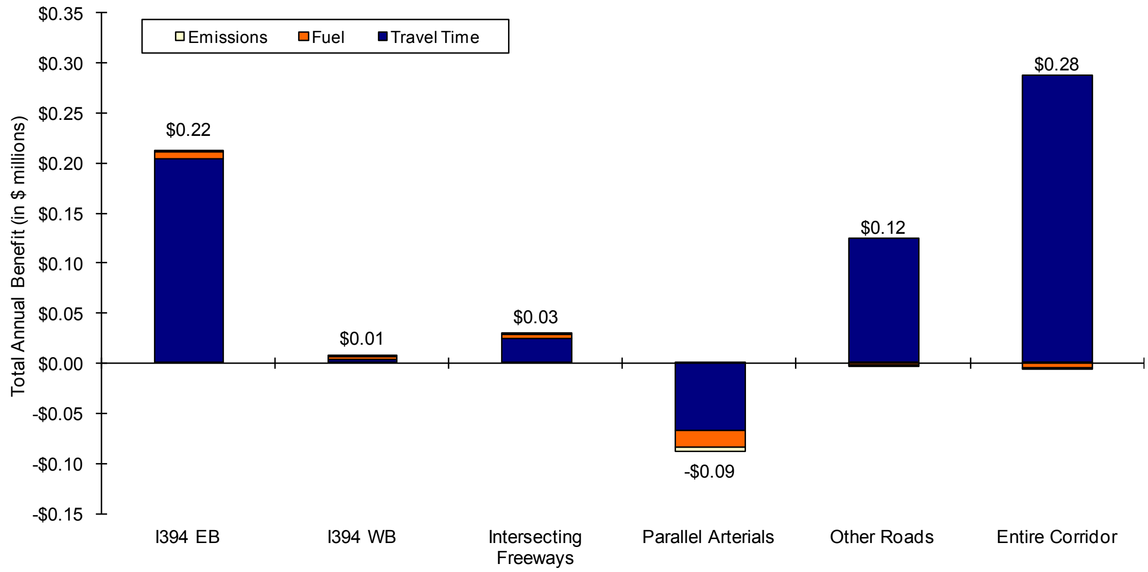


Figure 6-6. Total Estimated Annual Benefits from ICM Deployment – Major Freeway Blockage Incident (80 Minutes) at 7:30 AM

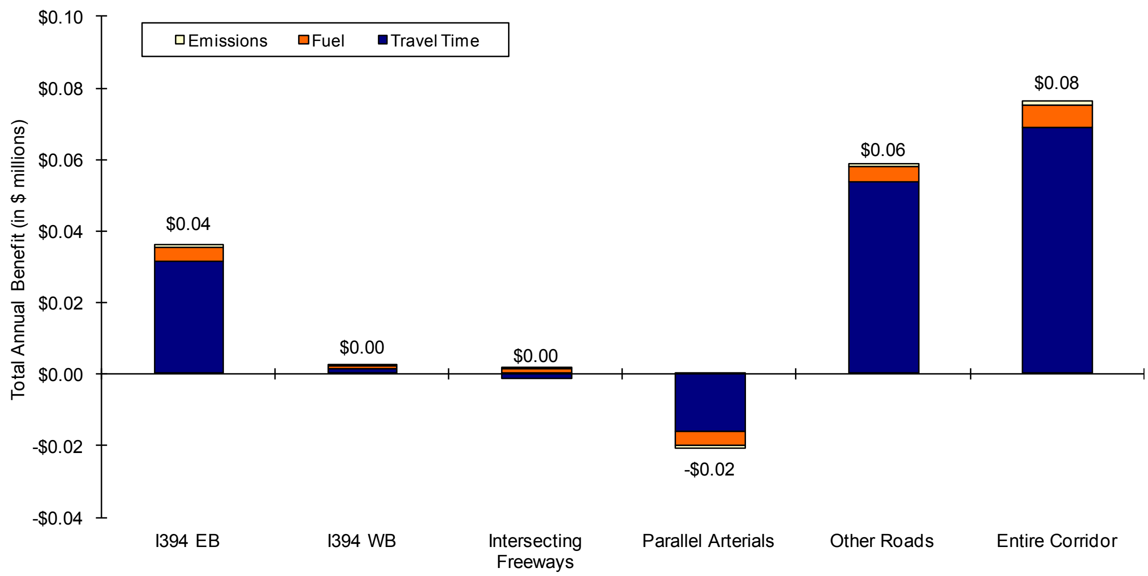


Figure 6-7. Total Estimated Annual Benefits from ICM Deployment – Minor Freeway Blockage Incident (45 Minutes) at 7:30 AM

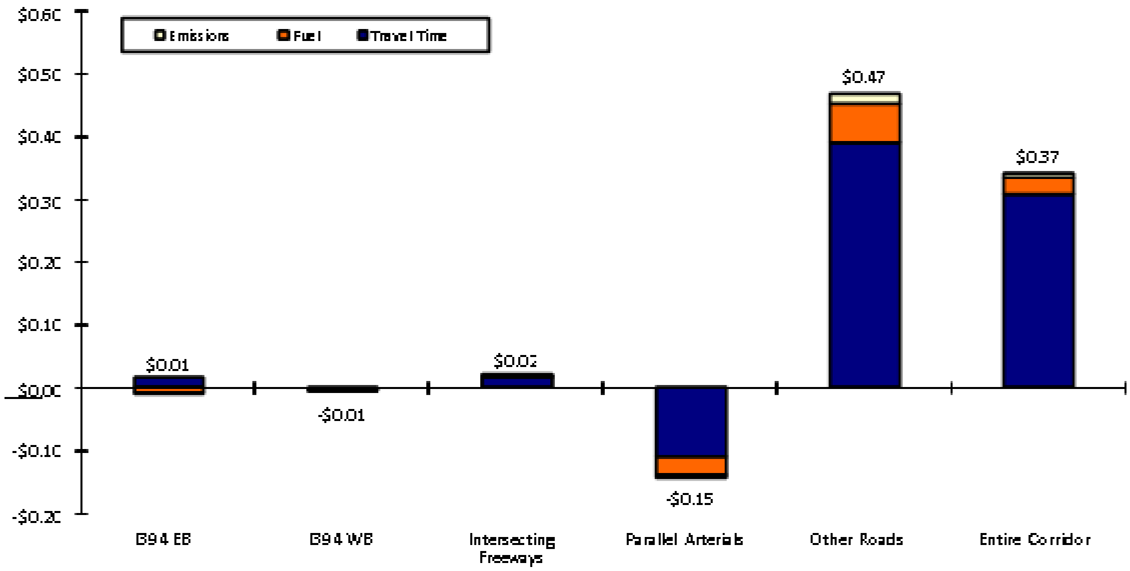


Figure 6-8. Total Estimated Annual Benefits from ICM Deployment – Minor Freeway Blockage Incident (45 Minutes) at 8:15 AM

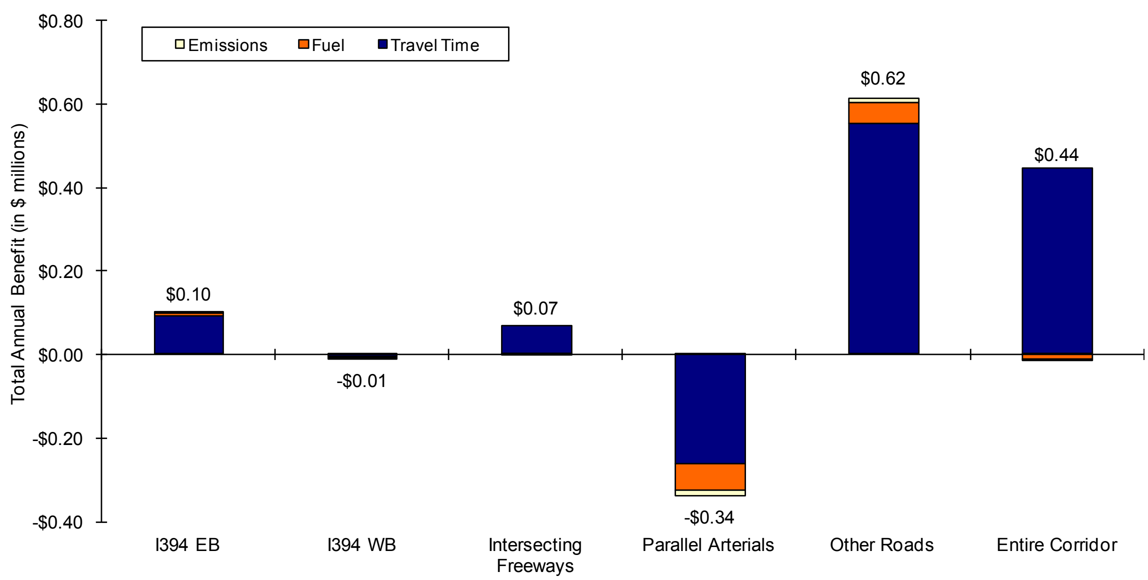


Figure 6-9. Total Estimated Annual Benefits from ICM Deployment – Minor Freeway Blockage Incident (30 Minutes) at 7:15 AM

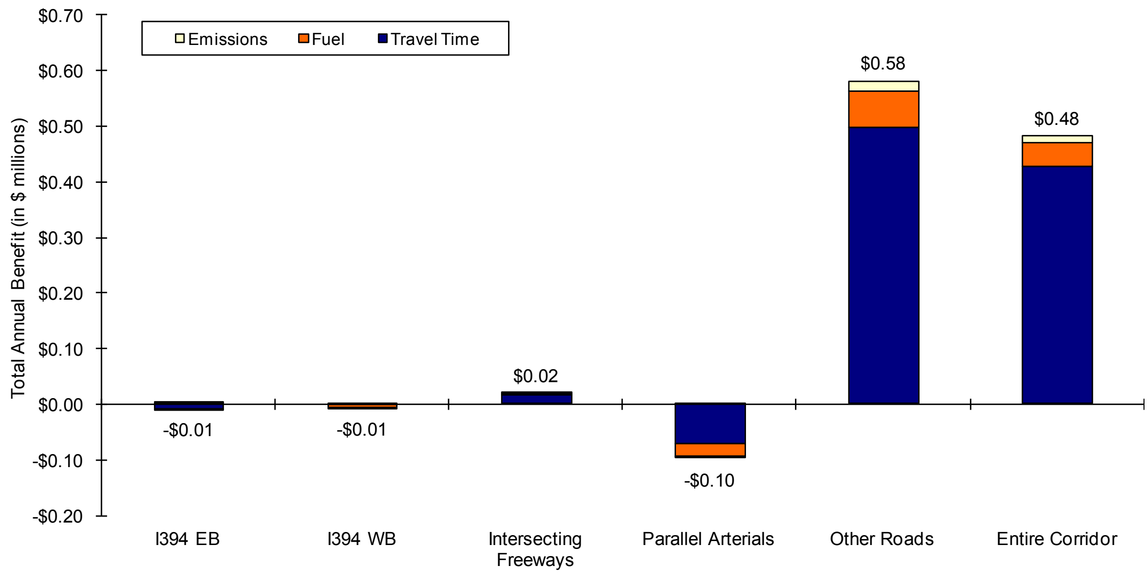


Figure 6-10. Total Estimated Annual Benefits from ICM Deployment – Minor Freeway Blockage Incident (30 Minutes) at 7:45 AM

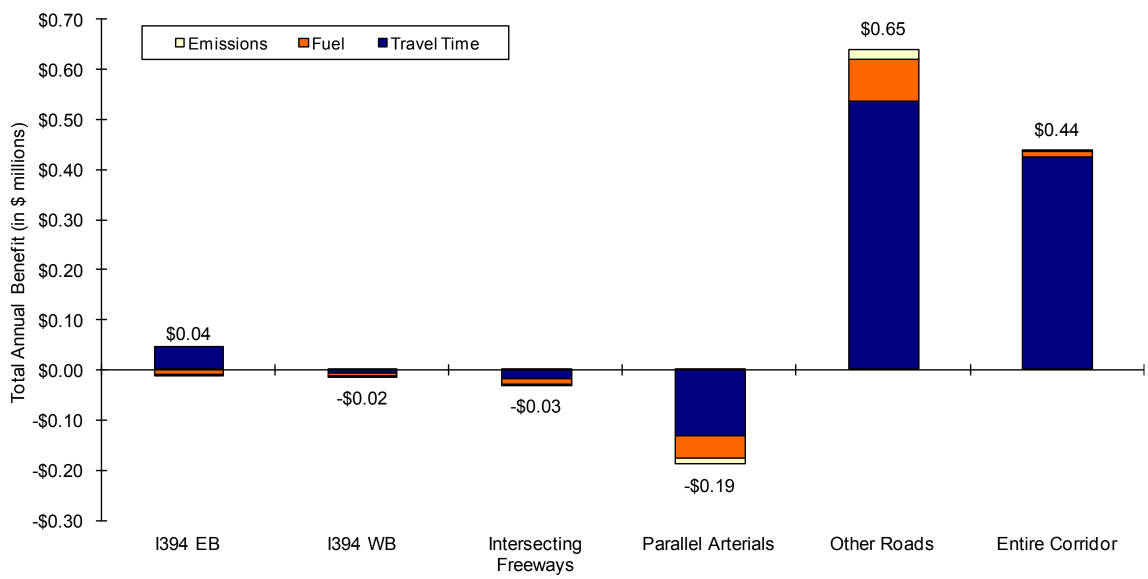
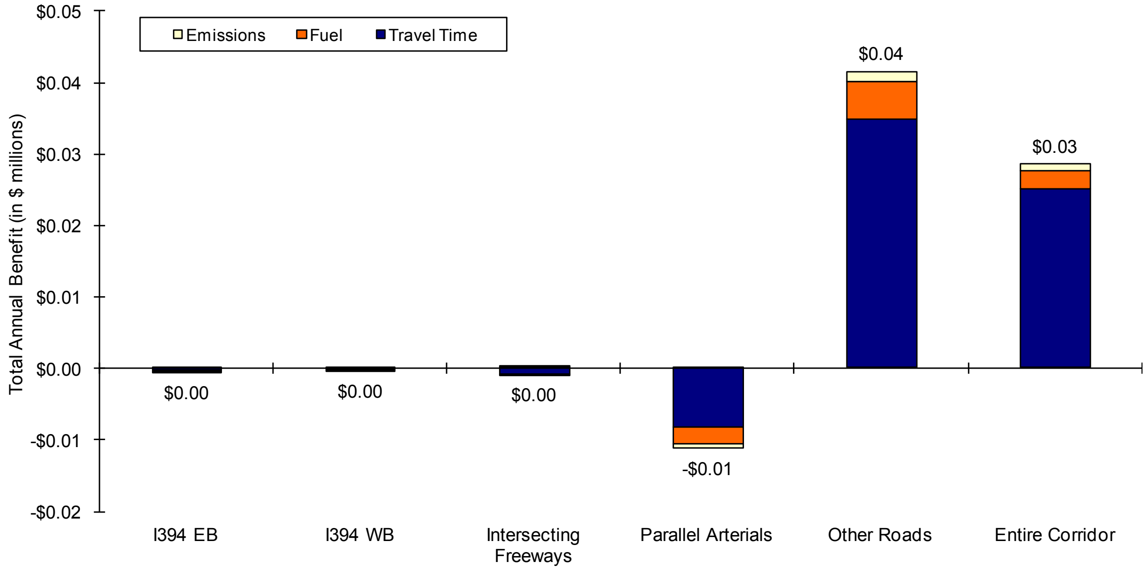


Figure 6-11. Total Estimated Annual Benefits from ICM Deployment – Major Arterial Closure Incident (65 Minutes) at 7:30 AM



As illustrated in Figure 6-5, significant benefits from reduced person hours traveled can be seen across the corridor during the ***freeway closure*** incident scenario, and in particular on I-394 Eastbound. This can be attributed to a combination of the improved dissemination of traveler information to advise travelers to seek alternative paths and from the implementation of the pre-designated freeway closure plan that strategically closes ramps feeding into the sections of I-394 approaching the closure location. The parallel arterials do see disbenefits, which can be attributed to the additional diverted traffic from I-394. Arterial disbenefits notwithstanding, the overall I-394 corridor experiences positive benefits.

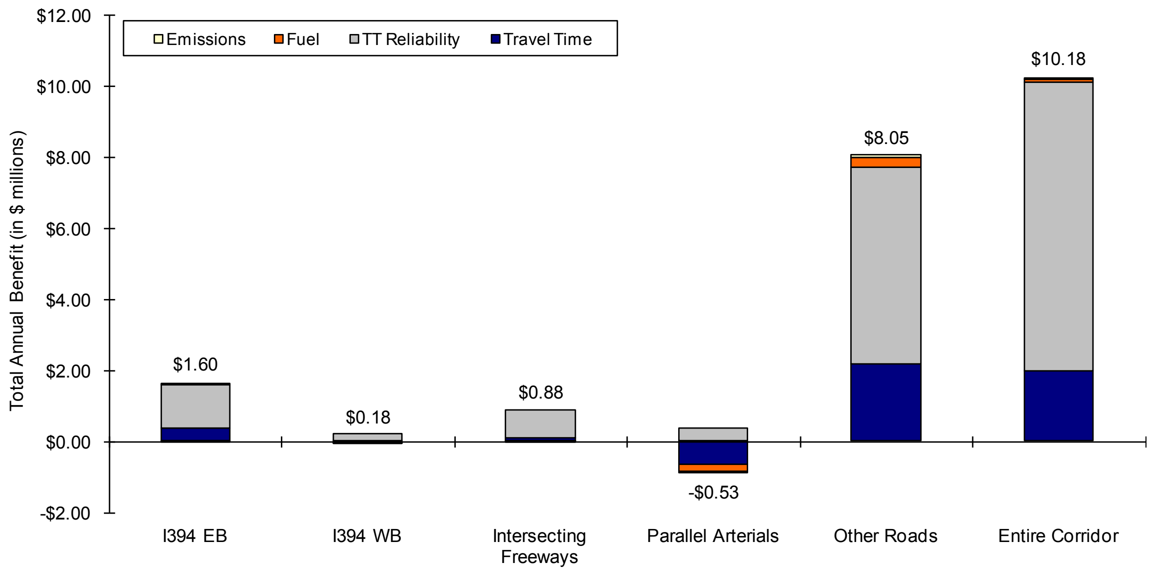
The benefits of the ICM strategies under the ***major freeway blockage*** scenarios are similar to those seen under the freeway closure scenario, but more muted (see Figure 6-6). I-394 still sees the majority of the benefits on the system, but under this incident scenario the benefits can be attributed in large part to the ICM strategy of opening the HOT lane to all travelers without tolling. The additional capacity on I-394 provides improved travel times on the corridor. In addition to the benefits seen on I-394 Eastbound and the disbenefits on the parallel arterials caused by diverted traffic, benefits are seen on all other roadways in the system. These benefits can be attributed to a combination of the improved traveler information being disseminated to the traveling public and the metering effect that the incident has on I-394. The incident site is upstream of a recurring congestion bottleneck, which under the tested incident conditions operates under improved conditions. Again, there are systemwide benefits in this operational condition.

The pattern of benefits from ICM deployment changes under the ***minor freeway incident*** scenarios, as shown in Figures 6-7 through 6-10. Under all minor incident scenarios, the only ICM strategies deployed are TSP and improved traveler information dissemination. In all scenarios, the benefits seen to I-394 and the intersecting freeways are minimal, while disbenefits are seen on the parallel arterials, and positive benefits are seen on the other roadways in the corridor. The ICM benefits under these scenarios can largely be attributed to the combination of the improved traveler information and the metering effect of the incident, as seen during the major freeway blocking scenario. Due to the much higher frequency of minor freeway incidents, the monetized benefits from ICM during these minor incident conditions are significant.

Finally, Figure 6-11 shows the ICM benefits gained in the corridor during a ***major arterial incident***. Negligible effects are seen on I-394 and the intersecting freeways, while parallel arterials see disbenefits and other roadways see more than offsetting benefits. The arterial incident provides a metering effect that improves conditions downstream of the incident on roadways that are normally congested. With improved traveler information to re-route themselves, travelers on the other roadways utilize the now improved roadways to access their destination quicker. Due to the low probability assigned to this scenario, the monetary benefits are minimal.

The total annual benefits generated from the deployment of ICM in the I-394 corridor are shown in Figure 6-12. Included in the total annual benefits estimate is the impact of the ICM on travel time reliability.

Figure 6-12. Total Estimated Annual Benefits from ICM Deployment – All Operating Conditions



Overall, there are significant travel time benefits in the corridor between pre- and post-ICM. Travel time reliability benefits (measured by the standard deviation of travel times) are even more significant and contribute the majority of the benefits seen from the implementation of ICM. The majority of reliability benefits are produced by a 2.2-percent reduction in the standard deviation of all trips systemwide. A significant amount of benefits is also seen from a 3.2-percent reduction in the standard deviation of travel time for trips using I-394 EB.

Total estimated benefits for the parallel arterials are negative because of travelers diverted onto these roadways from I-394. In addition to traffic from I-394, the deployment of incident signal timing plans on the parallel arterials can draw travelers from the other roadways in the corridor.
The deployment of ICM in the I-394 corridor has net positive benefits over a typical year. As analyzed, the average annual benefits are $10.2 million per year. Extended over the 10-year life cycle, a total benefit of $85.9 million is estimated.

ICM Costs

The costs presented in this section provide an estimate of the costs for various components needed for the development and operation of the ICM on the I-394 corridor. The costs presented in this section are defined as follows:

- **Capital Costs.** Includes up-front costs necessary to procure and install equipment. These costs are shown as a total (one-time) expenditure, and they include the capital equipment costs, as well as the soft costs required for design and installation of the equipment.
- **Operations and Maintenance (O&M) Costs.** Includes those continuing costs necessary to operate and maintain the deployed equipment, including labor costs. While these costs do contain provisions for upkeep and replacement of minor components of the system, they do not contain provisions for wholesale replacement of the equipment when it reaches the end of its useful life. These O&M costs are presented as annual estimates.
- **Annualized Costs.** Represents the average annual expenditure that would be expected in order to deploy, operate, and maintain the ICM improvement; and replace (or redeploy) the equipment as they reach the end of their useful life. Within this cost figure, the capital cost of the equipment is amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual O&M cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of Test Corridor ICM deployments.

Total Cost Estimates

The initial capital cost for the ICM deployments in the I-394 corridor is estimated at $2.06 million, with an additional $0.23 million per annum in O&M costs. Details listing the costs per item are listed in Table 6-7. The costs are lower than other ICM corridors due in part to the existence of significant ITS infrastructure on which the ICM system will be built.

Assuming a 10-year life cycle for all components, the total annualized cost for all the ICM deployments for the I-394 corridor is $0.47 million, which translates to $3.96 million in total life-cycle costs.

Table 6-7. I-394 ICM Cost Details

ICM Strategy	Capital Costs	Annual O&M	Annualized Cost	Life-Cycle Costs
Earlier Dissemination	$285,000	$30,000	$63,786	$538,060
Transit Signal Priority	$457,106	$85,346	$139,535	$1,177,024
Comparable Travel Times	$636,800	$25,000	$100,492	$847,683
Park-and-Ride Info	$532,002	$85,346	$148,414	$1,251,921
Signal Timing	$125,000	–	$14,819	$125,000
HOV Open to All	$25,000	–	$2,964	$25,000
Total	**$2,060,908**	**$225,691**	**$470,010**	**$3,964,688**

Source: Mn/DOT.

Conclusions and Lessons-Learned

The ICM AMS methodology offers the following benefits to corridor managers across the country:

- **Invest in the right strategies.** The methodology offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions.
- **Invest with confidence.** AMS allows corridor managers to “see around the corner” and discover optimum combinations of strategies, as well as conflicts or unintended consequences inherent in certain combinations of strategies that would otherwise be unknowable before implementation.
- **Improve the effectiveness/success of implementation.** With AMS, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.

  AMS provides a long-term capability to corridor managers to **continually improve implementation** of ICM strategies based on experience.

The I-394 corridor AMS results show positive benefit/cost ratios and net annual benefits, resulting from the deployment of ICM strategies.

- Overall, deployment of ICM on the I-394 corridor produces $10.2 million in user benefits per year. Over the 10-year life cycle of the ICM systems, benefits produced total **$85.9 million**.
- Costs to deploy ICM on the I-394 corridor are estimated to be $0.47 million annualized over the 10-year life cycle of the project. The total life-cycle costs to deploy the ICM system is estimated at **$3.96 million**.
- The estimated benefit/cost ratio for the ICM deployment over the 10-year life cycle of the project is approximated at **22:1**.
- The benefits from ICM are attributable to reduced travel times, improved reliability of travel times, reduced fuel consumption, and reduced mobile emissions. Expected annual savings include 132,000 hours of person-hours of travel, a reduction of fuel consumption by 17,600 gallons of fuel, and a reduction of 175 tons of vehicular emissions.
- Corridor throughput also improves across all operating conditions: ICM helps reduce the length of the extreme travel times in the corridor, and is more pronounced on trips using I-394 Eastbound. The percent improvement of these trips completed under the 90^{th} percentile baseline travel time ranges from 0.4 to 3.5 percent.
- Across all operational conditions, most of the ICM benefit is attributed to the travel time reliability and travel time savings on the eastbound freeway and other roads in the corridor. Other roads show travel time and travel time reliability benefits owing mostly to better traveler diversion due to better traveler information and arterial signal optimization. This can be attributed to a combination of the improved dissemination of traveler information to advise travelers to seek alternative paths, opening the HOT lane to all travelers without tolling during major incidents, and transit signal priority. The parallel arterials do see disbenefits during major incidents, which can be attributed to the additional diverted traffic from I-394. Arterial disbenefits notwithstanding, the overall I-394 corridor experiences positive benefits.
- An important finding of this analysis is that ICM strategies produce more benefits during nonrecurrent congestion. For individual travelers who primarily rely on the I-394 eastbound

facility the majority of benefits accrues under particular operational conditions associated with incidents. This finding validates the hypothesis that ICM is most effective under the worst operational conditions including incidents.

- The I-394 corridor AMS validates the ICM concept: dynamically applying ICM strategies in combination across a corridor is shown to reduce congestion and improve the overall productivity of the transportation system.

Appendix A Summary of Minneapolis I-394 ICM Strategies

The following table summarizes the ICM strategies for the Minneapolis I-394 Stage II (AMS) Project.

Table A-1. Minneapolis I-394 ICM – Assumptions of Outcomes and Effects and Model Inputs

Outcome of Strategies	Summary/Notes to Modeling Team	Model Assumptions/Inputs: Pre-ICM	Model Assumptions/Inputs: Post-ICM	Reference Values to be Determined by Models
1. Traveler Information				
1.1 Earlier Dissemination	• Because of quicker notification, pretrip and en-route traveler information systems will disseminate incident information earlier to travelers. The effect will be that more travelers will be able to alter routes and modes.	• Information disseminated 10 minutes after start of incident (on average).	• Information disseminated 2 minutes after start of incident (on average).	• Amount of traffic that spreads to other routes and modes (based on information of event). • Change in travel speeds, volumes, travel times, and reliability.
1.2 Comparative Travel Times (Mode and Route)	• Information dissemination (pretrip and en-route) will include travel time comparisons for freeway, arterial, and transit. The effect will be that more travelers will choose the best options (alter routes, modes, and departure times) to maintain consistent trip times.	• N/A	• Travel times available on 511, web, e-mail, DMS, e-mail push within 2 minutes from incident onset.	• Percentage of vehicles that alter route with information about shortest travel times. • Change in travel speeds, volumes, travel times, and reliability.
1.3 Parking Availability at Park-and-Ride Lots	• By disseminating parking availability at park-and-ride lots, travelers will feel comfortable choosing transit and know where they can park their car when appropriate; this will encourage more modal shifts, and avoid travelers being frustrated by driving to a park-and-ride and finding no parking available, and perhaps not trying it again. The effect will be increased modal shifts during incidents or congestion.	• N/A	• Park-and-ride availability/ capacity. • Percentage of vehicles that will not enter park-and-ride lots and search for unavailable spaces, wasting time before continuing on the freeway. Likely a small percentage. • Available to travelers on telephone and web.	• Percentage of commuters will switch to transit (based on information about parking availability). • Percentage of vehicles will not enter park-and-ride lots and search for spaces (unavailable), wasting time before continuing on the freeway. Change in travel speeds, volumes, travel times, and reliability.

Outcome of Strategies	Summary/Notes to Modeling Team	Model Assumptions/Inputs: Pre-ICM	Model Assumptions/Inputs: Post-ICM	Reference Values to be Determined by Models
2. Traffic and Incident Management				
2.1 Incident Signal Retiming Plans	• Mn/DOT, City of Minneapolis, and Hennepin County will develop 'flush' signal timing plans that are coordinated and allow progression through different jurisdictions. The effect will be reduced arterial travel times during incidents or special event situations.	• 60 minutes to implement optimized timing plans.	• 10 minutes to implement optimized timing plans. • Mn/DOT guidance on proposed flush plan operation (changes in green time, cycle lengths, etc.). Will need to be carefully implemented as to not disrupt overall arterial network performance.	• Reduced delays on Hwy 55 and Hwy 7. • Higher arterial capacity. • Reduced demand on I-394. • Change in travel speeds, volumes, travel times, and reliability.
2.2 Predefined Freeway and Arterial Closure Points	• By using predesignated freeway and major arterial closure points at intersections with freeways or major roads, this will avoid travelers being forced to exit at the last available exit point and entering a local road that causes more delay. The effects will be less delays to travelers forced to exit at closures, and less congestion on local arterials.	• 30 minutes to deploy closures. • Mn/DOT provided description of a roadway closure plan for the identified incident.	• 10 minutes to deploy planned closure points at nearest freeway interchange upstream of the incident. Avoids closures at local roads and vehicles being forced on to local roads. • Mn/DOT provided description of a proposed roadway closure plan for the identified incident.	• Reduced delays of vehicles forced to exit I-394 due to a closure (traveling freeways instead of local roads). • Reduced delays to local travelers on local roads due to I-394 rerouted traffic. • Change in travel speeds, volumes, travel times, and reliability.
3. HOT/HOV Lanes				
3.1 HOT Lanes	• Existing today; should be included in the modeling. Can be opened to all traffic during major incidents.	• Maintain HOT lanes during major incidents.	• Open HOT lanes to all traffic within 5 minutes of major incidents to maximize throughput.	• Increased throughput on I-394. • Reduced delays. • Change in travel speeds, volumes, travel times, and reliability.

Outcome of Strategies	Summary/Notes to Modeling Team	Model Assumptions/Inputs: Pre-ICM	Model Assumptions/Inputs: Post-ICM	Reference Values to be Determined by Models
4. Transit Management				
4.2 Transit Signal Priority (TSP)	• TSP at I-394 intersections next to park-and-ride lots will give priority to buses leaving park-and-ride lots and returning to I-394 (Note: TSP is not proposed along all of the arterial network). The effect will be more consistent bus travel times.	• No TSP.	• TSP for transit vehicles behind schedule.	• May avoid wait times at red lights until the vehicles are back on schedule. • Complex modeling task requires the tracking of transit vehicle travel time and modification of traffic signal timing, if performance is not within expected parameters.

Appendix B Performance Measure Calculation Using Simulation

This appendix describes the methodology used in calculating various performance measures for the ICM AMS as summarized in this report.

Calculation Procedures for Key Integrated Corridor Performance Measures from Simulation Outputs

A core element of the Integrated Corridor Management (ICM) initiative is the identification and refinement of a set of key performance measures. These measures represent both the bottom-line for ICM strategy evaluation and define what "good" looks like among key corridor stakeholders. To date, the emphasis on performance-driven corridor management among the participating Pioneer sites has been on measures derived from observed data. In the Analysis, Modeling and Simulation (AMS) phase of the effort, however, attention has turned to producing comparable measures derived from simulation outputs. This document provides a detailed process by which a set of key national measures of corridor performance can be calculated. It is the intent of the ICM program, and this document, that these processes will be implemented consistently in the three participating AMS sites applying the ICM AMS methodology.

This document provides a detailed description of how measures of ***delay***, ***travel time reliability*** and ***throughput*** are calculated from simulation outputs. A brief discussion of travel time variance is also provided given that travel time variance measures are used in ICM-related benefit-cost calculations. The algorithmic approaches defined here are software independent, that is, this process can be implemented with outputs from any of the time-variant simulation tools utilized in the three participating ICM AMS sites. The document begins with a discussion of the calculation of travel time, which informs both a calculation of delay as well as travel time reliability. Next, we provide a discussion of how corridor throughput is defined and measured. The document concludes with a discussion of how these measures are used to make comparisons between system performance in the pre-ICM case and in one or more distinct post-ICM cases.

Travel Time

Our basic unit of observation in calculating ICM-related performance measures is a trip i made between an origin o, finishing at a destination d, starting within a particular time interval τ using mode m.

We record travel time from a single run of the simulation under operational conditions k for this unit

of observation as $t_i^k = t_{o,d,\tau',m}^k$.[2] *Operational conditions* here refer to a specific set of simulation settings reflecting a specific travel demand pattern and collection of incidents derived from a cluster analysis of observed traffic count data and incident data. An example of an operational condition would be an AM peak analysis with 5 percent higher than normal demand and a major arterial incident. Let k be a specific operational condition and the set of all conditions K. Note that each condition has a probability of occurrence p_k and $\sum_k p_k = 1$.

First, for this particular run(s) representing a specific operational condition, we calculate an average travel time for trips between the same o-d pair that begin in a particular time window. Let τ represent this interval, e.g., an interval between 6:30 AM and 6:45 AM and $\mathbf{I}_{o,d,\tau,m}^k$ the set of $n_{o,d,\tau,m}^k$ trips from o to d starting in interval τ under operational condition k using mode m. Note that $\mathbf{I}_{o,d,\tau,m}^k$ is a collection of trips and $n_{o,d,\tau,m}^k$ the scalar value indicating the number of trips contained in $\mathbf{I}_{o,d,\tau,m}^k$. The set of all τ of interest is the set T. For example, we may be interested in consistently calculating performance measures over all trips that begin in the 12 quarter-hour intervals between 6:00 AM and 9:00 AM.

The classification of travel mode may be determined independently at each site, but the breakdown should capture the combination of all modes utilized in making the trip. For example, one may choose to classify non-HOV-auto trips as a mode separately from non-HOV-auto/HOV/walk trips to track the performance of travelers utilizing park-and-ride facilities. However, any classification of modes must be mutually exclusive and collectively exhaustive, that is, $\bigcup_m \mathbf{I}_{o,d,\tau,m}^k = \mathbf{I}_{o,d,\tau}^k$ and $\sum_m n_{o,d,\tau,m}^k = n_{o,d,\tau}^k$.

The average travel time of trips with origin and destination by mode staring in this time interval is:

$$T_{o,d,\tau,m}^k = \frac{\sum_{i \in \mathbf{I}_{o,d,\tau}^k} t_i^k}{n_{o,d,\tau,m}^k} \tag{1}$$

where $n_{o,d,\tau,m}^k > 0$. Let $T_{o,d,\tau,m}^k = 0$ when $n_{o,d,\tau,m}^k = 0$.

The calculation of Equation 1 must also include some estimated travel time for trips that cannot reach their destinations by the end of the simulation period. Later in this document, we will discuss the method for estimating travel times for these trips still underway when the simulation ends.

Next, we calculate the average travel time for this same set of trips across all operational conditions, that is, $\forall k \in K$. Note that it is possible that we may have trips for some o, d, τ, m under some

[2] In the case where multiple random seeds are varied, but the operational conditions are identical, this travel time represents an average for a single trip across the multiple runs. Also, note that this discussion of measures assumes that we are calculating measures for a single case (e.g., pre-ICM); later we will address comparisons between cases.

conditions and no trips for the same o, d, τ, m under other conditions. Let $K'_{o,d,\tau,m}$, $K'_{o,d,\tau,m} \subseteq K$ be the subset of conditions where $n^k_{o,d,\tau,m} > 0$.

Equation 2 finds the average travel time by mode for all trips from o to d starting in interval τ over all conditions where at least one trip is made, $k \in K'_{o,d,\tau,m}$:

$$T_{o,d,\tau,m} = \frac{\sum_{k \in K'_{o,d,\tau,m}} T^k_{o,d,\tau,m} p_k}{\sum_{k \in K'_{o,d,\tau,m}} p_k} \quad (2)$$

The average number of trips by mode from o to d starting in interval τ over all conditions $k \in K$:

$$n_{o,d,\tau,m} = \sum_{k \in K} n^k_{o,d,\tau,m} p_k \quad (2a)$$

Combining across modes, the average travel time of trips from o to d starting in interval τ under operational condition k:

$$T^k_{o,d,\tau} = \frac{\sum_m T^k_{o,d,\tau,m} n^k_{o,d,\tau,m}}{n^k_{o,d,\tau}} \quad (3)$$

where $n^k_{o,d,\tau} > 0$. Let $T^k_{o,d,\tau} = 0$ when $n^k_{o,d,\tau} = 0$.

The average travel time for all trips from o to d starting in interval τ under $K'_{o,d,\tau}$ the subset of conditions where $n^k_{o,d,\tau} > 0$, $K'_{o,d,\tau} \subseteq K$:

$$T_{o,d,\tau} = \frac{\sum_{k \in K'_{o,d,\tau}} T^k_{o,d,\tau} p_k}{\sum_{k \in K'_{o,d,\tau}} p_k} \quad (4)$$

The average number of trips from o to d starting in interval τ over all conditions $k \in K$:

$$n_{o,d,\tau} = \sum_{k \in K} n^k_{o,d,\tau} p_k \quad (4a)$$

Equation 5 defines the trip-weighted average travel time of the system across all o, d, τ :

$$\overline{T} = \frac{\sum_{\forall o,d,\tau} T_{o,d,\tau}\, n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \qquad (5)$$

Delay

Delay can be broadly defined as travel time in excess of some *subjective minimum* travel time threshold. Often, discussions of delay focus solely on roadway-only travel focus on either travel time at posted speeds or 85th percentile speeds. Delay for ICM must be defined differently since ICM explicitly includes multimodal corridor performance. Instead, we directly identify delay at the o, d, m level by deriving a zero-delay threshold $T^0_{o,d,m}$, considering travel times observed across all operating conditions $\forall k \in K$ and all time intervals $\forall \tau \in T$.

The zero-delay threshold for each o-d pair by mode is calculated looking across all operating conditions and all time intervals:

$$T^0_{o,d,m} = \min_{k \in K, \tau \in T} \left\{ T^k_{o,d,\tau,m} \right. \qquad (6)$$

In some cases, the cluster analysis will group low-demand, non-incident conditions into a large, high-probability operational condition. In this case, it is possible that a notionally “low” demand pattern will still produce significant congestion in the corridor, particularly in a peak-period analysis.

For this reason, the minimum threshold may also be calculated as the travel time derived in the pre-ICM case under a substantially reduced demand pattern with no incidents or weather impacts. The reduced demand pattern should produce enough trips to generate travel time statistics by mode for every set of trips from o to d starting in interval τ (i.e., $n^0_{o,d,\tau,m} > 0 \;\forall\, o, d, \tau, m$). At the same time, the reduced demand should generate no volume-related congestion in the network.

Alternatively, $T^0_{o,d,m}$ may be estimated directly from model inputs. For consistency, however, the travel time associated with these thresholds should include expected transfer time between modes and unsaturated signal delay as in the case where a low-demand pattern is used to drive a zero-delay model run.

From our previous calculation of travel time in Equation 1, recall the average travel time of all trips traversing the network from origin o to destination d starting in time interval τ using mode m under operational condition k , $T^k_{o,d,\tau,m}$

Using zero-delay thresholds $T^{0}_{o,d,\tau,m}$, calculate average trip delay under condition k for each o,d,τ,m:

$$D^{k}_{o,d,\tau,m} = max\left[T^{k}_{o,d,\tau,m} - T^{0}_{o,d,\tau,m}, 0\right] \tag{7}$$

Combining across all operational conditions, calculate the average delay for each o,d,τ,m over $K'_{o,d,\tau,m}$, the subset of conditions where $n^{k}_{o,d,\tau,m} > 0$.

$$D_{o,d,\tau,m} = \frac{\sum_{k \in K'_{o,d,\tau,m}} D^{k}_{o,d,\tau,m} p_k}{\sum_{k \in K'_{o,d,\tau,m}} p_k} \tag{7a}$$

Combining across modes, the average delay for trips from o to d starting in interval τ:

$$D_{o,d,\tau} = \frac{\sum_{m} D_{o,d,\tau,m}\, n_{o,d,\tau,m}}{n_{o,d,\tau}} \tag{8}$$

where $n_{o,d,\tau} > 0$. Let $D_{o,d,\tau} = 0$ when $n_{o,d,\tau} = 0$.

Systemwide average trip delay (Equation 9):

$$D = \frac{\sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \tag{9}$$

Aggregating this average delay over all trips produces total system delay (Equation 10):

$$\hat{D} = \sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau} \tag{10}$$

Travel Time Reliability

Corridor reliability measures are inherently measures of outlier travel times experienced by a traveler making the same (or similar) trip over many days and operational conditions. We have already defined and organized travel time measures from the simulation with respect to trips from o to d starting in interval τ over using mode m for all conditions $k \in K$. Just as in the case of the subjective notion of delay as travel time in excess of some minimum threshold, the notion of what reliable travel is depends on a *relative maximum* acceptable travel time threshold. For the ICM AMS effort, as in many studies with a travel reliability measure, a threshold based on the 95th percentile travel time is selected. Note that this percentile is calculated considering travel times for similar trips (i.e., o,d,τ,m) with respect to travel time variation induced by changes in operational conditions $k \in K$.

To identify the 95th percentile travel time, first we generate an ordered list of travel times for each o, d, τ, m across all operating conditions:

$$\mathrm{T}_{o,d,\tau,m} = \left[T^{1}_{o,d,\tau,m}, T^{2}_{o,d,\tau,m}, \cdots, T^{J}_{o,d,\tau,m}\right] \tag{11}$$

where $T^{j}_{o,d,\tau,m} \le T^{j+1}_{o,d,\tau,m}$ for all $j = 1 \cdots J$.

The 95th percentile travel time from this list is identified using the probabilities associated with each operational condition.

$$T^{[95]}_{o,d,\tau,m} = T^{j}_{o,d,\tau,m} \tag{11a}$$

where $\sum_{k=1}^{j} p_k = 0.95$.

Note the array of travel times $\mathbf{T}_{o,d,\tau,m}$ represents levels on a linear step-function. This implies that if 17.4 minutes is the travel time associated with an operational condition occupying the 92nd through 98th travel time percentile, we simply use the 17.4-minute travel time as the 95th percentile value. Also note that the specific operational conditions under which the 95th percentile travel time is found will vary among o, d, τ, m . For example, a major freeway incident creates congestion and high travel times for trips that originate upstream of the incident location, but creates free-flowing and uncongested conditions for trips that originate downstream of the incident location.

