USDOT Integrated Corridor Management (ICM) Initiative

Integrated Corridor Management Analysis, Modeling, and Simulation Results for the Test Corridor

June 2008
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Integrated Corridor Management

Analysis, Modeling, and Simulation Results for the Test Corridor

prepared for

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16. Abstract

This report documents the Integrated Corridor Management (ICM) Analysis Modeling and Simulation (AMS) tools and strategies used on a Test Corridor, presents results and lessons-learned, and documents the relative capability of AMS to support benefit-cost assessment for the successful implementation of ICM.

The analysis took into account both recurrent and nonrecurrent corridor operational conditions; key ICM impacts may be lost if only "normal" travel conditions are considered. Performance measures used in the analysis include mobility, reliability, safety, emissions, fuel consumption, and benefit-cost. To the extent possible, the measures were reported by mode, facility type, and jurisdiction. ICM strategies analyzed include highway traveler information, transit traveler information, freeway ramp metering, HOT lane, arterial traffic signal coordination, and combinations of these strategies.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Executive Summary

In order for decision-makers to select the most appropriate intelligent transportation systems (ITS) investment strategy for integrated corridor management (ICM), information needs to be available on the benefits and costs of implementing certain packages of ITS strategies. Currently, models and simulation tools are available for discrete strategy analysis, but a process and tool set to holistically look at the impacts of ITS strategies implemented in a multimodal corridor are not available. The integrated corridor management initiative is working with existing models to create a process that bridges this gap. This report documents lessons learned from the application of the ICM analysis, modeling, and simulation process on a test corridor. The next stage of the ICM analysis, modeling, and simulation process will be to test the process to model the ICM strategies and scenarios from three of the eight ICM Pioneer Sites. The "real world" analysis will enable the U.S. DOT to assess the potential impact resulting from a demonstration of an ICM system and further validate the ICM analysis, modeling and simulation process. After the demonstration is completed, the analysis, modeling, and simulation process will be updated to improve effectiveness and prepare for knowledge and technology transfer to the industry.

The approach adopted for the Test Corridor analysis applies the AMS methodology and framework developed in previous tasks. This approach encompasses tools with different resolutions (including macroscopic, mesoscopic, and microscopic transportation analysis tools) and provides the greatest degree of flexibility and robustness by combining the capabilities of these tools. The AMS methodology applies 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. The methodology also includes a simple pivot-point mode shift model and a transit travel-time estimation module, interfaces between different tools, and performance measurement and benefit-cost estimation modules. This approach supports: a) the analysis of traveler responses to traveler information; b) the analysis of strategies related to tolling/HOT lanes/congestion pricing; and c) the analysis of mode shift and transit.

The analysis took into account both recurrent and nonrecurrent corridor operational conditions; key ICM impacts may be lost if only "normal" travel conditions are considered. Performance measures used in the analysis include mobility, reliability, safety, emissions, fuel consumption and benefit-cost. To the extent possible, the measures were reported by mode, facility type and jurisdiction. ICM strategies analyzed include highway traveler information , transit traveler information, freeway ramp metering, HOT lane, arterial traffic signal coordination and combinations of these strategies.

Test 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 Test Corridor produces a 10-year benefit of approximately $570 million.
- Approximately one-half of ICM benefit is on high demand/major incident days (representing 25 percent of commute days.) This finding validates the hypothesis that ICM is most effective under the worst operational conditions, including heavy demand and major incidents.
- A comparison of benefits across operational conditions reveals that the effectiveness of ICM strategies varies under different prevailing conditions. 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.
- The results show that, in the presence of a major incident (two freeway lanes blocked for 45 minutes), one to four percent of travelers affected by the incident shifted to transit. This result compares well against before-after studies of mode shift under nonrecurrent congestion.
- For the Test Corridor, the HOT lane and highway traveler information were found to be the most effective ICM investments in terms of both benefit-cost and net annual benefit. This finding will not necessarily apply to other corridors; different geometric, demand, and operational characteristics will result in different effectiveness of variable ICM strategies across different corridors.

The 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.

1.0 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 multijurisdictional 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 underutilized capacity (in the form of parallel transit capacity (bus, rail, BRT, etc.) and/or arterials and underutilized 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 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' 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 up to four Stage 2 ICM Pioneer Sites, and conduct AMS tools post-demonstration evaluations. 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 the following:

- Help decision-makers identify gaps, evaluate ICM strategies, and invest in the best combination of strategies that would minimize congestion and improve safety – 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.

The overall AMS effort includes the following tasks:

1. Identify AMS data needs and assess Pioneer Site capabilities;
2. Develop methodologies to model ICM strategies;
3. Test and validate these methodologies in a test corridor – the results of this task are summarized in this document;
4. Use AMS methodologies and existing tools to model up to four Pioneer Site corridors. This will help identify cost-effective ICM strategies, and help prioritize ICM investments based on expected performance; and
5. Validate methodologies and tools based on Pioneer Site demonstrations. The overall effort will result in validated and tested methodologies to support ICM analysis.

This **AMS Results for the Test Corridor Report** documents the ICM AMS tools and strategies and the Test Corridor, presents high-level AMS results for the Test Corridor and lessons-learned, and documents the relative capability of AMS to support benefit-cost assessment for the successful implementation of ICM.

This document is organized as follows:

- The remainder of **Chapter 1.0** outlines the principles guiding the development and application of ICM AMS.
- **Chapter 2.0** presents the AMS methodology, and provides a summary of the Test Corridor site.
- **Chapter 3.0** presents the structure for the Test Corridor analysis approach, performance measures, how to take into account nonrecurrent congestion, and ICM strategies and analysis alternatives applied for the Test Corridor AMS.
- **Chapter 4.0** presents the Test Corridor AMS results, as well as conclusions and lessons-learned. The Test Corridor analysis compared annual benefits and costs for a number of ICM strategies (or combinations thereof) across a number of operational conditions, against the default case representing conventional transportation infrastructure with no ITS. This represents a measurement of "no ITS versus ICM" which is different than "pre-ICM versus post-ICM" that will be tested in Stage 2 AMS efforts.
- **Appendix A** presents detailed cost information used in the Test Corridor AMS.

- **Appendix B** describes how DynaSmart-P model runs are organized in the DVDs that accompany this report. Various folders and their contents are listed in this appendix, including results by operational condition, model calibration tool, and travel demand model files.
- **Appendix C** describes tools developed under the Test Corridor AMS effort, including the pivot-point mode shift model and post-processors to the DynaSmart-P model, and provides a user's guide to the post-processors.
- **Appendix D** presents the full AMS results for the Test Corridor for all operational conditions and for all ICM scenarios.

1.1 Principles in Developing and Applying AMS Methodologies

A number of principles apply in developing and applying AMS methodologies. These are summarized as follows:

- **Resource and schedule constraint –** The overall ICM AMS effort must take place within the budget and schedule specified in the Scope of Work and Work Plan. Data, models, and tools available at the Pioneer Sites will be leveraged in the AMS effort.
- **Focus on integration of existing tools –** The ICM AMS effort does not focus on developing new analytical tools; instead, it focuses on a relevant, meaningful application of **existing** modeling and simulation tools.
- **Recognize current limitations in available tools and data –** There are known gaps in existing analysis tools that the AMS methodology must bridge. Examples of these gaps include the dynamic analysis of transit and mode shift, and the dynamic analysis of ICM strategies such as traveler information or congestion pricing. Bridging these gaps requires the interface of existing analysis tools with different capabilities.
- **Be vendor-neutral –** Developed AMS methodologies and interfaces must be vendor-neutral and not favor one specific tool over other available tools. Interfaces developed under this effort must be universal enough to be able to function with the structure of major available tools used by transportation analysts.
- **Consistency of analytical approaches and performance measures –** ICM Pioneer Sites have different analysis tools at their disposal. The application of the AMS methodology to the various Pioneer Sites must be consistent in terms of analysis approach and performance measures. Consistency is important when trying to synthesize lessons learned in each site into national-level guidance.
- **Benefit-cost analysis –** Expected benefits resulting from the implementation of ICM strategies will be compared to expected costs to produce estimates of

benefit-cost ratios and net benefits associated with the deployment of ICM strategies. This will help identify cost-effective ICM strategies, help differentiate between low-payoff and high-payoff ICM strategies, and help prioritize ICM investments based on expected performance.

2.0 Test Corridor Site and AMS Methodology

The Test Corridor and AMS methodology are described in this section.

2.1 Test Corridor

The Test Corridor comprises the I-880 corridor between the Cities of Oakland and Fremont, California, with the I-580/I-80 interchange as the northern boundary and SR 237 as the southern boundary, for a distance of about 34 miles, or more than 250 lane-miles. The ICM AMS team evaluated a number of candidate Test Corridor sites and selected I-880 based on a number of criteria, including availability of macroscopic, mesoscopic, and microscopic simulation models; validation and calibration data; ease of modifications to these models; multitude of transportation modes (single-occupancy vehicle (SOV), high-occupancy vehicle (HOV), transit, etc.); multitude of transportation facilities (freeways, arterials, HOV lanes, transit, etc.); and transferability/applicability of results and methods tested on the Test Corridor.