Equation 12 defines planning time index for each o, d, τ, m , the ratio of the 95th percentile travel time to the zero-delay travel time for trips from o to d starting in interval τ using mode m over all conditions $k \in K$:

$$\rho_{o,d,\tau,m} = \frac{T^{[95]}_{o,d,\tau,m}}{T^{0}_{o,d,\tau,m}} \tag{12}$$

Equation 12a defines planning time index by o, d, τ across all modes:

$$\rho_{o,d,\tau} = \frac{\sum_{m} \rho_{o,d,\tau,m}\, n_{o,d,\tau,m}}{n_{o,d,\tau}} \tag{12a}$$

Average systemwide planning time index considers all o,d,τ, weighted average by trip volume:

$$\rho = \frac{\sum_{\forall o,d,\tau} \rho_{o,d,\tau}\, n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \tag{13}$$

We may also be interested in trip-weighted planning time index within a mode across all o,d,τ:

$$\rho_m = \frac{\sum_{\forall o,d,\tau} \rho_{o,d,\tau}\, n_{o,d,\tau,m}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \tag{13a}$$

Variance in Travel Time

Variance in travel time can be calculated in a variety of ways. The key here is that some care must be taken to isolate the specific variation of interest. Additionally, as variance is strongly influenced by outliers, in order to eliminate any potential bias introduced into the variance of travel times resulting from the estimation of a fulfilled travel time for incomplete travelers at the end of the simulation period, the variance calculation should be restricted to completed travelers defined as set $\ddot{\mathbf{I}}^k_{o,d,\tau}$ consisting of $\ddot{n}^k_{o,d,\tau}$ trips. While the inclusion of the fulfilled incomplete travelers' travel times in the other performance measures may be influenced by the same bias, the nature of the variance calculation magnifies the effects of that potential bias. This effect may be more significant in larger models where the calibration and validation efforts must be focused on the primary corridor or study area.

Given this, the variance in travel time among members of the same origin, destination, and time interval in a single run is:

$$V^k_{o,d,\tau} = \frac{\sum_{i \in \ddot{\mathbf{I}}^k_{o,d,\tau}} \left(\ddot{t}^k_i - \ddot{T}^k_{o,d,\tau} \right)^2}{\ddot{n}^k_{o,d,\tau} - 1} \tag{14}$$

Recall $K'_{o,d,\tau}$, $K'_{o,d,\tau} \subseteq K$ as the subset of conditions where $\ddot{n}^k_{o,d,\tau} > 0$. The variance of travel time for each o,d,τ under all operation conditions is then defined as:

$$V_{o,d,\tau} = \frac{\sum_{k \in K'_{o,d,\tau}} V^k_{o,d,\tau}\, p_k}{\sum_{k \in K'_{o,d,\tau}} p_k} \tag{14a}$$

The average variance among all o, d, τ is a weighted average of the variances:

$$V = \frac{\sum_{\forall o,d,\tau} V_{o,d,\tau}\, \ddot{n}_{o,d,\tau}}{\sum_{\forall o,d,\tau} \ddot{n}_{o,d,\tau}} \tag{14b}$$

Throughput

The role of a throughput measure in ICM is to capture the primary product of the transportation system: travel. Particularly in peak periods, the capability of the transportation infrastructure to operate at a high level of efficiency is reduced. One of the goals of ICM is to manage the various networks (freeway, arterial, transit) cooperatively to deliver a higher level of realized system capacity in peak periods. While throughput (e.g., vehicles per lane per hour) is a well-established traffic engineering point measure (that is, in a single location), there is no consensus on a systemwide analog measure. In the ICM AMS effort, we use the term *corridor throughput* to describe a class of measures used to characterize the capability of the integrated transportation system to efficiently and effectively transport travelers. We do not consider freight throughput in these calculations, although this could be revisited at a later date.

In order to support throughput measures, additional trip data need to be generated as simulation outputs. For each trip i made between an origin o, finishing at a destination d, starting at a particular time τ' we obtain from the simulation the travel time $t^k_{o,d,\tau'}$ and a distance traveled $s^k_{o,d,\tau'}$. In some cases, trip-level outputs from the simulation are only available at a vehicle level, so some trips may have multiple passengers associated with that trip (e.g., in the case of carpool travel). Let $x^k_{o,d,\tau'}$ represent the number of travelers associated with a particular trip record.

Passenger-miles traveled (PMT) are accumulated using a process similar to travel time. First, we convert individual trip PMT into an average PMT for trips from origin o to destination d with a trip start in time interval τ.

$$X^k_{o,d,\tau} = \frac{\sum_{i \in I^k_{o,d,\tau}} s^k_i x^k_i}{n^k_{o,d,\tau}} \tag{15}$$

For trips that cannot be completed before the end of the simulation, see the following section for the estimation of total trip distance.

Equation 16 finds the average PMT for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$X_{o,d,\tau} = \sum_{k \in K} X^k_{o,d,\tau} p_k \tag{16}$$

Equation 17 defines the aggregate PMT across all o,d,τ :

$$X = \sum_{\forall o,d,\tau} X_{o,d,\tau}\, n_{o,d,\tau} \tag{17}$$

Passenger-miles delivered (PMD) and Passenger-trips delivered (PTD) are measures that introduce notions of travel quality into throughput. Simple PMT measures often cannot differentiate between a well-managed system and a poorly managed system because passenger-trip distances are counted equally regardless of trip duration. In other words, a five-mile trip completed in 15 minutes counts equally with the same five-mile trip completed in two hours. Here, we restrict the accounting of passenger-miles traveled (or passenger-trips delivered) to trips that successfully complete their trips prior to the end of the simulation (or some other logical time-point). Let $\dot{\mathbf{I}}^k_{o,d,\tau}$ be the set of $\dot{n}^k_{o,d,\tau}$ trips from o to d starting in interval τ under operational condition k that complete their trip before the simulation ends (or some other logical time-cutoff).

Equation 18 shows passenger-trips delivered (PTD) calculated at the o,d,τ level.

$$Y^k_{o,d,\tau} = \frac{\sum_{i \in \dot{\mathbf{I}}^k_{o,d,\tau}} x^k_i}{\dot{n}^k_{o,d,\tau}} \tag{18}$$

Equation 19 finds the average PTD for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$Y_{o,d,\tau} = \sum_{k \in K} Y^k_{o,d,\tau}\, p_k \tag{19}$$

Equation 19b finds the average number of completed trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$\dot{n}_{o,d,\tau} = \sum_{k \in K} \dot{n}^k{}_{o,d,\tau}\, p_k \tag{19b}$$

Equation 20 defines the aggregate PTD across all o,d,τ :

$$Y = \sum_{\forall o,d,\tau} Y_{o,d,\tau}\, \dot{n}_{o,d,\tau} \tag{20}$$

Passenger-miles delivered (PMD) is a distance-weighted measure of throughput based on PTD:

$$Z^k_{o,d,\tau} = \frac{\sum_{i \in \dot{\mathbf{I}}^k_{o,d,\tau}} s^k_i x^k_i}{\dot{n}^k_{o,d,\tau}} \tag{21}$$

Equation 22 finds the average PMD for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$Z_{o,d,\tau} = \sum_{k \in K} Z^k_{o,d,\tau} p_k \qquad (22)$$

Equation 23 defines the aggregate PMD across all o, d, τ :

$$Z = \sum_{\forall o,d,\tau} Z_{o,d,\tau} \, \dot{n}_{o,d,\tau} \qquad (23)$$

For example, in the Dallas ICM Corridor, the simulation period is from 5:30 AM to 11:00 AM, while the peak hours are from 6:30 AM to 9:00 AM. It is anticipated that with or without an ICM strategy in place, all trips that begin in the peak period should be completed before the simulation ends at 11:00 AM. In this case, there may be little difference in PMT or PMD when 11:00 AM is used as the logical time cutoff. In order to measure the peak capability of the system to deliver trips, the set of trips counting towards PMD could potentially be restricted to those trips that can both begin and complete their trips in the peak period (6:30-9:00 AM). At this point, it is premature to define a specific time cut-off for PMD to be applied in all three sites.

Restricting the calculation of measures to selected cohorts is also relevant to the calculation of delay and travel time reliability measures. Although peak periods vary among the AMS sites in terms of the onset and duration of congestion, a consistent set of trips that contribute to measure calculation (others simply run interference) should be identified. As in the case of the throughput time cut-off point, U.S. DOT may wish to prescribe specific times in the future.

At this time, it is unclear whether PMT, PMD, or PTD will be the selected performance measure for corridor throughput, pending clarification that all ICM models can support these measures.

Estimation of Travel Times and Travel Distance for Incomplete Trips

Trips that cannot complete their trips by the time that the simulation ends are still included in the calculation of all delay and travel time calculations. Our approach is to estimate total travel time including any additional time that would be required to complete the trip given the average speed of travel.

First, let $\ddot{\mathbf{I}}^0_{o,d,\tau}$ be the set of $\ddot{n}^0_{o,d,\tau}$ trips from origin o , destination d starting a trip in time interval τ that can be completed under the low-demand operational condition used to identify the zero-delay travel times.

The average distance traveled over these trips is:

$$\ddot{X}^0_{o,d,\tau} = \frac{\sum_{i \in \ddot{\mathbf{I}}^0_{o,d,\tau}} s_i}{\ddot{n}^0_{o,d,\tau}} \qquad (24)$$

Note: If $\ddot{n}^{0}_{o,d,\tau} = 0$ then $\ddot{X}^{0}_{o,d,\tau}$ is indeterminate. In this case, find τ', the closest time interval such that $\underset{\tau'}{\arg\min} |\tau' - \tau|$ where $n^{0}_{o,d,\tau'} > 0$. Approximate $\ddot{X}^{0}_{o,d,\tau}$ using $\ddot{X}^{0}_{o,d,\tau'}$.

Next, let $\overleftarrow{\mathbf{I}}^{k}_{o,d,\tau}$ be the set trips from origin o, destination d starting a trip in time interval τ that *cannot* be completed under operational condition k. For all $i \in \overleftarrow{\mathbf{I}}^{k}_{o,d,\tau}$, let $\overleftarrow{x}^{k}_{i}$ be the distance traveled on the trip i up to the point where the simulation ends, and let $\overleftarrow{t}^{k}_{i}$ the travel time on trip i up to the point where the simulation ends. Average travel speed for a trip that cannot be completed is expressed in Equation 25:

$$\overleftarrow{v}^{k}_{i} = \frac{\overleftarrow{x}^{k}_{i}}{\overleftarrow{t}^{k}_{i}} \tag{25}$$

Estimated total trip travel time for a trip that cannot be completed before the simulation ends is the accumulated travel time plus the time to travel the remaining distance at average trip speed:

$$t^{k}_{i} = \overleftarrow{t}^{k}_{i} + max\left\{\frac{\left(\ddot{X}^{0}_{o,d,\tau} - \overleftarrow{x}^{k}_{i}\right)}{\overleftarrow{v}^{k}_{i}}, 0\right\} \tag{26}$$

$$x^{k}_{i} = max\left\{\ddot{X}^{0}_{o,d,\tau}, \overleftarrow{x}^{k}_{i}\right\} \tag{27}$$

Comparing Pre-ICM and Post-ICM Cases

All of the travel time and throughput measure calculation procedures defined above are conducted under a single set of simulation settings reflecting a specific set of corridor management policies, technologies and strategies (here referred to as a *case*, but often called an *alternative*). The complete suite of delay, travel time reliability and throughput measures are calculated independently for each case (e.g., Pre-ICM). Comparisons of the resulting measures are then made to characterize corridor performance under each case.

Comparing Observed and Simulated Performance Measures

These few key measures have been defined in detail for national consistency across all AMS sites. Sites have also identified measures. This document has dealt in detail with the calculation of measures from simulation outputs. However, the calculation of comparable measures using observed data demands an equivalent level of detailed attention. These observed measures will be critical in the AMS effort to validate modeling accuracy and in performance measurement in the demonstration phase. Because of the nature of the simulation output, the modeling analyst is able to resolve and track performance at a level of detail that is not available to an analyst working with field counts, speeds and transit passenger-counter outputs. However, it is the responsibility of the site and the AMS contractor to ensure that these measures are similar in intent, if not in precise calculation. In many cases, the simulation tools or their basic outputs can be manipulated to produce measures quite comparable with field data. An example of this is in throughput calculation, where a site may wish to pursue a screenline passenger throughput measure from field data. In addition to the system-level throughput measures detailed above, the simulation model can be configured to produce passenger-weighted counts across the same screenline to match the field throughput measure.

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ANNEX 3.
Integrated Corridor Management

Analysis, Modeling, and Simulation Results for the I-15 Corridor in San Diego, California

www.its.dot.gov/index.htm
Final Report – November 2010

U.S. Department of Transportation
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15. Supplementary Notes

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16. Abstract

The objective of the Integrated Corridor Management (ICM) initiative is to demonstrate how Intelligent Transportation Systems (ITS) technologies can efficiently and proactively manage the movement of people and goods in major transportation corridors. The ICM initiative aims to pioneer innovative multimodal and multi-jurisdictional strategies – and combinations of strategies – that optimize existing infrastructure to help manage congestion in our nation's corridors. There are many corridors in the country with under-utilized capacity (in the form of parallel transit capacity (bus, rail, Bus Rapid Transit (BRT), etc.) and/or arterials and under-utilized travel lanes) that could benefit from ICM.

The maturation of ITS technologies, availability of supporting data, and emerging multi-agency institutional frameworks make ICM practical and feasible. There are a large number of freeway, arterial, and transit optimization strategies available today and in widespread use across the U.S. Most of these strategies are managed locally by individual agencies on an asset-by-asset basis. Even those managed regionally are often managed in a stove-piped manner (asset-by-asset) rather than in an integrated fashion across a transportation corridor. Dynamically applying these strategies in combination across a corridor in response to varying conditions is expected to reduce congestion "hot spots" in the system and improve the overall productivity of the system. Furthermore, providing travelers with actionable information on alternatives (such as mode shift, time of travel shift, and/or route shift) is expected to mitigate bottlenecks, reduce congestion, and empower travelers to make more informed travel choices.

17. Key Words	18. Distribution Statement
Integrated corridor management, transit, simulation, optimization strategies, congestion, San Diego, bottlenecks traveler information, incidents	No Restrictions.

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Executive Summary

This report documents the analysis methodologies, tools and performance measures used to analyze Integrated Corridor Management (ICM) strategies for the I-15 Corridor, and presents high-level results and lessons-learned for the successful implementation of ICM. The I-15 Corridor is an 8-10-lane freeway, providing an important connection between San Diego, California and destinations to the northeast. The Corridor study area consists of the freeway including managed/HOT lanes and general purpose lanes, frontage roads, Bus Rapid Transit, park-and-ride lots, and regional arterial streets.

The analysis investigated various operating conditions on the I-15 Corridor including high, medium, and low travel demand, daily operations, and freeway and arterial incidents. ICM strategies analyzed include pre-trip and en-route traveler information, mode shift to transit, freeway ramp metering, signal coordination on arterials with freeway ramp metering, physical bus priority, and congestion pricing on managed lanes.

The I-15 Corridor AMS results show significant benefits, resulting from the deployment of ICM strategies:

- Overall, deployment of ICM on the I-15 Corridor produces $13.7 million in user benefits per year. Over the 10-year life cycle of the ICM systems, benefits produced a total benefit of **$115.9 million**.
- Costs to deploy ICM on the I-15 Corridor are estimated to be $1.42 million annualized over the 10-year life cycle of the project. The total life-cycle cost to deploy the ICM system is estimated at **$12.0 million**.
- The estimated benefit/cost ratio for the ICM deployment over the 10 life cycle of the project is approximated at **9.7:1**.
- The benefits from ICM are attributable to reduced travel times, improved travel time reliability, reduced fuel consumption, and reduced mobile emissions. Expected annual savings include 245,594 hours of vehicle-hours of travel, a reduction of fuel consumption by 322,767 gallons of fuel, and an annual reduction of 3,057 tons of vehicular emissions.
- Across all operational conditions, most of the ICM benefit is attributed to the travel time, travel time reliability, and fuel savings on the southbound freeway and arterials. With the provision of improved traveler information, more arterial travelers are attracted to the freeway thus improving arterial performance and overall system performance.
- Managed lanes show some disbenefits as a result of opening these lanes to all traffic during major freeway incidents. However, vehicles using the open managed lane are not in the adjacent general purpose lane and arterials, thus improving overall corridor performance. Arterials show a considerable amount of travel time and travel time reliability benefits owing mostly to arterial signal optimization.
- An important finding of this analysis is that ICM strategies produce more benefits at higher levels of travel demand, and during non-recurrent congestion. Approximately

93 percent of the total ICM benefits result from the high- and medium-demand scenarios (representing 69 percent of commute days). Also, two-thirds of the total benefit is attributed to high- and medium-demand scenarios with an incident. For individual travelers who primarily rely on the I-15 southbound facility the majority of benefits accrues under particular operational conditions associated with high travel demand and incidents. This finding validates the hypothesis that ICM is most effective under the worst operational conditions including heavy-demand and major incidents.

- Other corridor-wide travelers see smoothed benefit over most travel days as the system reacts more intelligently and more rapidly to variations in congestion conditions. These travelers experience small benefits accrued over many days rather than on particular days. Benefits from ICM are related to a ripple effect from better addressing the impacts of major disruptions. Benefits that accrue from multiple, distant ripples are smoothed over travel time, reliability and fuel consumption. Those that are close to the source of disruption experience more reliability benefits.
- Transit excess capacity is better utilized overall, and particularly under incident conditions, drawing additional travelers to the BRT facility without overwhelming the BRT.
- The I-15 corridor AMS validates the ICM concept: dynamically applying ICM strategies in combination across a corridor is shown to reduce congestion and improve the overall productivity of the transportation system.

This analysis offers the following benefits:

- **Invest in the right strategies.** The analysis offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions.
- **Invest with confidence.** The analysis allows corridor managers to “see around the corner” and discover optimum combinations of strategies, as well as conflicts or unintended consequences that would otherwise be unknowable before implementation. For example, the I-15 AMS helped identify a potential unintended consequence resulting from opening the managed lanes to all traffic during major incidents on the freeway; this policy would have resulted in Bus Rapid Transit (BRT) losing mode share because the managed lanes would be slower than before thus providing less incentive to travelers to shift to BRT. A policy solution tested and proven beneficial in the model involves making BRT free during major incidents.
- **Improve the effectiveness/success of implementation.** With this analysis, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.
- The analysis provides a long-term capability to corridor managers to **continually improve implementation** of ICM strategies based on experience.

Chapter 1 Introduction and Background

The objective of the ***Integrated Corridor Management (ICM)*** initiative is to demonstrate how Intelligent Transportation Systems (ITS) technologies can efficiently and proactively manage the movement of people and goods in major transportation corridors. The ICM initiative aims to pioneer innovative multimodal and multi-jurisdictional strategies – and combinations of strategies – that optimize existing infrastructure to help manage congestion in our nation's corridors. There are many corridors in the country with under-utilized capacity (in the form of parallel transit capacity (bus, rail, Bus Rapid Transit (BRT), etc.) and/or arterials and under-utilized travel lanes) that could benefit from ICM.

The maturation of ITS technologies, availability of supporting data, and emerging multi-agency institutional frameworks make ICM practical and feasible. There are a large number of freeway, arterial, and transit optimization strategies available today and in widespread use across the U.S. Most of these strategies are managed locally by individual agencies on an asset-by-asset basis. Even those managed regionally are often managed in a stove-piped manner (asset-by-asset) rather than in an integrated fashion across a transportation corridor. Dynamically applying these strategies in combination across a corridor in response to varying conditions is expected to reduce congestion "hot spots" in the system and improve the overall productivity of the system. Furthermore, providing travelers with actionable information on alternatives (such as mode shift, time of travel shift, and/or route shift) is expected to mitigate bottlenecks, reduce congestion, and empower travelers to make more informed travel choices.

The objectives of the ***"ICM – Tools, Strategies and Deployment Support"*** project are to refine Analysis Modeling and Simulation (AMS) tools and strategies, assess Pioneer Site data capabilities, conduct AMS for three Stage 2 ICM Pioneer Sites, and conduct AMS tools post-demonstration evaluations. Current efforts under this project focus on analyzing the ICM systems proposed by the Stage 2 Pioneer AMS Sites and evaluating the expected benefits to be derived from implementing those ICM systems.

The overall benefits of this effort include:

- Help decision-makers identify gaps, evaluate ICM strategies, and invest in the best combination of strategies that would minimize congestion; comprehensive modeling increases the likelihood of ICM success, and helps minimize unintended consequences of applying ICM strategies to a corridor.
- Help estimate the benefit resulting from ICM across different transportation modes and traffic control systems; without being able to predict the effects of ICM strategies corridor transportation agencies may not take the risk of making the institutional and operational changes needed to optimize corridor operations.

- Transfer knowledge about analysis methodologies, tools, and possible benefits of ICM strategies to the Pioneer Sites and to the entire transportation community.

This ***Analysis Simulation and Modeling Results for the I-15 Corridor in San Diego, California Report*** documents the ICM AMS tools and strategies for the I-15 Corridor, presents high-level AMS results for the Corridor and lessons-learned, and documents the benefit-cost assessment for the successful implementation of ICM.

The remainder of this document is organized as follows:

- **Chapter 2.0** provides a brief description of the I-15 Corridor in San Diego, California, and the methodology used for the AMS;
- **Chapter 3.0** lays out ICM strategies that will be tested and provides a list of the AMS scenarios;
- **Chapter 4.0** defines performance measures that will be utilized in the analysis of the ICM strategies on the Pioneer Corridor;
- **Chapter 5.0** summarizes the simulation model calibration approach, methodology, and results;
- **Chapter 6.0** presents the results and benefit-cost analysis of the future alternatives tested as part of the AMS effort for the I-15 corridor;
- **Appendix A** presents a summary of the ICM strategies for the I-15 corridor in San Diego;
- **Appendix B** presents the Performance Measure calculation procedures from the simulation output for the San Diego I-15 corridor;
- **Appendix C** presents the methodology employed for simulating en-route mode shift to transit in the San Diego I-15 corridor; and
- **Appendix D** presents the methodology employed for simulating congestion based dynamic pricing of the managed lanes in the San Diego I-15 corridor.

Chapter 2 I-15 Corridor Site and AMS Methodology

The Pioneer Site identified for this analysis is the Interstate 15 corridor in San Diego, California. The corridor extends from the interchange with State Road (SR) 163 in the south to the interchange with SR 78 in the north, a freeway stretch of approximately 20 miles. Also included in the study area are the following roadways:

- Centre City Parkway;
- Pomerado Road;
- Rancho Bernardo Road;
- Camino Del Norte Road;
- Ted Williams Parkway;
- Black Mountain Road; and
- Scripps Parkway.

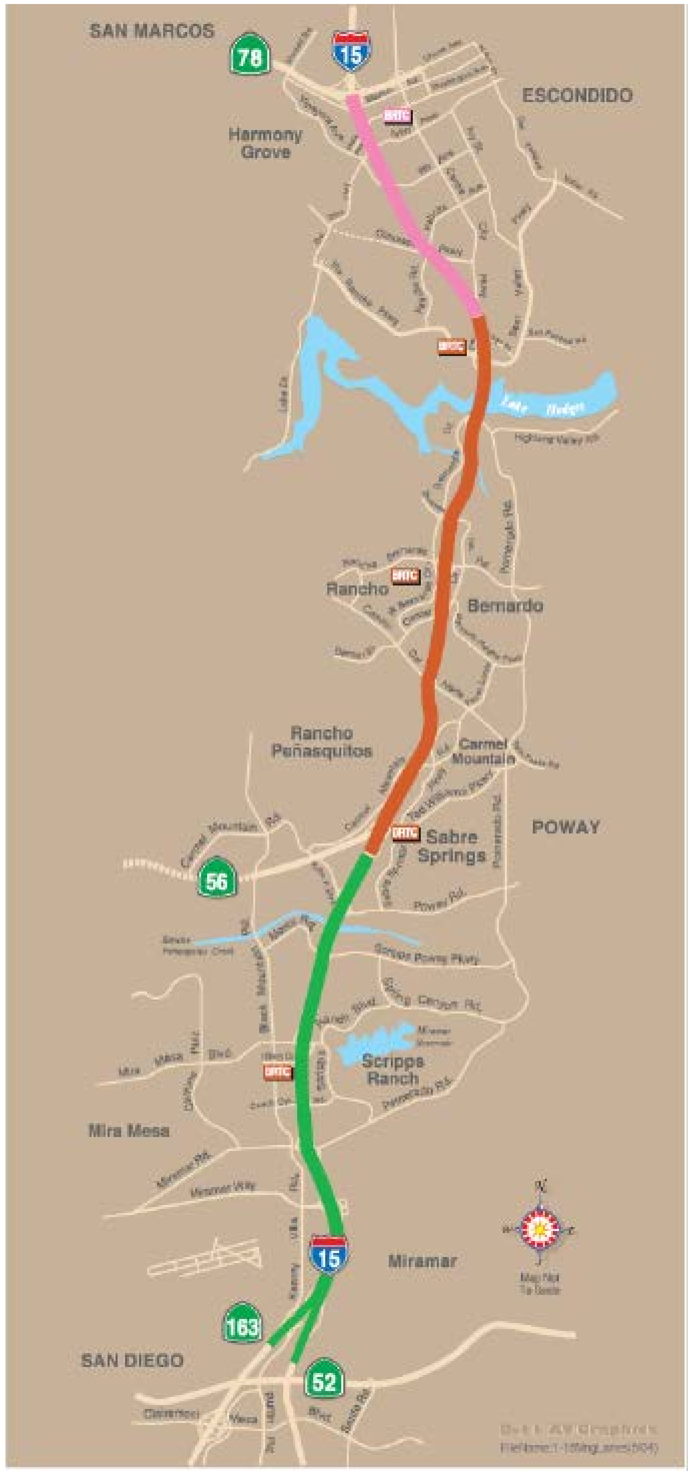
Figure 2-1 illustrates the study area routes utilized for analysis at this Pioneer Site. The I-15 corridor will be utilized as a test bed for various ITS strategies identified in consultation with the San Diego Association of Governments (SANDAG) and other local stakeholders. These strategies are defined in the Concept of Operations report for the I-15 Corridor, and explained in Chapter 3 of this document.[1] The following sections provide a detailed overview of the study corridor and describe the process for the ICM analysis.

I-15 Corridor Description

Figure 2-1 illustrates the Pioneer Corridor and the roadways included in the study area. I-15 is an 8- to 10-lane freeway section in San Diego providing an important connection between San Diego and cities like Poway, Mira Mesa, and Escondido, and destinations to the northeast. Figure 2-2 indicates the geographic location of the corridor along with the extents of the mainline study area.

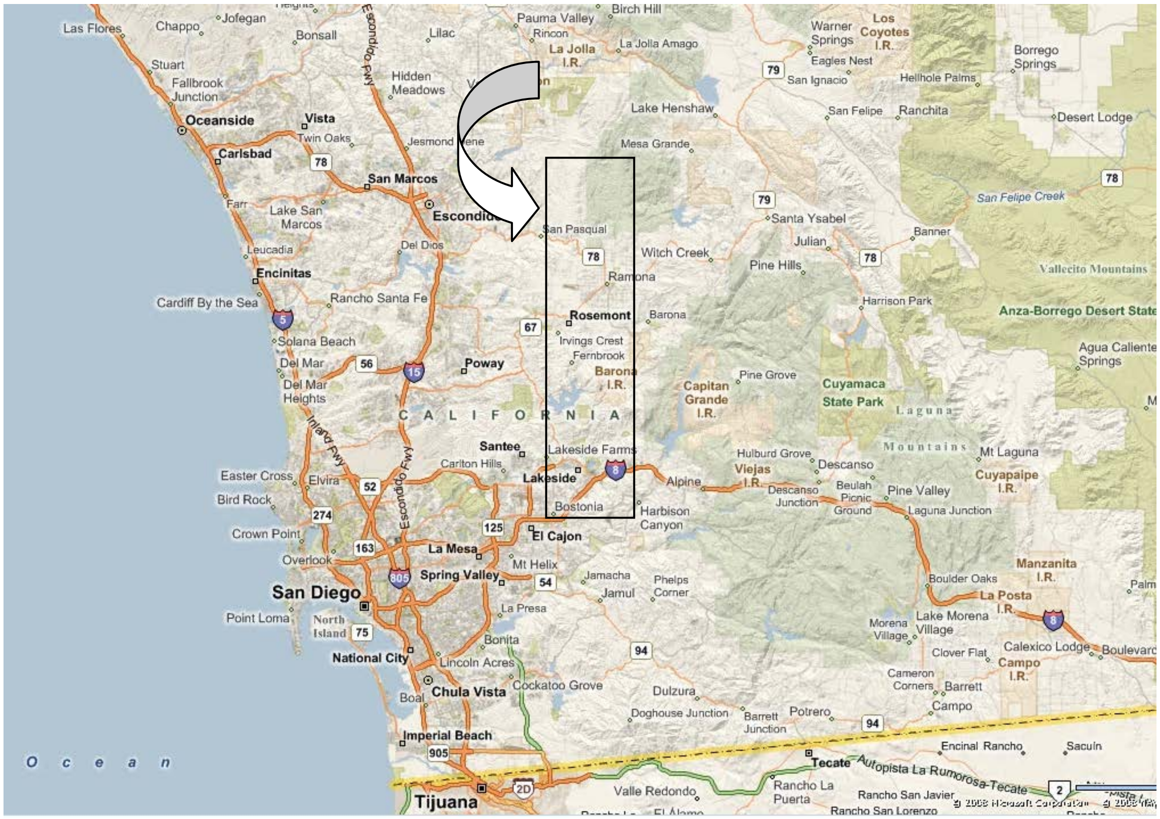
[1] Source: Concept of Operations for the I-15 Corridor in San Diego, California, March 2008, FHWA-JPO-08-009, EDL Number 14395

Figure 2-1. Study Area – I-15 Corridor in San Diego, California



Source: SANDAG: AV Graphics, September 2009.

Figure 2-2. Location and Geographic Boundaries of Corridor



Source: Microsoft© Corporation NAVTEC©, September 2009.

The current operations on I-15 include two center-median lanes that run along eight miles of I-15 between SR 163 in south and Ted William Pkwy (SR 56) in the north. These center-median lanes are reversible High-Occupancy Vehicle (HOV) lanes that operate in the southbound direction in the AM peak period and in the northbound direction during the PM peak period. The current operations also allow Single Occupancy Vehicles (SOV) to utilize the roadway for a price, thereby operating as High-Occupancy Toll (HOT) lanes.

The section between SR 78 and SR 163 (study area) will eventually include four center median lanes, which will have two lanes in each direction operating as HOT lanes in the peak direction. Current weekday traffic volumes range from 170,000 to 290,000 vehicles on the general purpose lanes of I-15; and approximately 20,000 vehicles use the I-15 Express Lanes during weekdays. The I-15 corridor is one of three primary north-south transportation corridors in San Diego County, and is the primary north-south highway in inland San Diego County, serving local, regional, and interregional travel. The corridor is a heavily-utilized regional commuter route, connecting communities in northern San Diego County with major regional employment centers. The corridor is situated within a major interregional goods movement corridor, connecting Mexico with Riverside and San Bernardino counties, as well as Las Vegas, Nevada.

Modeling Approach

The modeling approach that emerged from the analysis of capabilities found in existing AMS tools as well as from the ICM Test Corridor project, was an ***integrated platform that can support corridor management planning, design, and operations by combining the capabilities of existing tools.*** The overall integrated approach is based on ***interfacing travel demand models, mesoscopic simulation models, and microscopic simulation models***. The ICM AMS approach encompasses tools with different traffic analysis resolutions. All three classes of simulation modeling approaches – macroscopic, mesoscopic, and microscopic – may be applied for evaluating ICM strategies.

Within the I-15 corridor, the AMS methodology applied includes the macroscopic trip table manipulation for the determination of overall trip patterns and mesoscopic analysis of the impact of driver behavior in reaction to ICM strategies (both within and between modes) and a microscopic analysis of the impact of traffic control strategies at roadway junctions (such as arterial intersections or freeway interchanges.) The methodology also includes the development of interfaces between different tools, and the application of a performance measurement and benefit/cost module.

In this AMS framework, macroscopic, mesoscopic, and microscopic traffic analysis tools interface with each other, passing trip tables and travel times back and forth looking for natural stability within the system. Absolute convergence may not be achieved because of inherent differences at the various modeling levels. This methodology seeks a natural state for practical convergence between different models, and the iterative process is terminated or truncated at a point where reasonable convergence is achieved. This iterative process includes the use of mode shift, Time of Day shift, and dynamic traffic assignment.

In order to estimate the full benefits of the ICM strategies for the I-15 Corridor, the simulation period for the microscopic model encompassed not only the time that it took to reopen the lane(s) after an incident (incident clearance time), but the time that it took to return to normal operations. Based on a cluster analysis, the time of day with the highest probability for an incident to occur and the average time it took to return to normal operating conditions were assessed. As such, a simulation period was used covering the hours of 6:00 AM to 11:00 AM. It also was determined that the AM peak would allow the testing of a greater number of strategies than the PM peak, including strategies that support mode shift.

The following paragraphs provide an overview of the various modeling components utilized in the AMS modeling framework for the I-15 Corridor. Additional details are available in the separate report titled *AMS Analysis Plan for the I-15 Corridor in San Diego, California*.

Travel Demand Forecasting Model

Predicting travel demand requires specific analytical capabilities, such as the consideration of destination choice, mode choice, time-of-day travel choice, and route choice, as well as the representation of traffic flow in the highway network. These attributes are found in the structure and orientation of travel demand models, which serve as mathematical models that forecast future travel demand from current conditions and future projections of household and employment characteristics. SANDAG's Travel Demand Model (TDM) for the region was used to develop the trip tables and networks for the I-15 Corridor. Subarea trip tables and networks were developed from the TDM – for use in the simulation models. Parameters from the TDM also were used to analyze mode shifts in response to congestion and to ICM strategies.

Microscopic Simulation Model

Microscopic simulation models simulate the movement of individual vehicles, based on theories of car-following and lane-changing. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process) and are tracked through the network over small time intervals (e.g., one second or fraction of a second.) Typically, upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. In many microscopic simulation models, the traffic operational characteristics of each vehicle are influenced by vertical grade, horizontal curvature, and superelevation, based on relationships developed in prior research. The primary means of calibrating and validating microscopic simulation models is through the adjustment of driver sensitivity factors.

For the analysis of this corridor the microscopic component of TransModeler was utilized. The microsimulation model supports the evaluation of traffic control aspects of ICM strategies, such as freeway ramp metering and arterial traffic signal coordination, as well as managed-lane operations. At any time the route choice model can be reevaluated in order to update the path choices of drivers en route to their destinations. This model was used to evaluate the response of drivers to incident situations when they are faced with high levels of congestion. When a driver's path choice is reevaluated, the path costs (e.g., segment travel times) are reconsidered. For driver groups defined in the model parameters as having access to real time travel information (i.e., informed drivers), an updated travel time table can be used to evaluate path costs. Drivers belonging to a driver group that does not have access to real time information reconsider their paths using the same (i.e., historical) travel time information used to evaluate their pre-trip paths.

In addition, the microsimulation model was used to evaluate the nature of temporal mitigation decisions that need to be taken in response to congestion. The micro-simulation model operates by simulating all the key system components such as traffic signals, ramp meters, speed limits, and transit vehicles, so it can be utilized to identify and test different congestion hotspots.

For the analysis, Static User Equilibrium (SUE) was utilized for calibration and validation of the base year model. The use of SUE is also consistent with the utilization of managed use lane scripts, which utilize the cost of different paths with a logit-based route choice model, to assign en-route mode and route choice.

Time-of-Departure Choice

The methodology used in the I-15 AMS assumes that the level of congestion along the shortest path between any Origin-Destination (O-D) pair affects the degree of peak spreading that is likely to occur for that O-D pair. This methodology is based on a set of temporal distributions that vary by the ratio of the Average Daily Traffic to hourly Capacity (ADT/C). It has the effect of moving demand from peak hours to off-peak hours as congestion increases, which becomes especially important as future year traffic volumes grow. The shift in demand from peak hours to off-peak hours is directly proportional to the level of congestion on the route thereby simulating an effective change in the departure choice of the drivers. The Time-of-Departure (TOD) choice was implemented for the base year model and calibrated based on the 24-hour trip tables from the regional travel demand model. The future year utilized year 2012 future volumes and a TOD adjustment based on the ADT/C ratios in the future networks. The future number of trips in the O-D matrix is kept constant for all alternatives analyzed.

The main input to simulation models in travel demand is in the form of O-D tables. Ideally, these O-D tables come from regional travel demand models and represent travel demand in small time increments, usually 15-minute slices, to support the dynamic traffic assignment process.

Unfortunately, most regional travel demand models, including SANDAG's, are calibrated and validated to much longer time periods and are estimated by applying regional factors to every O-D pair based on observations from a travel survey. These same factors are usually applied to future year forecasts as well. This approach therefore assumes that the temporal distribution of trips is constant by geography, regardless of the location and longevity of congestion.

The employed methodology for the I-15 AMS assumes a different temporal distribution for every O-D pair and is related to the level of congestion between each O-D pair. For O-D pairs that experience little or no congestion, no peak spreading occurs. For O-D pairs that experience high congestion levels, significant peak spreading occurs and continues to spread as congestion increases over time. In other words, the level of temporal redistribution is sensitive to changes in demand over time or in response to changes in supply.

The estimation of hourly demand is sensitive to changes in supply and/or demand assuming that the amount of temporal spreading that is likely to occur between any O-D pair is based on the level of congestion that is present along the shortest path between that particular O-D pair. A set of temporal distributions were developed by Margiotta[2] et al. that vary based on the level of congestion, as measured by the daily volume to hourly capacity ratio (ADT/C). These distributions were developed as a mechanistic way of moving demand from one time period to another as the level of congestion changes. Table 2-1 shows the initial average weekday temporal distributions by two-way ADT/C. It was determined that direct application of these distributions could lead to illogical results if ADT/C values are at the boundary (e.g., ADT/C = 11). Therefore, a smoothing procedure was developed to account for these boundary problems and provide distributions for ADT/C ratios above 13. Finally, different sets of curves were developed[3] for each trip purpose as the temporal distribution varies by trip type. For example, home-based work trips have a temporal distribution that is quite different from a home-based shopping trip.

For the I-15 AMS, these temporal distributions were refined to represent local conditions in the San Diego region by applying the models for the base year, summing the hourly trips to the peak period, and comparing to the SANDAG travel model's peak-period trip totals for each trip purpose. Additionally, the process being utilized to calibrate the base year travel demand, Origin Destination Matrix Estimation (ODME), further refines the O-D tables to local conditions.

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[2] Margiotta, R., H. Cohen, and P. DeCorla-Souza, *Speed and Delay Prediction Models for Planning Applications*, Sixth National Conference on Transportation Planning for Small and Medium-Sized Communities, Spokane, Washington, 1999.

[3] Simons, C., I-285 Matrix Variegator: Practical Method for Developing Trip Tables for Simulation Modeling from Travel Demand Modeling Inputs, Transportation Research Board, Journal Article, Volume 1961, Washington, D.C., 2006.

Table 2-1. Initial Weekday Temporal Distribution by Two-Way ADT/C

Hour	< = 7	7 – 11	> 11	Hour	< = 7	7 – 11	> 11
1	1.00	1.01	1.01	13	5.36	5.43	5.53
2	0.60	0.61	0.59	14	5.47	5.56	5.68
3	0.48	0.48	0.44	15	6.05	6.08	6.12
4	0.45	0.42	0.36	16	7.27	7.08	6.81
5	0.67	0.63	0.56	17	8.28	7.81	7.10
6	1.85	1.81	1.78	18	8.27	7.71	7.06
7	5.01	5.06	5.04	19	5.89	5.86	6.04
8	7.73	7.64	7.17	20	4.18	4.22	4.48
9	6.13	6.56	6.70	21	3.32	3.33	3.48
10	4.82	5.05	5.47	22	3.03	3.13	3.28
11	4.79	4.84	5.17	23	2.44	2.58	2.73
12	5.12	5.22	5.42	24	1.77	1.88	1.96

Analysis of Mode Shift and Transit

A known gap in the analysis of ICM relates to the performance and impacts of transit services. Mode shift in the San Diego I-15 Corridor can be influenced by adverse traffic conditions (incidents, heavy demand, and inclement weather) and by ICM strategies (such as traveler information systems.) Modeling of mode shift requires input of transit travel times, which are calculated by network segment and at key decision points in the corridor. This can support comparison of network and modal alternatives, and facilitate the analysis of traveler shifts among different transportation modes. For the San Diego I-15 Corridor, the available mode choice models were identified and their applicability was explored.

In order to identify the base mode shift, the mode-choice component of the SANDAG travel demand model was utilized. This component calculates the number of vehicles at the beginning of the simulation that decide to drive as opposed to take transit. After this mode split is set, there is also the need to model users' choice of mode as en-route information becomes available to them. This is applicable to the I-15 corridor for two reasons: First, the corridor is currently being equipped with reversible HOT lanes that will also serve a corridor-wide Bus Rapid Transit (BRT) service. The BRT service is proposed to have five stations within the study corridor, each having direct connections to the HOT lane and also access to the General Purpose Lanes. This combination allows for significant mode shift opportunities especially in the occurrence of a major incident. Secondly, the analysis is being conducted at a micro-simulation level, where the behavior of every driver in the simulation can be monitored and modified, if necessary, and this behavior does impact the operation of the model.

Once the initial mode-share is available at start-up, the availability of en-route information would cause drivers to modify their route choices as well as mode choices. Driver groups are provided with different levels of quality of information. Drivers equipped with smart phones or in-vehicle route guidance systems and those that are 511 users are assumed to make their decision based on real-time information on managed lane and general purpose lane travel times and costs, as well as transit travel time information. Drivers without in-vehicle or 511-based information are assumed to consider route- or mode shift based on VMS-posted information only. The perceptions of travel times for the two categories of drivers are different: more in-vehicle information or 511 users will consider mode- or route-shift than drivers who get their traveler information from VMS.

The detailed methodology for modeling this en-route mode shift is presented in Appendices C and D, which details the key variables and assumptions utilized in modeling mode shift to BRT as well as HOT lanes.

Chapter 3 Analysis Scenarios and ICM Strategies

This section provides an overview of priority ICM strategies for this Pioneer Corridor and the scenarios that were studied to analyze the impacts of these strategies. The analysis will assist local agencies to:

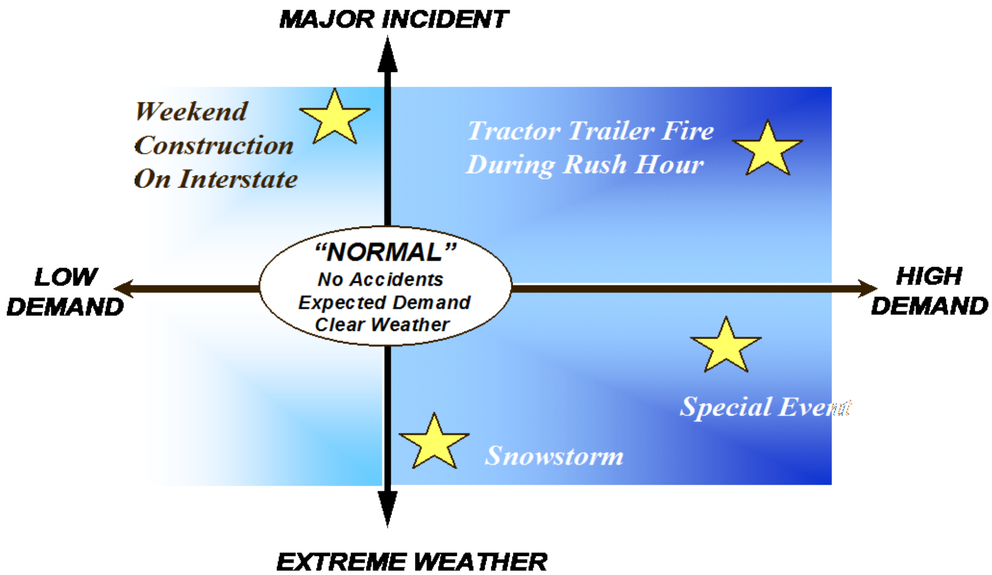
- **Invest in the right strategies –** The analysis offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions;
- **Invest with confidence –** AMS will allow corridor managers to “see around the corner” and discover optimum combinations of strategies, as well as conflicts or unintended consequences inherent in certain combinations of strategies that would otherwise be unknowable before implementation;
- **Improve the effectiveness/success of implementation –** With AMS, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful; and
- AMS provides a long-term capability to corridor managers to **continually improve implementation** of ICM strategies based on experience.

Analysis Scenarios

The *I-15 AMS Analysis Plan* (Integrated Corridor Management - I-15 San Diego, California - Analysis Plan - Final Report - EDL#: 14946) describes tools and procedures capable of supporting the analysis of both recurrent and nonrecurrent congestion scenarios. The San Diego I-15 Corridor nonrecurrent congestion scenarios entail combinations of increases of demand and decreases of capacity. Figure 3-1 depicts how key ICM impacts may be lost if only “normal” travel conditions are considered. The relative frequency of nonrecurrent conditions also is important to estimate in this process – based on archived traffic conditions, as shown in Figure 3-2.

The proposed analysis scenarios for the I-15 AMS focus on high-demand periods during a typical day, with and without incidents. The nonrecurrent congestion scenarios modeled for this corridor include some incident scenarios that were identified in the Concept of Operations document. The typical day is identified based on PeMS data for I-15 from April to May and September to November of the base year, and choosing the weekday closest to the average volume for the entire peak season. The determination of closeness is based on a calculation of the deviation for the entire time series. The volumes from this day are balanced to reflect the conservation of flow on the corridor.

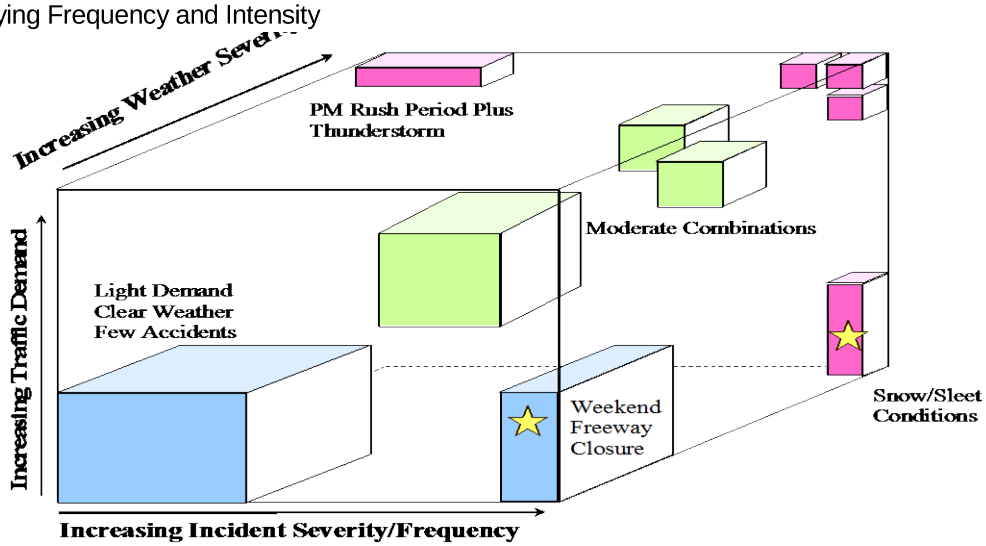
Figure 3-1. Key ICM Impacts May Be Lost If Only "Normal" Conditions Are Considered



Source: Wunderlich, Karl E., Incorporating Intelligent Transportation Systems into Planning Analysis: Summary of Key Findings From a 2020 Case Study - Improving Travel Time Reliability With ITS. This document is available at the RITA NTL (http://ntl.bts.gov/lib/jpodocs/repts_te/13605.html), May 2002.

Figure 3-2. Sources of System Variation

Classifying Frequency and Intensity



Source: Wunderlich, Karl E., Incorporating Intelligent Transportation Systems into Planning Analysis: Summary of Key Findings From a 2020 Case Study - Improving Travel Time Reliability With ITS. This document is available at the RITA NTL (http://ntl.bts.gov/lib/jpodocs/repts_te/13605.html), May 2002.

For the purpose of this study, an analysis of incident and demand data was undertaken. The primary source of incident data was the CHP and TASAS database within PeMS and the focus of the examination was on incidents that occurred on the southbound general purpose lanes of I-15 between Post Miles 15 and 35 during the Baseline year of 2003. The analysis focused on the distribution of the number of days in 2003 by incident type and by travel demand level during the AM peak period over the course of the baseline year as shown in Tables 3-1 and 3-2.

Table 3-1. Distribution of Number of Days in 2003 by Incident Type and by Demand Level

Number of Days in a Year		Incident			Total
		Major	Minor	No Incident	
Demand	High	38	5	128	171
	Medium	17	4	60	81
	Low	31	1	81	113
Total		**86**	**10**	**269**	**365**

Table 3-2. Percentage Distribution of Number of Days in 2003 by Incident Type and by Demand Level

Number of Days in a Year		Incident			Total
		Major	Minor	No Incident	
Demand	High	10.4%	1.4%	35.1%	46.8%
	Medium	4.7%	1.1%	16.4%	22.2%
	Low	8.5%	0.3%	22.2%	31.0%
Total		**23.6%**	**2.7%**	**73.7%**	**100.0%**

Demand is measured in terms of vehicle miles traveled (VMT) and demand levels are divided into three categories – low, medium, and high – based on their percentage of median VMT as follows:

- Low, if VMT is less than 75 percent of the median VMT value;
- Medium, if VMT is greater than 75 percent of and less than 102 percent of the median VMT value; and
- High, if VMT is greater than 102 percent of the median VMT value.

This classification was based on an analysis of demand bins of all the days in 2003, for the AM peak period. The nature of the I-15 corridor, being a linear access facility with limited alternative freeway options, makes the typical weekday demand fall in the high-demand classification. As shown in Table 3-1, a total of 171 days (i.e., close to 47 percent of the days operate in the same demand bin) has demands that fall within the high-demand class.

Incident severity was marked as major if incident duration was more than 20 minutes, while other incidents are defined as minor incidents. However, because incident duration is not typically available in PeMS, incident descriptions were employed to characterize the incident. For example, if the description included "Ambulance Responding" and the duration was missing, this incident was considered as a major incident.
Table 3-2 shows that there is strong correlation between the number of days with incidents and number of days with high demand, with close to 45 percent of the incidents taking place within the same demand class. The table also provides the absolute distribution of different demand-incident scenarios, and counts at any day with one or more incidents. While close to 74 percent of the days are showing normal operations during the peak period, around 10 percent of the days in the year have major incidents occurring during the high-demand regime.

Tables 3-3 and 3-4 show the distribution of vehicle hours of delay by incident type and by travel demand level during the AM peak period over the course of the baseline year 2003. The most striking, yet not surprising, element of the data from these tables is the observation that total delay associated with low level of demand contributes only negligible amounts to total delay.

Table 3-3. Distribution of Vehicle Hours of Delay in 2003 by Incident Type and by Demand Level

Delay		Incident			
		Major	Minor	No Incident	Total
Demand	High	109,304	18,276	381,466	509,046
	Medium	70,040	23,724	265,704	359,468
	Low	123	0	295	418
Total		**179,467**	**42,000**	**647,465**	**868,932**

Table 3-4. Distribution of Percentage of Delay in 2003 by Incident Type and by Demand Level

Percentage of Delay		Incident			
		Major	Minor	No Incident	Total
Demand	High	12.6%	2.1%	43.9%	58.6%
	Medium	8.1%	2.7%	30.6%	41.5%
	Low	0.0%	0.0%	0.0%	0.0%
Total		**20.7%**	**4.8%**	**74.5%**	**100.0%**

Table 3-2 shows that low-demand conditions with minor incidents occurred only one day in the year, leading to negligible amounts of delay as compared to the other conditions (viz. high demand and major incident), as shown in Table 3-3.

In addition to the above analysis that determines the percentages (probabilities) of occurrence of different demand and incident combinations, additional analysis looked at incidents and incident frequency versus volume-to-capacity ratio (V/C) during average weekdays; that is, Tuesdays, Wednesdays, and Thursdays, to better understand nonrecurring congestion.

There were a total of 432 incidents for this study road section that occurred not just during the AM peak period, but also the PM and off-peak periods. During the off-peak, AM peak, and PM peak periods there were 268, 100, and 64 incidents, respectively, in the southbound I-15 direction. Figures 3-3 and 3-4 show the relationships between the number of incidents and their frequency, to V/C ratios for both off-peak and peak-hour incidents, respectively. When the V/C ratio is relatively low (<0.65), the incident frequency in the off-peak period is always higher than that of the peak period. When the V/C ratio is relatively high (>=0.65), the incident frequency for the off-peak period is always lower than that for the peak hour. The maximum incident frequency for the off-peak period (approximately 1.8 incidents per mile for V/C ratio 0.5 to 0.55) is higher than for the peak period (1.2 incidents per mile for V/C ratio 0.7 to 0.75).

Figures 3-5 and 3-6 show similar trends for the AM peak period. The maximum incident frequency for the AM peak period is 0.85 incident per mile for a V/C ratio range 0.65 to 0.75.

Figure 3-3. Distribution of the Number of the Incidents by V/C Ratio

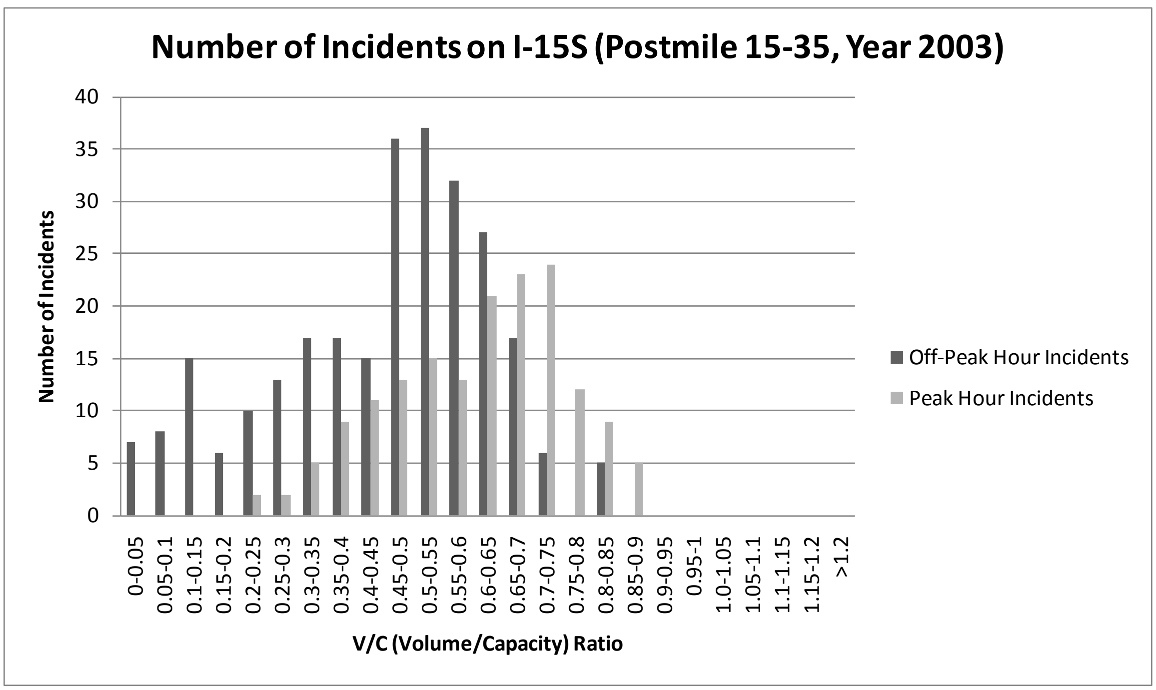


Figure 3-4. Distribution of Incident Frequency by V/C Ratio

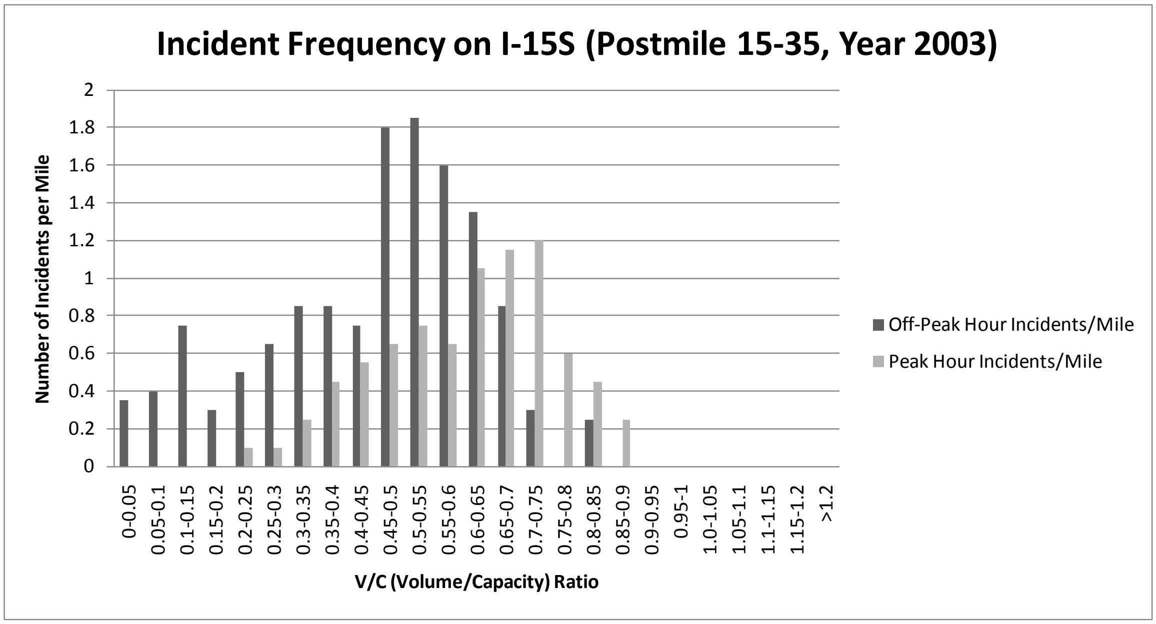


Figure 3-5. Distribution of the Number of the Incidents by V/C Ratio for the AM Peak

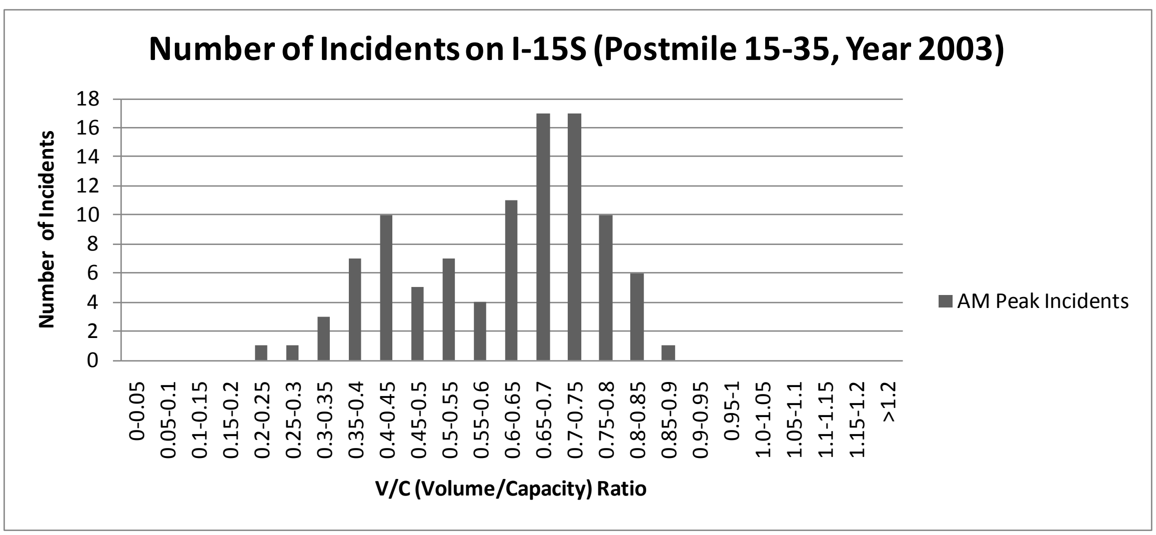
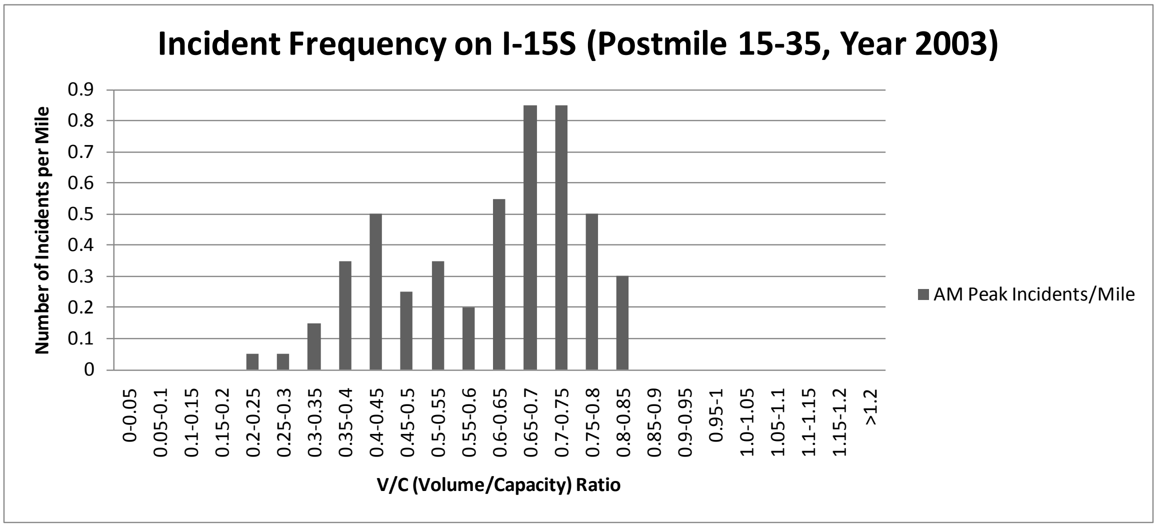


Figure 3-6. Distribution of Incident Frequency by V/C Ratio for the AM Peak

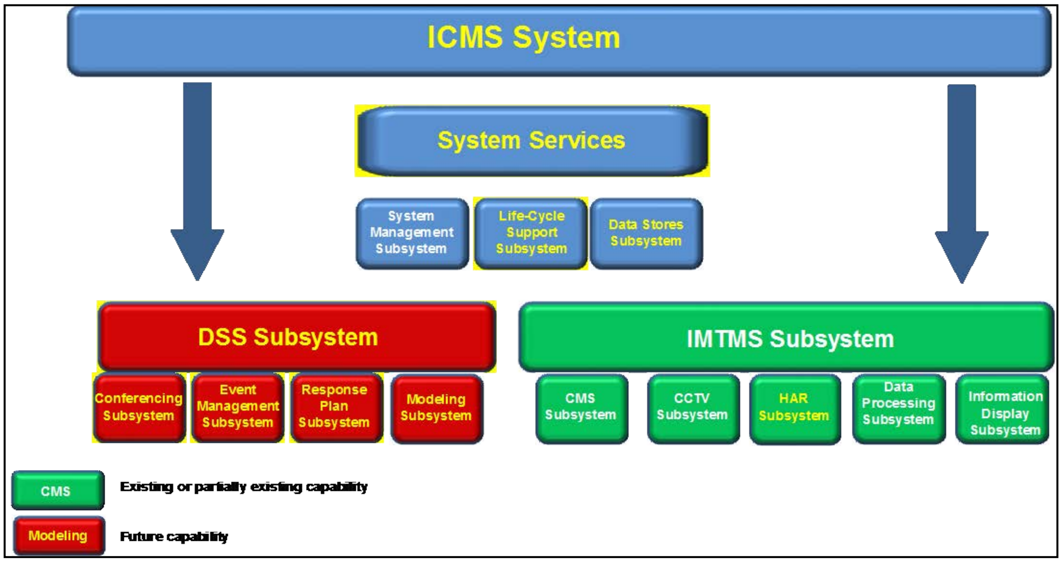


The San Diego region has made significant capital investments in transit, highway, and arterial systems to derive maximum ITS benefits, while focusing on data sharing. SANDAG, its member agencies, and diverse stakeholders are attempting to optimize the operational coordination of multiple transportation networks and cross-network connections to improve corridor mobility within the region. The I-15 corridor represents one of the efforts furthest along in developing such a framework that integrates a monitoring and management system providing information to a Decision Support System (DSS) for incident response.

Figure 3-7 shows the I-15 Operational Concept, and depicts the components of this concept that have already been implemented and those that need to be implemented. The ones that need to be implemented represent the area of maximum benefit for a modeling analysis to help build a DSS by using the AMS to identify necessary components of the decision-making. Among the components that are being implemented is the Intermodal Transportation Management System (IMTMS).

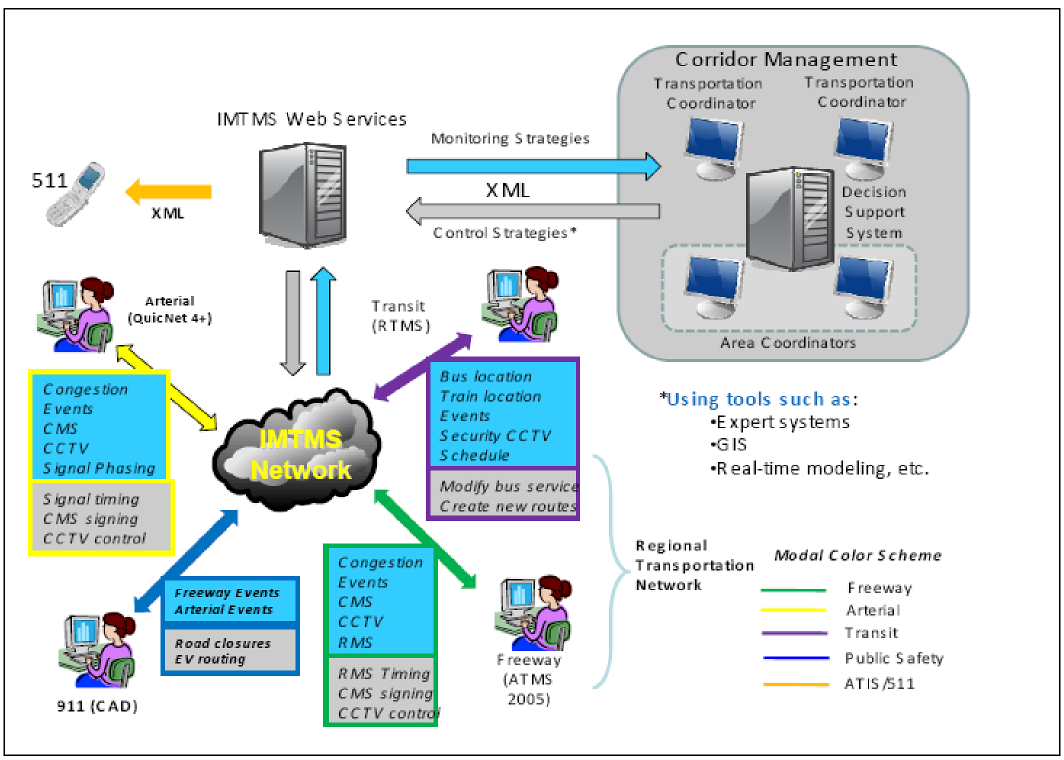
IMTMS became operational in May 2007, and has a modular, standards-based web service architecture that helps collect information from a variety of modal management systems. The San Diego region envisions the use of these IMTMS informational inputs to create a DSS based on increased sharing of data among corridor agencies. The DSS represents a higher level of decision-making that translates into actionable control strategies, in response to different operational scenarios on the corridor. Figure 3-8 depicts the conceptual monitoring and control strategies, along with the data elements needed to support these strategies. In addition, this figure presents the IMTMS system as an informational exchange utility that interfaces with a variety of decision-making layers.

Figure 3-7. ICMS Operational Concept



Source: SANDAG, September 2009.

Figure 3-8. Sample DSS



Source: SANDAG, September 2009.

The I-15 Concept of Operations (ConOps) report lists the following scenarios for the ICM systems that would need to be supported by the DSS:

1. Daily Operations;
2. Freeway Incident;
3. Arterial Incident;
4. Transit Incident;
5. Special Event; and
6. Disaster Response.

These scenarios relate to incidents in different parts of the multimodal system. The detailed information on the scenarios, timelines, and agency responsibilities can be found in the ConOps report. The interpretations of each of these scenarios for the purpose of AMS are:

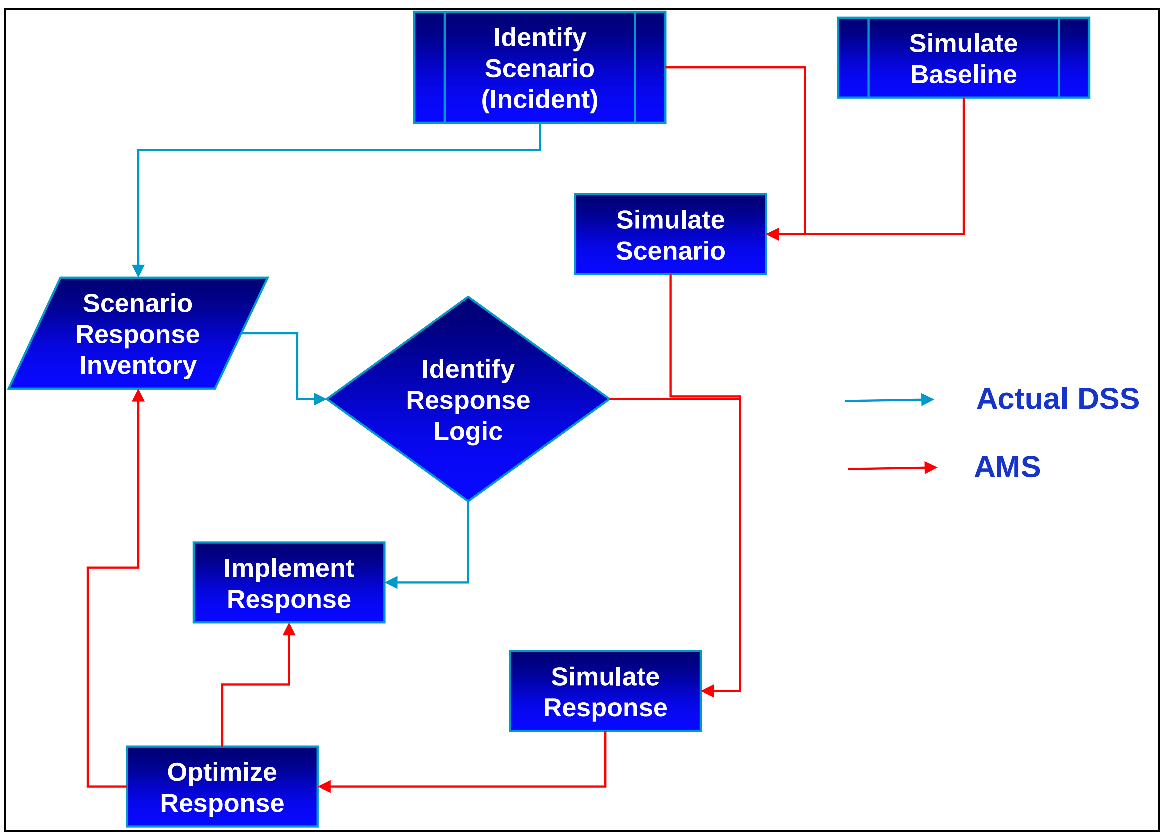
- **Daily Operations –** No incident for projected 2012 demands (future baseline) and optimized for operations using the different ICM strategies. The scenario includes a combination of ICM strategies meant to improve daily operations.
- **Freeway Incident –** One major freeway incident simulated at a central location of the general purpose lanes on I-15 corridor. A major incident leads to closure of a number of lanes. From year 2001 to 2006, the number of major freeway incidents on the I-15 southbound section increased from 164 to 244. Major incidents have been classified as those that cause multiple lane closures. The spike in crashes is attributable to construction activity that has been consistently going on in the corridor. The frequency of these incidents is determined by using AADTs. The estimated AADT for the I-15 South corridor in 2005 was 225,657. Based on this number and the number of major incidents on the southbound corridor in 2005 (242), the Initial Crash Rate (ICR) is determined to be 2.94.
- **Arterial Incident –** One major arterial incident simulated at a central location of one of the arterials in the I-15 study area. A major incident will lead to arterial closure for the segment. The frequency of arterial incidents was determined based on data acquired from studies in Caltrans District 11. These data were available on major arterials in the study area, including Pomerado Road – North and South, Black Mountain Road, and Centre City Parkway. The ICR for Pomerado Road in Poway was 1.15 from 2005 to 2008. The directional ADT estimates for the same time period were 30,700. This information was used to estimate the frequencies of arterial crashes for 2012 future baseline using travel demand forecasts for ADTs.

The development of a DSS for any of these scenarios involves the development of a decision logic that combines different response measures, which can be implemented once a particular scenario has been identified to have occurred. The decision logic would consist of the implementation of centrally-controlled measures like Ramp Metering, Signal Optimization, En-Route Diversion Information, etc., in a certain sequence. The AMS would focus on implementation of four sample decision logics, representing the DSS, within the simulation to develop different responses to different scenarios. The framework developed to test the DSS would become part of the inventory that considers all possible conditions and also consists of the optimal response strategy, which would be the basis of the DSS.

Figure 3-9 shows the assimilation of the simulation process into the DSS. The knowledge-based DSS can be enhanced by including scenarios through model runs. The DSS can also be simultaneously driven by simulation as new events occur. The simulation model plays the key role of optimizing the output (response) from the DSS.

Each of the DSS scenarios included in the AMS for evaluation was compared with a scenario without DSS. For the purpose of the analyses, this scenario refers to the Future Baseline scenario that includes the systems that are planned to be operational on the roadway by 2012. The Future Baseline scenario and non-DSS scenarios were induced with an identical incident scenario; however, the systems did not operate under a DSS-based response, but continued to function with whatever feedback is programmed for 2012. The incident was identified by taking into account the maximum clearance time to allow the simulation to run through without gridlock (e.g., incident is cleared within 45 minutes). This control case without DSS is intended to show the incident impact to the system with all the programmed changes in place in order to isolate the effective impact of a DSS-based smart response. The I-15 corridor will already have many of the components of system management in place by 2012; however, the benefits of integrating these components are of interest as part of this AMS effort. The non-DSS scenario, therefore, has the IMTMS (green part in Figure 3-7) architecture that is scheduled to be deployed by 2012, but does not include the DSS subsystem (red Part in Figure 3-7) that in effect coordinates the operations of different components of the IMTMS.

Figure 3-9. Simulation as Part of DSS Response



Source: SANDAG, September 2009.

Table 3-5 provides a list of the different scenarios that was evaluated as part of the AMS effort. The table presents each scenario number along with the analysis settings for demand levels and probability assigned to each scenario. The high demand refers to 102 percent of the typical demand (which is classified as median (medium) demand for purpose of this analysis), and low demand refers to 75 percent of the typical demand. The next section provides an overview of the ICM strategies that can be considered as part of the DSS. The AMS scenarios identified in Table 3-5 represent the different combinations of these strategies implemented as part of the DSS in response to the incident or no incident scenarios. The corresponding probabilities have been derived from the occurrence of these conditions during regular annual operations, as was identified in Tables 3-3 and 3-4.

Table 3-5. Scenarios for AMS

Scenario	Year	Demand Class	Incident	DSS Operational	Probability (Percentage)
Baseline	2003	Typical Day	None	No	–
A	2012	High	None	No	34%
B	2012	Medium	None	No	16%
C	2012	Low	None	No	21%
D	2012	High	None	Yes	34%
E	2012	Medium	None	Yes	16%
F	2012	Low	None	Yes	21%
G	2012	High	Freeway	No	11%
H	2012	Medium	Freeway	No	6%
I	2012	Low	Freeway	No	8%
J	2012	High	Freeway	Yes	11%
K	2012	Medium	Freeway	Yes	6%
L	2012	Low	Freeway	Yes	8%
M	2012	High	Arterial	No	1.9%
N	2012	Medium	Arterial	No	0.9%
O	2012	Low	Arterial	No	1.2%
P	2012	High	Arterial	Yes	1.9%
Q	2012	Medium	Arterial	Yes	0.9%
R	2012	Low	Arterial	Yes	1.2%

ICM Strategies

Travelers can have multiple responses to congestion and mitigation ICM strategies: route diversion, temporal diversion, mode change, changing travel destination, or canceling their trip are some of these possible traveler responses. The I-15 Corridor will have a number of ICM strategies in operation in the near future. The base year chosen for analysis is 2003, as the most relevant time where no significant construction activity was ongoing on the corridor, and for which there is a validated travel demand model. The number of projects under construction on the corridor makes it imperative that a future baseline scenario be included in the analysis with all these design changes incorporated. This would serve as the Future Baseline scenario, and will be used as the basis of comparison for all the ICM strategies being tested. The Future Baseline scenario is modeled using information on the 2012 configuration of the roadway available as of December 2008, and utilizes projected 2012 travel demand.

The number of ICM strategies considered for the I-15 corridor has made it necessary to analyze only one peak period in order to stay within the time and budget constraints. The analysis is, however, being developed so that a different set of peak-period conditions can also be developed if resources become available.

An analysis of a typical peak-day demand during the AM and PM peak periods for the corridor indicated higher Vehicle Miles Traveled (VMT) in the southbound direction in AM peak period than the VMT in the northbound direction during the PM peak. The AM peak period might be a more useful modeling option, as it represents a higher traffic volume on the HOT lanes and a narrower window of time for time of departure choice, whose effect could be captured effectively within the simulation model.

A number of ICM strategies, like Dynamic Pricing and Managed Lanes, are incorporated into the Future Year Baseline scenario to account for development currently being undertaken on the I-15 corridor. SANDAG provided a list of prioritized ICM strategies that are shown in detail in Appendix A. The following ICM strategies are tested in the future scenarios.

- Pre-Trip Traveler Information,
- En-Route Traveler Information,
- Freeway Ramp Metering,
- Signal Coordination on Arterials with Freeway Ramp Metering,
- Physical Bus Priority, and
- Congestion Pricing on Managed Lanes.

These strategies are discussed in further detail in the ensuing sections.

Pre-Trip Traveler Information

Pre-trip traveler information includes any pre-trip travel information accessible to the public that can be used in planning trip routes, estimating departure times, and/or choosing travel mode. Such information can be available through the 511 system, via the phone, the Internet, or public access television. The analysis captures the impacts of such information on traveler’s route choice, departure times, and/or choice of travel mode. The fraction of I-15 users, who access such information prior to making their trip, is estimated based on data sources available in the region, such as available information on utilization of 511 and traffic web sites in San Diego. This, “informed traveler”, portion of the driving population is identified as a particular driver class within the model. In order to effectively analyze this strategy, the methodology to model mode shift, as described in Section 2.2, is utilized. This methodology utilizes the trip tables from the travel demand model, and travel times estimated by simulation models to create a feedback loop for estimation of mode choice. In addition to trip tables, the model utilizes historical travel time estimates on major routes as basis of initial traffic assignment.

En-Route Traveler Information

Modeling the impact of en-route information available to drivers relates to two traveler responses: 1) change in route choice, and 2) change in mode en-route.

Change in Route Choice

This relates to real-time change in route choice of drivers based on travel time or congestion updates they receive via radio, 511, or wireless-equipped Personal Digital Assistant (PDA) devices, or smart phones. This feature is incorporated in the analysis as a fixed percentage of drivers who would be likely to have this information (e.g., sample set of PDA users or number of 511 users), along with a corresponding "use rate."

The current information available through the San Diego 511 system deals exclusively with usage statistics. San Diego 511 has been operational since February 2007. The number of requests for I-15 traffic information for 2007 and 2008 were 73,168 and 65,669, respectively. This is the extent of the 511 information available dealing with I-15. No user survey has yet been conducted. Current estimates of PDA/smart phone market penetration by the Consumer Electronics Association (CEA) shows that 20 percent of households in the United States own such portable units. An additional 9 percent of U.S. households have cars with in-built GPS/smart phone units. These numbers are expected to rise significantly in the future. The current technology supports the real-time update of GPS units to current traffic conditions – a subscription service that not all GPS units have. Future efforts might make GPS unit information more active, and create some well-informed drivers that are always being updated of their route choices all the way to their destinations. Based on the current information available, it is assumed that the en-route traveler information device market penetration in 2012 will rise to 30 percent – that is, 30 percent of the population will be able to use the traffic diversion information through en route information systems. The baseline year (2003) market penetration on e-route traveler information devices was assumed to be 5 percent.

In TransModeler, a certain percentage of drivers who have the ability to access such information, are placed under a particular driver class. At the onset of a particular incident, a macro is activated to update the route choices of drivers falling within this class. The percentage of drivers who stay on their original route, divert their route, or change modes are based upon the level of diversion stemming from the probabilistic route choice model within TransModeler. The compliance rates and the amount of route diversion that occurs also vary based on the type of scenario being modeled. This driver type is part of the multiple categories of drivers that are able to view the information on VMS, and base their mode choice decisions on the logit model mentioned in Section 2.2. This means that an informed driver is able to change route or mode based on the availability of information, and the percentage that do is based on the traffic conditions and every driver's value of time (which is distributed randomly for the entire driver population).

To facilitate modeling, sensors are placed along the route upstream of the message sign. As drivers approach the message sign, they pass through these sensors, which in turn call up a macro that updates these drivers' route choice decisions. When the macro is activated, new routes are assigned to the percentage of drivers that divert their routes based on the posted information. Depending on the scenario or type of incident that may have occurred, compliance rates associated with each message sign vary, and hence the amount of route diversion also differ throughout the simulation runtime.

Change in Mode En-Route

BRT is being introduced along the I-15 corridor, and there will be direct access to “Bus Transit Hubs” from HOT lanes, as well as from General Purpose lanes. This mode shift is analyzed by evaluating a fixed number of options for a certain percentage of drivers as they approach a Transit Hub. The methodology described for changes in route choice is fairly similar to how the model addresses drivers’ reactions, as they approach a message sign near a transit hub exit. In this situation, a macro can be used to update drivers’ route choice decisions as they near the hub. Drivers at this point have the option of staying on their original route; diverting to a different path (i.e., choose the HOT lanes if they are on the General Purpose Lanes); or shift to BRT. Depending on parking availability at the transit hub, or traffic conditions on either the General Purpose or HOT lanes, traveler information use rates can be set to assign a certain percentage of travelers who receive real-time information, and the percentage of drivers diverting is based on a nested logit-based decision model. The distinction between use and diversion is important in this context. Use indicates a percentage of travelers with information provided to them, and diversion counts only those travelers that actually shift mode or route based on this use rate.

Ramp Metering

The I-15 freeway currently has a number of ramps that are metered in both the northbound and southbound directions. The meters operate on a local occupancy-based algorithm working off the San Diego Ramp Metering Software (SDRMS). The current ramp metering algorithm implemented in the corridor is incorporated into TransModeler utilizing the GIS – Development Kit (DK) framework.

Alternative ramp metering algorithms, as well as new signal timing plans, can be created and customized to fit a particular incident scenario. In TransModeler, when the incident occurs, the appropriate set of metering strategies and signal timing plans can be called up to replace the current signal and metering operation in order to address the present traffic conditions. The ramp metering algorithm and signal timing plans used can also vary based on the signal coordination plan set to address the particular incident scenario (addressed in the next section on signal coordination).

Signal Coordination on Arterials with Freeway Ramp Metering

In addition to simulating Signal Coordination on Arterials, which involves implementing the QuicNet traffic signal control platform within the simulation model, the ramp metering algorithms can be introduced within this framework to evaluate the best possible strategy to optimize operations on both the freeway and the arterials. The Ramp Metering strategy can be coordinated with the signal timing set-up on the arterials, and the performance of both the corridor and impacted roadway network can be evaluated based on input from the QuicNet system.

Physical Bus Priority

Physical bus priority improvements on the arterials and freeways have the ability to improve transit service within the corridor. These strategies can also prevent transit vehicles from crossing paths with other movements and alleviate the presence of existing difficult maneuvers. In order to model this strategy, bus routes and arterials suitable for such strategies are identified in discussions with SANDAG and U.S. DOT. Bus priority is implemented along the I-15 HOT lanes to include exclusive bus lanes and ramps.

Congestion Pricing on Managed Lanes

Currently, I-15 managed lanes are set to use dynamic pricing, setting toll rates based on the changing level of traffic congestion. The impacts of different levels of congestion on toll prices and subsequently on traffic management on the corridor are evaluated in this scenario. The congestion pricing scenario is evaluated based on planned pricing scenarios provided by SANDAG. The analysis method used includes the following capabilities:

- Dynamic traffic assignment, so that travelers can divert to and from another mode, route, or time of travel in response to congestion or to congestion pricing strategies;
- The ability to evaluate changes in the Value of Time (VOT);
- The ability to evaluate changes in toll rates in response to congestion or to the travel times in the managed lanes and the general purpose lanes.

The *I-15 AMS Analysis Plan* (Integrated Corridor Management - I-15 San Diego, California - Analysis Plan - Final Report - EDL#: 14946) provides more detail on the method employed for the analysis of congestion pricing.

Summary of Analysis Settings

Table 3-6 summarizes the analysis settings for the I-15 Corridor. All analysis scenarios are compared against a Future Baseline scenario. The main difference between the Future Baseline and the different scenarios being evaluated is that the future baseline model introduces the different ICM strategies in an uncoordinated approach. In contrast, the different alternative scenarios make use of a Decision Support System to take advantage of coordination benefits between different ICM strategies.