As one of the main arteries of the freeway system in the San Francisco Bay Area, I-880 includes 34 miles of freeway connecting Silicon Valley with the East Bay. I-880 serves the Port of Oakland, Oakland International Airport, and the Oakland Coliseum, as well as a major concentration of residential, office, industrial, and warehouse land uses. I-880 serves both as an access route for major interregional and international shippers and a primary intraregional goods-movement corridor. Facilities in the Test Corridor include the I-880 freeway, arterial highways, the Alameda County (AC) bus transit routes, the Bay Area Rapid Transit (BART) rail, and intercity passenger and freight rail lines. An illustration of the Test Corridor is shown in Figure 2.1. The Test Corridor is described in more detail in the "Test Corridor Model Description" document, one of the ICM AMS deliverables.

2.2 Modeling Approach

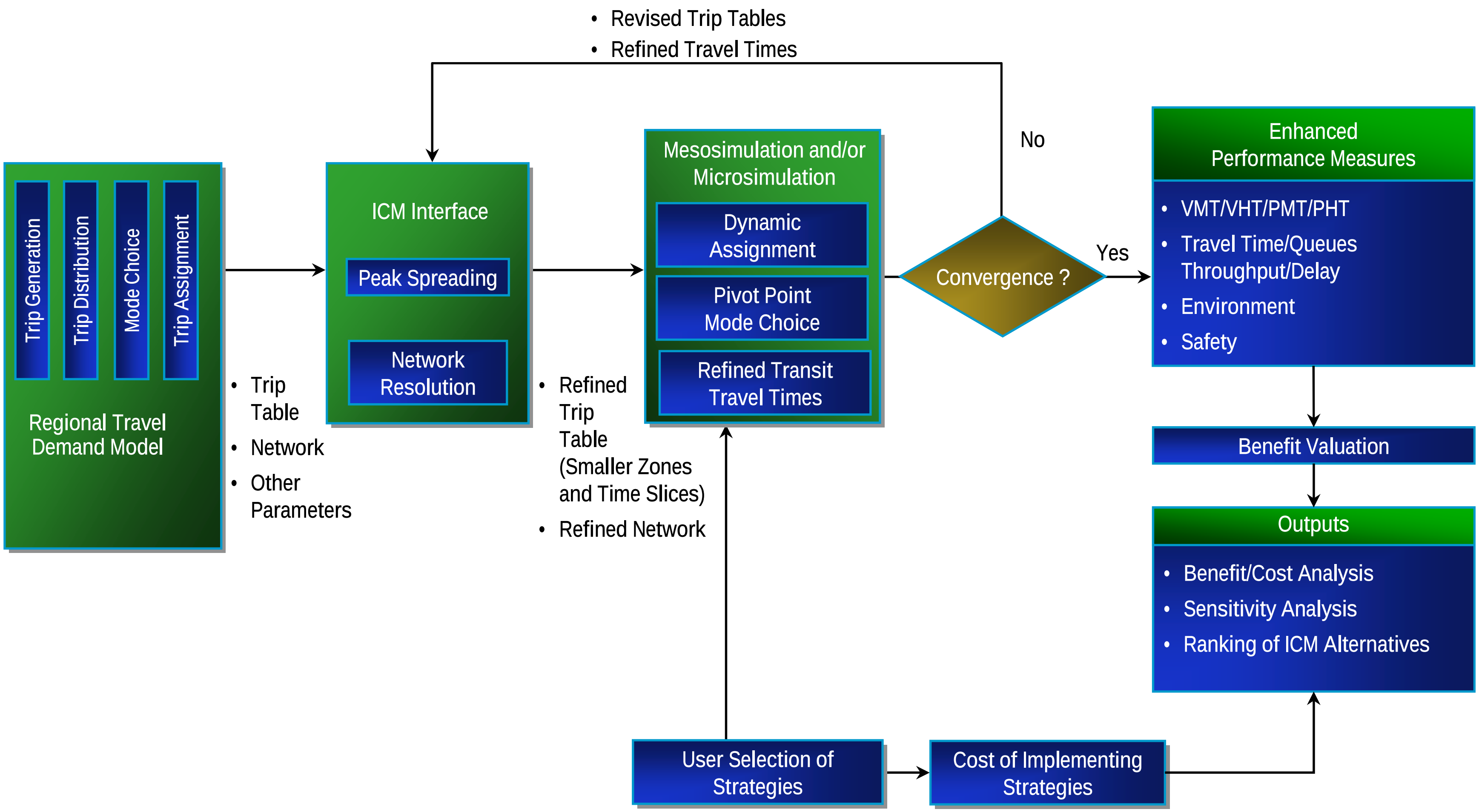
Three major findings emerged from the analysis of capabilities found in existing AMS tools:

- Different tool types have different advantages and limitations. There is no one tool type at this point in time that can successfully address the analysis capabilities required by ICM AMS requirements. There is no single model available that provides visibility into the cascading impacts of various congestion management strategies, much less combinations of strategies, across the entire network, transportation modes, and facility types. **An integrated approach can support corridor management planning, design, and operations by combining the capabilities of existing tools.**

Figure 2.1 The Test Corridor

- The integrated approach is based on **interfacing between travel demand models, mesoscopic simulation models, and microscopic simulation models.** This approach may present integration challenges that can be addressed by identifying interface requirements that focus on: a) maintaining the consistency across analytical approaches in the different tools; and b) maintaining the consistency of performance measures used in the different tool types.
- **Key modeling gaps** in existing tool's capabilities include: a) the analysis of traveler responses to traveler information; b) the analysis of strategies related to tolling/HOT lanes/congestion pricing; and c) the analysis of mode shift and transit.

Figure 2.2 Test Corridor AMS Framework



The approach adopted for the test corridor analysis applies the AMS Methodology findings and the AMS framework shown in Figure 2.2. The Test Corridor 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. This modeling approach provides the greatest degree of flexibility and robustness in supporting subsequent tasks for AMS support of Pioneer Sites.

The AMS methodology applies 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 includes a simple pivot-point mode shift model and a transit travel-time estimation module, the development of interfaces between different tools, and the development of a performance measurement and benefit-cost module.

In this AMS framework, macroscopic, mesoscopic, and microscopic traffic analysis tools can 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 will seek a natural state for practical convergence between different models, and the iterative process will be terminated or truncated at a point where reasonable convergence is achieved.

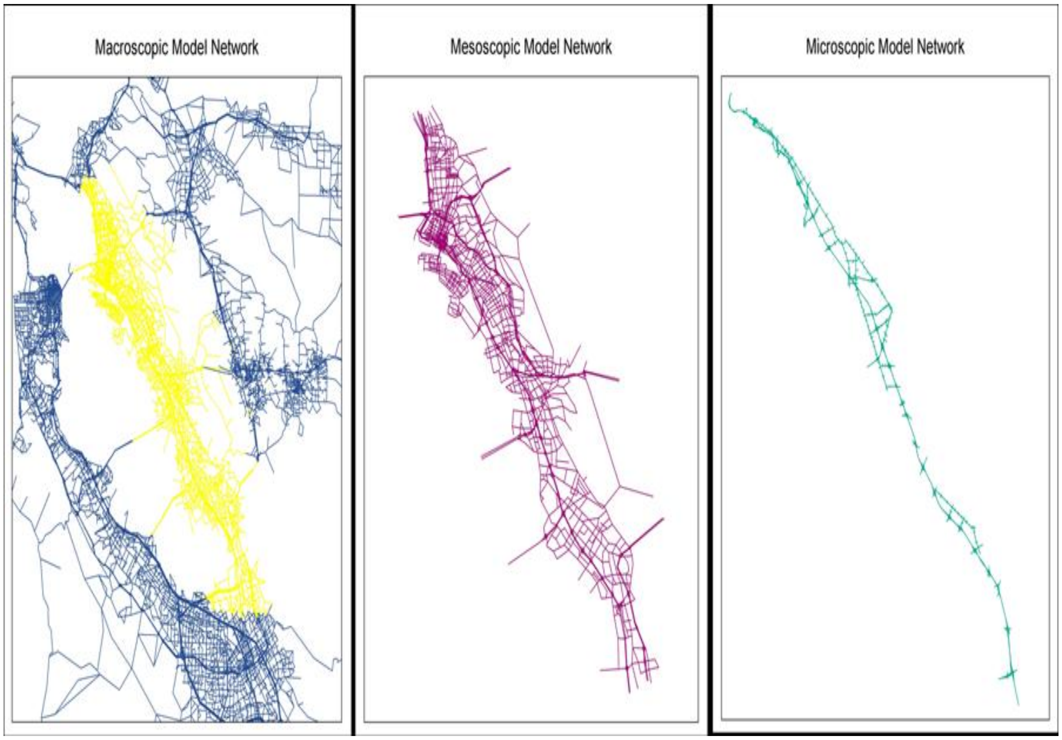
This section describes the various off-the-shelf and custom tools applied for the Test Corridor to conduct the modeling of the ICM strategies.

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; these are mathematical models that forecast future travel demand from current conditions, and future projections of household and employment characteristics.

A validated CUBE travel demand model (TDM) of the Alameda County Congestion Management Agency was used to develop the trip tables and networks for the Test Corridor. Subarea trip tables and networks were developed from the TDM for use in the simulation models. Parameters from the TDM also were used in a simple pivot-point mode-choice model, which analyzed mode shifts in response to congestion and to ICM strategies. Figure 2.3 shows Test Corridor model networks for the macro, meso, and microscopic traffic analysis tools.