The following is a summary of the ICM strategies for each of the analysis scenarios, as determined by SANDAG. The list shows the scenario with the corresponding ICM strategies that were modeled. Table 3-7 following the strategies lists the assumptions for pre-/post-ICM implementation.

- Daily Operations:
  - Pre-Trip and En-Route Traveler Information;
  - Ramp-Metering and Arterial Signal Coordination;
  - BRT; and
  - Congestion Pricing for ML.
- Freeway Incident:
  - Pre-Trip and En-Route Traveler Information;
  - Ramp-Metering and Arterial Signal Coordination;
  - BRT; and
  - Congestion Pricing for ML.
- Arterial Incident:
  - Pre-Trip and En-Route Traveler Information;
  - Ramp-Metering and Arterial Signal Coordination;
  - BRT; and
  - Congestion Pricing for ML.

Table 3-6. San Diego I-15 Corridor – Summary of Analysis Settings

Parameter	Value	Comment
Base year	2003	The base analysis year is based on the available validated model year in the regional travel demand model, and in the absence of major construction activity within the corridor.
Analysis year	2012	The analysis year is derived from the anticipated completion of construction of the I-15 system, and the implementation of ICM strategies.
Time period of analysis	AM	The analysis of the AM peak period provides the most benefit in terms of assessing the proposed ICM strategies.
Simulation period	3-5 hrs	6 AM – 9 AM is the primary analysis period. Future baseline scenarios run through 6 AM – 11 AM to calculate performance metrics.
Freeway incident location	South of Ted Williams Pkwy	This location experiences a high number of incidents, offers the potential for route diversion, and has a high impact on corridor travel.
Freeway incident duration	45 minutes	This duration is chosen to represent a major blockage in the peak period. Incident occurs at 7 AM and is cleared by 7:45 AM.
Freeway incident severity	Lane closures	3 lanes closed and reduced speeds on lanes 4 and 5 from 7 AM to 7:30 AM. Only 2 lanes closed for the remaining duration of the incident and reduced speeds on lanes 3, 4, and 5.
Arterial incident location	On Carmel Mountain Rd east of I-15	Based on 2012 demand projections to calculate ICRs for different arterials under study.
Arterial incident duration	40 minutes	This duration is chosen to represent a major blockage in the peak period. Incident occurs at 7:30 AM and is cleared by 8:10 AM.
Arterial incident severity	Lane closures	Variable lane closures and speed reduction.

Table 3-7. Model Assumptions/Inputs

Outcome of Strategies	Summary/Notes to Modeling Team	Without ICM	With ICM in Place
1. En-Route Information			
1.1 Earlier dissemination of en-route incident and travel time information	Because of quicker notification, en-route traveler information systems will disseminate incident information earlier to travelers. The effect will be that more travelers will be able to alter routes, modes, and departure times. Incident duration stays the same with and without ICM.	10 minutes to dissemination	• 2 minutes to dissemination; and • 30% of travelers (smart phones, 511, radio combined) with traveler information. In the baseline year of 2003, 5% of travelers were assumed to have traveler information.
1.2 Comparative travel times (mode and route)	Information dissemination (pre-trip and en-route) will include travel time comparisons for freeway, general purpose lanes, arterial, and transit. The effect will be that more travelers will choose the best options to maintain consistent trip times.	General purpose lane and mainline travel time	Travelers will make diversion choices at equal intervals of time (for the next time period). The decision choice is based on a generalized cost that feeds into a decision model. The effect will be that as conditions worsen, more travelers will take more alternative options including transit.
2. Improved Traffic Management			
2.1 Incident signal retiming plans	'Flush' signal timing plans that are coordinated and allow progression through different jurisdictions. The effect will be reduced arterial travel times during incidents or special event situations.	30 minutes to implement	• Based on Location in Primer on Signal Coordination provided; • 10 minutes to implement (variable based on severity); • Higher throughput; and • Off-ramp and diversion planning.
2.2 Freeway ramp metering and signal coordination	Incident location-based strategy to coordinate arterial traffic signals with ramp meters.	None	Coordination under RAMS framework.

Table 3-7. Model Assumptions/Inputs (continued)

Outcome of Strategies	Summary/Notes to Modeling Team	Without ICM	With ICM in Place
2.3 HOT lanes	Existing today, HOT lanes are included in the modeling. Can be opened to all traffic during major incidents. Option of adding additional lane in incident direction using movable barrier.	Maintain HOT lanes during major incidents	Open HOT lanes to all traffic during major incidents to maximize throughput (I-15 managed lanes operations and traffic incident management plans).
3. Improved Transit Management			
3.1 Reduced time of detection, notification, and verification of incidents	Currently, incident management is handled by Caltrans and other responders. The system will be streamlined to provide coordination of major traffic incidents between TMC/Caltrans and FasTrak CSC/SANDAG. Clear-cut procedures and understanding of decision-making process and delegation of authority/responsibility of actions will reduce response times.	All agencies notified within 30-60 min. Incident clearance in less than 90 minutes.	All agencies notified within 5 minutes. I-15 managed lanes and traffic incident management plans provide a blue print for coordination.

Chapter 4 Performance Measures

This section provides an overview of the performance measures that are used in the evaluation of ICM strategies for the I-15 Corridor. To be able to compare different investments within a corridor, a consistent set of performance measures are applied. These performance measures:

- Provide an understanding of traffic conditions in the study area;
- Demonstrate the ability of ICM strategies to improve corridor mobility, throughput, and reliability based on current and future conditions; and
- Help prioritize individual investments or investment packages within the Test Corridor for short- and long-term implementation.

The performance measures, which are reported by the facility type, focus on the following key areas:

- **Mobility –** Describes how well the corridor moves people and freight;
- **Reliability and Variability –** Captures the relative predictability of the public's travel time; and,
- **Emissions and Fuel Consumption –** Captures the impact on emissions and fuel consumption.

The U.S. DOT, in collaboration with the Pioneer sites and Cambridge Systematics, developed guidance for mobility and reliability performance measures utilizing outputs from the simulation models. The following sections provide an overview of the selected performance measures, while Appendix B provides the U.S. DOT guidance.

Mobility

Mobility describes how well the corridor moves people and freight. The mobility performance measures are readily forecast. Three primary types of measures were used to quantify mobility in the I-15 Corridor, including the following:

- **Travel time –** This is defined as the average travel time for the entire length of the corridor or segment within the corridor by facility type (e.g., mainline, HOV, and local street) and by direction of travel. Travel times are computed for the peak period.
- **Delay –** This is defined as the total observed travel time less the travel time under uncongested conditions, and is reported both in terms of vehicle-hours and person-hours of delay. Delay is calculated for freeway mainline and HOV facilities, transit, and surface streets.
- **Throughput –** Throughput is measured by comparing the total number of vehicles entering the network and reaching their destination within the simulation time period. The corresponding VMT, PMT, Vehicle Hours Traveled (VHT), and Person Hours Traveled (PHT) are reported as macroscopic measures of the general mobility of the corridor.

Reliability and Variability of Travel Time

Reliability and variability capture the relative predictability of the public's travel time. Unlike mobility, which measures how many people are moving at what rate, the reliability/variability measures focus on how much mobility varies from day to day.

Reliability benefits attributed to I-15 SB were calculated from the change in the travel time variance for any trip using I-15 in the SB direction, either the general purpose or managed lanes. Similarly, I-15 NB reliability benefits were calculated from trips using any I-15 NB lane. Benefits were split between the general purpose and managed lanes based on the portion of vehicle hours of travel. The total systemwide benefits were calculated from the change in variance for all trips in the system. The I-15 SB and NB benefits were then subtracted from the entire network benefits, and the remaining reliability benefits were distributed amongst the non-I-15 facilities based on the share of vehicle hours of travel. Appendix B describes the methodology used in calculating reliability and variability impacts.

Safety

While the Analysis Plan identifies safety as one of the performance measures to be produced by the analysis, it has become apparent that available safety analysis methodologies are not sensitive to ICM strategies. The best available safety analysis methods rely on crude measures such as V/C and cannot take into account ICM effects on smoothing traffic flow. Clearly, this is an area deserving new research. As such, the analysis results presented in this report do not include safety as one of the performance measures.

Emissions and Fuel Consumption

Estimation of emissions and fuel consumption is based on the methodology applied in the Test Corridor AMS. The method utilizes the IDAS methodology that incorporates reference values to identify the emissions and fuel consumption rates based on variables such as facility type, vehicle mix, and travel speed. The emissions and fuel consumption rates were based on currently available sources such as California Air Resources Board EMFAC 2007 and the EPA's MOBILE6. Emissions and fuel consumption is then monetized using costs per ton of pollutants released and the purchase price of fuel, for use in the benefit/cost analysis.

Cost Estimation

For the identified ICM strategies, planning-level cost estimates were prepared, including life-cycle costs (capital, operating, and maintenance costs). Costs were expressed in terms of the net present value of various components and are defined as follows:

- **Capital Costs –** Includes up-front costs necessary to procure and install ICM equipment. These costs are shown as a total (one-time) expenditure, and include the capital equipment costs as well as the soft costs required for design and installation of the equipment.
- **Operations and Maintenance (O&M) Costs –** Includes those continuing costs necessary to operate and maintain the deployed equipment, including labor costs. While these costs do contain provisions for upkeep and replacement of minor components of the system, they do not contain provisions for wholesale replacement of the equipment when it reaches the end of its useful life. These O&M costs are presented as annual estimates.

- **Annualized Costs –** These represent the average annual expenditure that would be expected in order to deploy, operate, and maintain the ICM improvement, and replace (or redeploy) the equipment as they reach the end of their useful life. Within this cost figure, the capital cost of the equipment is amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual O&M cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of Pioneer Corridor ICM deployments.

The complexity of these deployments warrants that these cost figures be further segmented to ensure their usefulness. Within each of the capital, O&M, and annualized cost estimates, the costs are further disaggregated to show the infrastructure and incremental costs. These are defined as follows:

- **Infrastructure Costs –** Include the basic “backbone” infrastructure equipment necessary to enable the system. For example, in order to deploy a camera (CCTV) surveillance system, certain infrastructure equipment must first be deployed at the traffic management center to support the roadside ITS elements. This may include costs such as computer hardware/software, video monitors, and the labor to operate the system. Once this equipment is in place, however, multiple roadside elements may be integrated and linked to this backbone infrastructure without experiencing significant incremental costs (i.e., the equipment does not need to be redeployed every time a new camera is added to the system.) These infrastructure costs typically include equipment and resources installed at the traffic management center, but may include some shared roadside elements as well.
- **Incremental Costs –** Include the costs necessary to add one additional roadside element to the deployment. For example, the incremental costs for the camera surveillance example include the costs of purchasing and installing one additional camera. Other deployments may include incremental costs for multiple units. For instance, an emergency vehicle signal priority system would include incremental unit costs for each additional intersection and for each additional emergency vehicle that would be equipped as part of the deployment.

Structuring the cost data in this framework provides the ability to readily scale the cost estimates to the size of potential deployments. Infrastructure costs would be incurred for any new technology deployment. Incremental costs are multiplied with the appropriate unit (e.g., number of intersections equipped, number of ramps equipped, number of VMS locations, etc.) and added to the infrastructure costs to determine the total estimated cost of the deployment.

The annualized benefits for each of the measures mentioned above were calculated to estimate a benefit-cost ratio for the overall effect of implementing the ICM strategies. The benefit cost analysis is presented in Section 6.5.

Chapter 5 Model Calibration

Accurate calibration is a necessary step for proper simulation modeling. Before modeling ICM strategies, model calibration ensures that base scenarios represent reality, creating confidence in the scenario comparison. The following section summarizes the model calibration and validation approach and results. Details of the model calibration are available in a separate report titled *Integrated Corridor Management Analysis, Modeling, and Simulation - Calibration Report for I-15 Corridor in San Diego*.

Simulation Model Calibration

Each simulation software program has a set of user-adjustable parameters that enable the practitioner to calibrate the software to better match specific local conditions. These parameter adjustments are necessary because no simulation model can include all of the possible factors (both on- and off-street) that might affect capacity and traffic operations. The calibration process accounts for the impact of these "unmodeled" site-specific factors through the adjustment of the calibration parameters included in the software for this specific purpose. Therefore, model calibration involves the selection of a few parameters for calibration and the repeated operation of the model to identify the best values for those parameters. Calibration improves the ability of the model to accurately reproduce local traffic conditions. The key issues in calibration are:

- Identification of necessary model calibration targets;
- Selection of the appropriate calibration parameter values to best match locally measured street, highway, freeway, and intersection capacities;
- Selection of the calibration parameter values that best reproduce current route choice patterns; and
- Validation of the overall model against overall system performance measures, such as travel time, delay, and queues.

Calibration Approach

The approach outlined below was followed to validate and calibrate the simulation model for the I-15 corridor. Selected steps are described in more detail in later sections. Some steps were performed simultaneously, while others were performed iteratively until the best results were achieved.

- The first step was to import the roadway network from the regional macroscopic travel demand model. A geometry check was performed to ensure correct lane configurations and traffic signal locations.
- The AM peak-period, origin-destination trip table (6:00-9:00 AM Peak) was extracted from the regional travel demand model for the I-15 Corridor study area. For modeling purposes, this trip table was expanded to reflect the desired 6:00-11:00 AM simulation period.

- Next, several metrics were used to evaluate the model's performance, including freeway volumes, speed profiles, and congestion patterns and bottleneck locations.
- In addition to the year 2003 baseline model calibration, a "known incident" scenario was evaluated to test the sensitivity of the simulation model to a major incident along southbound I-15.

The model validation and calibration was performed with the year 2003 network, which did not include the managed lanes along the I-15 corridor.

Available data on bottleneck locations, traffic flows, and travel times were used for calibrating the I-15 corridor simulation model. The model calibration strategy was based on the three-step strategy recommended in the FHWA Guidelines for Applying Traffic Microsimulation Modeling Software:[4]

- **Capacity calibration –** An initial calibration performed to identify the values for the capacity adjustment parameters that cause the model to best reproduce observed traffic capacities in the field. A global calibration is performed first, followed by link-specific fine-tuning. The Capacity calibration was done utilizing volume data collected from the PeMS database for the year 2003 between the periods of September to November.
- **Route choice calibration –** The I-15 Corridor has parallel arterial streets, making route choice calibration important. A second calibration process was performed with the route choice parameters. A global calibration was performed first, followed by link-specific fine-tuning.
- **System performance calibration –** Finally, the overall model estimates of system performance (travel times and queues) were compared to the field measurements for travel times and queues. Fine-tuning adjustments were made to enable the model to better match the field measurements.

Calibration Criteria

The Calibration criteria presented in Table 5-1 were applied to the I-15 Corridor simulation model validation.

[4] Dowling, R., A. Skabardonis, and V. Alexiadis, *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*, FHWA-HRT-04-040, Federal Highway Administration, July 2004.

Table 5-1. Model Calibration Criteria

Calibration Criteria and Measures	Calibration Acceptance Targets
Hourly Flows, Model vs. Observed	
Traffic flows within 15% of observed volumes for links with peak-period volumes greater than 2,000	For 85% of cases for links with peak-period volumes greater than 2,000
Sum of all link flows	Within 5% of sum of all link counts
Travel times within 15%	>85% of cases
Visual Audits	
Individual Link Speeds: Visually acceptable Speed-Flow relationships	To analyst's satisfaction
Bottlenecks: Visually Acceptable queuing	To analyst's satisfaction

Model Calibration Results

This section summarizes the model validation and calibration results for the I-15 Corridor in San Diego, California. The model validation and calibration methodology used a diversified set of data, including the following:

- Traffic flows at individual links along the I-15 corridor;
- Speed profiles along critical segments of the corridor; and
- Queue observations along critical segments of the corridor freeway and arterial components.

Link Count Comparisons – Typical Day

A total of 110 freeway link counts on the I-15 corridor were compared against the modeled count output from the TransModeler simulation runs. Two criteria were used to validate the model for each of three hourly time periods comprising the peak period of 6:00 AM to 9:00 AM: a comparison of observed versus modeled hourly flows for links with greater than 2,000 vehicles per hour (veh/h), and a comparison of aggregate link flows versus aggregate link counts.

06:00–07:00 AM Link Count Validation

A summary of the link count validation statistics for the first modeled hour, 06:00-07:00, is presented in Table 5-2.

07:00–08:00 AM Link Count Validation

A summary of the link count validation statistics for the second modeled hour, 07:00-08:00, is presented in Table 5-3.

Table 5-2. 06:00-07:00 AM Link Count Summary

Criteria and Measures	Model Versus Observed	Percentage
Within 15%, for Flow > 2,000 veh/h (for > 85% of links)	35 (35) {pass counts (total)}	100%
Within 5%, sum of all link flows	252,291 (264,021) {model flow (observed counts)}	4.4%

Table 5-3. 07:00-08:00 AM Link Count Summary

Criteria and Measures	Model Versus Observed	Percentage
Within 15%, for Flow > 2,000 veh/h (for > 85% of links)	33 (35) {pass counts (total)}	94%
Within 5%, sum of all link flows	277,783 (292,133) {model flow (observed counts)}	4.9%

08:00–09:00 AM Link Count Validation

A summary of the link count validation statistics for the third modeled hour, 08:00-09:00, is presented in Table 5-4.

Table 5-4. 08:00-09:00 AM Link Count Summary

Criteria and Measures	Model Versus Observed	Percentage
Within 15%, for Flow > 2,000 veh/h (for > 85% of links)	35 (35) {pass counts (total)}	100%
Within 5%, sum of all link flows	263,735 (264,320) {model flow (observed counts)}	0.2%

All hourly flow criteria were met for the three modeled hours (06:00 to 09:00 hrs), as per the guidelines set in the AMS Experimental Plan for I-15, San Diego.

Figures 5-1 through 5-3 show a comparison of freeway traffic volumes at individual detector stations against modeled freeway volumes for the peak direction on the I-15 corridor. As the figures show, ***simulated volumes are within 15 percent of observed volumes for more than 99 percent of the observations.***

Figure 5-1. Detector Volume Comparison for Southbound I-15 – 06:00-07:00 AM

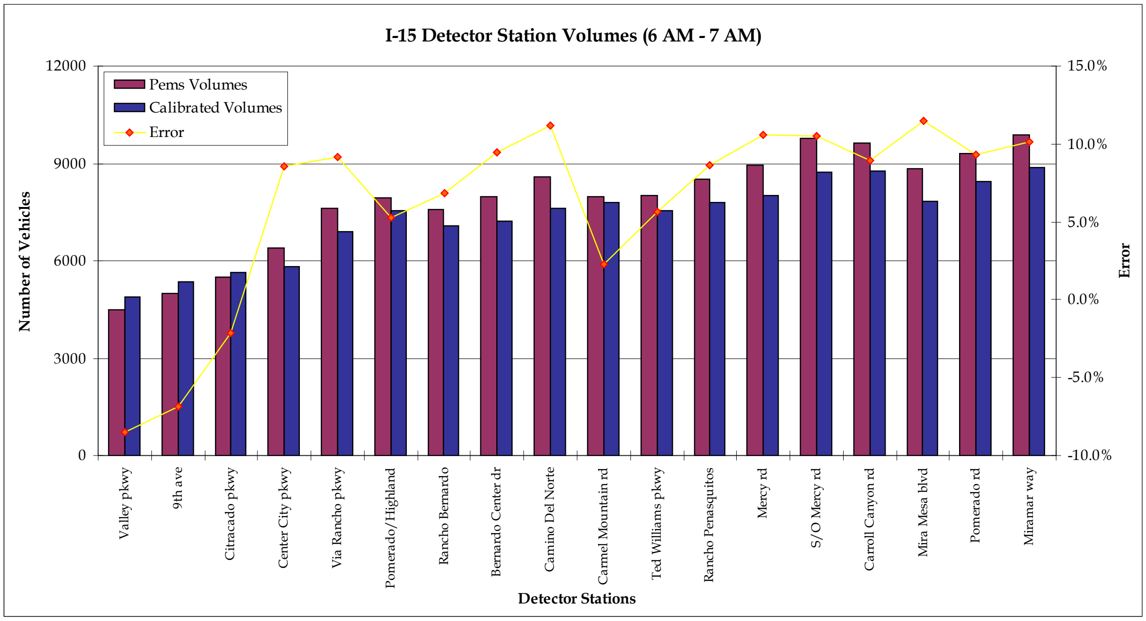


Figure 5-2. Detector Volume Comparison for Southbound I-15 – 07:00-08:00 AM

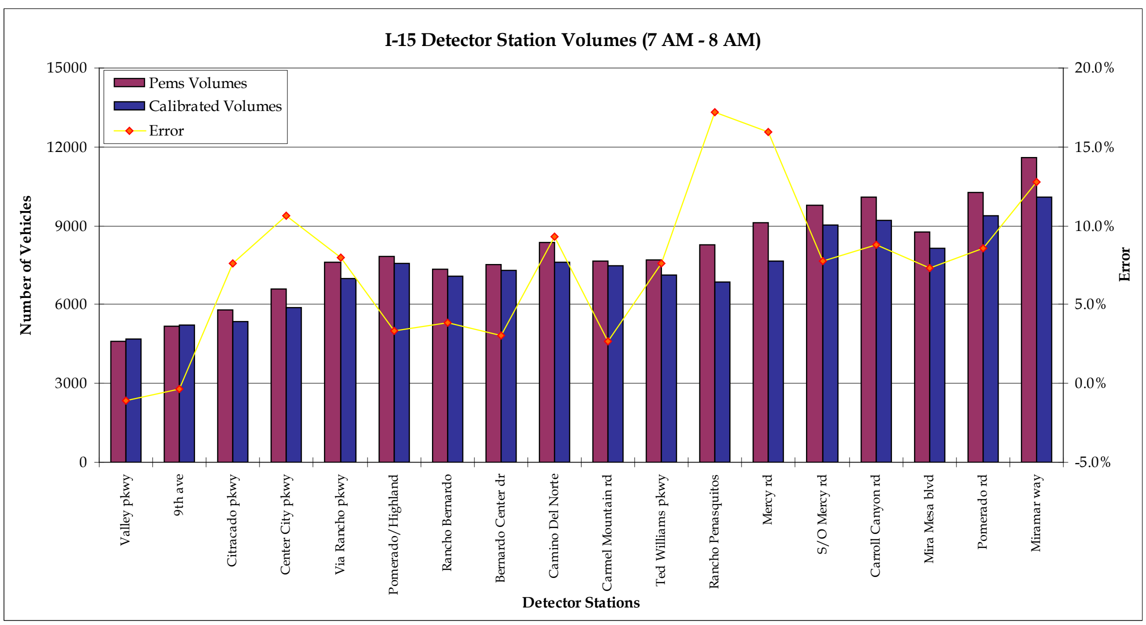
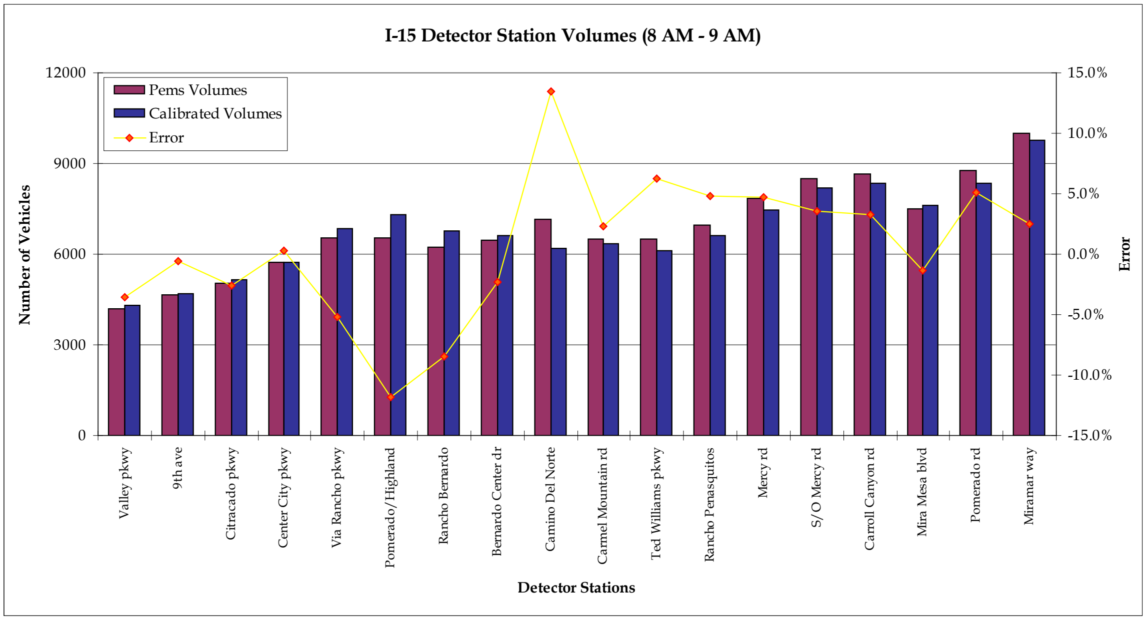


Figure 5-3. Detector Volume Comparison for Southbound I-15 – 08:00-09:00 AM



Speed Profile Comparisons – Typical Day

Observed speed contours were developed based on the PeMS database for September to October 2003. These observed speed contours were compared against simulation model-generated speed contour profiles. The PeMS database provided 5-minute speed data between 6:00 AM and 9:00 AM at 16 locations along the southbound I-15 corridor and at 15 locations along the northbound I-15 corridor. The northbound I-15 speed contours, from the PeMS database and from the calibrated simulation model, are shown in Tables 5-5 and 5-6, respectively. Corresponding speed contours for the southbound I-15 corridor, from the PeMS database and from the calibrated simulation model, are shown in Tables 5-7 and 5-8, respectively.

In the southbound direction, PeMS data suggest heavy congestion north of Lake Hodges during the AM peak period. This observed bottleneck extends all the way to the north end of the study corridor. The calibrated simulation model duplicates this bottleneck very closely, as can be seen in the observed and simulated speed profiles. The PeMS database also suggests some congestion between Mercy Road and Bernardo Center Drive sections of the freeway in the southbound direction. The simulation model approximates the severity and extent of this congestion and shows two separate bottlenecks at Mercy Road and Camino Del Norte, as observed in the PeMS speed profile.

I-15 in the northbound direction flowed freely during the AM peak period in year 2003. The PeMS speed database, as well as the calibrated simulation model, both suggest free-flowing traffic in the northbound direction.

Table 5-5. 06:00-09:00 AM Northbound Observed Speed Contours at Five-Minute Intervals *PeMS, 2003*

Northbound I-15 PeMS Speed Contours at 5-Minute Intervals															
	PeMS Detector Stations														
Segment	Miramar Way	EB Miramar Rd	Carroll Canyon Rd	EB Mira Mesa Blvd	Mercy Rd	EB Poway Rd	Carmel Mountain Rd	Camino Del Norte	Bernardo Center Dr	Rancho Bernardo	Pomerado/Highland	Via Rancho Pkwy	Citracado Pkway	Auto Park Way	Valley Pkwy
Detector	1108536	1108454	1108439	1108415	1108717	1108585	1108590	1108592	1108597	1108595	1108562	1108767	1108769	1108771	1108773
Time Period (a.m.)															
6:00-6:05	70.5	69.6	69.5	67.9	71.3	68.4	67.9	70.5	69.1	69.3	68.8	64.6	69.0	68.3	69.0
6:05-6:10	70.5	69.2	68.9	67.7	70.8	67.6	66.9	69.7	68.3	69.0	68.6	64.4	69.0	68.3	69.0
6:10-6:15	69.4	68.8	68.7	67.7	70.5	67.1	66.8	69.3	67.8	68.7	68.0	63.8	68.9	68.2	68.9
6:15-6:20	68.9	68.2	67.7	68.0	70.6	67.1	66.7	69.2	67.7	68.7	68.1	64.0	69.1	68.4	69.1
6:20-6:25	68.5	67.8	67.4	67.9	70.3	66.3	66.9	69.7	68.0	68.9	68.3	64.3	69.1	68.4	69.1
6:25-6:30	68.1	67.4	67.2	67.7	70.3	66.5	67.0	69.5	68.0	69.0	68.7	64.7	69.1	68.4	69.1
6:30-6:35	67.8	67.5	67.5	67.6	69.8	66.0	66.6	69.3	68.2	69.4	69.2	65.4	69.2	68.5	69.2
6:35-6:40	67.6	67.6	67.3	67.8	69.8	66.0	66.8	69.2	68.1	69.2	69.0	65.0	69.4	68.7	69.4
6:40-6:45	68.0	67.9	68.0	68.2	70.0	66.0	66.6	69.0	68.0	69.2	69.1	65.0	69.5	68.8	69.5
6:45-6:50	67.8	68.2	68.1	68.4	70.5	66.5	67.1	68.7	68.0	68.8	69.5	65.4	69.9	69.2	69.9
6:50-6:55	68.2	68.2	67.9	68.3	71.0	65.9	67.8	69.1	68.5	69.0	69.3	65.0	70.2	69.5	70.2
6:55-7:00	68.6	68.8	68.5	68.7	71.5	66.7	67.8	69.5	68.8	69.3	69.8	65.6	70.2	69.5	70.2
7:00-7:05	68.6	67.8	65.9	68.2	71.6	67.3	68.3	69.7	69.3	69.6	69.7	65.1	70.1	69.4	70.1
7:05-7:10	68.6	67.2	65.0	68.0	71.1	66.7	67.8	69.2	69.4	69.7	70.0	65.5	70.0	69.3	70.0
7:10-7:15	67.0	66.1	64.8	67.8	70.8	66.4	67.7	68.9	69.1	69.4	69.7	65.3	69.9	69.2	69.9
7:15-7:20	65.9	65.6	64.9	67.7	70.4	66.0	67.6	68.7	68.6	69.3	69.5	65.2	69.6	68.9	69.6
7:20-7:25	66.0	65.7	65.4	67.7	70.4	64.6	67.4	68.5	68.4	69.3	69.4	65.0	69.4	68.7	69.4
7:25-7:30	65.5	65.5	65.4	67.9	70.0	62.5	67.6	68.5	68.4	69.6	69.6	65.3	69.4	68.7	69.4
7:30-7:35	65.6	65.7	65.5	67.4	69.2	61.3	67.6	68.0	68.7	69.6	69.6	65.4	69.2	68.5	69.2
7:35-7:40	65.6	65.3	65.0	67.4	69.0	60.7	67.4	68.3	68.8	69.5	69.7	65.2	69.2	68.5	69.2
7:40-7:45	65.7	65.3	65.0	67.4	68.3	57.2	67.3	68.4	68.8	69.8	69.7	65.5	69.2	68.5	69.2
7:45-7:50	65.3	65.6	65.1	67.1	66.7	54.5	67.4	68.3	68.7	69.9	69.7	65.4	69.2	68.5	69.2
7:50-7:55	65.1	65.2	65.0	65.8	62.4	52.2	67.2	68.1	68.8	69.9	70.0	65.6	69.5	68.8	69.5
7:55-8:00	65.6	65.4	64.8	64.6	60.3	47.5	67.5	68.1	68.9	69.9	70.0	65.7	69.4	68.7	69.4
8:00-8:05	65.5	66.1	65.5	63.6	58.1	45.5	67.1	67.9	68.8	69.7	70.2	65.8	69.6	68.9	69.6
8:05-8:10	66.0	66.4	66.0	63.4	57.8	48.7	66.8	67.2	68.2	69.5	69.8	65.3	69.3	68.6	69.3
8:10-8:15	65.8	66.1	65.7	63.7	59.1	49.2	66.6	67.2	68.5	69.4	69.4	65.2	69.0	68.3	69.0
8:15-8:20	65.8	66.3	65.4	62.9	58.1	47.4	66.5	67.0	67.9	69.1	69.2	64.8	68.8	68.1	68.8
8:20-8:25	65.8	66.2	65.6	62.1	56.6	45.3	65.9	66.6	67.5	68.5	69.0	64.8	68.7	68.0	68.7
8:25-8:30	65.5	65.7	65.6	62.6	57.7	44.1	66.0	66.3	67.3	68.0	68.3	64.3	68.5	67.8	68.5
8:30-8:35	66.1	66.3	66.0	62.5	57.6	43.1	65.4	66.3	67.0	67.7	68.1	64.5	68.5	67.8	68.5
8:35-8:40	66.6	66.9	66.5	61.1	55.9	43.6	65.7	66.2	66.9	67.8	68.1	63.8	68.2	67.5	68.2
8:40-8:45	67.0	67.2	66.5	61.1	55.3	43.4	65.0	65.7	66.6	67.5	68.1	64.0	68.1	67.4	68.1
8:45-8:50	66.7	66.5	66.1	62.0	57.8	45.8	65.2	65.9	66.9	67.7	68.2	64.3	67.9	67.2	67.9
8:50-8:55	66.9	66.7	65.9	62.3	59.0	48.9	65.2	65.7	66.6	67.6	68.3	64.4	68.1	67.4	68.1
8:55-9:00	68.4	67.1	66.0	62.7	60.6	51.5	65.0	65.5	66.4	67.5	68.1	64.0	68.1	67.4	68.1

Table 5-6. 06:00-09:00 AM Northbound Simulation Model Speed Contours at Five-Minute Intervals

Northbound I-15 Calibrated Simulation Model Speed Contours at 5-Minute Intervals															
	PeMS Detector Stations														
Segment	Miramar Way	EB Miramar Rd	Carroll Canyon Rd	EB Mira Mesa Blvd	Mercy Rd	EB Poway Rd	Carmel Mountain Rd	Camino Del Norte	Bernardo Center Dr	Rancho Bernardo	Pomerado/Highland	Via Rancho Pkwy	Citracado Pkway	Auto Park Way	Valley Pkwy
Detector	1108536	1108454	1108439	1108415	1108717	1108585	1108590	1108592	1108597	1108595	1108562	1108767	1108769	1108771	1108773
Time Period (a.m.)															
6:00-6:05	63.6	65.1	63.1	65.8	63.2	63.4	65.7	66.5	66.2	65.4	64.8	68.2	66.8	64.0	66.7
6:05-6:10	64.8	64.7	65.2	65.5	64.7	62.5	65.2	66.5	65.3	64.5	62.9	68.1	64.8	64.2	67.8
6:10-6:15	63.3	66.6	64.5	66.0	65.5	63.4	65.7	64.0	63.4	65.8	63.3	66.9	65.8	62.9	68.6
6:15-6:20	64.5	65.4	65.8	66.6	62.2	62.4	63.9	66.8	65.9	65.5	63.4	66.7	65.6	63.8	66.6
6:20-6:25	64.1	63.8	61.7	66.2	62.6	62.9	64.6	67.7	65.1	64.9	63.6	65.7	65.4	64.5	66.3
6:25-6:30	65.3	65.6	63.4	64.9	62.8	64.7	65.4	66.3	67.0	65.6	63.1	66.6	64.3	64.0	65.7
6:30-6:35	62.8	63.5	64.9	67.2	65.3	64.3	66.6	66.8	65.4	65.8	62.5	67.0	65.6	64.5	66.5
6:35-6:40	63.9	65.0	66.0	66.8	65.0	63.9	65.4	64.2	63.8	67.1	64.6	68.3	67.3	66.3	68.5
6:40-6:45	63.4	66.0	64.5	67.1	63.6	65.9	65.3	66.2	62.9	64.7	64.7	67.0	65.6	64.9	65.9
6:45-6:50	63.5	65.9	63.6	66.7	65.5	64.6	65.6	66.9	65.0	66.0	63.1	66.9	65.3	65.0	69.9
6:50-6:55	63.8	65.1	66.8	65.8	64.0	65.5	66.0	64.4	64.0	66.2	61.5	65.6	64.8	63.3	65.9
6:55-7:00	63.8	65.1	62.7	66.2	62.4	64.2	64.3	65.8	63.8	63.7	62.4	66.8	65.8	64.9	65.4
7:00-7:05	63.7	62.5	65.9	66.7	64.2	61.2	66.2	65.7	65.3	66.5	63.9	65.6	66.4	64.7	66.2
7:05-7:10	62.8	64.2	63.9	67.4	57.3	63.0	66.6	63.1	62.5	63.9	63.9	67.5	66.4	62.6	66.2
7:10-7:15	62.3	65.2	61.6	68.3	64.8	60.1	64.4	63.9	65.1	62.8	63.1	68.0	65.1	63.5	64.7
7:15-7:20	62.6	63.4	60.3	67.4	61.4	65.2	65.2	62.8	65.1	65.5	64.5	66.5	65.2	63.4	67.9
7:20-7:25	63.0	66.2	56.3	69.0	63.1	66.0	66.7	61.8	64.8	66.8	62.5	65.8	67.0	65.4	66.8
7:25-7:30	63.9	64.6	57.4	68.9	60.9	63.9	63.8	62.0	65.6	65.3	63.6	66.5	65.7	65.0	67.1
7:30-7:35	63.4	64.2	58.5	69.3	61.1	63.9	65.6	64.0	65.6	67.0	63.3	67.8	65.8	63.5	65.8
7:35-7:40	63.7	64.2	63.5	68.7	63.5	64.8	64.7	63.3	64.2	65.9	62.2	65.8	65.2	64.8	66.9
7:40-7:45	63.8	64.2	60.3	66.7	62.7	64.3	65.3	63.4	65.7	66.5	63.3	65.8	64.7	64.4	65.5
7:45-7:50	62.7	63.2	63.3	67.3	62.2	63.0	66.4	63.7	53.5	69.1	64.5	66.7	65.8	63.4	64.6
7:50-7:55	64.6	64.3	62.1	70.4	62.5	63.2	64.5	65.2	52.2	67.0	64.6	66.0	65.0	64.8	65.4
7:55-8:00	64.1	64.5	63.7	66.2	63.3	63.6	64.4	64.3	52.0	67.6	64.3	68.5	66.0	63.9	65.3
8:00-8:05	64.3	62.6	63.8	68.4	61.3	61.5	65.0	63.8	51.5	65.9	64.3	66.9	63.9	63.0	66.9
8:05-8:10	62.3	62.0	64.8	67.0	63.8	58.7	64.6	63.6	53.2	67.9	65.4	66.1	64.7	62.7	65.4
8:10-8:15	61.7	60.3	61.3	68.4	62.4	65.1	65.0	66.3	52.8	66.6	63.5	65.4	64.5	63.4	68.1
8:15-8:20	62.3	62.5	58.3	68.3	62.9	59.2	66.0	63.3	55.6	67.8	64.6	65.8	64.7	63.7	64.3
8:20-8:25	62.7	60.5	56.5	67.1	62.4	56.6	64.1	60.7	49.5	72.3	66.5	69.3	66.2	63.4	67.6
8:25-8:30	64.7	62.8	55.7	67.3	60.0	59.1	65.5	60.3	50.1	66.7	65.3	69.7	68.2	68.3	68.4
8:30-8:35	64.1	66.1	55.4	66.7	64.6	60.5	65.1	58.9	51.8	64.0	67.8	67.5	66.6	65.3	66.3
8:35-8:40	62.7	62.4	64.0	68.8	67.3	61.6	64.6	56.7	50.3	69.2	67.1	69.3	67.4	66.2	67.5
8:40-8:45	64.9	63.9	64.0	67.5	63.1	60.4	60.1	56.5	50.7	68.9	68.6	69.5	66.7	67.0	67.0
8:45-8:50	64.9	62.2	65.3	67.8	64.6	60.0	59.3	55.9	54.8	60.6	63.2	65.6	65.2	66.8	67.6
8:50-8:55	64.2	63.5	64.0	66.9	59.3	61.8	57.2	55.4	58.2	51.8	60.8	64.1	66.3	61.4	64.5
8:55-9:00	64.6	63.4	64.8	67.1	65.5	61.5	55.1	53.2	64.7	63.9	63.2	69.4	65.4	52.8	61.0

Table 5-7. 06:00-09:00 AM Southbound Observed Speed Contours at Five-Minute Intervals *PeMS, 2003*