Figure 2.3 Model Networks for the Test Corridor



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 they assign vehicle types and driver behavior, as well as their relationships with the roadway characteristics. Their movement, however, follows the approach of macroscopic models and is 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.

A DynaSmart-P mesoscopic model of the subarea extending beyond the mainline I-880 corridor was used for the analysis of ICM strategies in the Test Corridor. The model was used to support the analysis of the dynamic impact of ICM strategies that may induce shifts of trips from one network to another, such as pricing, and corridor-specific traveler information (pretrip and e-route).

Micro-Scopic 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.

A Paramics microsimulation model for the Test Corridor was being developed as part of the California Department of Transportation (Caltrans) Model Corridor study. The schedule of this parallel effort did not allow for this model to become available for Test Corridor AMS. Had it been available, the microsimulation model would have further supported the evaluation of traffic control aspects of ICM strategies, such as ramp metering and traffic signal coordination. Microscopic simulation analysis can output detailed travel times that can be used to augment the mesoscopic simulation analysis. This augmentation would entail the conversion of operational impacts identified at the microscopic level into adjustment factors at the mesoscopic level.

Time-of-Departure Choice

Generally, there is little information on travelers' choice of their time-of-departure. In the Test Corridor AMS, there were only two University-led studies on traveler's stated (not revealed) preferences regarding time-departure choice. And, there were no locally derived or calibrated choice models available for time-of-day choice. The analysis used these studies plus anecdotal information from local experts (especially as they relate to observed behavior after major incidents).

Currently, the mesoscopic model used in the Test Corridor AMS does not include a time-departure model, although efforts are being made to provide some of this capability for Pioneer Site AMS. The general idea is to apply a time-of-day departure model that takes into account network supply conditions (congestion, pricing, etc). A promising option is the constrained departure time MNL model (Small, 1982; Noland, Small, Koskenoja et al., 1998; Yamamoto, Fujii and Kitamura, 1999; Lam and Small, 2001; Ben-Akiva and Bierlaire, 2003; Bellei G and et al., 2006). It includes a nested structure rather than a simultaneous structure. That is the outer loop is the departure time choice while the inner loop is the route choice algorithms. Both the departure time choice model and the inner loop DTA model would be modifying vehicle and path files.

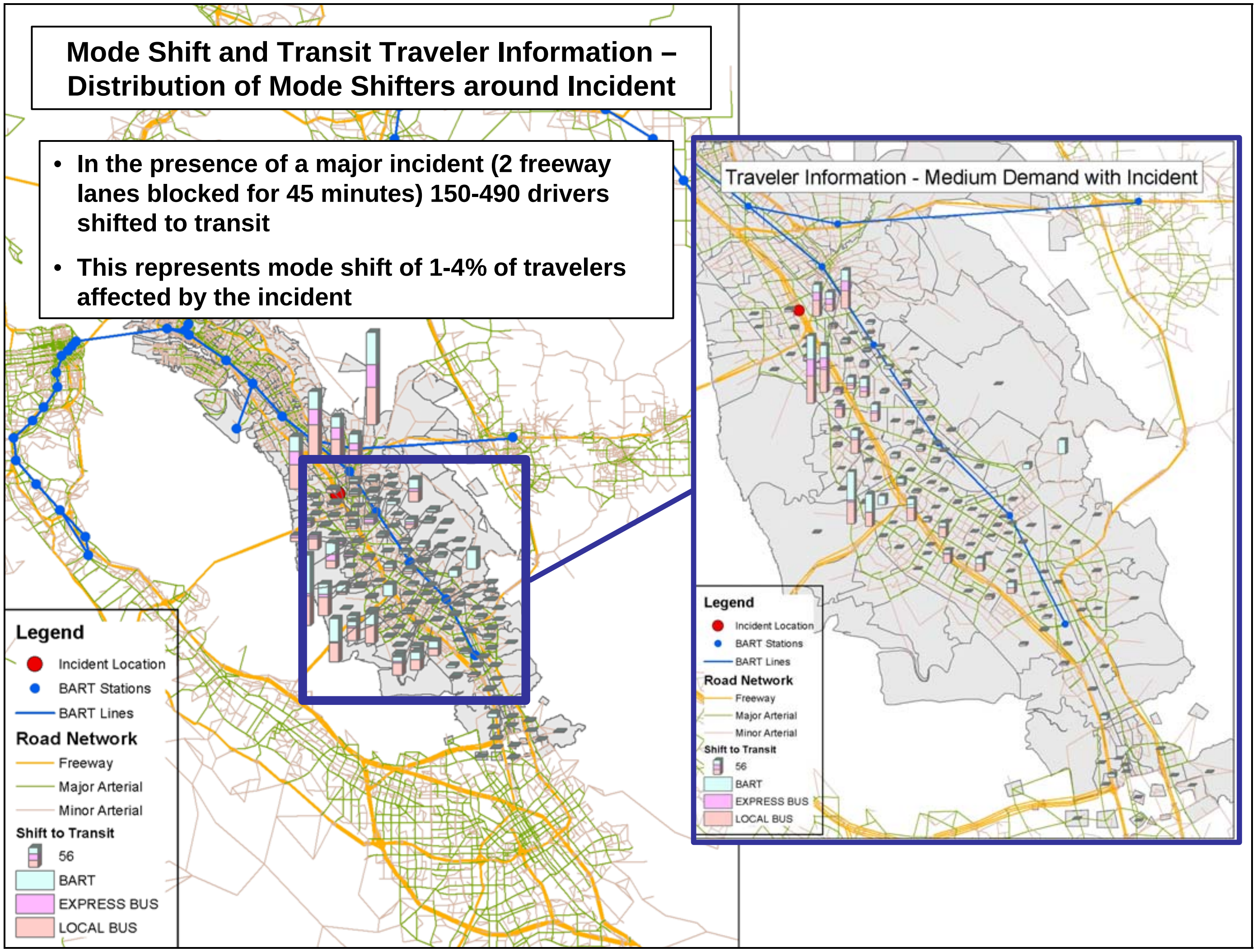
Analysis of Mode Shift and Transit

A known gap in the analysis of ICM relates to the performance and impacts of transit services. Mode shift in the Test Corridor can be influenced by adverse traffic conditions (incidents, heavy demand, and inclement weather) and by ICM strategies (such as traveler information systems, etc.) 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 pivot-point mode shift model developed for Test Corridor AMS works with trip tables from the travel demand model, and with more accurate travel times estimated by simulation models. This approach provides: 1) calculation of transit travel times for each requested level of analysis given the corridor conditions or operations input; 2) incorporation of inputs from each level of analysis to adjust transit travel times per segment and decision point; and 3) generation of outputs that can be incorporated into the other modeling tools as analysis adjustment factors. This approach supports the corridor analysis of transit in an ICM environment, and provides the information necessary to account for the interrelation of impacts with the traffic operations in the corridor.

The output from the mode choice analysis and trip table manipulation takes into account trip impacts associated with corridor conditions, current operations, or operational changes. Furthermore, a Geographic Information System (GIS) capability associated with the mode shift model provides information on origins/destinations of shifted trips, and takes into account transit capacity and capacity at parking lots adjacent to transit stations. Figure 2.4 shows the distribution of mode shifters around a major freeway incident tested for the Test Corridor AMS.

Figure 2.4 Mode Shift and Transit Traveler Information
Distribution of Mode Shifters around Incident



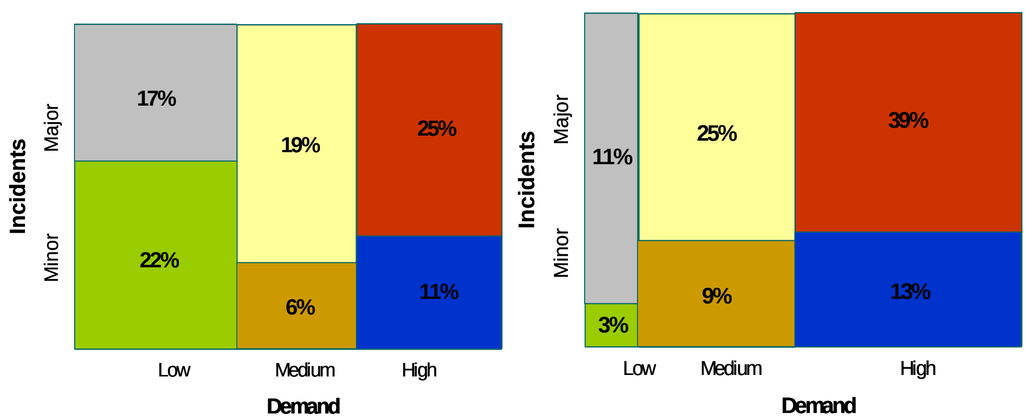
3.0 Analysis Design

This section describes the ICM strategies applied to the Test Corridor, the operational conditions studied to analyze the impacts of the strategies, analysis settings, and performance measures used in the analysis.

3.1 Operational Conditions

The ICM AMS framework provides tools and procedures capable of supporting the analysis of both recurrent and nonrecurrent corridor operational conditions. In the Test Corridor AMS, nonrecurrent congestion conditions entail combinations of increases of demand and decreases of capacity. Key ICM impacts may be lost if only "normal" travel conditions are considered. As shown in Figure 3.1, the different operational conditions take into account medium- and high-travel demand, with major and minor incidents.