Southbound I-15 PeMS Speed Contours at 5-Minute Intervals																	
	PeMS Detector Stations																
Segment	Miramar Way	WB Pomerado Rd	Carrol Canyon Rd**	WB Mira Mesa Blvd	Mercy Rd	WB Rancho	Ted Williams Pkwy	Carmel Mountain Rd	Camino Del Norte	Bernardo Center Dr	Rancho Bernardo	Pomerado/Highland	Via Rancho Pkwy	Center City Pkwy	Citracado Pkwy	9th Ave	Valley Pkwy
Detector	1108607	1108495		1108491	1108450	1108489	1108429	1108427	1108425	1108519	1108538	1108541	1108543	1108545	1108516	1108558	1108556
Time Period (a.m.)	13.35	14.61		16.23	17.39	18.49	19.03	20.68	22.05	23.05	24.00	26.10	27.03	27.70	28.88	30.22	30.93
6:00-6:05	69.0	68.4	-	67.1	66.3	64.4	65.9	61.9	67.4	65.5	66.0	54.8	27.6	17.1	22.3	20.6	15.1
6:05-6:10	68.5	67.7	-	66.2	65.5	64.0	65.9	60.6	67.1	63.9	65.1	55.2	28.2	17.5	20.8	16.3	12.9
6:10-6:15	68.3	67.2	-	64.9	64.8	63.7	66.2	58.7	66.4	64.1	64.6	54.9	28.1	18.2	19.9	14.0	11.0
6:15-6:20	68.1	67.4	-	64.8	64.3	63.5	65.8	56.2	66.4	64.3	65.2	54.7	27.3	17.0	19.8	12.4	9.9
6:20-6:25	68.3	67.1	-	64.2	63.5	63.8	66.3	55.6	64.2	64.2	65.1	56.7	27.0	15.2	18.9	12.9	8.9
6:25-6:30	68.3	67.3	-	64.1	63.3	64.4	66.3	54.6	60.3	64.5	65.1	56.7	27.5	15.0	16.5	12.3	9.0
6:30-6:35	68.0	66.9	-	63.5	61.1	65.1	66.7	53.2	56.6	64.2	65.6	56.8	27.8	15.0	16.8	10.9	8.4
6:35-6:40	68.0	66.8	-	62.5	57.8	65.4	67.2	52.6	53.5	63.4	66.1	56.2	27.4	15.1	16.8	11.1	7.6
6:40-6:45	68.8	67.0	-	61.4	55.4	63.0	67.8	51.7	48.5	61.2	65.6	54.8	29.0	15.4	16.6	11.1	7.7
6:45-6:50	69.2	67.0	-	60.2	51.8	61.2	66.2	51.7	44.1	57.7	65.0	54.0	26.5	17.1	16.4	11.1	7.5
6:50-6:55	69.5	67.2	-	58.2	49.9	58.6	64.3	50.8	41.7	54.4	63.6	55.5	27.0	16.1	19.1	10.8	7.4
6:55-7:00	69.0	66.6	-	57.2	45.9	55.6	61.6	49.4	38.4	53.9	62.0	57.6	26.6	17.2	16.6	12.3	7.6
7:00-7:05	68.8	66.9	-	55.8	42.9	52.2	59.6	48.0	37.2	51.3	60.0	56.8	26.9	16.9	18.9	11.2	8.0
7:05-7:10	68.2	66.5	-	56.3	40.4	47.6	55.8	47.4	34.7	49.6	57.6	55.0	28.2	16.9	18.8	11.4	7.7
7:10-7:15	67.9	65.9	-	55.7	37.8	41.9	50.7	46.9	33.9	47.0	53.8	54.7	28.3	16.4	18.7	11.7	8.0
7:15-7:20	68.2	66.2	-	55.6	36.2	35.0	44.1	46.8	32.0	45.0	51.7	54.8	27.7	16.4	18.3	12.4	8.3
7:20-7:25	67.5	65.7	-	54.8	34.6	28.9	34.9	44.3	30.5	43.1	50.8	51.6	25.6	16.7	18.4	12.3	8.3
7:25-7:30	66.8	64.0	-	54.5	34.9	25.5	29.0	41.3	27.7	45.0	52.2	54.3	25.0	15.6	18.4	12.8	8.2
7:30-7:35	66.5	64.7	-	54.5	33.7	22.5	26.1	37.3	27.1	40.5	53.8	54.1	25.7	16.6	17.7	12.1	8.4
7:35-7:40	66.8	64.6	-	52.4	33.3	22.1	23.6	34.4	24.7	40.7	53.3	57.4	26.8	17.0	19.6	12.4	8.2
7:40-7:45	66.5	63.9	-	53.9	31.4	22.3	22.6	30.7	23.9	41.0	54.3	58.3	25.7	16.8	20.1	13.0	8.2
7:45-7:50	66.7	63.9	-	54.2	31.1	19.9	20.7	28.0	23.1	43.9	52.8	55.1	25.0	16.0	19.1	13.7	8.9
7:50-7:55	66.5	64.5	-	53.1	32.5	19.9	17.9	28.4	23.7	45.3	51.9	56.1	25.7	15.9	18.9	13.6	9.3
7:55-8:00	66.2	65.2	-	52.9	34.9	20.2	18.7	28.4	25.3	43.6	52.6	55.6	25.7	16.1	18.9	13.7	9.1
8:00-8:05	66.4	66.0	-	52.9	34.6	20.7	19.1	31.4	26.7	42.5	52.1	54.8	25.6	17.5	18.9	13.2	9.8
8:05-8:10	66.5	65.7	-	53.1	33.2	21.8	18.7	30.2	29.7	42.2	50.3	54.9	26.0	16.8	20.6	13.9	9.6
8:10-8:15	66.3	65.6	-	52.7	34.2	21.6	19.6	34.2	29.4	42.0	48.2	53.0	25.0	17.2	21.2	17.0	10.1
8:15-8:20	66.0	65.3	-	52.7	35.9	23.0	19.3	32.3	29.8	41.0	47.6	54.9	25.4	17.0	21.5	17.7	11.4
8:20-8:25	66.2	65.7	-	53.1	36.2	23.7	20.6	32.2	30.6	44.4	48.5	53.9	25.5	17.9	20.5	17.8	14.0
8:25-8:30	66.1	65.8	-	52.6	37.7	25.1	22.0	32.1	30.6	43.3	50.7	53.3	24.5	17.8	21.2	17.7	15.8
8:30-8:35	66.3	65.5	-	52.7	38.3	28.3	24.5	36.2	29.9	43.7	51.4	54.4	24.5	16.7	23.5	19.6	18.6
8:35-8:40	66.0	65.5	-	53.4	38.7	29.2	26.8	39.6	32.8	45.0	51.9	55.1	25.4	16.4	22.4	22.9	22.4
8:40-8:45	66.3	65.9	-	52.7	35.0	32.7	28.0	41.3	38.9	46.3	52.9	55.0	25.1	18.1	20.8	24.9	26.2
8:45-8:50	66.0	65.6	-	52.3	36.4	30.8	32.5	42.0	44.1	50.1	53.9	54.5	24.4	19.3	26.0	26.9	30.5
8:50-8:55	65.8	65.4	-	52.2	39.4	31.6	32.3	44.6	46.5	54.7	56.0	54.5	24.6	19.7	30.2	31.1	37.7
8:55-9:00	66.0	65.4	-	52.4	40.7	36.7	35.9	45.1	48.4	57.6	58.6	54.2	26.3	24.3	30.6	33.0	46.6

Table 5-8. 06:00-09:00 AM Southbound Simulation Model Speed Contours at Five-Minute Intervals

Southbound I-15 Calibrated Simulation Model Speed Contours at 5-Minute Intervals																		
	PeMS Detector Stations																	
Segment	Miramar Way	WB Pomerado Rd	Carrol Canyon Rd	WB Mira Mesa Blvd	Mercy Rd	WB Rancho	Ted Williams Pkwy	Carmel Mountain Rd	Camino Del Norte	Bernardo Center Dr	Rancho Bernardo	Pomerado/Highland	Via Rancho Pkwy	Center City Pkwy	Citracado Pkway	9th Ave	Valley Pkwy
Detector	1108607	1108495		1108491	1108450	1108489	1108429	1108427	1108425	1108519	1108538	1108541	1108543	1108545	1108516	1108558	1108556
Time Period (a.m.)	13.35	14.61		16.23	17.39	18.49	19.03	20.68	22.05	23.05	24.00	26.10	27.03	27.70	28.88	30.22	30.93
6:00-6:05	62.7	64.3	-	55.8	61.6	64.0	65.1	53.9	33.1	49.4	65.3	62.9	22.0	13.5	33.2	59.7	43.6
6:05-6:10	62.9	65.3	-	56.7	64.7	63.3	64.9	59.2	39.5	43.8	65.1	63.0	21.1	14.6	23.6	56.2	41.5
6:10-6:15	63.3	64.2	-	58.0	63.0	62.4	64.3	51.3	41.0	40.8	64.9	63.9	20.4	13.1	21.8	57.6	45.3
6:15-6:20	61.7	62.6	-	56.7	63.7	63.1	64.4	52.5	43.9	51.4	67.0	62.1	21.6	13.7	17.1	54.5	38.4
6:20-6:25	64.3	63.9	-	56.8	64.4	62.7	64.5	60.4	34.9	54.3	64.7	64.1	19.7	13.6	14.1	56.1	43.5
6:25-6:30	64.6	65.3	-	58.7	63.8	64.3	64.8	52.2	41.3	55.0	66.5	62.8	20.0	13.5	13.0	53.4	45.1
6:30-6:35	62.8	64.1	-	59.6	48.5	62.9	63.8	60.1	36.6	46.2	64.6	62.1	21.6	13.6	12.8	52.4	43.3
6:35-6:40	64.6	66.6	-	57.6	23.8	63.0	63.5	54.2	55.4	38.8	64.8	63.3	20.6	13.9	12.3	49.2	40.0
6:40-6:45	62.7	64.8	-	60.1	12.8	62.7	65.3	56.2	41.6	41.6	66.9	63.9	19.5	12.9	12.3	47.5	40.0
6:45-6:50	64.4	63.4	-	58.2	13.5	64.1	64.9	55.8	42.8	46.4	66.8	61.5	19.2	13.5	11.7	49.5	47.1
6:50-6:55	63.4	65.4	-	58.5	12.7	63.3	64.2	46.5	38.9	55.0	66.9	64.6	19.3	13.2	11.8	45.8	46.1
6:55-7:00	63.3	64.9	-	59.6	11.6	63.5	65.0	51.1	33.7	59.1	65.7	62.8	19.1	13.4	11.8	32.7	41.7
7:00-7:05	61.9	62.6	-	59.1	12.4	63.5	66.1	57.5	45.7	55.3	64.7	62.9	19.5	13.3	11.6	24.9	41.9
7:05-7:10	62.4	65.0	-	59.5	11.9	64.5	65.4	53.2	36.2	56.0	65.9	63.3	19.4	14.0	11.8	15.2	35.1
7:10-7:15	63.7	67.1	-	58.7	13.2	64.3	65.6	36.5	29.6	52.6	64.9	62.8	18.7	12.9	12.8	10.9	21.5
7:15-7:20	61.5	64.5	-	60.0	11.6	60.7	65.1	16.9	27.4	49.8	65.5	63.7	19.9	13.6	11.5	10.4	13.4
7:20-7:25	62.3	67.3	-	59.5	10.6	21.0	65.2	15.9	23.2	56.4	65.4	62.4	21.0	15.5	12.0	10.0	10.6
7:25-7:30	61.5	64.1	-	56.1	12.6	12.5	65.7	13.2	25.5	49.1	66.5	63.7	18.4	13.6	13.6	10.1	9.7
7:30-7:35	62.2	64.5	-	58.3	12.4	12.8	60.3	14.4	32.0	45.8	65.4	62.6	19.3	13.1	12.1	10.8	10.6
7:35-7:40	63.6	64.9	-	59.2	11.9	14.7	44.2	14.0	24.0	50.2	66.5	63.0	22.4	16.3	11.7	10.9	11.0
7:40-7:45	63.3	66.1	-	60.2	13.9	13.4	26.1	16.2	27.2	54.0	64.9	63.6	22.8	16.2	13.8	10.3	11.0
7:45-7:50	62.9	63.1	-	61.3	11.2	15.0	18.3	14.4	23.8	52.4	66.4	63.2	23.0	16.1	14.2	11.0	11.8
7:50-7:55	63.4	64.3	-	59.5	11.7	13.6	16.2	13.3	21.6	53.9	66.2	62.8	20.0	15.7	14.1	11.4	12.7
7:55-8:00	63.8	64.6	-	59.7	11.3	12.1	13.4	14.7	19.7	57.1	65.0	62.0	21.9	14.5	13.6	11.6	13.0
8:00-8:05	63.5	65.9	-	58.3	12.2	13.3	11.1	13.2	15.6	52.5	64.9	64.1	21.4	15.7	12.4	12.1	11.6
8:05-8:10	62.6	66.0	-	59.3	12.6	12.9	11.2	13.8	14.5	48.0	67.0	61.3	21.7	15.0	13.0	11.8	11.8
8:10-8:15	62.6	64.0	-	58.1	12.0	12.8	11.4	13.8	14.7	37.7	66.2	62.0	21.5	15.1	13.6	11.2	11.5
8:15-8:20	62.9	65.8	-	59.5	11.7	13.4	11.6	11.0	13.3	34.5	65.4	63.9	20.6	15.5	14.0	10.9	10.2
8:20-8:25	64.1	64.8	-	59.1	12.0	14.2	12.3	10.6	9.9	41.0	66.6	62.5	20.9	15.1	13.7	11.9	9.8
8:25-8:30	62.9	66.6	-	58.9	13.0	13.6	12.1	10.5	9.5	54.0	67.0	64.5	21.2	16.4	12.7	12.0	10.8
8:30-8:35	63.4	65.0	-	60.5	13.7	14.8	12.1	10.9	11.0	50.3	67.3	62.8	22.3	15.3	13.8	11.9	11.7
8:35-8:40	63.1	62.9	-	60.8	12.0	16.4	13.1	10.9	9.7	35.9	65.8	64.2	20.5	15.5	13.7	11.4	11.5
8:40-8:45	63.8	65.3	-	60.0	12.2	14.8	15.1	12.3	11.6	23.9	65.4	62.9	23.2	16.4	13.7	12.6	11.1
8:45-8:50	63.7	65.4	-	60.1	13.6	13.8	11.8	14.3	11.9	19.4	66.9	63.1	22.8	17.7	15.0	11.4	11.0
8:50-8:55	64.4	61.5	-	59.1	12.4	15.1	11.6	14.9	12.3	23.5	72.0	63.4	23.7	19.1	15.5	12.4	10.6
8:55-9:00	63.3	63.5	-	59.1	14.1	13.7	13.7	11.7	11.8	60.1	67.4	63.4	25.1	18.9	16.1	13.0	11.4

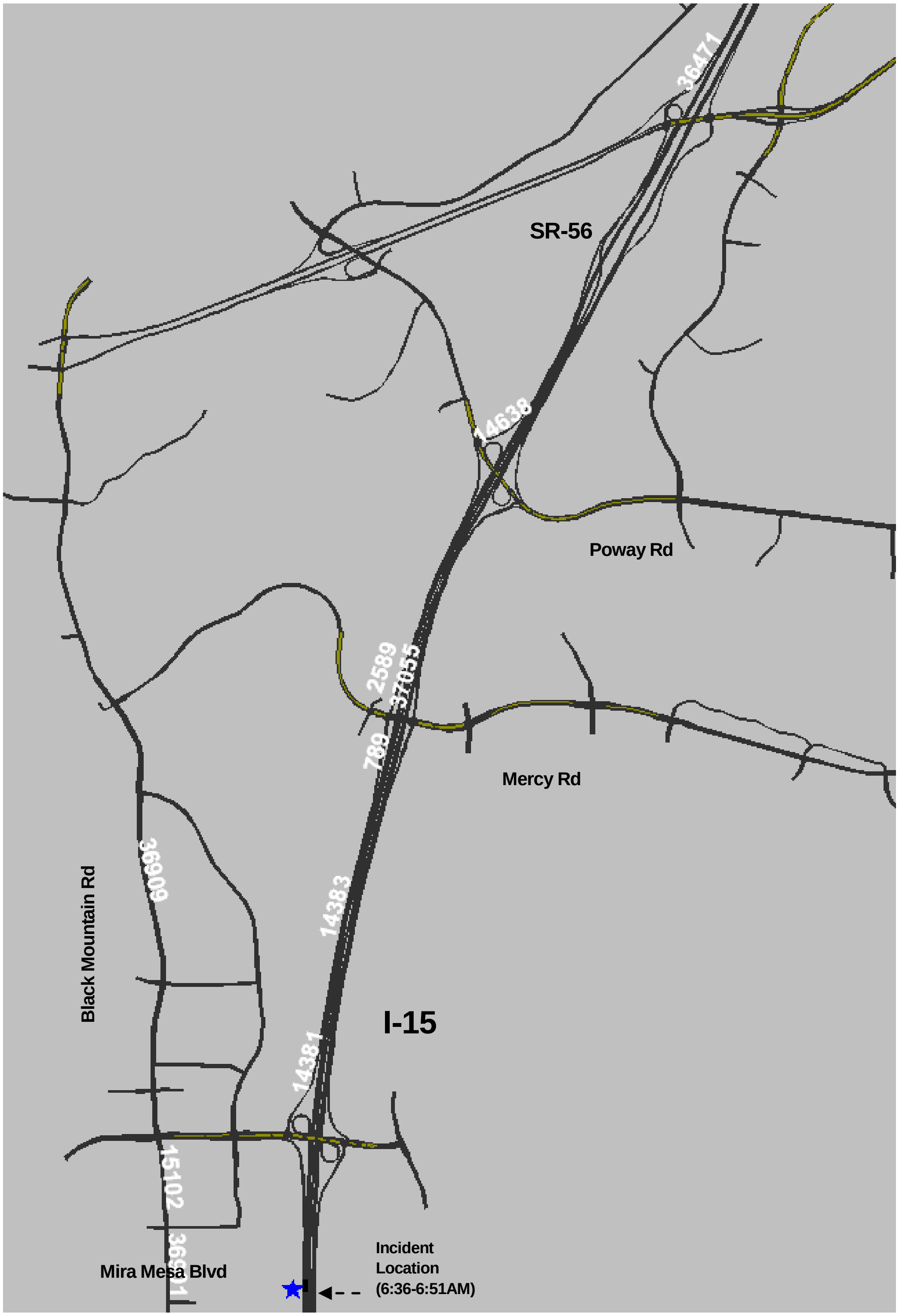
Overall, the similarities between observed and model speed patterns signify that the model adequately replicates bottlenecks, travel times, and congestion on the I-15 Corridor for a typical day.

Baseline Model Validation Results – Incident Day

This section provides a summary of the simulation model calibration results for an incident day on I-15. The I-15 model calibration findings are listed below, following the U.S. DOT incident calibration guidance.

- **Freeway bottleneck locations should be on a modeled segment that is consistent in location, design, and attributes of the representative roadway section.** The incident modeled on I-15 is located at the freeway southbound south of the Mira Mesa Boulevard interchange, blocking one lane of traffic, starting at 6:36 AM and ending at 6:51 AM. Traveler information for diversion is dispersed starting at 6:40 AM and ending at 7:30 AM. Figure 5-4 shows the incident location and affected links. **Calibration criterion is met** – modeled segment is consistent in location, design, and attributes of the representative roadway section.
- **Duration of incident-related congestion – duration where observable within 25 percent.** Tables 5-9 through 5-13 show speed contours for PeMS baseline with no incident (Table 5-9), PeMS baseline with incident (Table 5-10), Model baseline with no incident (Table 5-11), Model baseline with incident and no diversion information to travelers (Table 5-12), and Model baseline with incident and diversion information to 20 percent of travelers (Table 5-13). **Qualitative expectations are met**: a) modeled congestion is more with incident than without, as is in PeMS, b) modeled congestion is less with 20 percent informed travelers than with no informed travelers. **Quantitative expectations are also met**: a) incident-caused (6:40 AM to 7:30 AM) congested speeds (red or under 30 mph) in PeMS occupy **53** five-minute periods/segments (Table 5-10), while model incident-congested speeds occupy **50** five-minute periods/segments (Table 5-12). **The difference of three periods/segments is well within the 25-percent range recommended by the U.S. DOT.**
- **Extent of queue propagation: should be within 20 percent**. The bulk of incident-caused (6:40 AM to 7:30 AM) congestion (red or speeds under 30 mph) in PeMS extends for **seven** freeway segments upstream of the incident (Table 5-11 – up to Rancho Bernardo), while model incident caused congestion extends for **five** freeway segments upstream of the incident (Table 5-13 – up to Camino del Norte). **The difference of two segments is not within the 20-percent range recommended by the U.S. DOT – this criterion is not met in the strict sense.** However, PeMS congestion in the last segment (Rancho Bernardo – 25 minutes of red) can be countered by the 25 minutes of congestion in the model at the incident location (westbound Mira Mesa Boulevard), which does not appear in PeMS.

Figure 5-4. I-15 Transportation Network Showing Incident Location and Affected Links



Source: TransModeler output screen capture, Caliper© Corporation, September 2010.

Table 5-9. PeMS Baseline Without Incident

Segment	Miramar Way	WB Pomerado Rd	WB Mira Mesa Blvd	Mercy Rd	WB Rancho	Ted Williams Pkwy	Carmel Mountain Rd	Camino Del Norte	Bernardo Center Dr	Rancho Bernardo	Pomerado /Highland	Via Rancho Pkwy	Center City Pkwy	Citracado Pkway	9th Ave	Valley Pkwy
Detector	1108607	1108495	1108491	1108450	1108489	1108429	1108427	1108425	1108519	1108538	1108541	1108543	1108545	1108516	1108558	1108556
Segment Ids	37332	14407	37344	789	14660	570	37338	37339	37342	37022	8810	722	562	12946	12944	36530
Time Period (a.m.)																
6:00-6:05	69.0	68.4	67.1	66.3	64.4	65.9	61.9	67.4	65.5	66.0	54.8	27.6	17.1	22.3	20.6	15.1
6:05-6:10	68.5	67.7	66.2	65.5	64.0	65.9	60.6	67.1	63.9	65.1	55.2	28.2	17.5	20.8	16.3	12.9
6:10-6:15	68.3	67.2	64.9	64.8	63.7	66.2	58.7	66.4	64.1	64.6	54.9	28.1	18.2	19.9	14.0	11.0
6:15-6:20	68.1	67.4	64.8	64.3	63.5	65.8	56.2	66.4	64.3	65.2	54.7	27.3	17.0	19.8	12.4	9.9
6:20-6:25	68.3	67.1	64.2	63.5	63.8	66.3	55.6	64.2	64.2	65.1	56.7	27.0	15.2	18.9	12.9	8.9
6:25-6:30	68.3	67.3	64.1	63.3	64.4	66.3	54.6	60.3	64.5	65.1	56.7	27.5	15.0	16.5	12.3	9.0
6:30-6:35	68.0	66.9	63.5	61.1	65.1	66.7	53.2	56.6	64.2	65.6	56.8	27.8	15.0	16.8	10.9	8.4
6:35-6:40	68.0	66.8	62.5	57.8	65.4	67.2	52.6	53.5	63.4	66.1	56.2	27.4	15.1	16.8	11.1	7.6
6:40-6:45	68.8	67.0	61.4	55.4	63.0	67.8	51.7	48.5	61.2	65.6	54.8	29.0	15.4	16.6	11.1	7.7
6:45-6:50	69.2	67.0	60.2	51.8	61.2	66.2	51.7	44.1	57.7	65.0	54.0	26.5	17.1	16.4	11.1	7.5
6:50-6:55	69.5	67.2	58.2	49.9	58.6	64.3	50.8	41.7	54.4	63.6	55.5	27.0	16.1	19.1	10.8	7.4
6:55-7:00	69.0	66.6	57.2	45.9	55.6	61.6	49.4	38.4	53.9	62.0	57.6	26.6	17.2	16.6	12.3	7.6
7:00-7:05	68.8	66.9	55.8	42.9	52.2	59.6	48.0	37.2	51.3	60.0	56.8	26.9	16.9	18.9	11.2	8.0
7:05-7:10	68.2	66.5	56.3	40.4	47.6	55.8	47.4	34.7	49.6	57.6	55.0	28.2	16.9	18.8	11.4	7.7
7:10-7:15	67.9	65.9	55.7	37.8	41.9	50.7	46.9	33.9	47.0	53.8	54.7	28.3	16.4	18.7	11.7	8.0
7:15-7:20	68.2	66.2	55.6	36.2	35.0	44.1	46.8	32.0	45.0	51.7	54.8	27.7	16.4	18.3	12.4	8.3
7:20-7:25	67.5	65.7	54.8	34.6	28.9	34.9	44.3	30.5	43.1	50.8	51.6	25.6	16.7	18.4	12.3	8.3
7:25-7:30	66.8	64.0	54.5	34.9	25.5	29.0	41.3	27.7	45.0	52.2	54.3	25.0	15.6	18.4	12.8	8.2
7:30-7:35	66.5	64.7	54.5	33.7	22.5	26.1	37.3	27.1	40.5	53.8	54.1	25.7	16.6	17.7	12.1	8.4
7:35-7:40	66.8	64.6	52.4	33.3	22.1	23.6	34.4	24.7	40.7	53.3	57.4	26.8	17.0	19.6	12.4	8.2
7:40-7:45	66.5	63.9	53.9	31.4	22.3	22.6	30.7	23.9	41.0	54.3	58.3	25.7	16.8	20.1	13.0	8.2
7:45-7:50	66.7	63.9	54.2	31.1	19.9	20.7	28.0	23.1	43.9	52.8	55.1	25.0	16.0	19.1	13.7	8.9
7:50-7:55	66.5	64.5	53.1	32.5	19.9	17.9	28.4	23.7	45.3	51.9	56.1	25.7	15.9	18.9	13.6	9.3
7:55-8:00	66.2	65.2	52.9	34.9	20.2	18.7	28.4	25.3	43.6	52.6	55.6	25.7	16.1	18.9	13.7	9.1
8:00-8:05	66.4	66.0	52.9	34.6	20.7	19.1	31.4	26.7	42.5	52.1	54.8	25.6	17.5	18.9	13.2	9.8
8:05-8:10	66.5	65.7	53.1	33.2	21.8	18.7	30.2	29.7	42.2	50.3	54.9	26.0	16.8	20.6	13.9	9.6
8:10-8:15	66.3	65.6	52.7	34.2	21.6	19.6	34.2	29.4	42.0	48.2	53.0	25.0	17.2	21.2	17.0	10.1
8:15-8:20	66.0	65.3	52.7	35.9	23.0	19.3	32.3	29.8	41.0	47.6	54.9	25.4	17.0	21.5	17.7	11.4
8:20-8:25	66.2	65.7	53.1	36.2	23.7	20.6	32.2	30.6	44.4	48.5	53.9	25.5	17.9	20.5	17.8	14.0
8:25-8:30	66.1	65.8	52.6	37.7	25.1	22.0	32.1	30.6	43.3	50.7	53.3	24.5	17.8	21.2	17.7	15.8
8:30-8:35	66.3	65.5	52.7	38.3	28.3	24.5	36.2	29.9	43.7	51.4	54.4	24.5	16.7	23.5	19.6	18.6
8:35-8:40	66.0	65.5	53.4	38.7	29.2	26.8	39.6	32.8	45.0	51.9	55.1	25.4	16.4	22.4	22.9	22.4
8:40-8:45	66.3	65.9	52.7	35.0	32.7	28.0	41.3	38.9	46.3	52.9	55.0	25.1	18.1	20.8	24.9	26.2
8:45-8:50	66.0	65.6	52.3	36.4	30.8	32.5	42.0	44.1	50.1	53.9	54.5	24.4	19.3	26.0	26.9	30.5
8:50-8:55	65.8	65.4	52.2	39.4	31.6	32.3	44.6	46.5	54.7	56.0	54.5	24.6	19.7	30.2	31.1	37.7
8:55-9:00	66.0	65.4	52.4	40.7	36.7	35.9	45.1	48.4	57.6	58.6	54.2	26.3	24.3	30.6	33.0	46.6

Table 5-10. PeMS Baseline with Incident

Segment	Miramar Way	WB Pomerado Rd	WB Mira Mesa Blvd	Mercy Rd	WB Rancho	Ted Williams Pkwy	Carmel Mountain Rd	Camino Del Norte	Bernardo Center Dr	Rancho Bernardo	Pomerado/ Highland	Via Rancho Pkwy	Center City Pkwy	Citracado Pkway	9th Ave	Valley Pkwy
Detector	1108607	1108495	1108491	1108450	1108489	1108429	1108427	1108425	1108519	1108538	1108541	1108543	1108545	1108516	1108558	1108556
Segment Ids	37332	14407	37344	789	14660	570	37338	13664	13653	37022	8810	722	562	12946	12944	36530
Time Period (a.m.)	28.66	27.07	26.81	25.79	24.85	24.18	22.26	19.71	18.45	16.29	15.79	13.83	13.11	12.27	11.35	10.21
6:00	68.3	68.1	61.2	64.5	62.2	66.0	61.2	66.8	61.3	63.1	59.4	25.0	16.6	23.7	25.7	24.8
6:05	69.0	69.0	62.6	65.5	63.5	65.7	60.6	68.6	62.4	65.4	60.3	25.1	14.4	19.7	20.1	17.7
6:10	69.6	68.1	55.9	57.9	65.9	67.4	61.7	68.6	64.5	66.0	59.1	24.2	16.1	17.7	15.7	13.9
6:15	70.3	69.1	58.7	57.7	64.9	66.5	62.3	67.9	64.7	66.3	59.8	27.3	15.1	25.6	12.4	12.4
6:20	69.9	68.7	58.9	61.6	63.9	65.3	59.4	68.5	67.0	67.3	58.1	27.7	15.7	21.0	17.2	9.8
6:25	69.2	67.5	58.9	65.3	64.7	67.7	61.5	69.4	67.3	67.4	45.9	29.6	14.9	20.5	13.7	11.8
6:30	70.0	69.2	62.0	66.4	65.8	68.2	63.6	69.4	65.6	66.5	57.1	27.6	14.0	16.4	12.3	9.3
6:35	70.2	69.3	52.3	51.4	66.7	69.4	63.5	69.6	59.4	60.8	60.8	33.9	15.8	15.3	11.2	10.4
6:40	71.9	70.7	49.0	30.7	48.3	69.3	62.7	68.0	60.0	59.9	61.8	35.9	16.4	16.1	10.6	8.6
6:45	73.3	71.1	48.4	21.6	28.3	40.1	54.8	67.9	65.0	65.1	62.1	34.0	18.0	22.0	12.6	7.7
6:50	73.7	71.6	50.1	17.2	21.1	24.5	53.3	69.0	67.5	67.1	62.0	37.3	18.2	20.4	13.8	7.7
6:55	73.3	70.9	51.0	16.3	15.6	17.3	40.2	68.4	68.3	68.5	63.9	29.3	17.0	21.3	12.6	10.2
7:00	71.4	68.2	50.5	20.8	13.1	13.0	26.7	64.8	69.3	68.1	63.2	26.9	19.7	17.7	12.7	9.9
7:05	69.3	68.2	47.6	31.4	15.8	12.3	20.8	38.2	67.0	65.7	60.6	33.6	20.1	25.6	11.5	9.1
7:10	69.3	67.6	48.6	38.3	20.6	17.8	17.1	24.9	39.4	55.6	63.4	36.3	20.9	23.3	15.2	8.2
7:15	69.7	68.4	51.4	39.9	22.7	20.6	20.4	17.4	25.6	37.7	61.9	30.6	22.8	21.3	13.2	9.0
7:20	71.3	69.2	50.9	29.6	26.0	20.1	24.9	15.9	17.7	27.4	63.4	27.5	17.1	24.7	12.7	10.7
7:25	70.2	67.4	50.4	36.7	19.9	20.3	40.6	14.4	17.5	24.0	62.8	27.4	22.0	18.8	18.4	9.2
7:30	70.5	67.6	47.5	43.5	25.4	16.4	44.2	21.0	14.9	20.9	38.3	25.5	16.7	20.2	13.4	10.3
7:35	70.7	69.9	44.7	35.0	26.3	25.6	32.9	26.1	30.0	20.8	25.5	18.3	14.9	16.2	15.1	9.9
7:40	69.5	68.4	48.5	37.7	20.8	22.3	29.1	19.6	43.3	28.8	31.4	14.5	11.4	14.7	12.8	9.2
7:45	68.8	68.4	48.9	34.7	23.6	19.3	41.6	17.3	28.7	43.2	30.2	15.5	9.4	12.2	10.6	8.4
7:50	69.9	68.8	48.5	30.5	24.1	19.0	30.3	25.9	22.3	41.2	32.0	20.8	10.0	10.1	9.1	7.3
7:55	69.9	67.6	51.2	31.4	21.9	18.0	30.9	22.1	40.1	39.4	46.6	26.0	12.3	11.3	7.4	6.5
8:00	68.9	67.6	51.3	31.5	20.0	17.9	34.4	17.2	37.4	51.9	40.2	29.8	13.5	13.8	7.7	5.8
8:05	68.4	67.7	51.8	36.5	19.4	16.0	32.0	18.6	27.6	59.3	52.6	26.3	16.4	19.6	8.5	6.7
8:10	68.8	68.9	50.6	35.4	21.6	14.5	28.2	17.6	28.6	57.3	60.1	25.8	15.3	18.5	10.8	6.4
8:15	68.2	68.7	50.4	29.0	23.6	21.6	36.8	15.5	25.7	62.5	61.2	26.8	17.7	17.6	11.6	8.6
8:20	69.3	69.7	52.3	24.8	19.3	24.2	29.6	21.9	21.0	63.0	60.5	28.5	16.8	20.9	11.6	10.3
8:25	68.2	69.7	47.8	23.5	15.6	20.2	42.3	17.0	29.9	54.9	60.2	24.5	15.2	19.8	12.8	9.3
8:30	68.5	69.3	51.0	29.6	16.1	17.6	40.9	23.0	25.2	54.8	59.6	28.0	13.7	18.8	17.9	10.7
8:35	67.5	69.5	54.8	27.8	22.3	16.7	32.2	24.7	40.2	47.4	59.7	27.3	18.7	15.7	14.4	10.1
8:40	69.4	70.1	53.1	25.6	19.0	22.2	27.4	21.2	48.8	55.8	57.3	25.7	20.2	28.1	11.1	10.2
8:45	69.1	69.3	50.8	28.3	18.1	19.2	30.7	18.5	39.5	62.1	57.8	24.0	22.3	25.0	27.8	8.8
8:50	68.8	68.4	51.0	25.2	26.6	18.0	30.1	17.6	27.1	64.7	60.4	23.6	16.9	25.7	18.9	14.1
8:55	68.5	68.5	49.8	23.7	19.3	20.0	30.9	28.0	24.2	54.4	59.6	26.3	16.1	22.3	20.4	12.6

Table 5-11. Model Baseline Without Incident

Segment	Miramar Way	WB Pomerado Rd	WB Mira Mesa Blvd	Mercy Rd	WB Rancho	Ted Williams Pkwy	Carmel Mountain Rd	Camino Del Norte	Bernardo Center Dr	Rancho Bernardo	Pomerado /Highland	Via Rancho Pkwy	Center City Pkwy	Citracado Pkway	9th Ave	Valley Pkwy
Detector	1108607	1108495	1108491	1108450	1108489	1108429	1108427	1108425	1108519	1108538	1108541	1108543	1108545	1108516	1108558	1108556
Segment Ids	37332	14407	37344	789	14660	570	37338	13664	13653	37022	8810	722	562	12946	12944	36530
Time Period (a.m.)	28.7	27.1	26.8	25.8	24.9	24.2	22.3	19.7	18.5	16.3	15.8	13.8	13.1	12.3	11.4	10.2
6:00	63.6	65.1	58.7	64.4	62.3	66.4	53.5	46.0	52.9	63.6	62.9	19.3	15.2	62.8	60.3	48.5
6:05	66.0	65.3	60.8	64.4	63.4	64.1	58.1	48.8	48.7	65.1	62.5	20.8	13.4	60.2	62.6	44.7
6:10	64.1	65.4	56.8	62.0	62.0	61.6	56.7	28.2	52.0	66.5	63.4	19.1	14.2	56.8	62.0	46.6
6:15	64.4	62.4	58.1	57.4	64.8	64.9	47.6	40.7	56.3	67.4	62.2	18.3	13.1	49.4	59.6	51.4
6:20	62.8	64.6	58.8	23.4	62.8	65.2	45.3	54.9	56.7	64.8	63.2	21.9	12.3	38.7	62.3	41.9
6:25	63.8	64.9	57.6	13.0	63.0	65.7	55.9	42.2	55.7	65.5	59.9	20.5	13.7	28.8	57.0	46.5
6:30	62.7	66.3	59.8	11.3	63.5	64.4	53.4	54.7	55.3	67.0	62.2	21.1	13.7	23.5	62.8	32.9
6:35	64.9	65.0	58.4	11.5	63.0	64.9	57.3	46.4	55.8	66.5	63.4	20.7	13.4	18.4	59.4	43.2
6:40	64.9	64.2	59.8	11.3	63.2	65.1	54.9	53.4	54.9	67.5	64.0	20.5	12.4	14.9	63.8	50.4
6:45	64.2	61.8	58.3	11.4	62.5	65.2	51.6	48.1	53.6	65.7	62.7	20.9	13.8	13.7	62.6	44.8
6:50	63.0	64.9	56.2	11.4	62.6	64.9	53.4	35.7	48.4	66.9	63.5	19.5	13.4	13.2	58.6	45.8
6:55	64.4	66.5	59.6	12.3	51.6	65.1	47.0	42.4	47.9	64.5	62.5	20.5	13.8	12.4	61.5	43.5
7:00	63.9	66.1	60.1	11.4	24.2	64.6	46.0	31.3	46.7	63.6	61.1	21.0	13.2	11.8	52.9	46.5
7:05	62.0	64.2	57.3	11.5	17.6	65.0	23.8	26.6	50.2	63.9	63.4	20.4	13.7	12.0	43.9	45.2
7:10	63.3	64.9	61.3	11.4	12.2	64.9	17.0	27.4	47.2	68.1	61.4	19.2	12.9	12.3	28.7	28.5
7:15	62.5	66.1	58.6	11.6	11.5	39.3	14.7	23.8	54.1	64.5	63.9	19.7	13.2	11.6	15.8	41.1
7:20	63.3	65.7	57.9	13.1	12.5	18.3	14.9	24.0	53.4	66.3	61.4	22.2	13.1	11.2	12.2	30.4
7:25	61.4	63.6	58.9	12.3	13.6	12.8	13.6	34.5	49.1	65.8	62.4	21.4	13.3	12.0	11.1	25.3
7:30	63.6	62.6	57.4	13.8	13.8	12.3	12.9	42.3	50.4	66.1	62.1	20.9	14.1	12.1	10.6	23.6
7:35	63.2	63.6	59.7	12.9	13.1	11.3	15.1	32.6	51.7	65.2	62.4	21.2	13.7	12.6	11.5	20.2
7:40	62.1	64.5	58.4	13.2	14.7	12.2	13.6	25.2	53.0	64.1	61.2	20.8	13.6	12.3	11.3	20.4
7:45	64.0	65.2	57.7	13.6	15.4	13.6	14.8	18.7	52.0	66.6	62.8	21.5	14.1	12.2	10.9	20.7
7:50	62.3	63.1	59.0	11.9	15.4	13.9	10.9	19.7	54.5	67.0	62.8	22.3	14.7	13.2	10.9	18.8
7:55	62.6	63.8	58.9	11.0	12.9	13.8	11.5	14.8	49.8	65.5	63.1	22.1	13.9	13.1	11.2	16.9
8:00	62.0	64.5	59.2	13.3	12.5	11.8	11.8	11.4	51.8	65.0	61.7	20.4	14.0	12.4	11.1	16.5
8:05	63.3	63.9	60.1	11.0	13.9	11.6	12.4	12.5	45.1	66.4	61.8	21.6	14.3	12.4	10.9	12.9
8:10	62.6	64.6	57.7	13.6	12.8	11.9	9.1	10.4	50.3	66.5	62.4	21.0	13.8	12.6	11.0	11.8
8:15	63.8	64.9	57.9	11.8	13.1	10.2	10.1	9.7	47.6	65.8	62.6	21.3	13.4	12.1	10.9	10.2
8:20	62.3	63.7	59.5	11.7	14.4	11.3	9.2	9.2	26.0	66.4	62.6	22.0	14.1	12.3	10.6	10.7
8:25	63.3	66.2	59.1	12.5	13.2	12.0	10.3	8.7	17.3	65.3	61.6	21.9	14.2	13.1	10.4	9.1
8:30	63.5	64.7	60.8	12.6	13.4	12.1	11.3	9.9	14.0	66.6	62.9	21.4	14.1	13.1	11.6	10.4
8:35	63.7	65.6	63.2	11.1	14.9	12.5	11.1	9.9	12.6	65.5	62.0	21.6	15.3	13.0	10.9	10.7
8:40	63.8	64.2	61.7	13.1	14.3	14.2	11.6	9.6	11.0	66.7	63.3	21.9	16.4	13.7	10.9	8.9
8:45	64.3	63.4	58.6	12.2	14.3	12.8	13.4	10.6	12.6	67.2	64.5	22.5	16.0	14.9	10.7	11.5
8:50	63.4	63.2	59.5	11.9	16.9	13.1	12.9	16.9	13.4	65.3	62.0	25.1	15.8	13.9	12.1	13.8
8:55	63.9	63.6	59.5	11.7	12.6	14.6	10.1	18.2	12.3	65.0	61.3	24.1	17.8	14.4	13.0	16.1

Table 5-12. Model Baseline with Incident – *No Informed Drivers*

Segment	Miramar Way	WB Pomerado Rd	WB Mira Mesa Blvd	Mercy Rd	WB Rancho	Ted Williams Pkwy	Carmel Mountain Rd	Camino Del Norte	Bernardo Center Dr	Rancho Bernardo	Pomerado /Highland	Via Rancho Pkwy	Center City Pkwy	Citracado Pkway	9th Ave	Valley Pkwy
Detector	1108607	1108495	1108491	1108450	1108489	1108429	1108427	1108425	1108519	1108538	1108541	1108543	1108545	1108516	1108558	1108556
Segment Ids	37332	14407	37344	789	14660	570	37338	13664	13653	37022	8810	722	562	12946	12944	36530
Time Period (a.m.)	28.7	27.1	26.8	25.8	24.9	24.2	22.3	19.7	18.5	16.3	15.8	13.8	13.1	12.3	11.4	10.2
6:00	64.3	62.9	58.6	58.1	65.0	64.7	58.7	52.4	55.7	63.5	61.3	21.3	13.3	19.3	64.6	45.0
6:05	63.7	64.2	59.2	40.6	62.8	63.3	51.7	44.1	52.0	62.2	62.2	20.5	14.3	17.3	64.2	46.8
6:10	64.5	63.7	56.8	22.1	58.5	63.5	54.4	41.6	60.5	65.0	65.0	19.5	13.7	15.7	63.8	40.1
6:15	63.5	64.7	58.4	16.4	66.2	66.5	52.3	43.7	57.5	66.4	62.9	21.6	14.1	13.3	60.5	46.5
6:20	62.4	64.4	57.1	13.4	63.4	66.7	55.0	48.4	60.4	65.0	62.0	21.6	14.1	13.1	62.5	42.1
6:25	64.1	64.7	58.1	12.6	62.5	60.3	49.7	55.3	57.0	66.3	65.0	21.0	14.3	12.9	61.3	49.4
6:30	64.7	65.3	58.2	11.6	59.2	64.9	56.3	41.3	56.1	67.7	62.3	24.3	14.6	12.7	63.2	51.2
6:35	64.7	66.2	57.5	12.3	63.3	65.6	50.2	47.6	54.7	64.7	63.0	22.2	15.0	12.8	60.2	43.0
6:40	65.5	67.3	22.7	11.6	62.2	64.4	51.1	41.0	53.1	64.6	63.1	20.5	14.3	13.2	55.7	41.1
6:45	65.4	67.1	12.4	9.9	64.2	65.1	45.9	38.6	58.7	66.1	63.4	21.4	12.9	12.5	46.4	43.8
6:50	65.1	66.4	15.1	7.7	27.0	66.2	37.8	44.3	55.5	65.1	64.4	19.3	14.4	11.9	48.1	37.2
6:55	63.2	64.9	23.6	9.9	8.2	51.6	20.2	46.4	60.6	65.5	63.4	20.6	13.7	12.6	35.6	40.8
7:00	64.0	66.4	26.1	13.1	11.0	15.1	17.1	45.1	59.5	66.0	63.0	19.8	14.3	12.3	28.8	42.6
7:05	61.4	64.9	34.5	13.0	12.0	9.7	16.0	36.1	51.3	64.7	63.9	20.5	13.8	12.1	20.4	36.7
7:10	62.0	65.7	57.8	11.9	13.9	12.6	15.0	31.4	51.9	64.8	61.9	22.0	13.5	12.2	13.7	27.4
7:15	63.7	63.0	59.6	11.9	14.4	12.0	11.4	35.3	53.9	68.2	64.5	19.6	14.7	12.5	10.6	17.8
7:20	62.7	63.9	59.2	11.3	13.0	12.6	11.1	31.8	56.3	64.7	62.5	19.8	14.4	13.2	10.1	12.6
7:25	63.9	65.7	58.6	11.5	12.2	11.1	11.5	17.8	43.4	65.1	61.6	20.6	14.9	12.5	11.2	13.2
7:30	60.3	63.9	60.0	12.4	13.2	11.4	10.5	10.9	58.0	66.3	63.2	21.9	16.4	12.6	10.2	11.8
7:35	62.9	61.9	60.6	13.5	14.2	12.3	10.9	9.1	52.3	66.1	62.6	22.0	15.5	13.7	10.3	11.8
7:40	63.4	66.3	60.2	12.1	14.9	13.6	10.2	9.5	44.4	66.2	62.4	21.1	14.5	13.7	11.4	11.9
7:45	61.1	63.6	59.2	11.8	14.7	13.7	12.1	10.0	24.3	68.2	63.8	21.7	15.8	12.7	11.7	13.2
7:50	62.3	64.9	59.7	12.1	13.2	12.6	13.2	10.1	17.5	65.5	62.3	20.6	14.4	14.2	11.0	12.0
7:55	63.5	64.8	61.8	10.6	13.8	13.0	14.0	10.4	14.6	65.8	61.9	21.5	14.7	13.2	11.6	12.7
8:00	62.6	63.5	56.5	10.7	11.4	11.1	10.0	11.5	16.7	65.1	62.8	21.2	14.9	13.3	11.0	12.6
8:05	62.4	66.5	58.4	12.4	11.8	10.7	12.1	8.5	15.4	66.4	62.9	20.8	15.6	13.2	11.5	12.5
8:10	61.4	65.9	59.1	11.9	13.5	11.8	9.5	10.6	13.9	66.2	64.1	21.1	15.2	13.9	11.8	10.8
8:15	63.3	65.2	60.5	11.1	13.3	11.4	8.1	8.4	14.8	66.9	61.9	22.5	14.8	13.3	12.0	11.2
8:20	62.0	64.6	59.9	11.4	12.1	12.0	10.4	7.2	10.5	64.8	62.5	21.8	15.8	13.8	11.5	9.9
8:25	62.5	64.5	58.6	11.4	11.9	10.7	11.3	10.4	12.7	67.1	63.1	20.8	16.5	14.3	11.6	10.6
8:30	63.5	63.2	61.0	10.6	12.4	9.5	10.2	9.8	13.2	65.7	62.9	22.1	16.4	14.6	11.9	10.6
8:35	62.7	64.4	58.6	12.6	13.5	11.3	9.4	9.3	14.7	61.6	63.4	23.1	16.7	14.5	11.7	10.4
8:40	63.9	63.7	59.9	12.3	15.1	12.9	8.4	8.8	12.9	30.9	65.0	23.4	17.5	14.5	12.6	11.7
8:45	62.6	64.6	62.6	12.4	13.0	12.4	11.8	8.1	10.8	16.5	63.8	24.3	18.9	14.8	12.5	14.8
8:50	62.2	65.6	62.8	11.5	13.6	13.1	12.4	10.4	14.0	9.4	62.2	24.2	18.5	15.3	12.0	14.6
8:55	62.5	65.5	58.6	11.6	11.6	10.9	13.9	9.6	12.6	9.3	63.0	23.7	20.4	16.2	13.1	18.9