Figure 3.1 Test Corridor Operational Conditions – Frequency and Intensity



The relative frequency of nonrecurrent conditions is important to estimate in this process – based on archived data. Figure 3.1 shows the overall frequency in operational conditions for the Test Corridor, including percentage of days in the year categorized by different incident and demand levels. Major incidents are defined as having duration over 20 minutes, and minor incidents as having duration under 20 minutes. In the Test Corridor, major incidents together with high demand characterize 25 percent of all workdays (red or upper-right cluster in the left part of Figure 3.1), while 22 percent of all workdays (green or lower-left cluster) feature both low demand and minor incident conditions. The right part of Figure 3.1 shows that 39 percent of total annual delay (red or upper-right cluster) occur on the worst 25 percent of days, while 64 percent of annual delay (red plus yellow) occur on the worst 44 percent of days. Conversely, only 14 percent of annual delay (grey plus green) occur on the remaining 39 percent of days.

Medium- and high-travel demand conditions were determined by analyzing archived data available locally at the Test Corridor (PeMS). The most likely incident location for the Test Corridor was determined by analyzing incident frequency. Figure 3.2 shows incident locations by frequency, northbound. Shown in Figure 3.3 is the highest incident location – between SR 23 and SR 92, an area of increased merging and weaving traffic. The incident represents two lanes being closed for 45 minutes, starting at 7:15 a.m. This represents the 85th percentile incident. The Test Corridor at the incident location provides alternative arterial routes and alternative transportation modes, including bus and rail (BART) lines.

Figure 3.2 Incident Locations/Frequency
Test Corridor NB

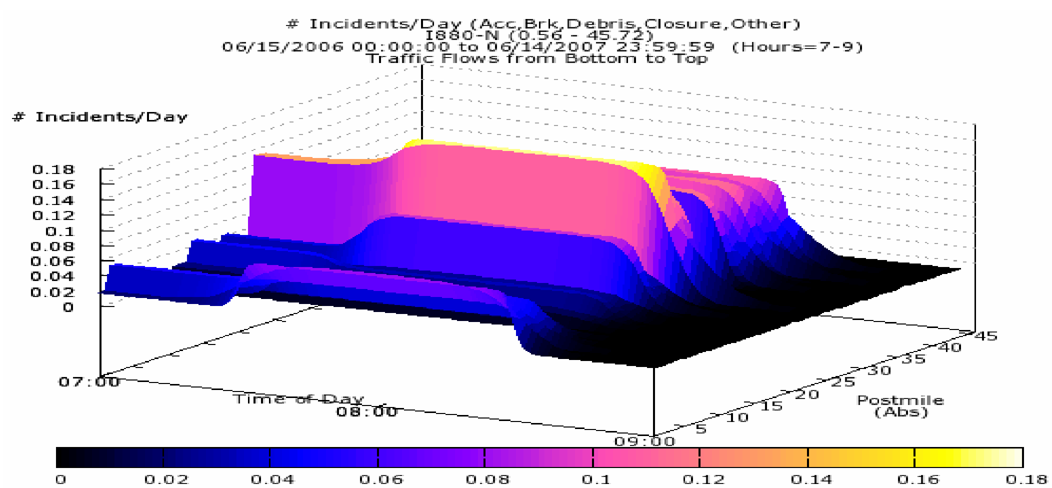


Figure 3.3 Highest Frequency Incident Location in the Test Corridor

3.2 Analysis Settings

Table 3.1 presents a summary of settings for the Test Corridor analysis.

Table 3.1 Test Corridor
Summary of Analysis Settings

Parameter	Value	Comment
Analysis year	2005	The analysis year is based on the available model year in the regional travel demand model.
Time period of analysis	A.M. peak – 2 hours (7:00 a.m. to 9:00 a.m.)	The analysis period is determined by the peak-hour trip table available in the regional travel demand model. The actual analysis period in the mesoscopic and microscopic simulation models will include an initialization period of 15 minutes and a demand dissipation period of 30 minutes.
Incident location	Postmile 23	Over 55 incidents have occurred around this postmile point between May 2006 and May 2007.
Incident duration	Two lanes closed for 45 minutes starting at 7:15 a.m.	Obtained from incident duration from the PeMS database and Caltrans "TMS Master Plan" study.

3.3 ICM Strategies

The remainder of this section identifies ICM strategies, analysis alternatives, and tools used in the analysis of implementation of ICM on the Test Corridor. This set of ICM strategies comprehensively tested the AMS methodology in terms of traveler responses (route diversion, mode shift, and temporal shift); and in terms of interfaces for flows of data between modeling tools.

ICM strategies modeled for the Test Corridor are not necessarily the strategies being proposed by the Oakland I-880 ICM Pioneer Site. The Test Corridor AMS strategies were selected with the sole purpose of testing the AMS methodology. ICM strategies selected for testing, and models used in the analysis, include the following:

- **Zero ITS baselines –** This baseline represents conventional transportation infrastructure with no ITS. This baseline strategy was run in four operational conditions representing combinations of medium-/high-travel demand and major/minor incidents. The local travel demand model and a mesoscopic simulation model (DynaSmart-P) were used in modeling these baselines. These results (annualized) represent the default cases in each operational condition. Benefits of ICM strategies (or combinations thereof) were calculated based on each strategy modeled in the four operational conditions and then compared against the default case. This represents a measurement of "no ITS versus ICM" which is different than "pre-ICM" and "post-ICM."
- **Highway traveler information –** Combinations of medium-/high-travel demand and presence of a major incident with: 1) pretrip and en-route traveler information; 2) Variable Message Signs (VMS); and 3) a combination

of 1 and 2. Traveler information on incident location and severity provided drivers with the opportunity to take alternative arterial routes. The analysis of these scenarios was conducted in DynaSmart-P. In this analysis travelers with access to real-time information on incident conditions chose routes that would minimize their travel time, while travelers with no access to information stayed on their historical paths. For pretrip and en-route traveler information the analysis assumed that 20 percent of travelers had access to such information and chose to take alternate routes or routes that would minimize their travel times. The analysis of VMS assumed that all travelers that passed the VMS point during the time of the incident, had access to real-time information about the incident, and chose to take alternate routes or routes that would minimize their travel times.

- **Transit traveler information –** Traveler information on incident location and severity provided drivers with the opportunity to drive to a transit station, where parking was available, and use transit to get to their destinations. It studied the impact of parking availability by manipulating parking search time. Parking capacity at different BART stations was taken into account. In this analysis, travel times from DynaSmart-P were imported in an external GIS-based, mode-shift pivot point model. An iterative process was applied to analyze mode choice at consecutive 15-minute periods. For transit traveler information the analysis assumed that 20 percent of travelers had access to real-time information (both pretrip and en-route) about incident conditions, expected delays, availability of transit and highway options, travel times for these options, and availability of parking. Informed travelers chose to consider alternate modes (BART or bus transit) that would minimize their travel times, and shifted to transit if the combined (transit access/egress + transit trip) travel times provided travel time savings greater than one minute.
- **Ramp metering –** Freeway traffic management can be obtained by controlling the vehicles entering the freeway through ramp metering. The analysis of ramp metering was conducted using DynaSmart-P to assess regional and local diversion effects. Locally adaptive ramp metering was modeled in this strategy, allowing vehicles to enter the freeway stream if there were available capacity immediately upstream of the on-ramp. Other, enhanced ramp metering strategies, including corridor adaptive ramp metering or ramp metering with ramp queue control, were not tested in this analysis.
- **HOT lane –** High-occupancy toll (HOT) lanes provide the potential to optimally use the HOV lanes while generating revenue. Converting the existing HOV lane in the Test Corridor was studied using DynaSmart-P. Mode shift effects were studied using the pivot point mode shift model. To model congestion pricing strategies, the analysis used dynamic traffic assignment where traveler expectations of potential time savings were equilibrated against the cost of using the HOT lane. The analysis used prespecified, time-dependent costs for the HOT lane. $8.00 per trip was used as the maximum price for using the HOT lane, based on local data. Diversion and mode shift

parameters remained the same across all analyses, and all trips were assumed to occur in all alternatives analyzed to maintain consistency in the comparison (so no trips were lost or new trips generated across analysis alternatives). The analysis did not take into account that the value of time may vary across travelers at different income levels, or across different zones or vehicle classes.

- **Arterial traffic signal coordination –** The evaluation of arterial traffic signal coordination strategies used Synchro, DynaSmart-P, and the pivot-point mode choice model. In the analysis, signalized arterials serving as alternate routes to the freeway had their traffic signals coordinated to reflect changing traffic conditions due to the incident or fluctuations in travel demand.
- **Combinations** of traveler information, transit, ramp metering, and HOT lane strategies were evaluated. A combination of DynaSmart-P and the pivot-point mode shift model was used in this analysis.

3.4 PERFORMANCE MEASURES

This section details the performance measures used in the evaluation of ICM strategies for the Test 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, reliability, and safety based on current and future conditions; and
- Help prioritize individual investments or investment packages within the Test Corridor for short- and long-term implementation.

To the extent possible, the measures were reported by:

- **Mode –** SOV, HOV, transit, freight, etc.;
- **Facility Type –** Freeway, expressway, arterial, local streets, etc.; and
- **Jurisdiction –** Region, county, city, neighborhood, and corridor-wide.

The performance measures focus on the following four key areas. Additional information on these measures is provided in the "ICM AMS Methodology" document.

1. **Mobility –** Describes how well the corridor moves people and freight;
2. **Reliability –** Captures the relative predictability of the public's travel time;
3. **Safety –** Captures the safety characteristics in the corridor, including crashes (fatality, injury, and property damage); and
4. **Emissions and Fuel Consumption –** Captures the impact on emissions and fuel consumption.

Mobility

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

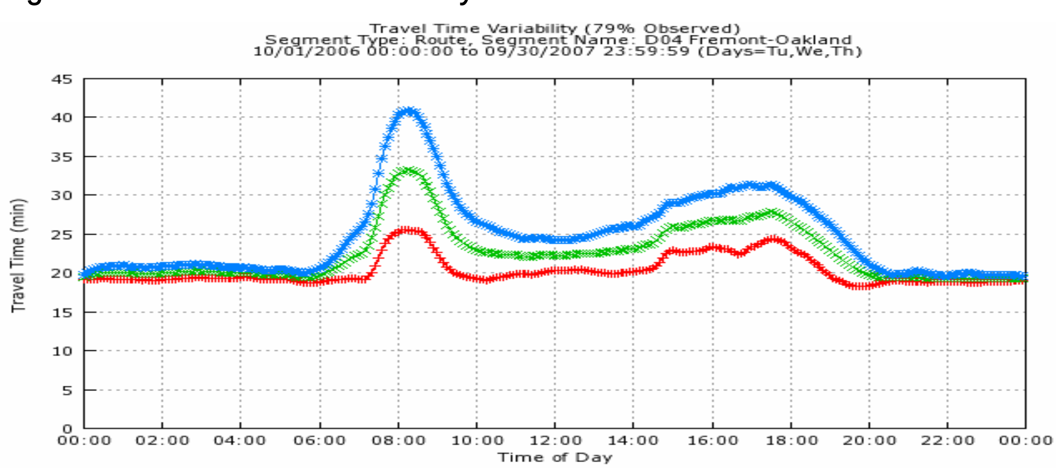
1. **Travel time –** This is defined as the average travel time for the entire length of the corridor or segment within a study corridor by facility type (e.g., mainline, HOV, and local street) and by direction of travel. Travel times were computed for the peak-period.

2. **Delay –** This is defined as the total observed travel time less the travel time under uncongested conditions, and was reported both in terms of vehicle-hours and person-hours of delay. Delays were calculated for freeway mainline and HOV facilities, transit, and surface streets.

Reliability of Travel Time

Reliability captures the relative predictability of the public's travel time. Unlike mobility, which measures how many people are moving at what rate, the reliability measure focuses on how much mobility varies from day-to-day. Figure 3.4 shows travel time variability in the Test Corridor. The top (blue), middle (green) and bottom (red) lines depict the 95th, 50th, and 5th percentile travel times for the full length of the Test Corridor. As seen in the figure, increased travel times during peak-periods are accompanied by increased variability of travel times. For example in the a.m. peak, 95th percentile travel time is approximately eight minutes longer than the 50th percentile travel time. In addition to reducing travel time, ICM strategies also are expected to improve the reliability of travel time.

Figure 3.4 Travel Time Variability in the Test Corridor



For the Test Corridor, travel-time reliability was calculated by performing 10 simulation model runs for each ICM strategy based on variations of travel demand as observed in the Test Corridor data archival system. Travel time reliability was calculated for trips across operational conditions (variations in demand) using the standard deviation of travel time across the 10 model runs, and then was aggregated for each ICM strategy. For each ICM strategy simulation model runs were conducted until the model reached an equilibrium threshold that was less than a prespecified percentage (the same percentage across all strategies).

The methodology described above is similar to the "Buffer Index" method but uses the standard deviation of travel time for the a.m. peak-period to report travel-time reliability for the Test Corridor. The buffer index is 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. The buffer index is the difference between the 95th percentile travel time and the average travel time for the peak-period divided by the average travel time:

$$BufferIndex = \frac{([95thPercentileTravelTime] - [AverageTravelTime])}{[AverageTravelTime]}$$

Safety

For the safety performance measure, the number of accidents and accident rates from accident databases were used for the Test Corridor.

Emissions and Fuel Consumption

The Test Corridor AMS also produced estimates of emissions and fuel consumption, associated with the deployment of ICM strategies. Currently, modeling of emissions/fuel impacts is being redesigned to account for impacts on global warming (the Environmental Protection Agency (EPA) is in the process of rethinking their methodology for analyzing vehicular emissions, and California also is revamping its emissions/fuel analysis methodologies). These research efforts are not expected to become available in time for Pioneer Site AMS. Instead, for the Test Corridor AMS the analysis used a relatively simpler methodology based on the IDAS method.

Cost Estimation

For the identified mitigation strategies, the analysis team prepared planning-level cost estimates, including lifecycle costs (capital, operating, and maintenance costs). Costs were expressed in terms of the net present value of various components.

4.0 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. Details of the methodology used for model calibration are provided below.

4.1 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
- Calibration of the overall model against overall system performance measures, such as travel time, delay, and queues.

4.2 Calibration Approach

Available data on bottleneck locations, traffic flows, and travel times were used for calibrating the simulation model for the analysis of the Test Corridor. The Test Corridor calibration strategy was based on the three-step strategy recommended in the FHWA Guidelines for Applying Traffic Microsimulation Modeling Software:[1]

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[1] 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.

1. **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.
2. **Route choice calibration –** The Test Corridor has parallel arterial streets, making route choice calibration important. A second calibration process was performed with the route choice parameters. A global calibration is performed first, followed by link-specific fine-tuning.
3. **System performance calibration –** Finally, the overall model estimates of system performance (travel times and queues) are compared to the field measurements for travel times and queues. Fine-tuning adjustments are made to enable the model to better match the field measurements.

Calibration Criteria

Calibration criteria presented in Table 4.1 were applied for the Test Corridor simulation, subject to the budget and schedule constraints for the Test Corridor AMS.

Table 4.1 Calibration Criteria for the Test Corridor AMS

Calibration Criteria and Measures	Calibration Acceptance Targets
• 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 Relationship.*	• To analyst's satisfaction.
• Visual Audits: *Bottlenecks: Visually Acceptable Queuing.*	• To analyst's satisfaction.

4.3 Model Calibration Results

Results for the calibration of the Test Corridor DynaSmart-P model are presented in this section.

- Figure 4.1 shows observed versus simulated traffic volumes across seven consecutive iterations in the calibration process. Progressively the calibration results have become better from Iteration 1 to Iteration 7. For most links with high-traffic volumes (greater than peak-period traffic flows of 2,000), simulated volumes fall within the 15 percent range (dotted lines in Figure 4.1).

- Figure 4.2 shows percent error between observed and simulated traffic volumes for the calibrated DynaSmart-P baseline simulation. Again, for most links with high-traffic volumes (greater than peak-period traffic flows of 2,000), simulated volumes fall within the 15 percent error range (dotted lines in Figure 4.2).
- Table 4.2 shows observed, simulated, and free-flow average travel times at six segments of the Test Corridor in the southbound direction. Overall, the simulated corridor travel time is within the 15 percent range.
- Table 4.3 shows observed, simulated, and free-flow average travel times at seven segments of the Test Corridor in the northbound direction. Overall, the simulated corridor travel time is within a 20 percent range.
- Figure 4.3 shows observed, simulated, and free-flow average travel times for the full length of the Test Corridor in both directions.