Table 5-13. Model Baseline with Incident

Segment	Miramar Way	WB Pomerado Rd	WB Mira Mesa Blvd	Mercy Rd	WB Rancho	Ted Williams Pkwy	Carmel Mountain Rd	Camino Del Norte	Bernardo Center Dr	Rancho Bernardo	Pomerado /Highland	Via Rancho Pkwy	Center City Pkwy	Citracado Pkway	9th Ave	Valley Pkwy
Detector	1108607	1108495	1108491	1108450	1108489	1108429	1108427	1108425	1108519	1108538	1108541	1108543	1108545	1108516	1108558	1108556
Segment Ids	37332	14407	37344	789	14660	570	37338	13664	13653	37022	8810	722	562	12946	12944	36530
Time Period (a.m.)	28.7	27.1	26.8	25.8	24.9	24.2	22.3	19.7	18.5	16.3	15.8	13.8	13.1	12.3	11.4	10.2
6:00	63.3	63.4	59.0	62.9	62.7	64.0	52.1	45.7	52.6	66.3	64.7	19.9	13.7	29.3	62.9	48.0
6:05	63.7	64.3	57.5	64.4	60.6	63.4	58.9	47.7	60.7	64.9	62.4	19.9	12.9	22.8	61.4	47.7
6:10	61.8	64.4	60.5	62.9	63.0	63.7	61.3	42.5	57.8	66.7	62.4	19.2	13.2	18.0	59.8	43.8
6:15	62.2	65.2	57.8	59.4	63.0	64.7	54.5	46.0	60.8	66.2	64.0	20.9	12.5	14.9	60.1	38.1
6:20	63.4	65.5	59.3	34.8	63.7	64.5	55.0	28.6	58.9	65.4	63.2	19.9	14.3	12.4	55.3	41.6
6:25	63.4	65.5	59.1	18.1	62.5	66.4	52.9	48.0	54.9	65.1	62.4	21.6	12.4	12.9	62.0	42.2
6:30	63.2	64.8	59.3	12.7	62.5	65.2	52.1	36.3	55.4	66.7	63.5	21.4	14.1	11.5	55.1	46.5
6:35	65.7	67.0	59.3	12.7	62.8	65.8	54.3	40.2	49.2	65.5	63.8	20.2	13.4	12.3	50.3	44.6
6:40	64.2	65.7	24.2	12.5	62.0	65.4	53.4	48.8	49.6	65.5	64.0	20.6	14.0	12.3	44.5	46.5
6:45	65.8	65.9	14.8	11.0	65.6	66.8	50.0	50.1	61.2	66.9	68.3	20.8	14.0	13.4	43.9	47.3
6:50	61.7	63.9	15.5	11.8	65.3	65.8	53.3	49.5	61.0	65.7	64.7	20.2	13.3	12.5	45.6	44.2
6:55	61.1	64.9	27.0	9.7	64.1	65.2	56.4	49.9	57.4	66.7	66.0	18.4	13.7	11.9	42.7	45.9
7:00	61.8	65.1	52.1	12.3	62.8	66.2	56.6	40.4	58.5	65.4	64.2	20.6	12.6	11.9	32.5	42.9
7:05	61.9	66.1	57.6	11.7	62.5	62.8	54.0	39.7	60.0	64.3	64.0	20.4	13.4	11.5	20.1	38.6
7:10	62.5	64.2	57.0	12.9	49.1	65.0	52.2	32.7	60.9	62.3	63.3	18.6	13.3	12.1	13.1	30.6
7:15	61.7	63.0	56.4	13.4	17.3	65.6	51.9	35.2	59.9	65.3	63.1	21.5	12.3	12.3	10.5	21.6
7:20	62.7	64.4	58.8	11.7	13.4	65.7	35.2	35.5	49.2	65.2	63.8	19.8	15.0	12.1	10.5	13.8
7:25	60.9	65.5	61.6	11.9	12.6	63.5	28.2	43.1	57.9	64.5	62.4	20.3	17.3	13.2	10.0	12.6
7:30	62.9	62.9	58.6	12.5	13.2	42.5	26.6	37.0	48.7	64.5	62.9	21.6	16.2	14.4	11.2	14.8
7:35	61.3	65.4	60.4	11.5	13.4	26.8	21.3	37.4	54.4	65.7	62.7	20.6	15.9	14.2	11.5	15.4
7:40	61.6	66.0	59.6	13.1	12.5	17.0	18.5	37.6	47.5	65.7	63.4	21.6	13.6	13.8	11.9	16.6
7:45	63.3	67.1	63.0	12.9	13.9	11.5	16.5	32.3	51.9	66.2	62.5	20.1	15.7	12.2	11.9	15.8
7:50	64.9	66.3	63.6	6.0	14.3	13.4	14.7	37.6	58.6	64.7	62.8	22.0	14.6	13.4	10.9	13.8
7:55	65.0	66.2	64.2	6.4	6.2	7.4	12.7	42.4	58.3	64.0	62.0	22.9	14.4	13.5	11.1	13.2
8:00	65.3	67.9	61.8	7.4	7.1	7.1	10.8	43.0	57.1	67.4	64.0	21.6	15.7	12.9	11.4	12.2
8:05	67.1	66.9	62.8	7.3	7.5	6.8	6.5	31.0	52.4	66.3	63.6	20.7	14.7	13.4	11.1	11.0
8:10	65.4	70.0	60.2	7.1	6.7	6.3	5.2	6.8	52.7	66.5	63.2	21.1	15.5	13.0	11.5	10.9
8:15	65.2	68.3	61.5	6.4	7.9	6.1	4.8	5.2	31.3	65.8	64.0	21.6	15.8	13.1	11.1	10.6
8:20	66.2	67.1	62.3	4.8	5.9	7.0	6.1	4.7	9.3	66.9	62.6	22.0	15.9	14.2	10.7	10.3
8:25	67.4	69.5	61.8	6.4	6.1	4.8	6.5	6.2	5.5	65.8	62.9	23.8	15.1	14.1	11.2	10.7
8:30	66.7	67.6	62.8	5.8	7.2	6.7	3.9	4.4	8.8	51.5	62.4	24.1	17.7	13.8	12.1	11.2
8:35	66.5	67.8	60.7	6.8	6.6	5.7	5.7	4.1	6.2	11.1	64.7	22.9	18.2	14.9	11.5	10.5
8:40	65.1	68.0	61.9	6.1	8.0	7.1	5.3	5.1	5.0	5.3	64.2	22.2	18.2	15.9	12.1	10.7
8:45	65.7	68.0	60.9	5.9	5.8	6.4	5.9	4.8	6.8	5.3	64.1	22.5	16.6	15.6	13.1	12.5
8:50	64.7	67.9	63.2	5.8	6.0	6.9	4.9	5.2	7.7	5.5	63.4	22.7	17.2	14.3	12.9	13.6
8:55	68.2	67.8	57.7	5.1	6.5	5.9	5.7	4.5	6.4	7.3	39.6	22.1	19.2	14.7	12.6	16.8

- **Diversion flows: Increase in ramp volumes where diversion is expected to take place**. Table 5-14 shows a comparison of model traffic volumes on freeway southbound, off-ramps, and parallel arterials for: a) baseline without incident, b) baseline with incident and no traveler information, and c) baseline with incident and traveler information to 20 percent of travelers. Overall findings include: a) freeway volumes decrease upstream of the incident, and increase after incident information is provided to travelers; b) off-ramp volumes increase upstream of the incident especially between 6:00 AM and 7:00 AM; c) parallel arterial volumes increase upstream of the incident between 6:00 AM and 8:00 AM when diversion information is provided to travelers. **This criterion is met**. Freeway volumes decrease and off-ramp and parallel arterial volumes increase as a result of the incident.
- **Arterial breakdown when incident. Cycle failures or lack of cycle failures**. Diverted traffic of approximately 225 vph is not deemed enough to induce traffic signal cycle failures on the parallel arterial (Black Mountain Road).

Overall findings: Criteria 1, 2, and 4 are met. Criterion 3 is not. Criterion 5 is not applicable. ***The model adequately replicates traffic volumes, bottlenecks, travel times, and congestion on the I-15 Corridor for an incident day.***

Table 5-14. Comparison of Traffic Volumes for I-15 Incident Model Calibration

Road Locations (With Link ID# in TransModeler)	SB I-15 Freeway Mainlines (From North to South)			SB I-15 Off-Ramps (From North To South)			SB Arterial Roads (From North To South)			Vehicle Hours Traveled (Vehicle-Hours)
	Between Mercy Rd Ramps (#789)	Between Mercy Rd and Mira Mesa (#14383)	To SR 56 (#36471)	To Poway Rd (#14638)	To Mercy Rd (#2589)	To Mira Mesa Blvd (#14381)	Black Mountain Rd (#36909)	Black Mountain Rd (#15102)	Black Mountain Rd (#36901)	
6:00-7:00 AM										
A. Flow-baseline no incident	8,294	9,146	577	132	433	817	395	300	416	8,154.6
B. Flow-baseline w/incident w/o traveler information	7,546	8,399	578	127	404	781	378	282	391	8,309.7
C. Flow-baseline w/incident and improved traveler information (20% market penetration)	7,871	8,716	777	121	463	969	622	523	643	8,185.3
Percent change A to B	-9.0%	-8.2%	0.2%	-3.8%	-6.7%	-4.4%	-4.3%	-6.0%	-6.0%	1.9%
Percent change B to C	4.3%	3.8%	34.4%	-4.7%	14.6%	24.1%	64.6%	85.5%	64.5%	-1.5%

Table 5-15. Comparison of Traffic Volumes for I-15 Incident Model Calibration

Road Locations (With Link ID# in TransModeler)	SB I-15 Freeway Mainlines (From North to South)			SB I-15 Off-Ramps (From North To South)			SB Arterial Roads (From North To South)			Vehicle Hours Traveled (Vehicle-Hours)
	Between Mercy Rd Ramps (#789)	Between Mercy Rd and Mira Mesa (#14383)	To SR 56 (#36471)	To Poway Rd (#14638)	To Mercy Rd (#2589)	To Mira Mesa Blvd (#14381)	Black Mountain Rd (#36909)	Black Mountain Rd (#15102)	Black Mountain Rd (#36901)	
7:00-8:00 AM										
D. Flow-baseline no incident	7,816	8,815	597	122	371	937	914	441	675	12,040.1
E. Flow-baseline w/incident w/o traveler information	7,677	8,682	546	112	340	940	856	467	682	12,735.7
F. Flow-baseline w/incident and improved traveler information (20% market penetration)	7,252	7,843	633	126	346	720	1115	509	753	12,781.4
Percent change D to E	-1.8%	-1.5%	-8.5%	-8.2%	-8.4%	0.3%	-6.3%	5.9%	1.0%	5.8%
Percent change E to F	-5.5%	-9.7%	15.9%	12.5%	1.8%	-23.4%	30.3%	9.0%	10.4%	0.4%

Baseline Model Validation Results – Summary

Overall, the microscopic simulation model accurately captures AM peak characteristics on the I-15 freeway for baseline year 2003. Specifically:

- All hourly flow criteria were met for the three modeled hours (06:00 to 09:00 hrs), as per the guidelines set in the AMS Experimental Plan;
- The similarities between observed and model speed patterns signify that the model adequately replicates bottlenecks, travel times, and congestion on the I-15 Corridor for a typical day; and
- The model adequately replicates traffic volumes, bottlenecks, travel times, and congestion on the I-15 Corridor for an incident day.

Chapter 6 Analysis Results

The results for the I-15 corridor AMS are presented in this chapter. Results are presented for different operational conditions, ICM strategies, and performance measures employed in the analysis, including:

- ***Twelve operational conditions***, represented by combinations of high/medium/low demand with future baseline/freeway incident/arterial incident, as described in Section 3.1.
- ***ICM strategy alternatives***, including pre-ICM and post-ICM, pre-trip and en-route traveler information, ramp metering, congestion pricing for managed lanes, arterial traffic signal coordination, en-route mode shift, and combinations of these strategies.
- The analysis produced ***performance measures*** for all operational conditions and for all ICM strategies tested. Performance measures include mobility, reliability, fuel consumption, and emissions reported across different transportation modes, facility types, and jurisdictions.

Sections 6.1, 6.2, and 6.3 present the analysis results by incident scenario using the performance measures described in Appendix B. All measures presented in these sections are calculated on an origin-destination basis and are aggregated based on which corridors the travelers use, namely the I-15 SB, I-15 NB, SB HOT lanes, NB HOT lanes, or Arterial facilities. For example, if a traveler uses a section of I-15 SB, that traveler's entire trip is included in the I-15 SB trip set, and the entire trip travel distance and time is included in the VMT and VHT measures. This produces VMT and VHT that are greater than those values actually using the facilities, but represents the VMT and VHT for travelers that are influenced by the ICM strategies and operations on I-15. All travelers starting their trips between 6.00 to 11:00 AM are included in the analysis, including those travelers whose trips are incomplete at 11:00 AM. Estimations are made for the completed trip travel distance and time for these incomplete trips and are included in the analysis.

Section 6.4 presents and discusses the aggregated performance measures without ICM and with ICM, averaged over all operating conditions. As with results in the previous sections, performance measures discussed here are all O-D based as opposed to facility based.

Section 6.5 outlines the benefits that are estimated to result from ICM implementation. These benefits calculations are based on facility-specific performance measures. The one exception is travel time reliability, which is only definable at the O-D level. Reliability benefits attributed to I-15 SB were calculated from the change in the travel time variance for any trip using I-15 in the SB direction, either the general purpose or managed lanes. Similarly, I-15 NB reliability benefits were calculated from trips using any I-15 NB lane. Benefits were split between the general purpose and managed lanes based on the portion of vehicle hours of travel. The total systemwide benefits were calculated from the change in variance for all trips in the system. The I-15 SB and NB benefits were then subtracted from the entire network benefits, and the remaining reliability benefits were distributed amongst the non-I-15 facilities based on the share of vehicle hours of travel.
Section 6.6 outlines the costs associated with deploying the tested ICM system.

Section 6.7 outlines the conclusions and lessons-learned from the ICM analysis of the I-15 corridor in San Diego, California.

Future Baseline Scenarios

Peak-period volumes on roadways fluctuate throughout the year due to variations in travel demand by day of the week, time of the year, or other conditions. ICM strategies need to be evaluated under all the conditions throughout the year, not just the normal or average conditions. As such, future baseline or no incident conditions are simulated as occurring in three different demand conditions; low, medium, and high demand.

The future baseline scenarios under pre-ICM strategies were also used as the definition of the baseline conditions to determine the threshold for delay, or the zero-delay travel time, for the analysis. The minimum travel times for each origin, destination, and mode combination in the model in any of the three no incident pre-ICM scenarios were used to establish the zero delay travel time. These benchmark travel times were used in the ICM performance measure calculations presented later in this document. Further details of the use of the zero delay travel time in the performance measures are contained in Appendix B.

For the designated year of 2012, this future baseline model incorporated the geometric configuration and demand levels, anticipated for year 2012. Table 6-1 presents a comparison between the baseline models developed for years 2003 and 2012.

Table 6-1. Comparison Between 2003 Baseline and 2012 Future Baseline

	2003 Baseline			2012 Baseline		
Time Period	**VMT**	**VHT**	**Delay**	**VMT**	**VHT**	**Delay**
06:00-07:00	334,005	8,046	1,772	340,404	7,342	1,088
07:00-08:00	394,095	11,872	3,999	418,958	10,756	2,913
08:00-09:00	382,047	12,514	4,694	409,318	11,538	3,890
Total	**1,110,146**	**32,432**	**10,465**	**1,168,680**	**29,637**	**7,891**

As the results indicate, the entire network experiences a growth of 5 percent in VMT while experience a drop of 25 percent in overall delay. More importantly, the SB freeway section experiences an 11-percent increase in VMT while remaining free of delays for the most part. This can be largely attributed to the freeway improvements like auxiliary lanes, ramp metering, and additional lanes on ramps that are proposed to be built before 2012. The biggest contributor to this improvement, however, is the addition of Managed Lanes on the freeway, which delivers 22 percent of the SB Freeway VMT in 2012. The future baseline, thus, seems to indicate better performance on the freeways, which account for the majority of the anticipated improvements. The arterials experience a 4-percent growth in VMT delivered, but correspondingly get more congested, experiencing a 32-percent increase in overall delay. The overall network, however, still benefits from the improvements on the freeway.

ICM Strategies in Future Baseline Conditions

During the future baseline conditions, there is limited deployment of ICM strategies, but there are some elements at work. Through the use of VMS on roadways, the traveling population has an increased awareness of the roadway conditions. The following parameters were adjusted in the future baseline scenarios to model the without and with ICM conditions:

- The percentage of informed drivers (with real-time information) increased from 5 percent without ICM, to 30 percent with ICM; and
- The informed drivers receive updated travel time information every 20 minutes without ICM, and every 15 minutes with ICM.

Performance Measures in Future Baseline Conditions

The 2012 AM Peak model produces intuitive results. Tables 6-2 through 6-4 provide a comparison of VMT, VHT, and Delay without and with ICM for high, medium and low demand conditions in the baseline analysis year of 2012. As the results show, the introduction of ICM – which involves incorporating better and faster dissemination of information to users – produces reductions in delay and VHT, as shown in Figure 6-1. This figure (and similar figures in the remainder of this chapter) show travel time and delay savings in the same figure; for the reader's convenience, travel times are posted above the x-axis, and delays are posted below the x-axis. These figures show travel time and delay savings between with ICM (white columns) and without ICM (dark columns) for high, medium and low demand conditions.

Table 6-2. Year 2012 Baseline With and Without ICM – High Demand (06:00 to 11:00 AM)

Corridor Component	2012 Baseline Without ICM			2012 Baseline With ICM		
	VMT	VHT	Delay	VMT	VHT	Delay
SB I-15	595,100	10,147	42	588,230	9,934	15
SB HOT Lanes	154,858	2,470	0	155,476	2,479	0
Total SB	749,958	12,618	42	743,706	12,413	15
NB I-15	449,048	7,285	5	447,989	7,269	3
NB HOT Lanes	101,120	1,570	0	101,301	1,575	0
Total NB	550,168	8,855	5	549,289	8,844	3
Arterials	211,975	8,802	4,600	209,763	8,531	4,370
Entire Network	**1,808,386**	**43,183**	**11,619**	**1,799,407**	**42,546**	**11,219**

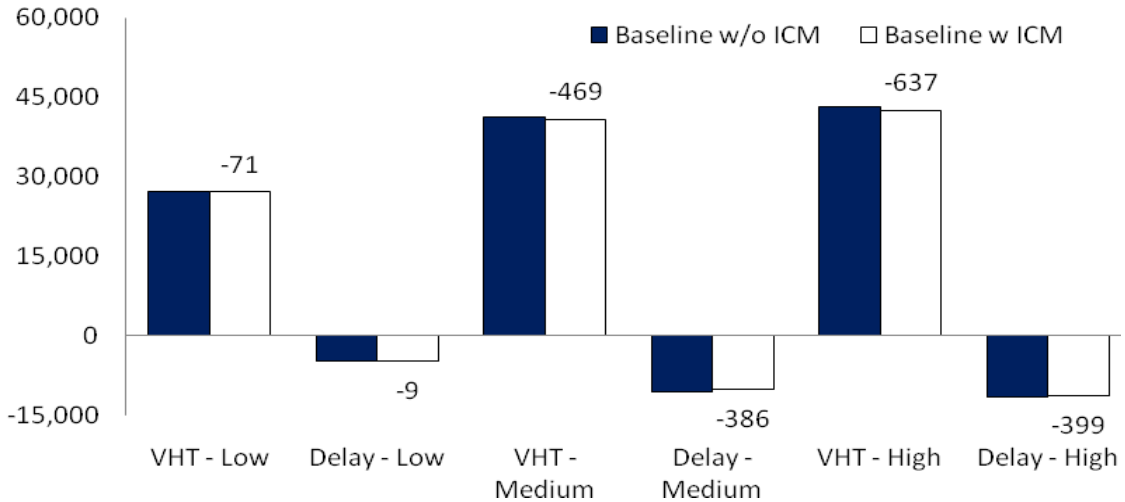
Table 6-3. Year 2012 Baseline With and Without ICM – Medium Demand (06:00 to 11:00 AM)

Corridor Component	2012 Baseline Without ICM			2012 Baseline With ICM		
	VMT	VHT	Delay	VMT	VHT	Delay
SB I-15	583,500	9,795	12	576,639	9,669	11
SB HOT lanes	152,105	2,418	0	153,399	2,438	0
Total SB	735,605	12,213	12	730,037	12,107	11
NB I-15	439,085	7,097	1	441,093	7,095	0
NB HOT Lanes	99,360	1,542	0	99,943	1,553	0
Total NB	538,446	8,639	1	541,036	8,648	0
Arterials	207,459	8,013	3,907	208,099	7,910	3,775
Entire Network	**1,774,532**	**41,345**	**10,547**	**1,771,601**	**40,876**	**10,161**

Table 6-4. Year 2012 baseline With and Without ICM – Low Demand (06:00 to 11:00 AM)

Corridor Component	2012 Baseline Without ICM			2012 Baseline With ICM		
	VMT	VHT	Delay	VMT	VHT	Delay
SB I-15	443,988	7,153	5	442,175	7,120	5
SB HOT lanes	113,556	1,774	0	113,608	1,767	0
Total SB	557,544	8,927	5	555,782	8,888	5
NB I-15	331,236	5,189	0	330,964	5,170	0
NB HOT Lanes	75,428	1,162	0	74,269	1,142	0
Total NB	406,663	6,351	0	405,233	6,312	0
Arterials	155,090	4,659	1,665	155,098	4,629	1,637
Entire Network	**1,339,560**	**27,233**	**4,769**	**1,336,876**	**27,163**	**4,759**

Figure 6-1. VHT and Delay Comparison for Year 2012 Baseline (*06:00 to 11:00 AM*



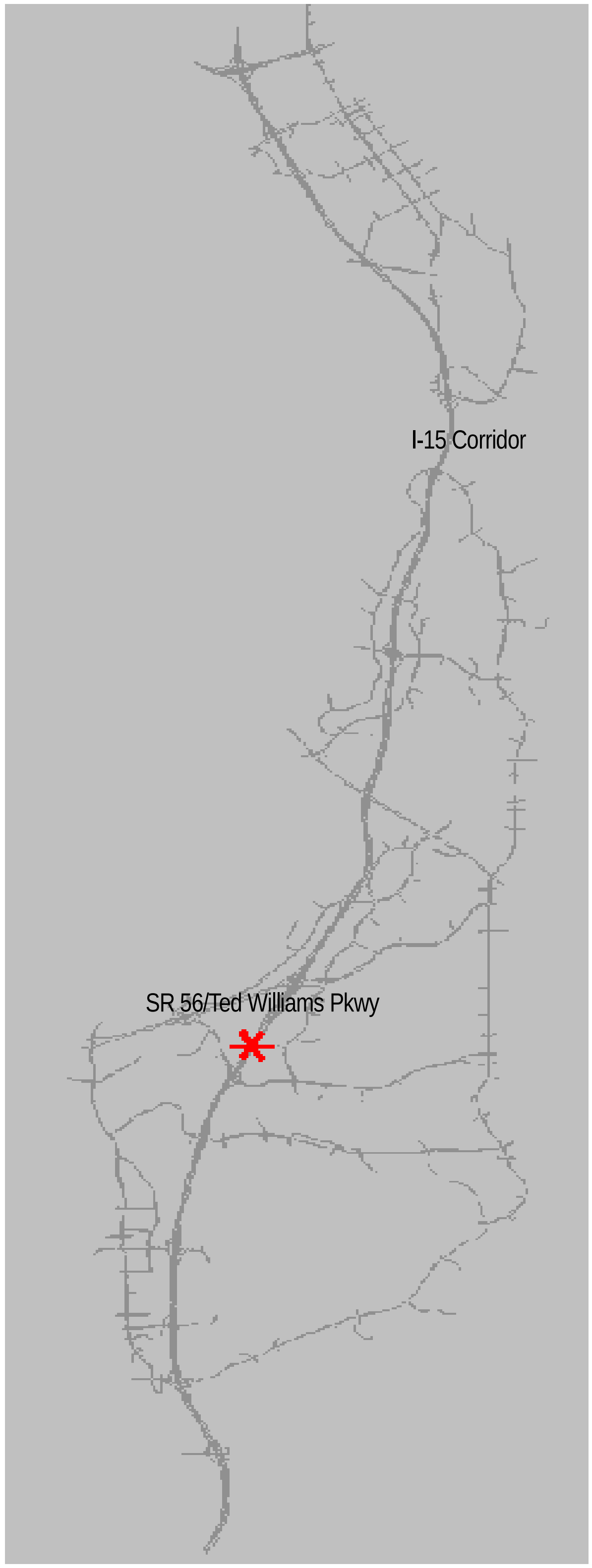
The overall system experiences a 3.4- and 3.7-percent reduction in delay for high- and medium-demand conditions, respectively, as drivers are able to utilize the improved traveler information to seek better routes to their destinations. The network also experiences reductions of 1.5 and 1.1 percent in total vehicle hours traveled for high- and medium-demand conditions, respectively. As expected, the benefits of ICM strategies are higher in high-demand scenarios, as compared to low-demand scenarios. AM peak travel time savings include 637, 469, and 71 person-hours for high, medium and low demand, respectively.

Freeway Incident Scenarios

One of the operational conditions tested in the ICM AMS effort involves a major incident on the freeway. In order to carry out this analysis, there was a need to understand the impact of the incident on the system in 2012, when no ICM strategies are in place. The without ICM scenario is used as the basis for measuring the benefits of the ICM strategies in case of a freeway incident.

The incident was introduced between Ted Williams Pkwy and Scripps Poway Rd on SB I-15 corridor (as shown below in Figure 6-2) at 7:00 AM in the simulation model. For the first 30 minutes (between 7:00 AM and 7:30 AM), the incident causes a closure of rightmost 3 of 5 lanes on the freeway. The remaining two lanes are restricted to maximum speeds of 20 mph and 30 mph for Lanes 4 and 5, respectively. This mimics the "rubbernecking" phenomenon observed during incident occurrence in adjacent lanes, which are not directly blocked as a result of the incident. These restrictions are effective for a length of 200 feet, which functions as the incident zone within the simulation. For the following 15 minutes (between 7:30 AM and 7:45 AM), only Lanes 1 and 2 (rightmost two lanes) are closed. The remaining lanes experience restricted speeds of 20 mph, 30 mph, and 40 mph for Lanes 3, 4, and 5, respectively. The incident is assumed to be physically cleared at the end of this period, allowing traffic use for all five lanes of the freeway.

Figure 6-2. Incident Location for the Freeway Incident Scenario



Source: TransModeler output screen capture, Caliper© Corporation, September 2010.

ICM Strategies in Freeway Incident Conditions

Table 6-5 shows the list of ICM strategies that are introduced without and with ICM for freeway incident conditions.

Table 6-5. ICM Strategies Introduced for the Freeway Incident Model

Parameter	Without ICM	With ICM
Incident information dissemination	Within 10 minutes of the incident occurrence	Within 2 minutes of the incident occurrence
Informed drivers	5 percent of the drivers	30 percent of the drivers
Route choice update	Every 20 minutes	Every 15 minutes
Managed lane operation	Tolled at all times	Open to all traffic during incident (from 7:15 to 8:00 AM) and tolled at all other times
Signal optimization	Comes into effect at 7:30 AM (30 minutes after the incident)	Comes into effect at 7:10 AM (10 minutes after the incident)

Performance Measures in Freeway Incident Conditions

Tables 6-6 through 6-8 provide a comparison of VMT, VHT and Delay, with and without ICM for freeway incident scenarios. Figures 6-3 and 6-4 provide a comparison between the baseline and freeway incident scenario, while Figure 6-5 summarizes the VHT and Delay improvements induced by the inclusion of ICM strategies in the freeway incident scenario.

Table 6-6. Freeway Incident Alternative With and Without ICM – High Demand (06:00 to 11:00 AM)

Corridor Component	Freeway Incident Without ICM			Freeway Incident With ICM		
	VMT	VHT	Delay	VMT	VHT	Delay
SB I-15	590,404	12,590	1,732	581,925	11,805	1,199
SB HOT lanes	156,914	2,591	47	185,142	3,097	24
Total SB	747,319	15,180	1,779	767,067	14,902	1,223
NB I-15	447,675	7,298	12	448,585	7,326	26
NB HOT Lanes	101,769	1,581	0	101,036	1,569	0
Total NB	549,444	8,879	12	549,621	8,895	26
Arterials	211,577	9,301	5,110	210,352	8,633	4,464
Entire Network	**1,804,699**	**46,167**	**13,759**	**1,824,095**	**45,265**	**12,603**

Table 6-7. Freeway Incident Alternative With and Without ICM – Medium Demand (06:00 to 11:00 AM)

Corridor Component	Freeway Incident Without ICM			Freeway Incident With ICM		
	VMT	VHT	Delay	VMT	VHT	Delay
SB I-15	581,573	12,266	1,691	570,422	11,204	1,072
SB HOT lanes	153,494	2,522	43	183,398	3,204	84
Total SB	735,067	14,789	1,734	753,820	14,408	1,156
NB I-15	439,908	7,116	2	439,100	7,097	1
NB HOT Lanes	98,656	1,531	0	99,535	1,544	0
Total NB	538,563	8,647	2	538,634	8,641	1
Arterials	206,609	8,266	4,192	206,441	7,989	3,908
Entire Network	**1,771,505**	**44,031**	**12,469**	**1,790,709**	**43,309**	**11,514**

Table 6-8. Freeway Incident Alternative With and Without ICM – Low Demand (06:00 to 11:00 AM)

Corridor Component	Freeway Incident Without ICM			Freeway Incident With ICM		
	VMT	VHT	Delay	VMT	VHT	Delay
SB I-15	444,434	7,471	235	446,042	7,462	216
SB HOT lanes	115,268	1,805	0	129,454	1,808	0
Total SB	559,703	9,276	235	575,496	9,269	216
NB I-15	331,035	5,186	0	331,798	5,188	0
NB HOT Lanes	74,141	1,140	0	74,667	1,132	0
Total NB	405,176	6,327	0	406,464	6,320	0
Arterials	155,597	4,658	1,658	155,067	4,640	1,653
Entire Network	**1,340,750**	**27,613**	**5,046**	**1,357,844**	**27,536**	**4,986**

Figure 6-3. VHT and Delay Comparison for the Baseline and Freeway Incident Without ICM Scenario (06:00 to 11:00 AM)

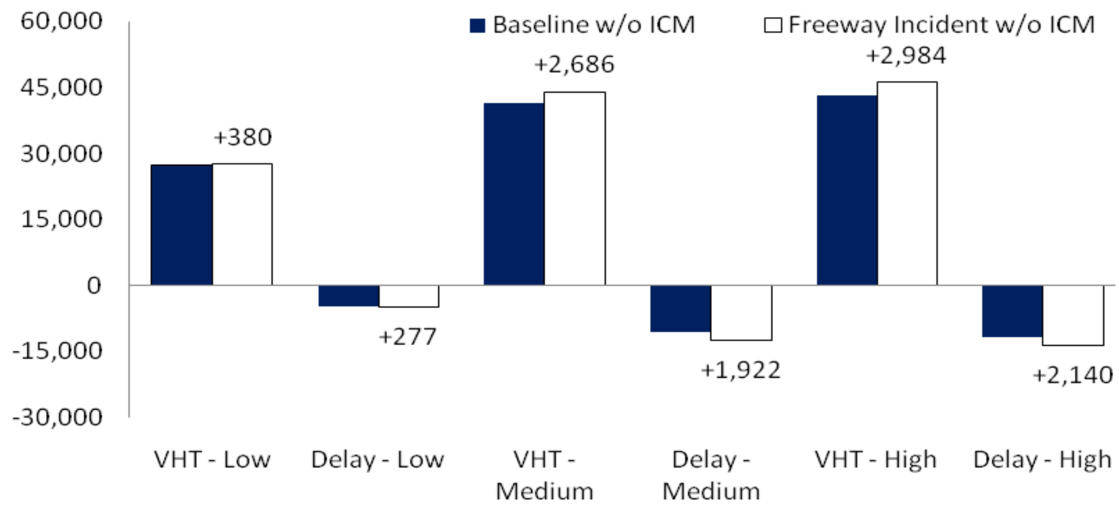


Figure 6-4. VHT and Delay Comparison for the Baseline and Freeway Incident With ICM Scenario (06:00 to 11:00 AM)

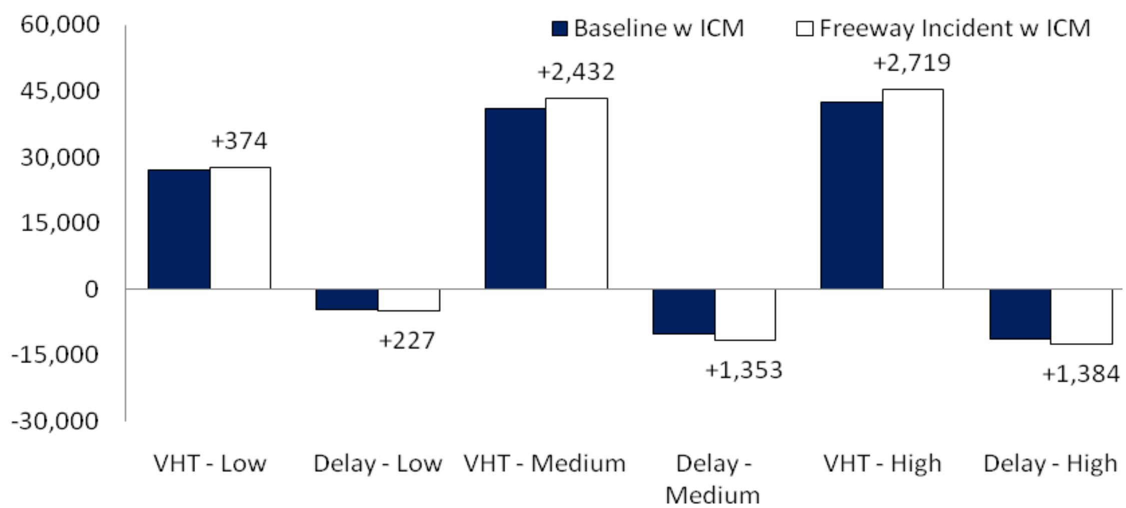
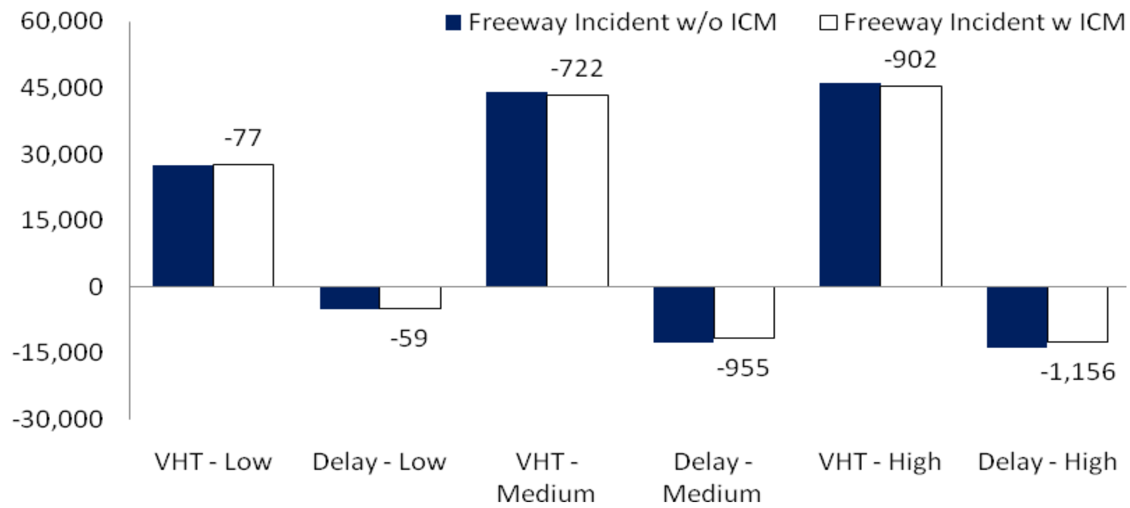


Figure 6-5. VHT and Delay Comparison for the Freeway Incident Scenario (06:00 to 11:00 AM)



In the high-demand scenarios, the freeway incident introduces around 2,000 hours of delay “without ICM”, while the additional delay is reduced to 1,350 hours when the ICM strategies are in place. As expected, the VMT for the system remains at roughly the same level, but higher levels of VHTs are observed when an incident is introduced.

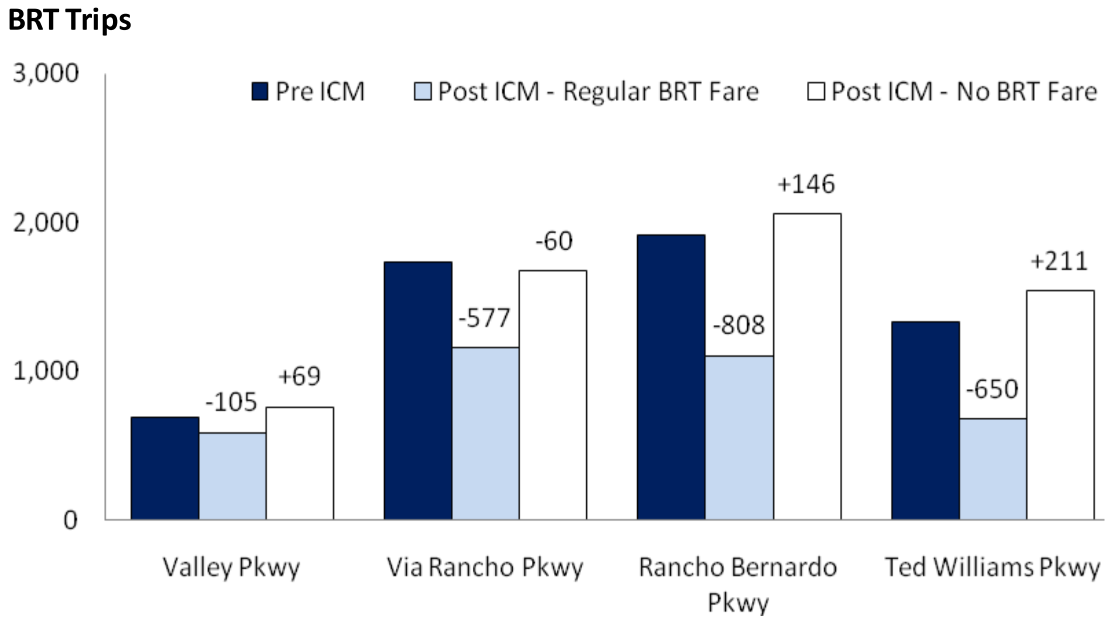
The results follow the general expectation that the introduction of ICM strategies would improve conditions in the 2012 Baseline with Incident, but the performance measures would fall somewhere between 2012 Baseline with ICM but no incident, and 2012 Baseline with incident but no ICM. The addition of ICM strategies for the freeway incident scenario results in 8.4-percent and 7.7-percent reduction in the total system delay for high- and medium-demand scenarios, respectively. Total VHT for the system also decreases by 2.0 percent and 1.6 percent, corresponding to AM peak savings of 900 and 725 hours for the high- and medium-demand scenarios, respectively. Improvements for the low-demand scenario are minimal, as expected.

Effects of Key ICM Strategies

Opening the managed lanes for all vehicles during a major freeway incident results in a 30-percent reduction in delay on the SB freeway and managed lanes for the medium- and high-demand scenarios. While the VHT on managed lanes in the SB direction increases considerably as a result of opening of the managed lanes, combined VHT for the SB freeway and managed lanes show a reduction of 1.8 and 2.6 percent for high- and medium-demand scenarios, respectively.

En-route mode shift to BRT is another key ICM strategy during a freeway incident. Figure 6-6 shows the effect of en-route mode shift to BRT for the high-demand freeway incident scenario.

Figure 6-6. BRT Trips by Transit Center for Freeway Incident Alternatives – High-Demand Scenario (06:00 to 11:00 AM)



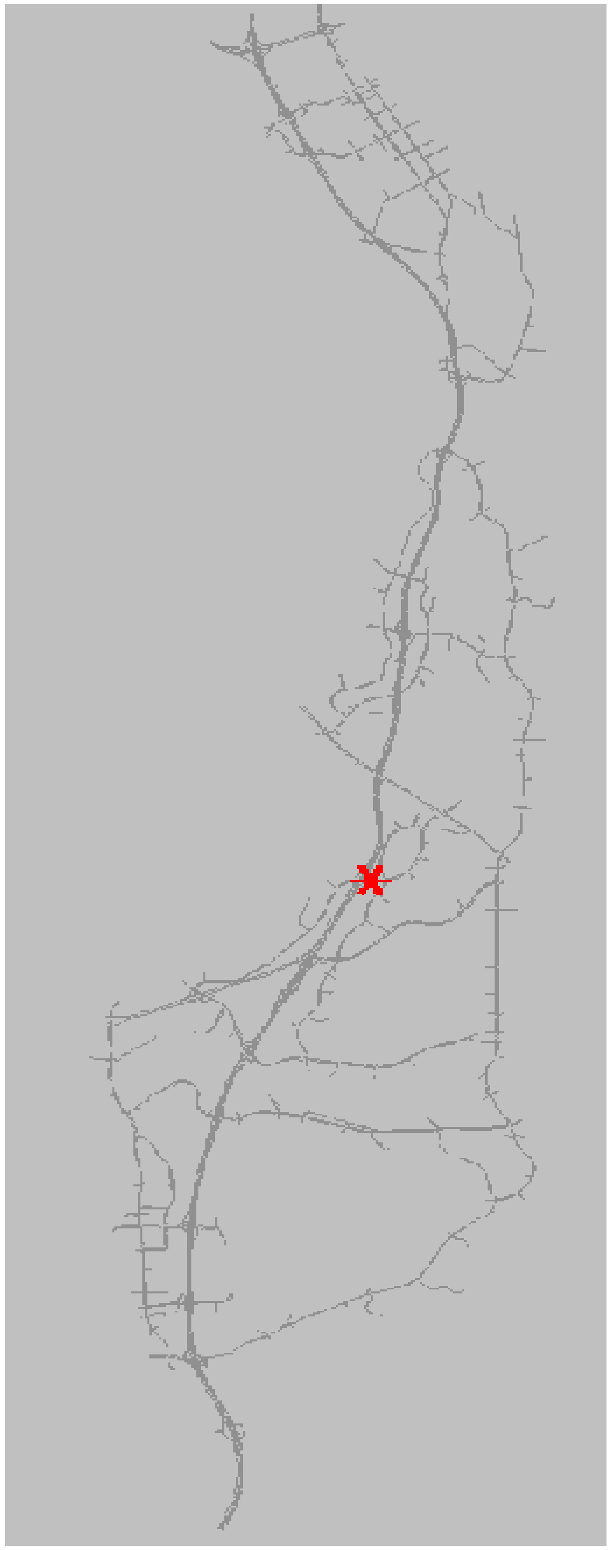
Opening of the managed lane to all traffic during a major incident results in a reduction in mode shift to BRT. Freeway drivers are provided with better travel times, resulting in a smaller diversion to BRT. However, simultaneously opening up the managed lanes to all traffic and making BRT free during a freeway incident makes the BRT mode more favorable. Making BRT free during major freeway incidents results in a 6.5-percent increase in BRT mode shift during high demand.

Arterial Incident Scenarios

The AMS effort for the I-15 corridor also involves analyzing the impact of ICM strategies during a major incident on an arterial. Arterial incident analysis is carried out without and with ICM strategies in place. Without ICM, modeling provides the baseline for measuring the effect of ICM strategies in case of an arterial incident.

The incident was introduced in the simulation model just east of I-15 freeway on the Carmel Mountain Rd (as shown below in Figure 6.7) at 7:30 AM. Table 6-9 describes the duration and severity of the incident.

Figure 6-7. Incident Location for the Arterial Incident Scenario



Source: TransModeler output screen capture Caliper© Corporation, September 2010.

Table 6-9. Incident Duration and Severity for Arterial Incident Model

Flow Direction	Duration	Incident Severity
Eastbound	07:70 – 07:40 AM	3 lanes – all closed
Eastbound	07:40 – 08:00 AM	Lanes 1 and 2 closed; 5 mph speed limit on lane 3 (rightmost lane)
Eastbound	08:00 – 08:10 AM	Lane 1 closed; 5 and 10 mph speed limit on lanes 2 and 3, respectively
Westbound	07:30 – 07:50 AM	2 lanes – both closed
Westbound	07:50 – 08:10 AM	Lane 1 closed; 10 mph speed limit on lane 2 (right lane)
Northbound	07:30 – 08:00 AM	2 lanes – both closed
Northbound	08:00 – 08:10 AM	Lane 1 closed; 5 mph speed limit on lane 2 (right lane)

ICM Strategies in Arterial Incident Conditions

Table 6-10 shows the ICM strategies introduced without and with ICM for the arterial incident conditions.

Table 6-10. ICM Strategies Introduced for the Arterial Incident Model

Parameter	Without ICM	With ICM
Incident information dissemination	Within 10 minutes of the incident occurrence	Within 2 minutes of the incident occurrence
Informed drivers	5 percent of the drivers	30 percent of the drivers
Route choice update	Every 20 minutes	Every 15 minutes
Managed lane operation	Tolled at all times	Tolled at all times
Signal optimization	Comes into effect at 08:00 AM (30 minutes after the incident)	Comes into effect at 07:40 AM (10 minutes after the incident)

Performance Measures in Arterial Incident Conditions

Tables 6-11 through 6-13 provide a comparison of VMT, VHT and Delay with and without ICM during an arterial incident. Figures 6-8 and 6-9 provide a comparison between the baseline and arterial incident scenario, while Figure 6-10 summarizes the VHT and Delay impacts induced by the inclusion of ICM strategies during the arterial incident.

Table 6-11. Arterial Incident Alternative With and Without ICM – High Demand (06:00 to 11:00 AM)

Corridor Component	Arterial Incident Without ICM			Arterial Incident With ICM		
	VMT	VHT	Delay	VMT	VHT	Delay
SB I-15	593,075	10,174	78	586,627	10,094	90
SB HOT lanes	154,596	2,463	0	155,853	2,492	0
Total SB	747,670	12,637	78	742,480	12,586	90
NB I-15	448,346	7,325	19	447,092	7,290	9
NB HOT Lanes	101,084	1,571	0	102,862	1,598	0
Total NB	549,430	8,896	19	549,953	8,888	9
Arterials	211,499	9,008	4,803	209,469	8,621	4,465
Entire Network	**1,805,083**	**43,797**	**12,210**	**1,798,396**	**43,226**	**11,745**

Table 6-12. Arterial Incident Alternative With and Without ICM – Medium Demand (06:00 to 11:00 AM)

Corridor Component	Arterial Incident Without ICM			Arterial Incident With ICM		
	VMT	VHT	Delay	VMT	VHT	Delay
SB I-15	584,110	9,986	89	577,772	9,937	111
SB HOT lanes	152,277	2,422	0	152,784	2,431	0
Total SB	736,387	12,408	89	730,557	12,368	111
NB I-15	440,507	7,147	9	439,715	7,115	1
NB HOT Lanes	100,157	1,557	0	99,875	1,548	0
Total NB	540,664	8,704	9	539,590	8,664	1
Arterials	206,520	8,522	4,419	207,116	8,372	4,243
Entire Network	**1,778,353**	**42,636**	**11,621**	**1,768,638**	**42,023**	**11,150**

Table 6-13. Arterial Incident Alternative With and Without ICM – Low Demand (06:00 to 11:00 AM)

Corridor Component	Arterial Incident Without ICM			Arterial Incident With ICM		
	VMT	VHT	Delay	VMT	VHT	Delay
SB I-15	448,048	7,295	38	440,671	7,132	11
SB HOT lanes	113,506	1,777	0	115,502	1,809	0
Total SB	561,554	9,072	38	556,173	8,941	11
NB I-15	331,899	5,225	1	331,974	5,193	1
NB HOT Lanes	74,145	1,139	0	75,342	1,158	0
Total NB	406,044	6,364	1	407,316	6,351	1
Arterials	155,379	5,006	2,003	155,461	4,875	1,869
Entire Network	**1,343,790**	**28,108**	**5,487**	**1,339,970**	**27,763**	**5,250**

Figure 6-8. VHT and Delay Comparison for the Baseline and Arterial Incident Without ICM Scenario (06:00 to 11:00 AM)

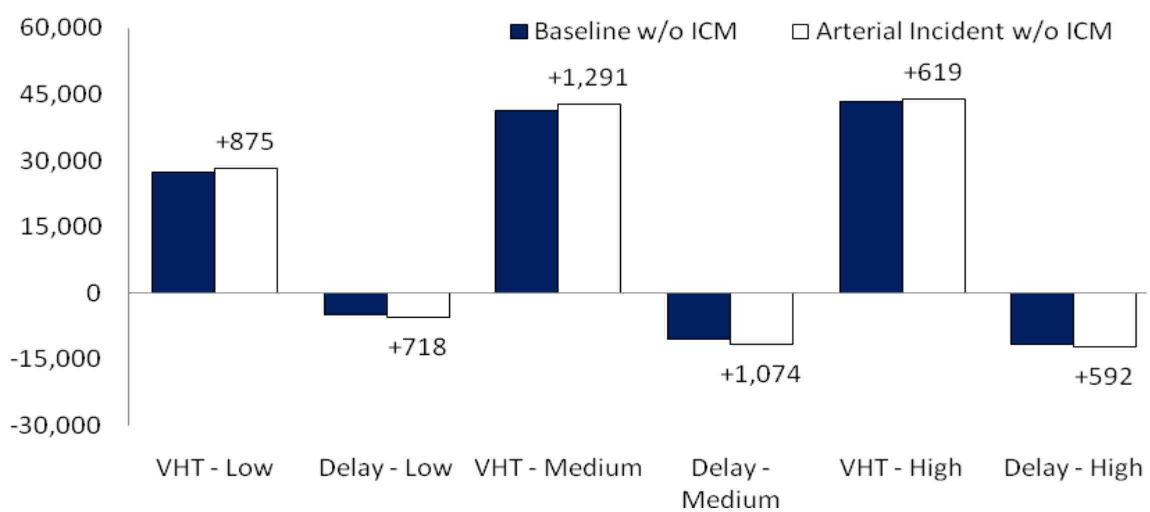


Figure 6-9. VHT and Delay Comparison for the Baseline and Arterial Incident With ICM Scenario (06:00 to 11:00 AM)

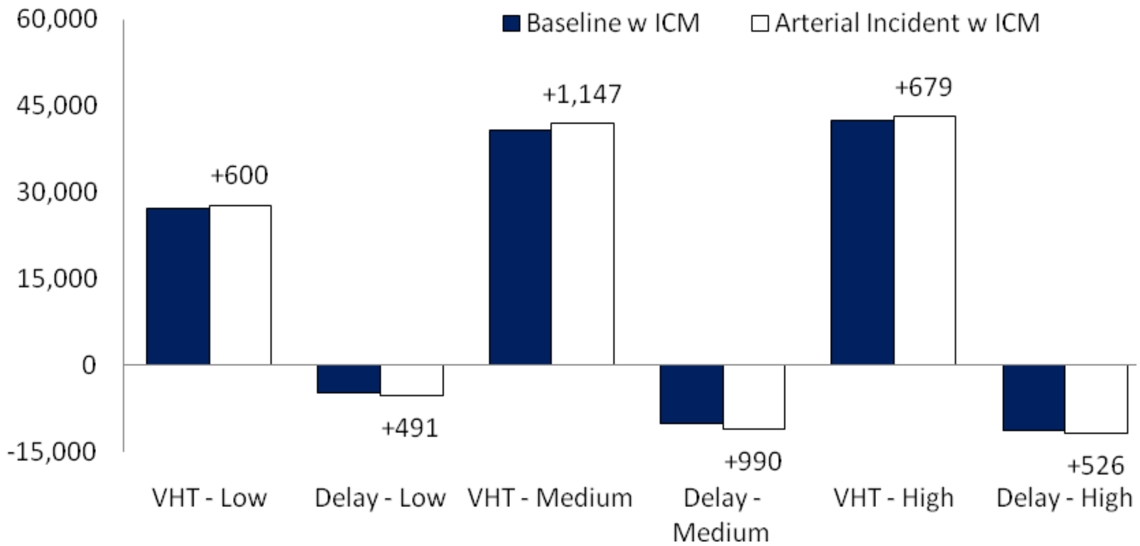
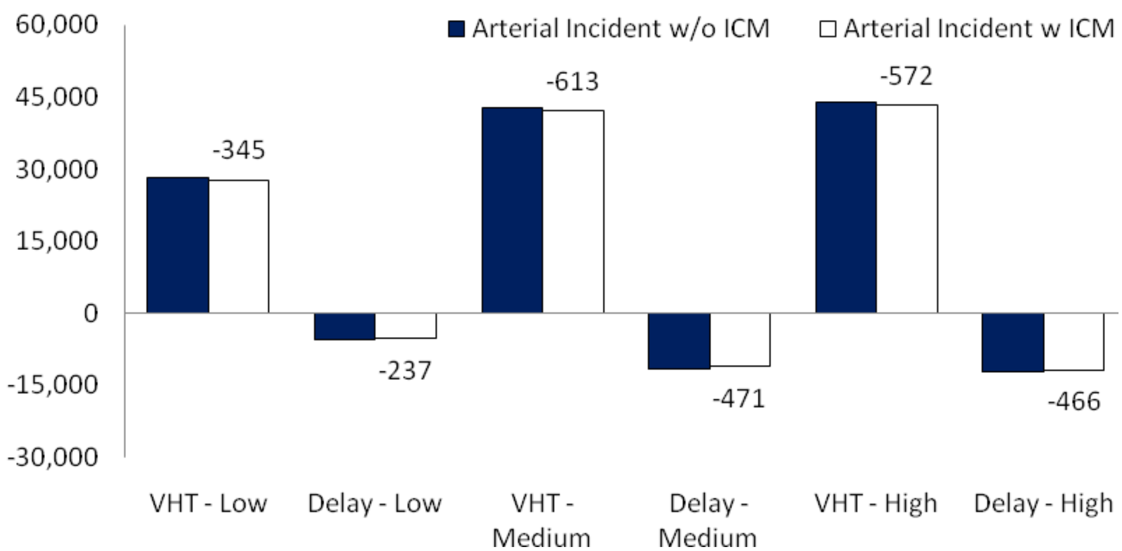


Figure 6-10. VHT and Delay Comparison for the Arterial Incident Scenario

06:00 to 11:00 AM



Compared to the future baseline alternative, the introduction of the arterial incident adds 525 to 600 hours and 1,000 to 1,075 hours of delay for the high-and medium-demand scenarios, respectively. The corresponding increase in VHT is around 1,150 to 1,300 and 620 to 680 person hours of travel for the high and medium scenarios, respectively. As expected, VMT shows minimal or no increase, given the availability of various parallel routes.

Inclusion of ICM strategies results in 3.8 and 4.1 percent reduction in the total system delay and 1.3 and 1.4 percent reduction in VHT for the medium- and high-demand scenarios, respectively. ICM strategies also cause the arterial delays to go down by 7.0 and 4.0 percent, and VHT to go down by 4.3 and 1.8 percent for the high- and medium-demand conditions, respectively. The arterial incident alternative also shows a significant effect of ICM strategies in case of low-demand scenario – the overall network delay and VHT improve by 4.3 and 1.2 percent, respectively.

ICM Performance Measures

A set of key performance measures is presented in the AMS Analysis Plan for the I-15 Corridor AMS. These performance measures are used in the benefit-cost analysis, which is presented later in this chapter. Within the methodology, the analyzed scenarios representing different operating conditions are combined together weighted by the probability of occurrence to arrive at an average annual daily performance measurement. The methodology used for generating these performance measures is outlined in Appendix B.

Tables 6-14 through 6-18 provide a comparison between without ICM and with ICM scenarios based on the basic network statistics.

Table 6-14. VMT Comparison for With and Without ICM Strategies

Corridor Component	Without ICM	With ICM
Entire Network	1,635,139	1,632,816
NB Managed Lanes	294,438	312,792
I-15 NB	598,400	599,921
NB Total	674,561	688,580
SB Managed Lanes	441,979	461,706
I-15 SB	782,083	801,657
SB Total	886,011	908,649
Arterials Total	209,320	206,316

Table 6-15. VHT Comparison for With and Without ICM Strategies

Corridor Component	Without ICM	With ICM
Entire Network	42,145	41,668
NB Managed Lanes	5,454	5,746
I-15 NB	12,905	12,634
NB Total	14,388	14,254
SB Managed Lanes	8,603	8,894
I-15 SB	18,540	18,216
SB Total	20,273	20,084
Arterials Total	6,098	5,953

Table 6-16. Delay Comparison for With and Without ICM Strategies (In Hours)

Corridor Component	Without ICM	With ICM
Entire Network	18,310	18,027
NB Managed Lanes	1,809	1,761
I-15 NB	3,675	3,578
NB Total	4,570	4,447
SB Managed Lanes	4,256	4,433
I-15 SB	9,417	9,200
SB Total	9,742	9,618
Arterials Total	2,318	2,217

Table 6-17. Planning Time Index Comparison for With and Without ICM Strategies

Corridor Component	Without ICM	With ICM
Entire Network	3.26	3.25
NB Managed Lanes	2.71	3.03
I-15 NB	1.69	1.66
NB Total	2.01	2.07
SB Managed Lanes	5.01	5.49
I-15 SB	4.09	4.26
SB Total	3.89	4.04
Arterials Total	2.58	2.52

Table 6-18. Travel Time Variance Comparison for With and Without ICM Strategies (min^2)

Corridor Component	Without ICM	With ICM
Entire Network	2.48	2.22
NB Managed Lanes	0.93	1.00
I-15 NB	0.89	0.84
NB Total	0.91	0.94
SB Managed Lanes	8.64	9.53
I-15 SB	6.01	6.19
SB Total	5.62	5.88
Arterials Total	1.63	1.30

The introduction of ICM strategies results in a 1.1-percent reduction in the total corridor-wide VHT weighted over all the demand scenarios and future alternatives; this corresponds to 477 person-hours of travel saved in the AM peak period. The corresponding network-wide delay reduces by 1.5 percent. Southbound freeway operation shows significant improvement with the inclusion of ICM strategies as VHT and Delay go down by 0.9 and 1.3 percent, respectively. Arterials show significant improvement with 2.4-percent reduction in total VHT and 4.3-percent reduction in total delay; the provision of improved traveler information attracts arterial travelers to the freeway thus improving arterial performance.

The implementation of ICM strategies results in the overall Planning Time index, which is a measure of travel time reliability, to improve by 0.3 percent across all future alternatives and demand scenarios. The corridor-wide travel time variance across all scenarios also improves by 10.6 percent, with ICM strategies in place. Travel time variance increases on the I-15 freeway are seen as a result of the ICM strategy to open the managed lanes to all traffic during a freeway incident.

More frequent route choice update, wider dissemination of travel time and network congestion data, opening up of managed lanes to general traffic during incidents, and en-route BRT mode shift all contribute to the VHT and Delay reduction.

Throughput Measures

In order to estimate the degree to which ICM affects network throughput and duration of trips with longer travel times, the travel times under the incident scenarios can be compared to those under the no incident for the same demand level. By comparing the percentage of trips under the same threshold travel time in both the without and with ICM scenarios, the relative influence of ICM on reducing extreme travel times can be estimated.

Table 6-19 lists the percentage of travel times in the incident scenarios that are less than the 90th percentile travel time in the no incident scenario for all trips in the system. Similarly, Table 6-20 lists the same only for trips that use I-15 Southbound. In both cases, only the trips with start times between 6:00 and 9:00 AM were included in the analysis. This was intended to focus on the trips that would most likely be affected by the simulated incident.

Table 6-19. Percentage of Travel Times Less than the 90th Percentile Travel Time of the No Incident Scenario, All Trips (Trips Starting 6:00 to 9:00 AM)

Operating Conditions	Without ICM	With ICM	Change
2012 Baseline Scenario			
Low Demand	90.00	89.97	-0.03
Medium Demand	90.00	90.16	0.16
High Demand	90.00	90.93	0.93
2012 Arterial Incident Scenario			
Low Demand	88.73	88.98	0.25
Medium Demand	88.65	88.30	-0.35
High Demand	89.90	90.03	0.13
2012 Freeway Incident Scenario			
Low Demand	89.13	88.58	-0.55
Medium Demand	87.38	86.54	-0.84
High Demand	88.11	87.93	-0.18

Table 6-20. Percentage of Travel Times Less than the 90th Percentile Travel Time of the No Incident Scenario, I-15 SB Trips (Trips Starting 6:00 to 9:00 AM)

Operating Conditions	Pre-ICM	Post-ICM	Change
2012 Baseline Scenario			
Low Demand	90.00	89.49	-0.51
Medium Demand	90.00	90.02	0.02
High Demand	90.00	90.56	0.56
2012 Arterial Incident Scenario			
Low Demand	87.38	88.00	0.62
Medium Demand	88.45	87.30	-1.15
High Demand	88.92	89.69	0.77
2012 Freeway Incident Scenario			
Low Demand	90.82	84.16	-6.66
Medium Demand	77.30	75.11	-2.19
High Demand	78.61	78.82	0.21

Tables 6-19 and 6-20 show small differences in throughput between “without ICM” and “with ICM”, across all operational conditions. The changes from “without ICM” to “with ICM” do not follow a clear trend: in some cases there is a throughput benefit resulting from ICM and in other cases there is a disbenefit. This lack of clear trend is probably due to the noise-to-signal ratio related to the relatively small size of the I-15 network and the relatively small amount of background congestion during the future baseline year of 2012; in other words, model-estimated throughput changes are too small to be separated from the model noise, especially for the no-incident and the arterial incident scenarios. The biggest changes are observed in the freeway incident scenario given the freeway-centric nature of the corridor. The throughput disbenefit in the freeway incident scenario can be largely attributed to the opening up of managed lanes to all traffic during an incident, and the corresponding rerouting to arterials that is observed during the freeway incident.

ICM Benefits

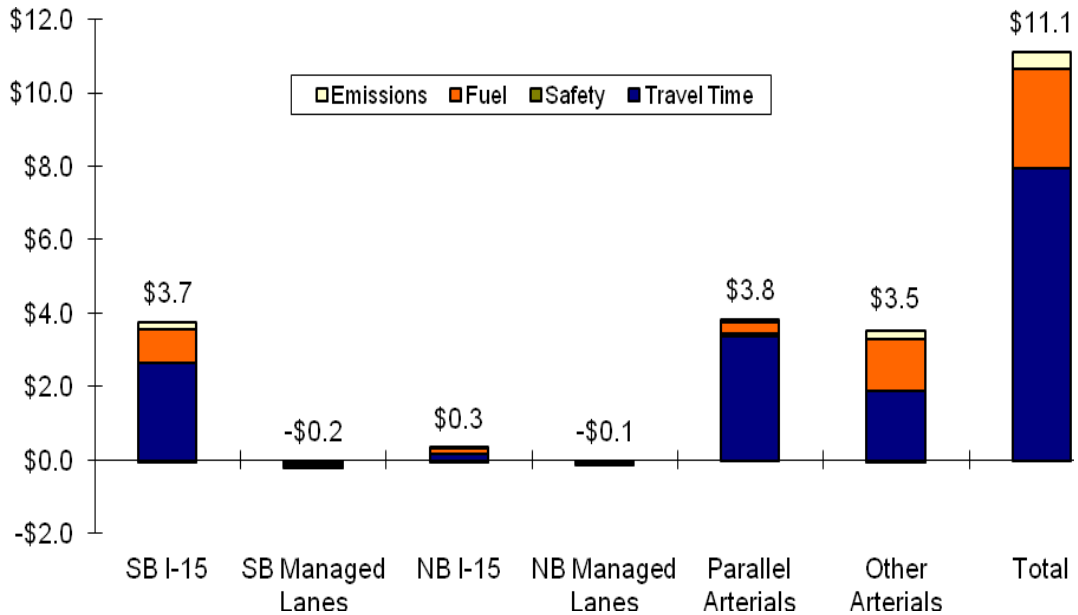
Monetized benefits are combinations of five performance measures, including travel time, travel time reliability, fuel consumption, and emissions. Steps involved in producing these benefits include the following:

- Using AMS tools the analysis produced performance measures associated with the baseline and each of the ICM alternatives for the AM peak period. The differences in performance measures between the alternative and baseline represent one-half of the daily benefit/disbenefit resulting from the deployment of a particular ICM strategy.
- The analysis then assumed that ICM implementation during the AM peak period produces approximately the same impact as the PM peak period. AM and PM peak-period impacts were added to produce daily impacts or benefits. Daily benefits were converted into annual benefits by multiplying times 260 workdays.
- Benefits were monetized by multiplying:
  - Hours of delay saved times $24 per hour (an average value of time for the test corridor area).
  - Hours of travel time reliability saved times $24 per hour. This is a conservative value of reliability time – typically, travel time reliability is valued at 2.5 to 3 times the average value of travel time.
  - Gallons of fuel saved at $4.00 per gallon.
  - Emissions saved at the emission cost per mile per speed category.

Summary of Benefits, Benefit-Cost and Net Annual Benefits

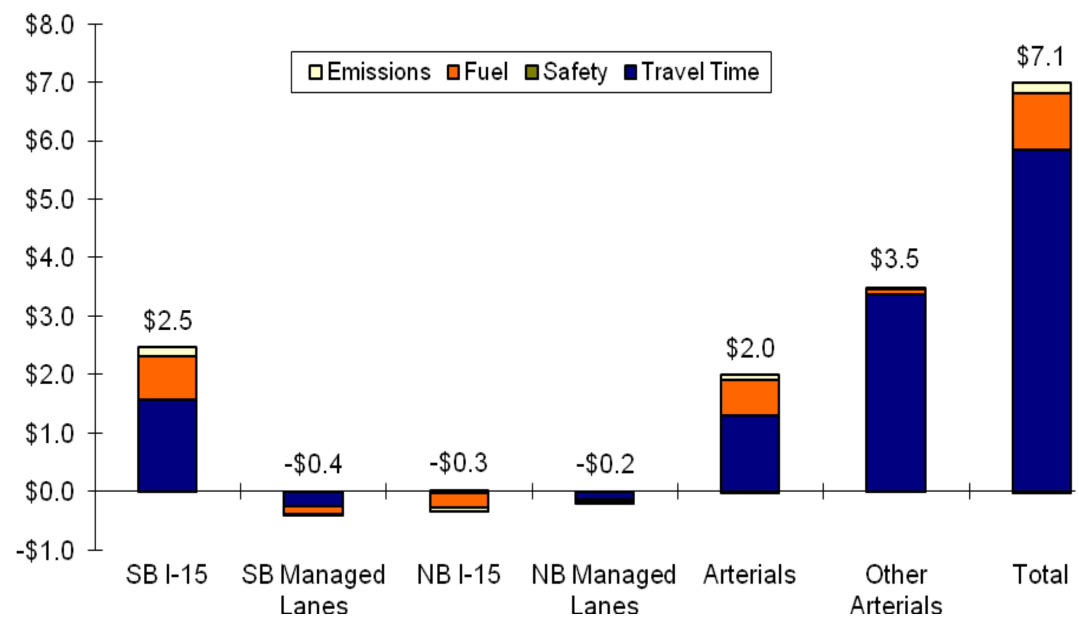
Figures 6-11 through 6-20 present summaries of monetized annual benefits for each ICM strategy alternative in each operational condition for the San Diego I-15 corridor. These figures present monetized benefits/disbenefits by performance measure and by facility type. Performance measures include travel time, safety, fuel consumption, emissions of pollutants. Facility types include general purpose lanes and managed lanes on both directions of the I-15 freeway, modeled major signalized arterials parallel to the freeway which act as diversion routes (shown as “parallel arterials”), and “other arterials” including all other feeder routes to major arterials.

Figure 6-11. Annual ICM Benefits – Future Baseline Alternative with High Demand (In Million Dollars)



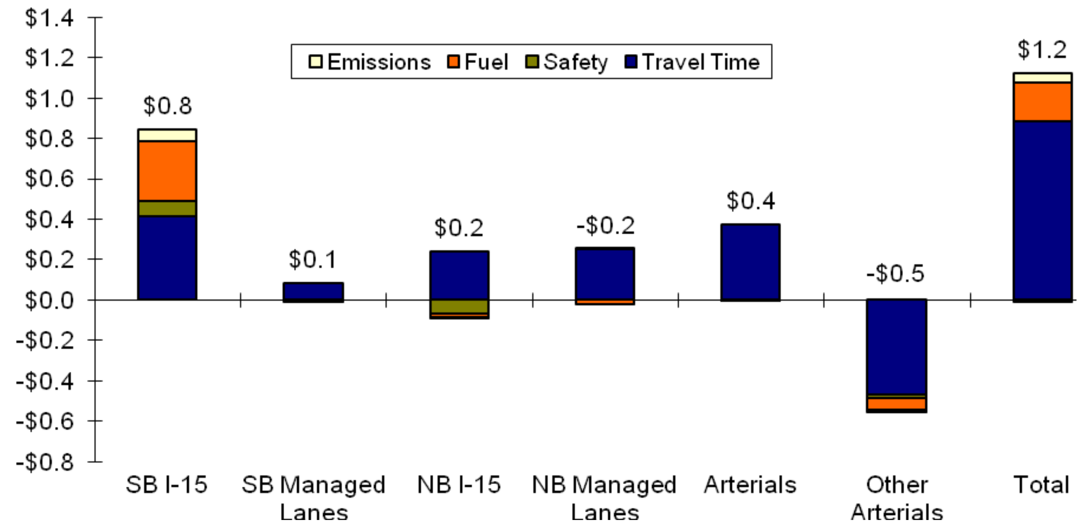
Source: San Diego ICM AMS Final Report, 2011.

Figure 6-12. Annual ICM Benefits – Future Baseline Alternative with Medium Demand (In Million Dollars)



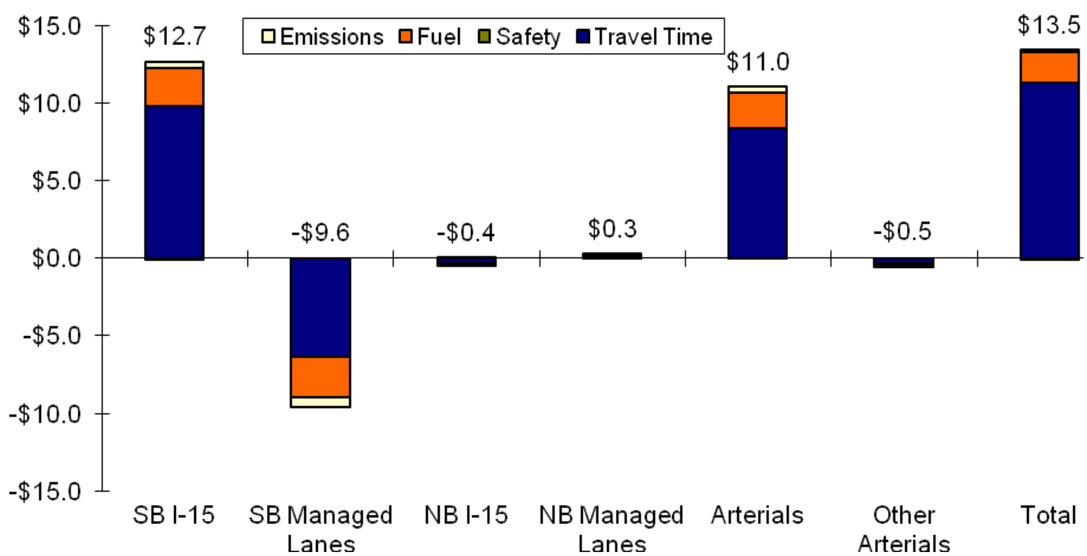
Source: San Diego ICM AMS Final Report, 2011.

Figure 6-13. Annual ICM Benefits – Future Baseline Alternative with Low Demand (In Million Dollars)



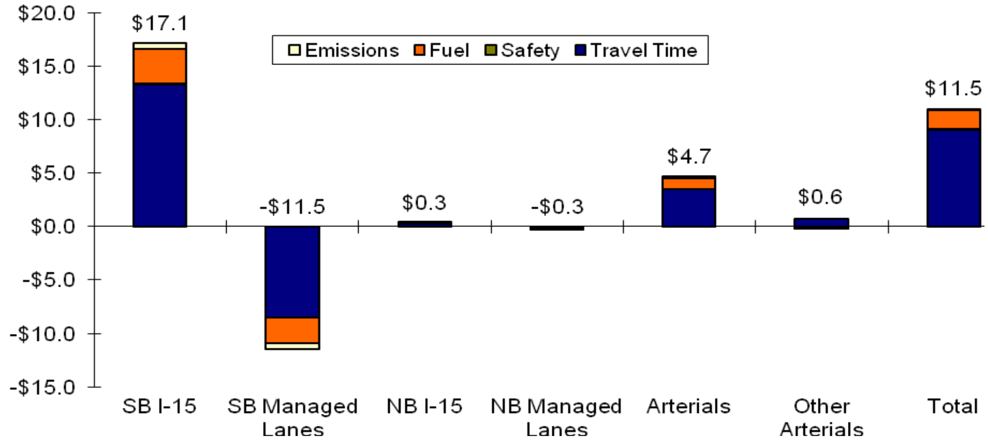
Source: San Diego ICM AMS Final Report, 2011.

Figure 6-14. Annual ICM Benefits – Freeway Incident Alternative with High Demand (In Million Dollars)



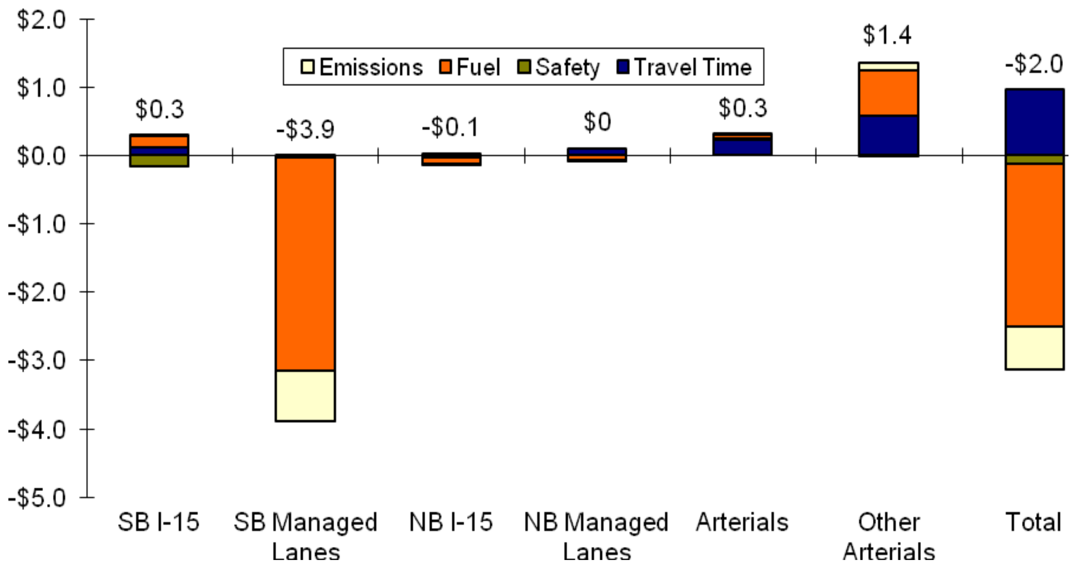
Source: San Diego ICM AMS Final Report, 2011.

Figure 6-15. Annual ICM Benefits – Freeway Incident Alternative with Medium Demand (In Million Dollars)



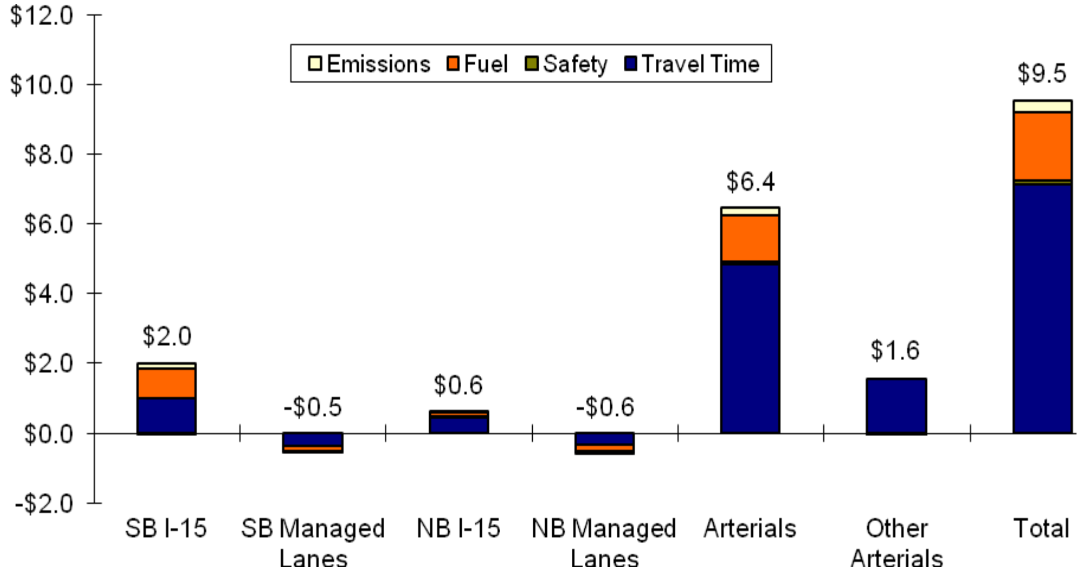
Source: San Diego ICM AMS Final Report, 2011.

Figure 6-16. Annual ICM Benefits – Freeway Incident Alternative with Low Demand (In Million Dollars)



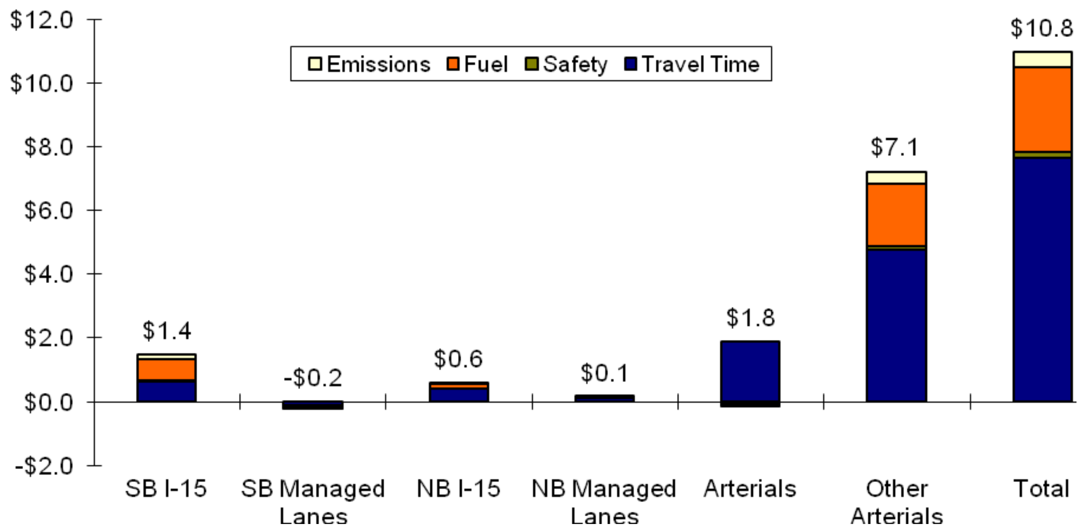
Source: San Diego ICM AMS Final Report, 2011.

Figure 6-17. Annual ICM Benefits – Arterial Incident Alternative with High Demand (In Million Dollars)



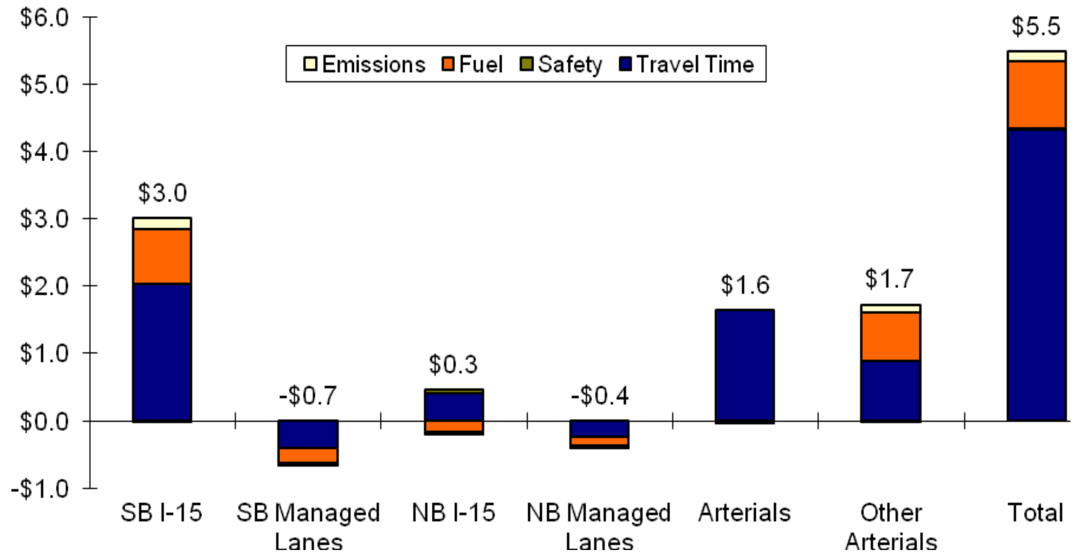
Source: San Diego ICM AMS Final Report, 2011.

Figure 6-18. Annual ICM Benefits – Arterial Incident Alternative with Medium Demand (In Million Dollars)



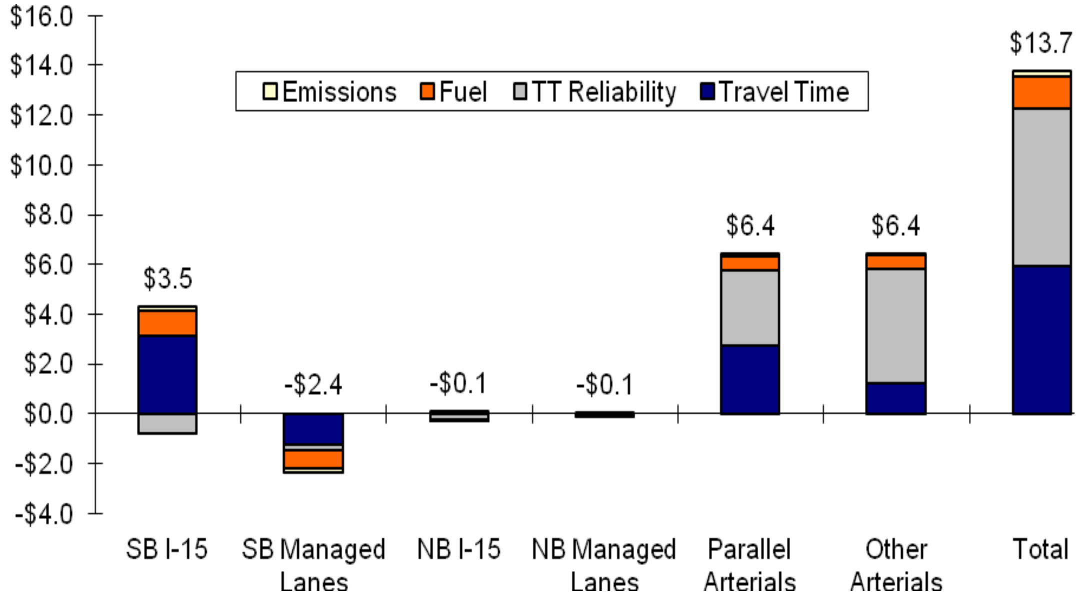
Source: San Diego ICM AMS Final Report, 2011.