Figure 4.1 DynaSmart-P Calibration
Observed versus Simulated Volumes

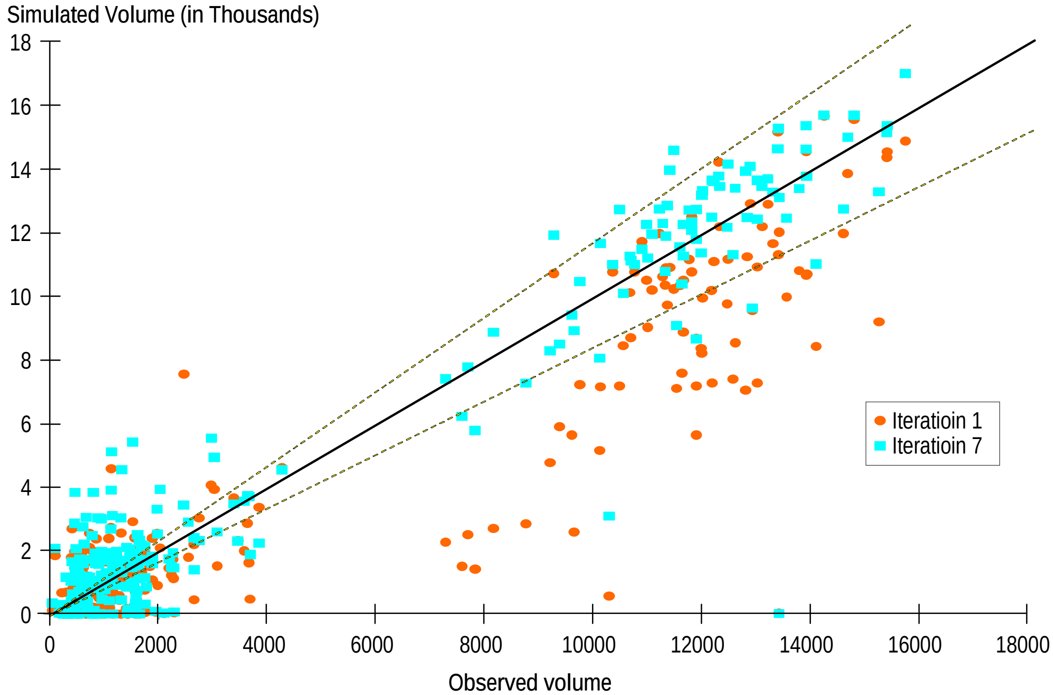


Figure 4.2 DynaSmart-P Calibration
Percent Deviation in Link Volumes

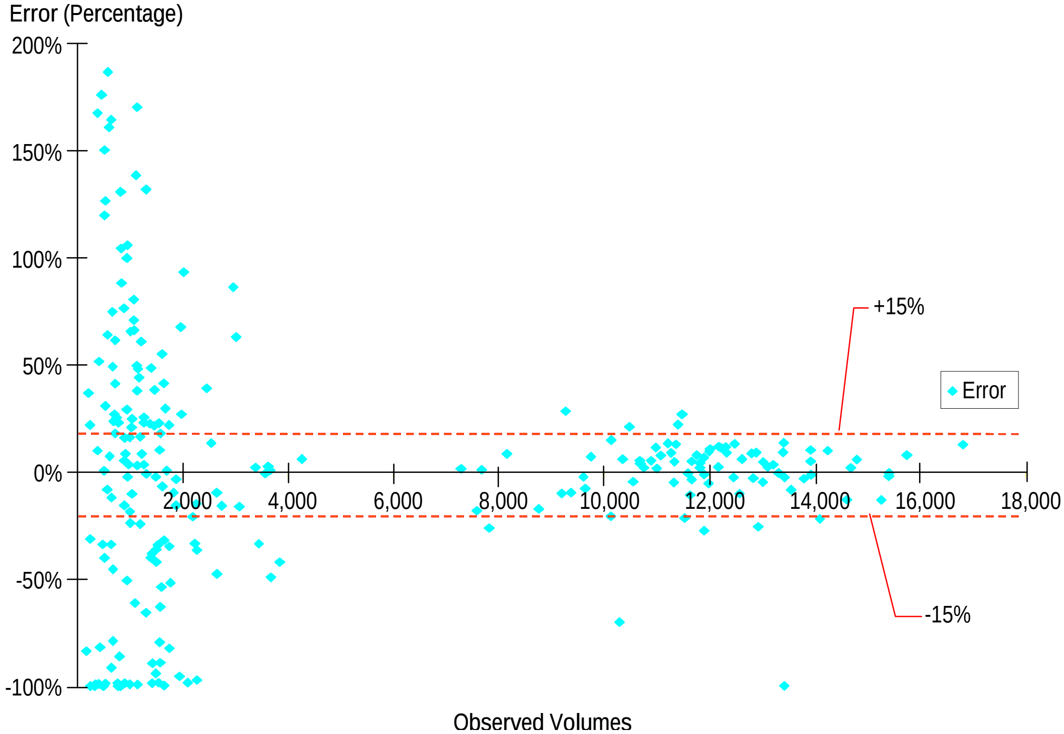


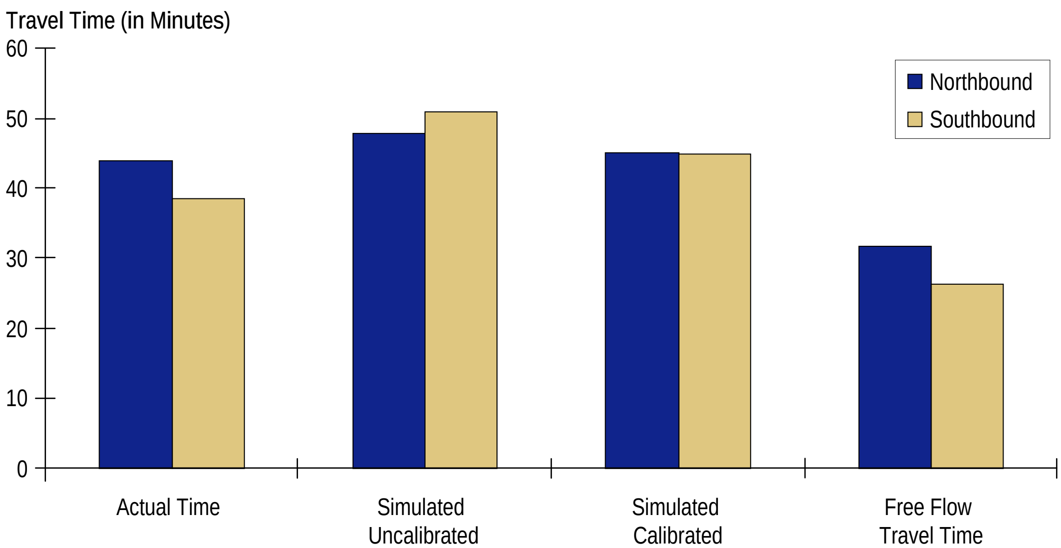
Table 4.2 Travel Time Calibration
Southbound – A.M.

Segment	Start	End	Observed Time (in Minutes)	Simulated Calibrated (in Minutes)	Free-Flow Travel Time (in Minutes)
1	N. end	29th Avenue	4.90	5.12	4.30
2	29th Avenue	98th Avenue	4.15	4.02	3.60
3	98th Avenue	I-238	8.10	8.79	3.70
4	I-238	SR 92	7.40	10.29	3.90
5	SR 92	SR 84	6.97	10.22	5.73
6	SR 84	Auto mall	6.92	5.51	5.01
Total			38.44	43.95	26.24

Table 4.3 Travel Time Calibration *Northbound – A.M.*

Segment	Start	End	Observed Time (in Minutes)	Simulated Calibrated (in Minutes)	Free-Flow Travel Time (in Minutes)
1	S. end	Auto mall	6.35	5.72	5.94
2	Auto mall	SR 84	5.12	12.18	5.04
3	SR 84	SR 92	11.27	16.37	5.91
4	SR 92	I-238	3.90	5.86	3.30
5	I-238	98th Avenue	6.45	3.97	3.90
6	98th Avenue	29th Avenue	5.37	3.58	3.63
7	29th Avenue	N. end	5.45	5.18	3.93
Total			43.91	52.86	31.65

Figure 4.3 Calibration for Travel Times



Some of these calibration results do not meet the calibration criteria presented in Table 4.1, primarily because meeting these criteria was assigned a lower priority, given the resource constraints for the Test Corridor AMS. In a real-corridor ICM application, continued calibration is needed, including: 1) calibration for average and nonaverage conditions; 2) meeting calibration targets for aggregate travel times and delay; and 3) more explicitly taking into account bottleneck flows, including temporal variation throughout the modeled time period. This more rigorous calibration approach will be applied in the selected Pioneer Site AMS.

5.0 Test Corridor AMS Results

Test Corridor AMS results are presented in this chapter. Results are presented for different operational conditions, ICM strategies, and performance measures employed in the analysis, including the following:

- **Four operational conditions,** represented by combinations of high/medium demand with major/minor incidents, as described in Chapter 3.1.
- **ICM strategy alternatives,** including zero ITS baseline, highway traveler information, transit traveler information, ramp metering, HOT lane, arterial traffic signal coordination, and combinations of these strategies.
- The analysis produced **performance measures** for each operational condition and for each ICM strategy tested. Performance measures include mobility, reliability, safety, fuel consumption, and emissions reported across different transportation modes, facility types, and jurisdictions.

5.1 ICM Benefits

Figures 5.1 through 5.4 present summaries of monetized annual benefits for each ICM strategy alternative in each operational condition. Appendix D presents the full Test Corridor AMS results for all operational conditions and for all alternatives.

Monetized benefits are combinations of five performance measures, including travel time, reliability of travel time, safety, 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 a.m. 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 the a.m. peak-period produces approximately the same impact as the p.m. peak-period. A.M. and p.m. 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 $14 per hour (an average value of time for the test corridor area);

- Hours of travel time reliability saved times $14 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;
- Number of crashes prevented times $55,000 (average loss from each crash based on insurance records);
- Gallons of fuel saved at $4.00 per gallon; and
- Ton of emissions saved at an average $67 per ton of emissions saved.

- For example, Table 5.1 shows that, on an annual basis, transit traveler information can be credited with saving 2.2 million hours of time related to reliability, which then represents approximately $30 million of annual savings (shown in Figure 5.5).
- Similar to travel time reliability, the analysis estimated annual benefits for travel time, safety, fuel consumption and emissions, monetized these and added them up to produce the annual benefits shown in Figures 5.1 through 5.4.

Summary of Benefits, Benefit-Cost, and Net Annual Benefits

This section presents a narrative on ICM benefits for the Test Corridor AMS. Figures 5.6 to 5.9 present benefits and costs, benefit-cost ratios, and net annual benefits for different ICM strategies under varying operational conditions.

Figure 5.1 ICM Benefits
Medium Demand With Major Incident

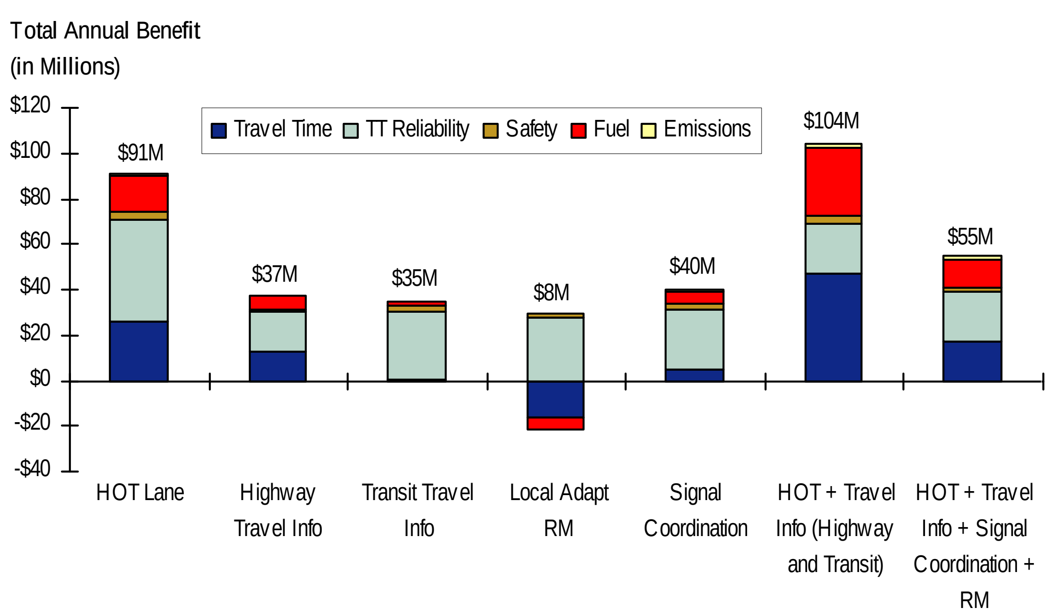


Figure 5.2 ICM Benefits
High Demand with Major Incident

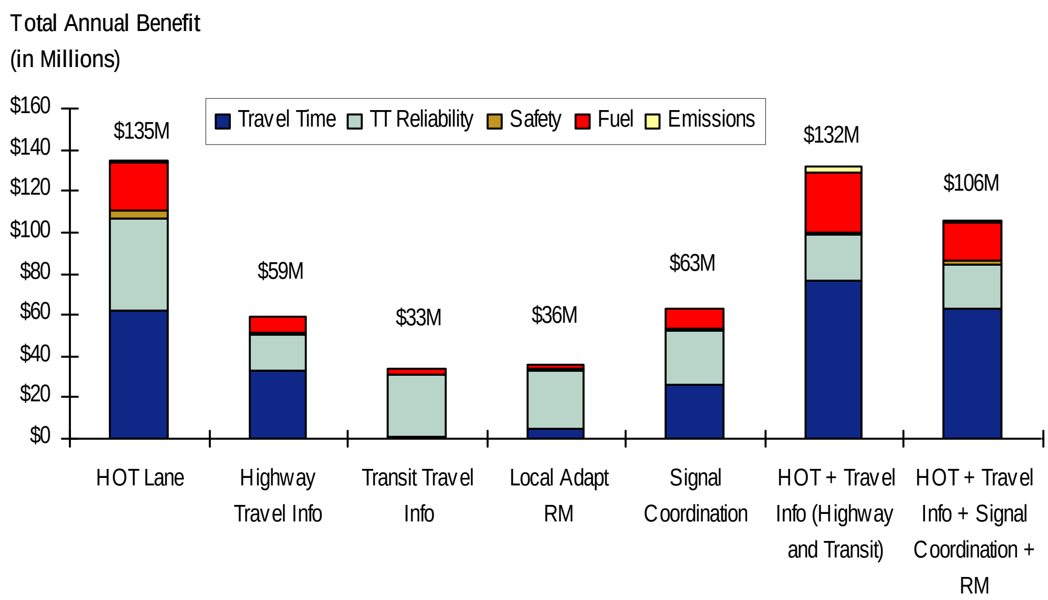


Figure 5.3 ICM Benefits
Medium Demand With Minor Incident

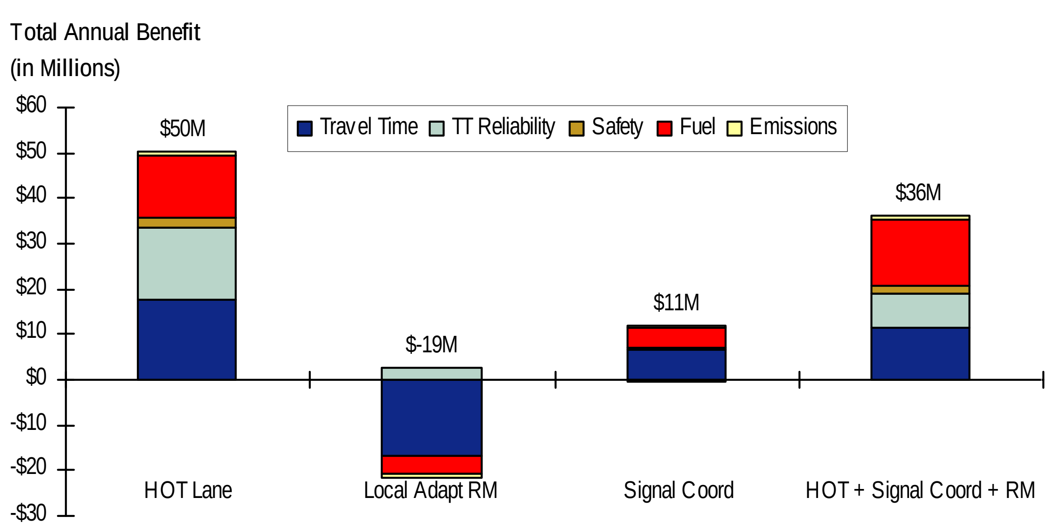


Figure 5.4 ICM Benefits
High Demand with Minor Incident

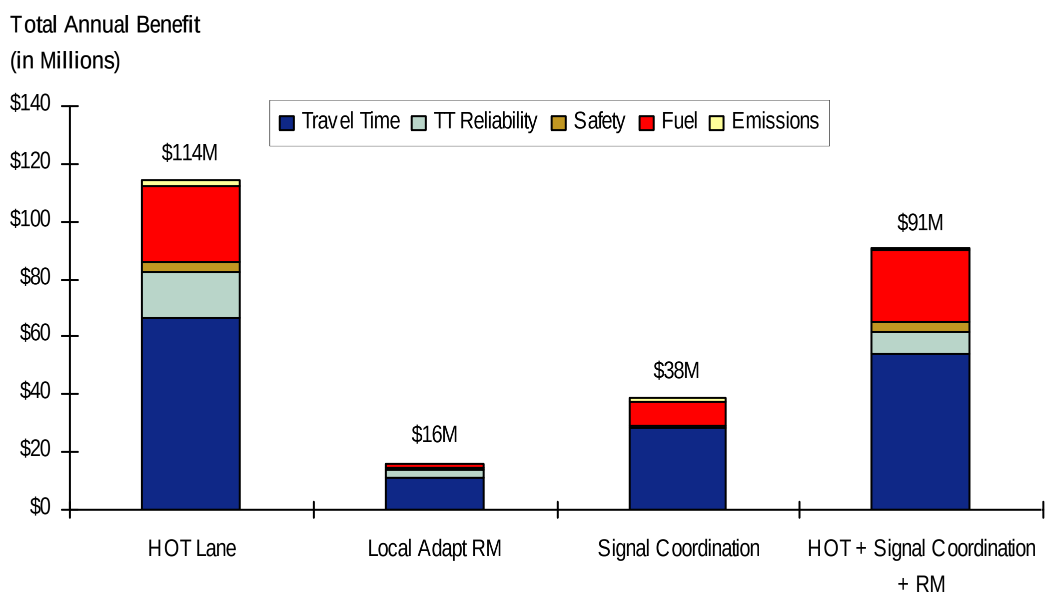


Figure 5.5 Annual Travel Time Reliability Benefits
Medium Demand With Major Incident

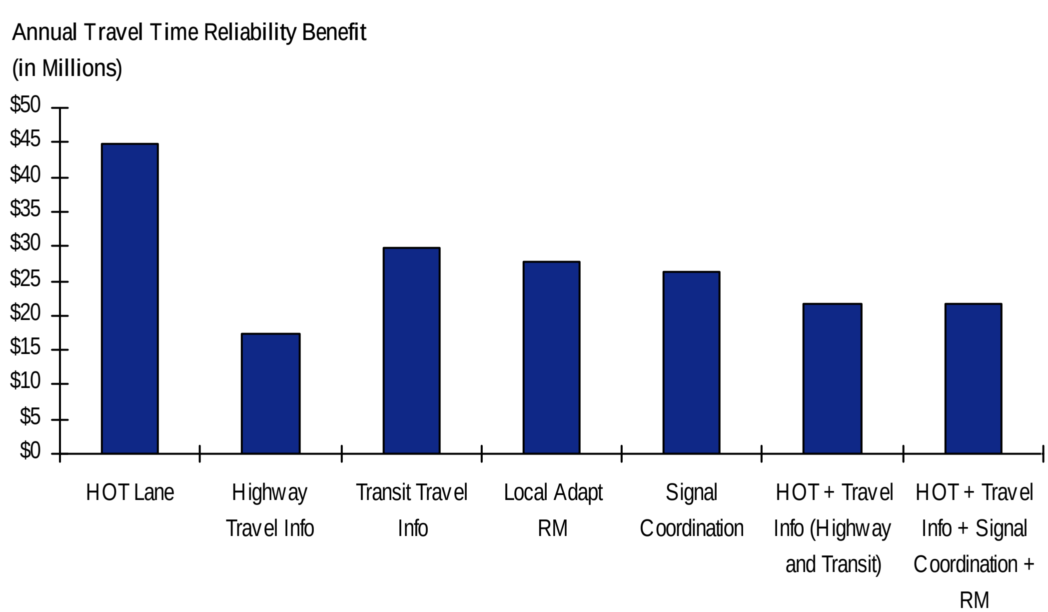


Table 5.1 Annual Travel Time Reliability Benefits
Medium Demand with Major Incident in Million-Hours of Delay Saved