Figure 6-19. Annual ICM Benefits – Arterial Incident Alternative with Low Demand (In Million Dollars)



Source: San Diego ICM AMS Final Report, 2011.

Figure 6-20. Annual ICM Benefits (In Million Dollars)



Source: San Diego ICM AMS Final Report, 2011.

Overall, deployment of ICM on the I-15 Corridor produces a 10-year benefit of approximately $116 million. Summary findings include the following:

- Across all operational conditions, most of the ICM benefit is attributed to the travel time, travel time reliability, and fuel savings on the southbound freeway and arterials. With the provision of improved traveler information, more arterial travelers are attracted to the freeway thus improving arterial performance and overall system performance.
- Managed lanes show some disbenefits as a result of opening these lanes to all traffic during major freeway incidents. However, vehicles using the open managed lane are not in the adjacent general purpose lane and arterials, thus improving overall corridor performance. Arterials show a considerable amount of travel time and travel time reliability benefits owing mostly to arterial signal optimization.
- Approximately 93 percent of the total ICM benefits result from the high- and medium-demand scenarios (representing 69 percent of commute days). Also, two-thirds of the total benefit is attributed to high- and medium-demand scenarios with an incident. This finding validates the hypothesis that ICM is most effective under the worst operational conditions including heavy-demand and major incidents.
- The I-15 corridor AMS validates the ICM concept: dynamically applying ICM strategies in combination across a corridor is shown to reduce congestion and improve the overall productivity of the transportation system.

ICM Costs

The costs presented in this section provide practical information that may be referenced to compare the costs for various ITS deployments, as part of the ICM Test Corridor. The estimated costs represent average costs that are consistent with the ITS National Architecture. The costs presented in this section are defined as follows:

- **Capital Costs –** Includes up-front costs necessary to procure and install ITS equipment. These costs are shown as a total (one-time) expenditure, and they include the capital equipment costs as well as the soft costs required for design and installation of the equipment.
- **Operations and Maintenance (O&M) Costs –** Includes those continuing costs necessary to operate and maintain the deployed equipment, including labor costs. While these costs do contain provisions for upkeep and replacement of minor components of the system, they do not contain provisions for wholesale replacement of the equipment when it reaches the end of its useful life. These O&M costs are presented as annual estimates.
- **Annualized Costs –** Represent the average annual expenditure that would be expected in order to deploy, operate, and maintain the ICM improvement, and replace (or redeploy) the equipment as they reach the end of their useful life. Within this cost figure, the capital cost of the equipment is amortized over the anticipated life of each individual piece of equipment. This annualized figure is added with the reoccurring annual O&M cost to produce the annualized cost figure. This figure is particularly useful in estimating the long-term budgetary impacts of Test Corridor ICM deployments.

Total Cost Estimates

The initial capital cost for the ICM deployments on the I-15 corridor is estimated at $7.55 million, with an additional $0.53 million per annum in operating and maintenance costs.

Assuming a 10-year life cycle for all components, the total annualized cost for all ICM deployments for the I-15 corridor is $1.42 million, which translates to $12.0 million in total life-cycle costs.

Conclusions and Lessons-Learned

The ICM AMS methodology offers the following benefits to corridor managers across the country:

- **Invest in the right strategies –** The methodology offers corridor managers a predictive forecasting capability that they lack today to help them determine which combinations of ICM strategies are likely to be most effective under which conditions.
- **Invest with confidence –** AMS allows corridor managers to "see around the corner" and discover optimum combinations of strategies, as well as conflicts or unintended consequences inherent in certain combinations of strategies that would otherwise be unknowable before implementation.
- **Improve the effectiveness/success of implementation –** With AMS, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.
- AMS provides a long-term capability to corridor managers to **continually improve implementation** of ICM strategies based on experience.

The I-15 Corridor AMS results show significant benefits, resulting from the deployment of ICM strategies:

- Overall, deployment of ICM on the I-15 Corridor produces $13.7 million in user benefits per year. Over the 10-year life cycle of the ICM systems, benefits produced a total benefit of **$115.9 million**.
- Costs to deploy ICM on the I-15 Corridor are estimated to be $1.42 million annualized over the 10-year life cycle of the project. The total life-cycle cost to deploy the ICM system is estimated at **$12.0 million**.
- The estimated benefit/cost ratio for the ICM deployment over the 10 life cycle of the project is approximated at **9.7:1**.
- The benefits from ICM are attributable to reduced travel times, improved travel time reliability, reduced fuel consumption, and reduced mobile emissions. Expected annual savings include 245,594 hours of vehicle-hours of travel, a reduction of fuel consumption by 322,767 gallons of fuel, and an annual reduction of 3,057 tons of vehicular emissions.
- Across all operational conditions, most of the ICM benefit is attributed to the travel time, travel time reliability, and fuel savings on the southbound freeway and arterials. With the provision of improved traveler information, more arterial travelers are attracted to the freeway thus improving arterial performance and overall system performance.

- Managed lanes show some disbenefits as a result of opening these lanes to all traffic during major freeway incidents. However, vehicles using the open managed lane are not in the adjacent general purpose lane and arterials, thus improving overall corridor performance. Arterials show a considerable amount of travel time and travel time reliability benefits owing mostly to arterial signal optimization.
- An important finding of this analysis is that ICM strategies produce more benefits at higher levels of travel demand, and during non-recurrent congestion. Approximately 93 percent of the total ICM benefits result from the high- and medium-demand scenarios (representing 69 percent of commute days). Also, two-thirds of the total benefit is attributed to high- and medium-demand scenarios with an incident. For individual travelers who primarily rely on the I-15 southbound facility the majority of benefits accrues under particular operational conditions associated with high travel demand and incidents. This finding validates the hypothesis that ICM is most effective under the worst operational conditions including heavy-demand and major incidents.
- Other corridor-wide travelers see smoothed benefit over most travel days as the system reacts more intelligently and more rapidly to variations in congestion conditions. These travelers experience small benefits accrued over many days rather than on particular days. Benefits from ICM are related to a ripple effect from better addressing the impacts of major disruptions. Benefits that accrue from multiple, distant ripples are smoothed over travel time, reliability and fuel consumption. Those that are close to the source of disruption experience more reliability benefits.
- Transit excess capacity is better utilized overall, and particularly under incident conditions, drawing additional travelers to the BRT facility without overwhelming the BRT.
- The I-15 corridor AMS validates the ICM concept: dynamically applying ICM strategies in combination across a corridor is shown to reduce congestion and improve the overall productivity of the transportation system.

Appendix A Summary of San Diego I-15 ICM Strategies

The following table summarizes the ICM strategies for the San Diego I-15 ICM Stage II (AMS) Project based on the ConOps from Stage I, together with notes to the AMS modeling team.

Table A-1. Prioritized List of Strategies

Strategies	Notes to AMS Modeling Team	High – Definitely needs to be modeled Medium – Borderline may not need modeling Low – Does not need modeling	Scenario					
			Daily	Freeway Incident	Arterial Incident	Transit Incident	Special Event (Planned)	Disaster Response
1. Share/Distribute Information								
1.1 Pre-trip traveler information	Information will be provided to the public via the 511 system (telephone, Internet) and the public access TV system. People will be able to decide whether to take their trip as originally planned or change departure time, trip route, and/or travel mode.	High	X	X	X	X	X	X
1.2 En-route traveler information	Information will be provided to the public via multiple media including changeable message signs (CMSs), Next Bus informational sign displays at bus stops/stations, phone, and PDA/Blackberry. This information will allow travelers to potentially change mode, alter route or departure time.	High	X	X	X	X	X	X
2. Junctions/Interfaces Improvement								
2.1 Signal pre-emption	Because of the urgent need to accommodate emergency vehicles, signal preemption has been a standard practice for a long time. This strategy helps identify the “best route” for emergency vehicles during incidents and response to emergency situations/disasters.	Low			X	X		X

Strategies	Notes to AMS Modeling Team	High – Definitely needs to be modeled Medium – Borderline may not need modeling Low – Does not need modeling	Scenario					
			Daily	Freeway Incident	Arterial Incident	Transit Incident	Special Event (Planned)	Disaster Response
2.2 Multimodal electronic payment	This is SANDAG's Universal Transportation Account (UTA) that will make it convenient for travelers to make intermodal trips. It will begin with a regional automated fare collection system, which will deploy a smart card-based fare collection network throughout San Diego County and initially used for transit. The UTA will combine elements so that the same electronic toll collection tag/smart card can be used to pay transit fares, tolls, and parking for added convenience.	Medium	X					
2.3 Transit Signal Priority	Transit signal priority on arterials can reduce transit vehicle travel time, improve reliability, and help maintain transit schedule adherence. It is a means of enhancing corridor management across networks. Although to-date transit signal priority has yet to be deployed on arterials in the corridor, it is being implemented on North County Transit District Bus Route 350 (bus feeder for corridor BRT system) with implementation complete in 2008. This is an important addition to the set of I-15 ICMS assets.	High	X				X	
2.4 Ramp meters/ arterial traffic signals coordination	At this crucially important junction of the freeway and arterial networks, it is very important to establish and successfully maintain coordinated activities across the networks. Doing so help achieve ICMS goals of accessibility for corridor travelers to travel options and attain enhanced mobility levels.	High	X	X	X	X	X	X

Strategies	Notes to AMS Modeling Team	High – Definitely needs to be modeled Medium – Borderline may not need modeling Low – Does not need modeling	Scenario					
			Daily	Freeway Incident	Arterial Incident	Transit Incident	Special Event (Planned)	Disaster Response
2.5 BRT	This strategy refers to operational and physical aspects of enhancing transit service, such as queue jumpers, dedicated bus lanes, or access ramps; and decreased headways and other transit-related enhancements anticipated through the implementation of BRT systems along the I-15 corridor.	High	X	X			X	
2.6 Transit hub connection protection	This means holding one transit service while waiting for another transit service to arrive. This strategy is governed by the Regional Transit Management System (RTMS), which is currently operational and supports all fixed-route transit operations for the San Diego Metropolitan Transit System and the North County Transit District; will support other regional transit operators in the future. RTMS allows data-sharing and information exchange, as needed, to promote more efficient regional transit operations and coordination of transit services between operators, such as to coordinate passenger transfers between transit systems.	Low				X	X	
3. Accommodate/Promote Network Shifts								
3.1 Modify ramp metering rates	This strategy will help accommodate traffic, including transit buses that are shifting from arterials.	High	X	X	X	X	X	X
3.2 Promote route and mode shifts	This strategy focuses on shifts between roadways and transit by means of en-route and pre-trip traveler information services.	Medium/High	X	X	X	X	X	

Strategies	Notes to AMS Modeling Team	High – Definitely needs to be modeled Medium – Borderline may not need modeling Low – Does not need modeling	Scenario					
			Daily	Freeway Incident	Arterial Incident	Transit Incident	Special Event (Planned)	Disaster Response
3.3 Congestion pricing for ML	Currently under phased construction; initial segment fully implemented in 2008.	High	X	X	X	X	X	X
3.4 Modify arterial signal timing	This strategy will help accommodate traffic that shifts from the I-15 freeway.	High	X	X	X	X	X	X
4. Capacity/Demand Management (Short-Term)								
4.1 Lane use control	This primarily involves changes to the Managed Lanes lane configuration from default of two lanes per direction to 3/1 or 4/0 split, especially for evacuation purposes during the Disaster Response Scenario.	Low		X			X	X
4.2 Modify HOV restrictions	This focuses on increasing the minimum number of occupants required in HOVs.	High		X				X
4.3 Increase roadway capacity by opening HOV/HOT lanes and shoulders	This has been successfully implemented as a one-year demonstration project allowing buses on shoulders from I-805 and Nobel Drive to SR 52 and Kearny Villa Road during moving and afternoon peak periods. The use of shoulders as a low-speed bypass of congested freeway lanes offers a low-cost, easily implemented strategy that should increase transit operating speeds, on-time performance, and trip reliability.	Medium		X				X
4.4 Temporary addition of transit capacity	This is primarily used during planned special events, though is applicable during incidents and the worst case scenario (Disaster Response).	Low			X		X	X

Strategies	Notes to AMS Modeling Team	High – Definitely needs to be modeled Medium – Borderline may not need modeling Low – Does not need modeling	Scenario					
			Daily	Freeway Incident	Arterial Incident	Transit Incident	Special Event (Planned)	Disaster Response
4.5 Modify parking fees	This refers to the Smart Parking System (SPS) that is currently undergoing a Pilot Test on I-5 in conjunction with the Coaster commuter rail system. SPS uses a variety of technologies to collect real-time parking data and provides this information to transit users. Focus is placed on parking facilities at Bus Rapid Transit stations.	Low	X					
5. Capacity/Demand Management (Long Term)								
5.1 Ride sharing programs	Can this be modeled given the inherent variability over time in such programs? Can this be viewed alternatively as an incentive for carpooling/HOV?	Medium	X				X	
5.2 Expand transit capacity	This refers to practices such as adding a route or decreasing headway.	Medium				X	X	

Appendix B Performance Measure Calculation Using Simulation

This appendix describes the methodology used in calculating various performance measures for the ICM AMS as summarized in this report.

Calculation Procedures for Key Integrated Corridor Performance Measures from Simulation Outputs

A core element of the Integrated Corridor Management (ICM) initiative is the identification and refinement of a set of key performance measures. These measures represent both the bottom-line for ICM strategy evaluation and define what “good” looks like among key corridor stakeholders. To date, the emphasis on performance-driven corridor management among the participating Pioneer sites has been on measures derived from observed data. In the Analysis, Modeling and Simulation (AMS) phase of the effort, however, attention has turned to producing comparable measures derived from simulation outputs. This document provides a detailed process by which a set of key national measures of corridor performance can be calculated. It is the intent of the ICM program, and this document, that these processes will be implemented consistently in the three participating AMS sites applying the ICM AMS methodology.

This document provides a detailed description of how measures of ***delay***, ***travel time reliability*** and ***throughput*** are calculated from simulation outputs. A brief discussion of travel time variance is also provided given that travel time variance measures are used in ICM-related benefit-cost calculations. The algorithmic approaches defined here are software independent, that is, this process can be implemented with outputs from any of the time-variant simulation tools utilized in the three participating ICM AMS sites. The document begins with a discussion of the calculation of travel time, which informs both a calculation of delay as well as travel time reliability. Next, we provide a discussion of how corridor throughput is defined and measured. The document concludes with a discussion of how these measures are used to make comparisons between system performance in the pre-ICM case and in one or more distinct post-ICM cases.

Travel Time

Our basic unit of observation in calculating ICM-related performance measures is a trip i made between an origin o, finishing at a destination d, starting within a particular time interval τ using mode m.

We record travel time from a single run of the simulation under operational conditions k for this unit

of observation as $t_i^k = t_{o,d,\tau',m}^k$.[5] *Operational conditions* here refer to a specific set of simulation settings reflecting a specific travel demand pattern and collection of incidents derived from a cluster analysis of observed traffic count data and incident data. An example of an operational condition would be an AM peak analysis with 5 percent higher than normal demand and a major arterial incident. Let k be a specific operational condition and the set of all conditions K. Note that each condition has a probability of occurrence p_k and $\sum_k p_k = 1$.

First, for this particular run(s) representing a specific operational condition, we calculate an average travel time for trips between the same o-d pair that begin in a particular time window. Let τ represent this interval, e.g., an interval between 6:30 AM and 6:45 AM and $\mathbf{I}_{o,d,\tau,m}^k$ the set of $n_{o,d,\tau,m}^k$ trips from o to d starting in interval τ under operational condition k using mode m. Note that $\mathbf{I}_{o,d,\tau,m}^k$ is a collection of trips and $n_{o,d,\tau,m}^k$ the scalar value indicating the number of trips contained in $\mathbf{I}_{o,d,\tau,m}^k$. The set of all τ of interest is the set T. For example, we may be interested in consistently calculating performance measures over all trips that begin in the 12 quarter-hour intervals between 6:00 AM and 9:00 AM.

The classification of travel mode may be determined independently at each site, but the breakdown should capture the combination of all modes utilized in making the trip. For example, one may choose to classify non-HOV-auto trips as a mode separately from non-HOV-auto/HOV/walk trips to track the performance of travelers utilizing park-and-ride facilities. However, any classification of modes must be mutually exclusive and collectively exhaustive, that is, $\bigcup_m \mathbf{I}_{o,d,\tau,m}^k = \mathbf{I}_{o,d,\tau}^k$ and $\sum_m n_{o,d,\tau,m}^k = n_{o,d,\tau}^k$.

The average travel time of trips with origin and destination by mode staring in this time interval is:

$$T_{o,d,\tau,m}^k = \frac{\sum_{i \in \mathbf{I}_{o,d,\tau}^k} t_i^k}{n_{o,d,\tau,m}^k} \qquad (1)$$

where $n_{o,d,\tau,m}^k > 0$. Let $T_{o,d,\tau,m}^k = 0$ when $n_{o,d,\tau,m}^k = 0$.

The calculation of Equation 1 must also include some estimated travel time for trips that cannot reach their destinations by the end of the simulation period. Later in this document, we will discuss the method for estimating travel times for these trips still underway when the simulation ends.

[5] In the case where multiple random seeds are varied, but the operational conditions are identical, this travel time represents an average for a single trip across the multiple runs. Also, note that this discussion of measures assumes that we are calculating measures for a single case (e.g., pre-ICM); later we will address comparisons between cases.

Next, we calculate the average travel time for this same set of trips across all operational conditions, that is, $\forall k \in K$. Note that it is possible that we may have trips for some o, d, τ, m under some conditions and no trips for the same o, d, τ, m under other conditions. Let $K'_{o,d,\tau,m}$, $K'_{o,d,\tau,m} \subseteq K$ be the subset of conditions where $n^k_{o,d,\tau,m} > 0$.

Equation 2 finds the average travel time by mode for all trips from o to d starting in interval τ over all conditions where at least one trip is made, $k \in K'_{o,d,\tau,m}$:

$$T_{o,d,\tau,m} = \frac{\sum_{k \in K'_{o,d,\tau,m}} T^k_{o,d,\tau,m} p_k}{\sum_{k \in K'_{o,d,\tau,m}} p_k} \quad (2)$$

The average number of trips by mode from o to d starting in interval τ over all conditions $k \in K$:

$$n_{o,d,\tau,m} = \sum_{k \in K} n^k_{o,d,\tau,m} p_k \quad (2a)$$

Combining across modes, the average travel time of trips from o to d starting in interval τ under operational condition k:

$$T^k_{o,d,\tau} = \frac{\sum_m T^k_{o,d,\tau,m} \, n^k_{o,d,\tau,m}}{n^k_{o,d,\tau}} \quad (3)$$

where $n^k_{o,d,\tau} > 0$. Let $T^k_{o,d,\tau} = 0$ when $n^k_{o,d,\tau} = 0$.

The average travel time for all trips from o to d starting in interval τ under $K'_{o,d,\tau}$ the subset of conditions where $n^k_{o,d,\tau} > 0$, $K'_{o,d,\tau} \subseteq K$:

$$T_{o,d,\tau} = \frac{\sum_{k \in K'_{o,d,\tau}} T^k_{o,d,\tau} p_k}{\sum_{k \in K'_{o,d,\tau}} p_k} \quad (4)$$

The average number of trips from o to d starting in interval τ over all conditions $k \in K$:

$$n_{o,d,\tau} = \sum_{k \in K} n^k_{o,d,\tau} p_k \quad (4a)$$

Equation 5 defines the trip-weighted average travel time of the system across all o, d, τ :

$$\overline{T} = \frac{\sum_{\forall o,d,\tau} T_{o,d,\tau}\, n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \tag{5}$$

Delay

Delay can be broadly defined as travel time in excess of some *subjective minimum* travel time threshold. Often, discussions of delay focus solely on roadway-only travel focus on either travel time at posted speeds or 85th percentile speeds. Delay for ICM must be defined differently since ICM explicitly includes multimodal corridor performance. Instead, we directly identify delay at the o, d, m level by deriving a zero-delay threshold $T^0_{o,d,m}$, considering travel times observed across all operating conditions $\forall k \in K$ and all time intervals $\forall \tau \in T$.

The zero-delay threshold for each o-d pair by mode is calculated looking across all operating conditions and all time intervals:

$$T^0_{o,d,m} = \min_{k \in K, \tau \in T} \left\{ T^k_{o,d,\tau,m} \right\} \tag{6}$$

In some cases, the cluster analysis will group low-demand, non-incident conditions into a large, high-probability operational condition. In this case, it is possible that a notionally “low” demand pattern will still produce significant congestion in the corridor, particularly in a peak-period analysis.

For this reason, the minimum threshold may also be calculated as the travel time derived in the pre-ICM case under a substantially reduced demand pattern with no incidents or weather impacts. The reduced demand pattern should produce enough trips to generate travel time statistics by mode for every set of trips from o to d starting in interval τ (i.e., $n^0_{o,d,\tau,m} > 0 \; \forall \; o, d, \tau, m$). At the same time, the reduced demand should generate no volume-related congestion in the network.

Alternatively, $T^0_{o,d,m}$ may be estimated directly from model inputs. For consistency, however, the travel time associated with these thresholds should include expected transfer time between modes and unsaturated signal delay as in the case where a low-demand pattern is used to drive a zero-delay model run.

From our previous calculation of travel time in Equation 1, recall the average travel time of all trips traversing the network from origin o to destination d starting in time interval τ using mode m under operational condition k, $T^k_{o,d,\tau,m}$

Using zero-delay thresholds $T^0_{o,d,\tau,m}$, calculate average trip delay under condition k for each o,d,τ,m:

$$D^k_{o,d,\tau,m} = max\left[T^k_{o,d,\tau,m} - T^0_{o,d,\tau,m}, 0\right] \quad (7)$$

Combining across all operational conditions, calculate the average delay for each o,d,τ,m over $K'_{o,d,\tau,m}$, the subset of conditions where $n^k_{o,d,\tau,m} > 0$.

$$D_{o,d,\tau,m} = \frac{\sum_{k \in K'_{o,d,\tau,m}} D^k_{o,d,\tau,m} p_k}{\sum_{k \in K'_{o,d,\tau,m}} p_k} \quad (7a)$$

Combining across modes, the average delay for trips from o to d starting in interval τ :

$$D_{o,d,\tau} = \frac{\sum_m D_{o,d,\tau,m}\, n_{o,d,\tau,m}}{n_{o,d,\tau}} \quad (8)$$

where $n_{o,d,\tau} > 0$. Let $D_{o,d,\tau} = 0$ when $n_{o,d,\tau} = 0$.

Systemwide average trip delay (Equation 9):

$$D = \frac{\sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \quad (9)$$

Aggregating this average delay over all trips produces total system delay (Equation 10):

$$\hat{D} = \sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau} \quad (10)$$

Travel Time Reliability

Corridor reliability measures are inherently measures of outlier travel times experienced by a traveler making the same (or similar) trip over many days and operational conditions. We have already defined and organized travel time measures from the simulation with respect to trips from o to d starting in interval τ over using mode m for all conditions $k \in K$. Just as in the case of the subjective notion of delay as travel time in excess of some minimum threshold, the notion of what reliable travel is depends on a *relative maximum* acceptable travel time threshold. For the ICM AMS effort, as in many studies with a travel reliability measure, a threshold based on the 95th percentile travel time is selected. Note that this percentile is calculated considering travel times for similar trips (i.e., o,d,τ,m) with respect to travel time variation induced by changes in operational conditions $k \in K$.

To identify the 95th percentile travel time, first we generate an ordered list of travel times for each o,d,τ,m across all operating conditions:

$$\mathrm{T}_{o,d,\tau,m} = \left[T^1_{o,d,\tau,m}, T^2_{o,d,\tau,m}, \cdots, T^J_{o,d,\tau,m}\right] \quad (11)$$

where $T^j_{o,d,\tau,m} \le T^{j+1}_{o,d,\tau,m}$ for all $j = 1 \cdots J$.

The 95th percentile travel time from this list is identified using the probabilities associated with each operational condition.

$$T^{[95]}_{o,d,\tau,m} = T^j_{o,d,\tau,m} \quad (11a)$$

$$\text{where } \sum_{k=1}^{j} p_k = 0.95 .$$

Note the array of travel times $\mathbf{T}_{o,d,\tau,m}$ represents levels on a linear step-function. This implies that if 17.4 minutes is the travel time associated with an operational condition occupying the 92nd through 98th travel time percentile, we simply use the 17.4-minute travel time as the 95th percentile value. Also note that the specific operational conditions under which the 95th percentile travel time is found will vary among o,d,τ,m. For example, a major freeway incident creates congestion and high travel times for trips that originate upstream of the incident location, but creates free-flowing and uncongested conditions for trips that originate downstream of the incident location.

Equation 12 defines planning time index for each o,d,τ,m, the ratio of the 95th percentile travel time to the zero-delay travel time for trips from o to d starting in interval τ using mode m over all conditions $k \in K$:

$$\rho_{o,d,\tau,m} = \frac{T^{[95]}_{o,d,\tau,m}}{T^{0}_{o,d,\tau,m}} \quad (12)$$

Equation 12a defines planning time index by o,d,τ across all modes:

$$\rho_{o,d,\tau} = \frac{\sum_m \rho_{o,d,\tau,m}\, n_{o,d,\tau,m}}{n_{o,d,\tau}} \quad (12a)$$

Average systemwide planning time index considers all o, d, τ, weighted average by trip volume:

$$\rho = \frac{\sum_{\forall o,d,\tau} \rho_{o,d,\tau} \, n_{o,d,\tau}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \tag{13}$$

We may also be interested in trip-weighted planning time index within a mode across all o, d, τ:

$$\rho_m = \frac{\sum_{\forall o,d,\tau} \rho_{o,d,\tau} \, n_{o,d,\tau,m}}{\sum_{\forall o,d,\tau} n_{o,d,\tau}} \tag{13a}$$

Variance in Travel Time

Variance in travel time can be calculated in a variety of ways. The key here is that some care must be taken to isolate the specific variation of interest. Additionally, as variance is strongly influenced by outliers, in order to eliminate any potential bias introduced into the variance of travel times resulting from the estimation of a fulfilled travel time for incomplete travelers at the end of the simulation period, the variance calculation should be restricted to completed travelers defined as set $\ddot{\mathbf{I}}_{o,d,\tau}^{k}$ consisting of $\ddot{n}_{o,d,\tau}^{k}$ trips. While the inclusion of the fulfilled incomplete travelers' travel times in the other performance measures may be influenced by the same bias, the nature of the variance calculation magnifies the effects of that potential bias. This effect may be more significant in larger models where the calibration and validation efforts must be focused on the primary corridor or study area.

Given this, the variance in travel time among members of the same origin, destination, and time interval in a single run is:

$$V_{o,d,\tau}^{k} = \frac{\sum_{i \in \ddot{\mathbf{I}}_{o,d,\tau}^{k}} \left(\ddot{t}_i^{k} - \ddot{T}_{o,d,\tau}^{k} \right)^2}{\ddot{n}_{o,d,\tau}^{k} - 1} \tag{14}$$

Recall $K'_{o,d,\tau}$, $K'_{o,d,\tau} \subseteq K$ as the subset of conditions where $\ddot{n}_{o,d,\tau}^{k} > 0$. The variance of travel time for each o, d, τ under all operation conditions is then defined as:

$$V_{o,d,\tau} = \frac{\sum_{k \in K'_{o,d,\tau}} V_{o,d,\tau}^{k} p_k}{\sum_{k \in K'_{o,d,\tau}} p_k} \tag{14a}$$

The average variance among all o, d, τ is a weighted average of the variances:

$$V = \frac{\sum_{\forall o,d,\tau} V_{o,d,\tau} \ddot{n}_{o,d,\tau}}{\sum_{\forall o,d,\tau} \ddot{n}_{o,d,\tau}} \tag{14b}$$

Throughput

The role of a throughput measure in ICM is to capture the primary product of the transportation system: travel. Particularly in peak periods, the capability of the transportation infrastructure to operate at a high level of efficiency is reduced. One of the goals of ICM is to manage the various networks (freeway, arterial, transit) cooperatively to deliver a higher level of realized system capacity in peak periods. While throughput (e.g., vehicles per lane per hour) is a well-established traffic engineering point measure (that is, in a single location), there is no consensus on a systemwide analog measure. In the ICM AMS effort, we use the term *corridor throughput* to describe a class of measures used to characterize the capability of the integrated transportation system to efficiently and effectively transport travelers. We do not consider freight throughput in these calculations, although this could be revisited at a later date.

In order to support throughput measures, additional trip data need to be generated as simulation outputs. For each trip i made between an origin o, finishing at a destination d, starting at a particular time τ' we obtain from the simulation the travel time $t^k_{o,d,\tau'}$ and a distance traveled $s^k_{o,d,\tau'}$. In some cases, trip-level outputs from the simulation are only available at a vehicle level, so some trips may have multiple passengers associated with that trip (e.g., in the case of carpool travel). Let $x^k_{o,d,\tau'}$ represent the number of travelers associated with a particular trip record.

Passenger-miles traveled (PMT) are accumulated using a process similar to travel time. First, we convert individual trip PMT into an average PMT for trips from origin o to destination d with a trip start in time interval τ.

$$X^k_{o,d,\tau} = \frac{\sum_{i \in I^k_{o,d,\tau}} s^k_i x^k_i}{n^k_{o,d,\tau}} \tag{15}$$

For trips that cannot be completed before the end of the simulation, see the following section for the estimation of total trip distance.

Equation 16 finds the average PMT for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$X_{o,d,\tau} = \sum_{k \in K} X^k_{o,d,\tau} p_k \tag{16}$$

Equation 17 defines the aggregate PMT across all o, d, τ :

$$X = \sum_{\forall o,d,\tau} X_{o,d,\tau} \, n_{o,d,\tau} \tag{17}$$

Passenger-miles delivered (PMD) and Passenger-trips delivered (PTD) are measures that introduce notions of travel quality into throughput. Simple PMT measures often cannot differentiate between a well-managed system and a poorly managed system because passenger-trip distances are counted equally regardless of trip duration. In other words, a five-mile trip completed in 15 minutes counts equally with the same five-mile trip completed in two hours. Here, we restrict the accounting of passenger-miles traveled (or passenger-trips delivered) to trips that successfully complete their trips prior to the end of the simulation (or some other logical time-point). Let $\dot{\mathbf{I}}^k_{o,d,\tau}$ be the set of $\dot{n}^k_{o,d,\tau}$ trips from o to d starting in interval τ under operational condition k that complete their trip before the simulation ends (or some other logical time-cutoff).

Equation 18 shows passenger-trips delivered (PTD) calculated at the o, d, τ level.

$$Y^k_{o,d,\tau} = \frac{\sum_{i \in \dot{\mathbf{I}}^k_{o,d,\tau}} x^k_i}{\dot{n}^k_{o,d,\tau}} \tag{18}$$

Equation 19 finds the average PTD for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$Y_{o,d,\tau} = \sum_{k \in K} Y^k_{o,d,\tau} p_k \tag{19}$$

Equation 19b finds the average number of completed trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$\dot{n}_{o,d,\tau} = \sum_{k \in K} \dot{n}^k{}_{o,d,\tau} p_k \tag{19b}$$

Equation 20 defines the aggregate PTD across all o, d, τ :

$$Y = \sum_{\forall o,d,\tau} Y_{o,d,\tau} \, \dot{n}_{o,d,\tau} \tag{20}$$

Passenger-miles delivered (PMD) is a distance-weighted measure of throughput based on PTD:

$$Z^k_{o,d,\tau} = \frac{\sum_{i \in \dot{\mathbf{I}}^k_{o,d,\tau}} s^k_i x^k_i}{\dot{n}^k_{o,d,\tau}} \tag{21}$$

Equation 22 finds the average PMD for all trips from o to d starting in interval τ over all operational conditions $k \in K$:

$$Z_{o,d,\tau} = \sum_{k \in K} Z^k_{o,d,\tau} p_k \qquad (22)$$

Equation 23 defines the aggregate PMD across all o,d,τ :

$$Z = \sum_{\forall o,d,\tau} Z_{o,d,\tau} \, \dot{n}_{o,d,\tau} \qquad (23)$$

For example, in the Dallas ICM Corridor, the simulation period is from 5:30 AM to 11:00 AM, while the peak hours are from 6:30 AM to 9:00 AM. It is anticipated that with or without an ICM strategy in place, all trips that begin in the peak period should be completed before the simulation ends at 11:00 AM. In this case, there may be little difference in PMT or PMD when 11:00 AM is used as the logical time cutoff. In order to measure the peak capability of the system to deliver trips, the set of trips counting towards PMD could potentially be restricted to those trips that can both begin and complete their trips in the peak period (6:30-9:00 AM). At this point, it is premature to define a specific time cut-off for PMD to be applied in all three sites.

Restricting the calculation of measures to selected cohorts is also relevant to the calculation of delay and travel time reliability measures. Although peak periods vary among the AMS sites in terms of the onset and duration of congestion, a consistent set of trips that contribute to measure calculation (others simply run interference) should be identified. As in the case of the throughput time cut-off point, U.S. DOT may wish to prescribe specific times in the future.

At this time, it is unclear whether PMT, PMD, or PTD will be the selected performance measure for corridor throughput, pending clarification that all ICM models can support these measures.

Estimation of Travel Times and Travel Distance for Incomplete Trips

Trips that cannot complete their trips by the time that the simulation ends are still included in the calculation of all delay and travel time calculations. Our approach is to estimate total travel time including any additional time that would be required to complete the trip given the average speed of travel.

First, let $\ddot{\mathbf{I}}^0_{o,d,\tau}$ be the set of $\ddot{n}^0_{o,d,\tau}$ trips from origin o , destination d starting a trip in time interval τ that can be completed under the low-demand operational condition used to identify the zero-delay travel times.

The average distance traveled over these trips is:

$$\ddot{X}^0_{o,d,\tau} = \frac{\sum_{i \in \ddot{\mathbf{I}}^0_{o,d,\tau}} s_i}{\ddot{n}^0_{o,d,\tau}} \qquad (24)$$

Note: If $\ddot{n}^0_{o,d,\tau} = 0$ then $\ddot{X}^0_{o,d,\tau}$ is indeterminate. In this case, find τ', the closest time interval such that $\arg\min_{\tau'} |\tau' - \tau|$ where $n^0_{o,d,\tau'} > 0$. Approximate $\ddot{X}^0_{o,d,\tau}$ using $\ddot{X}^0_{o,d,\tau'}$.

Next, let $\overleftarrow{\mathbf{I}}^k_{o,d,\tau}$ be the set trips from origin o, destination d starting a trip in time interval τ that *cannot* be completed under operational condition k. For all $i \in \overleftarrow{\mathbf{I}}^k_{o,d,\tau}$, let $\overleftarrow{x}^k_i$ be the distance traveled on the trip i up to the point where the simulation ends, and let $\overleftarrow{t}^k_i$ the travel time on trip i up to the point where the simulation ends. Average travel speed for a trip that cannot be completed is expressed in Equation 25:

$$\overleftarrow{v}^k_i = \frac{\overleftarrow{x}^k_i}{\overleftarrow{t}^k_i} \tag{25}$$

Estimated total trip travel time for a trip that cannot be completed before the simulation ends is the accumulated travel time plus the time to travel the remaining distance at average trip speed:

$$t^k_i = \overleftarrow{t}^k_i + max\left\{\frac{\left(\ddot{X}^0_{o,d,\tau} - \overleftarrow{x}^k_i\right)}{\overleftarrow{v}^k_i}, 0\right\} \tag{26}$$

$$x^k_i = max\left\{\ddot{X}^0_{o,d,\tau}, \overleftarrow{x}^k_i\right\} \tag{27}$$

Comparing Pre-ICM and Post-ICM Cases

All of the travel time and throughput measure calculation procedures defined above are conducted under a single set of simulation settings reflecting a specific set of corridor management policies, technologies and strategies (here referred to as a *case*, but often called an *alternative*). The complete suite of delay, travel time reliability and throughput measures are calculated independently for each case (e.g., Pre-ICM). Comparisons of the resulting measures are then made to characterize corridor performance under each case.

Comparing Observed and Simulated Performance Measures

These few key measures have been defined in detail for national consistency across all AMS sites. Sites have also identified measures. This document has dealt in detail with the calculation of measures from simulation outputs. However, the calculation of comparable measures using observed data demands an equivalent level of detailed attention. These observed measures will be critical in the AMS effort to validate modeling accuracy and in performance measurement in the demonstration phase. Because of the nature of the simulation output, the modeling analyst is able to resolve and track performance at a level of detail that is not available to an analyst working with field counts, speeds and transit passenger-counter outputs. However, it is the responsibility of the site and the AMS contractor to ensure that these measures are similar in intent, if not in precise calculation. In many cases, the simulation tools or their basic outputs can be manipulated to produce measures quite comparable with field data. An example of this is in throughput calculation, where a site may wish to pursue a screenline passenger throughput measure from field data. In addition to the system-level throughput measures detailed above, the simulation model can be configured to produce passenger-weighted counts across the same screenline to match the field throughput measure.

Appendix C Transit Mode Shift Methodology

This appendix describes the methodology used in determining whether a vehicle shifts to riding BRT (transit) in simulation for the ICM AMS effort underway for the San Diego I-15 site. The BRT service is proposed to have five stations within the study corridor, each having direct connections to the HOT lane and also access to the General Purpose Lanes.

The following variables are critical to the function of the algorithm.

- **BRT Cost (BRTCost).** This value represents the BRT fare in terms of dollars per ride. **Recommended value: $5 per ride**.
- **Auto Operating Cost (AutoOpCost).** This value represents the cost of driving. **Recommended value: $0.42/mile*Length(miles)**.
- **BRT Off-Vehicle Travel Time (BRTOVTT).** This value represents a traveler's time spent outside a BRT if the traveler decides to shift from driving to BRT riding. It includes the time that the traveler accessing the BRT station, waiting for a BRT, and exiting the BRT station at the destination station. **Recommended value: 20 minutes**. (5 minutes to access the BRT station, 10 minutes of waiting for BRT, and 5 minutes to exit the final BRT station).
- **Auto Off-Vehicle Travel time (AutoOVTT).** This value represents a traveler's time spent outside his/her vehicle if the traveler decides to continue driving. **Recommended value: 0 minute**.
- **BRT In-Vehicle Travel Time (BRTIVTT).** This value represents a traveler's time spent inside a BRT. It is assumed that BRT will travel at an average speed of 60 mph. **Recommended value: BRT Route Distance (miles) per 60 mph**.
- **Auto In-Vehicle Travel Time (AutoIVTT).** This value represents a traveler's time spent inside the vehicle he/she is driving. The travel time will be directly extracted from the simulation model.
- **Driver Income (Income).** This value represents the income of the driver, expressed in terms of dollars per hour. This value will be considered one of the factors influencing the driver's decision on either continuing driving or taking BRT. **Recommended value: $12 per hour – $100 per hour, with 50 percent of drivers at or below $24 per hour.**

The algorithm calculates whether a driver shifts to BRT in the following manner:

- The general purpose and managed lanes (ML) are divided into segments at each BRT station. A "segment" is defined as a length of roadway lying between successive access points to BRT stations.

- The cost of driving is calculated at the decision point upstream of each BRT access point based on the following utility function.

$$U_{Auto} = e^{-0.028*AutoIVTT - 0.054*AutoOVTT - 0.720*AutoOpCost + 0.000*Income}$$

- The cost of riding BRT is calculated at the decision point upstream of each BRT access point based on the following utility function.

$$U_{BRT} = e^{-0.500 - 0.028*BRTIVTT - 0.054*BRTOVTT - 0.720*BRTCost - 0.050*Income}$$

- The probability that a traveler would shift to using BRT is determined as shown below.

$$PROB_{BRT} = \frac{U_{BRT}}{U_{Auto} + U_{BRT}}$$

Appendix D Congestion-Based Dynamic Pricing on Managed Lanes

This appendix describes the methodology and assumptions for modeling congestion based dynamic pricing on managed lanes for the San Diego I-15 site.
The corridor has four lanes of physically-separated and reversible managed lanes with nine entry and seven exit points in the southbound direction and seven entry and exit points in the northbound direction. The managed lanes are free for HOV at all times. SOVs are tolled based on the level of congestion in the general purpose and managed lanes. The key variables in modeling the managed lanes operation is described in the following section.

The following variables are critical to the function of the dynamic pricing algorithm. The appropriate values assigned to all variables must be approved by SANDAG prior to implementing the algorithm.

- **Update Frequency.** This parameter represents the interval at which toll rates are updated on the managed lanes. **Recommended value: three minutes.**
- **Standard Value of Travel Time (VOTT).** This parameter represents the value of travel time used in calculating the monetary value of travel time savings. **Recommended value: $0.40 per minute.**
- **VOTT Increments/Decrements.** This value represents the step increment or decrement used in VOTT adjustment in the dynamic pricing algorithm. **Recommended value: $0.05 ~ $0.10 per minute.**
- **Minimum Toll Rate.** This value represents the minimum per mile toll that is charged to SOVs at any time irrespective of the level-of-service on general purpose and managed lanes. **Recommended value: $0.10 per mile.**
- **Maximum Toll Rate.** This value represents the maximum per mile toll that is charged to SOVs at any time irrespective of the level-of-service on general purpose and managed lanes. **Recommended value: $1.00 per mile.**
- **Minimum Acceptable Level-of-Service on Managed Lanes.** This value represents the minimum average speed that has to be maintained in the managed lanes at all times. **Recommended value: 60 mph.**

The toll rates are dictated by the travel timesavings and the average value of travel time, and are calculated using the following formula.

$$TollRate_i = \frac{VOTT_i \times \sum_{i}^{I} (TT_{GP_i} - TT_{ML_i})}{\sum_{i}^{I} Length_i}$$

Where:

$TollRate_i$ – per mile toll rate for segment i;

$VOTT_i$ – value of travel time for segment *i*;

TT_{GPi} – average travel time for segment *i* on general purpose lanes;

TT_{MLi} – average travel time for segment *i* on managed lanes; and

$Length_i$ – length of the segment *i*.

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