HOT Lane	Highway Trav. Info.	Transit Trav. Info.	Adapt RM	Signal Coord.	HOT + Trav. Info.	Combo.
3.3	1.3	2.2	2.0	1.9	1.6	1.6

Figure 5.6 Benefits versus Costs
Medium Demand with Major Incident

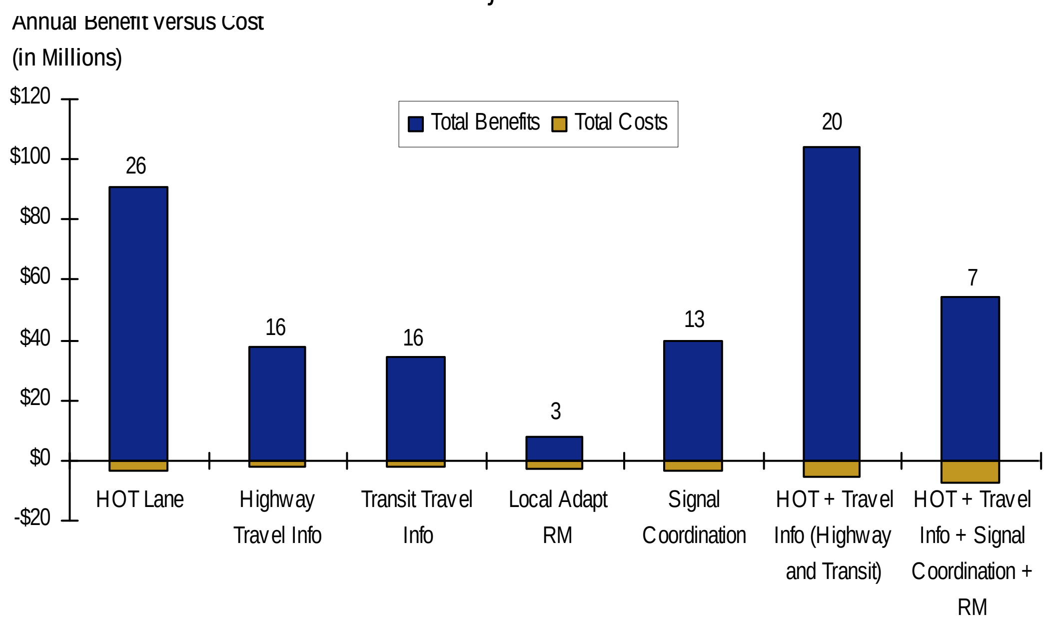


Figure 5.7 Benefits versus Costs
High Demand with Major Incident

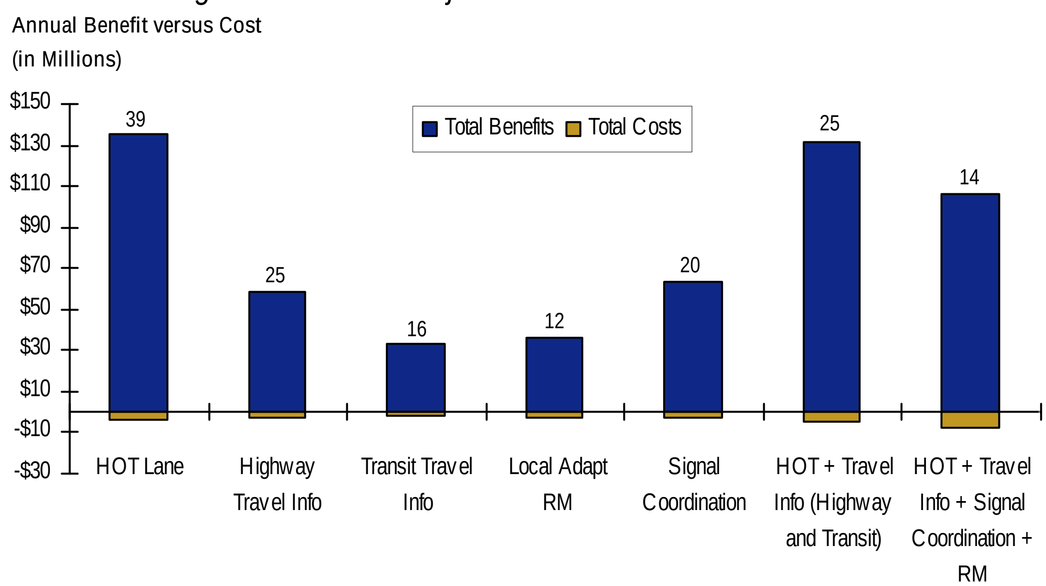


Figure 5.8 Benefits versus Costs
Medium Demand with Minor Incident

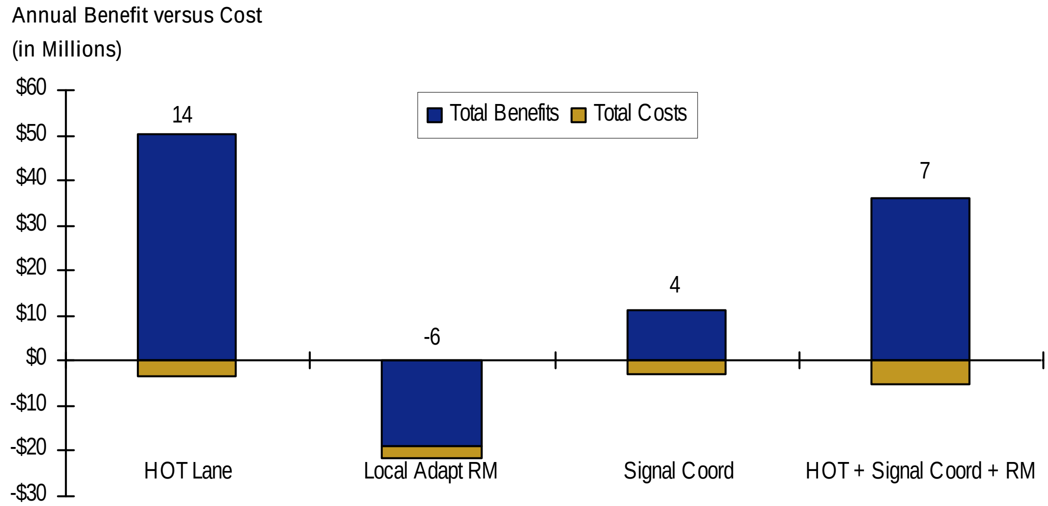
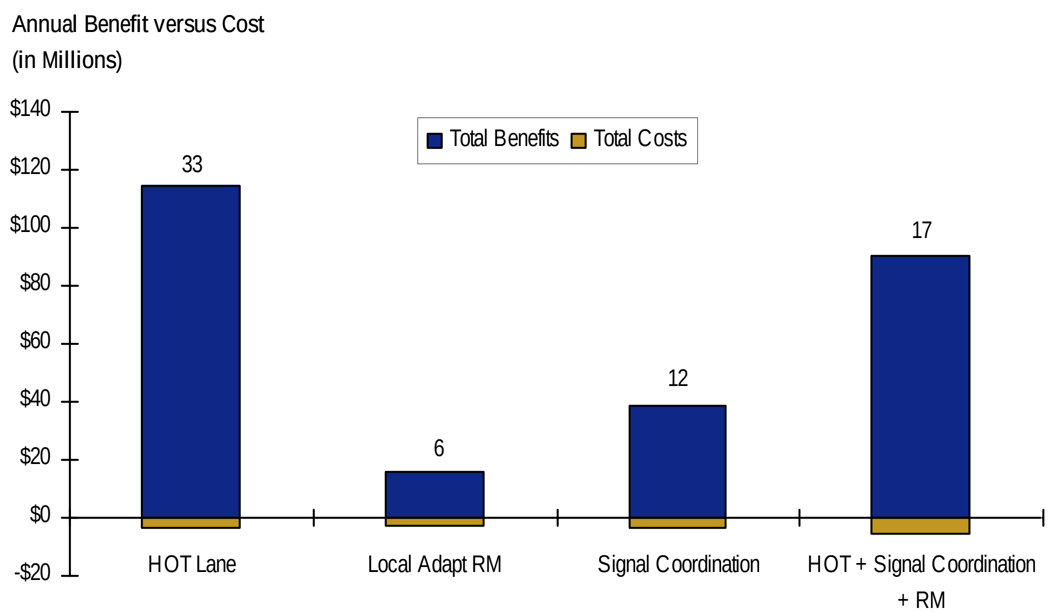


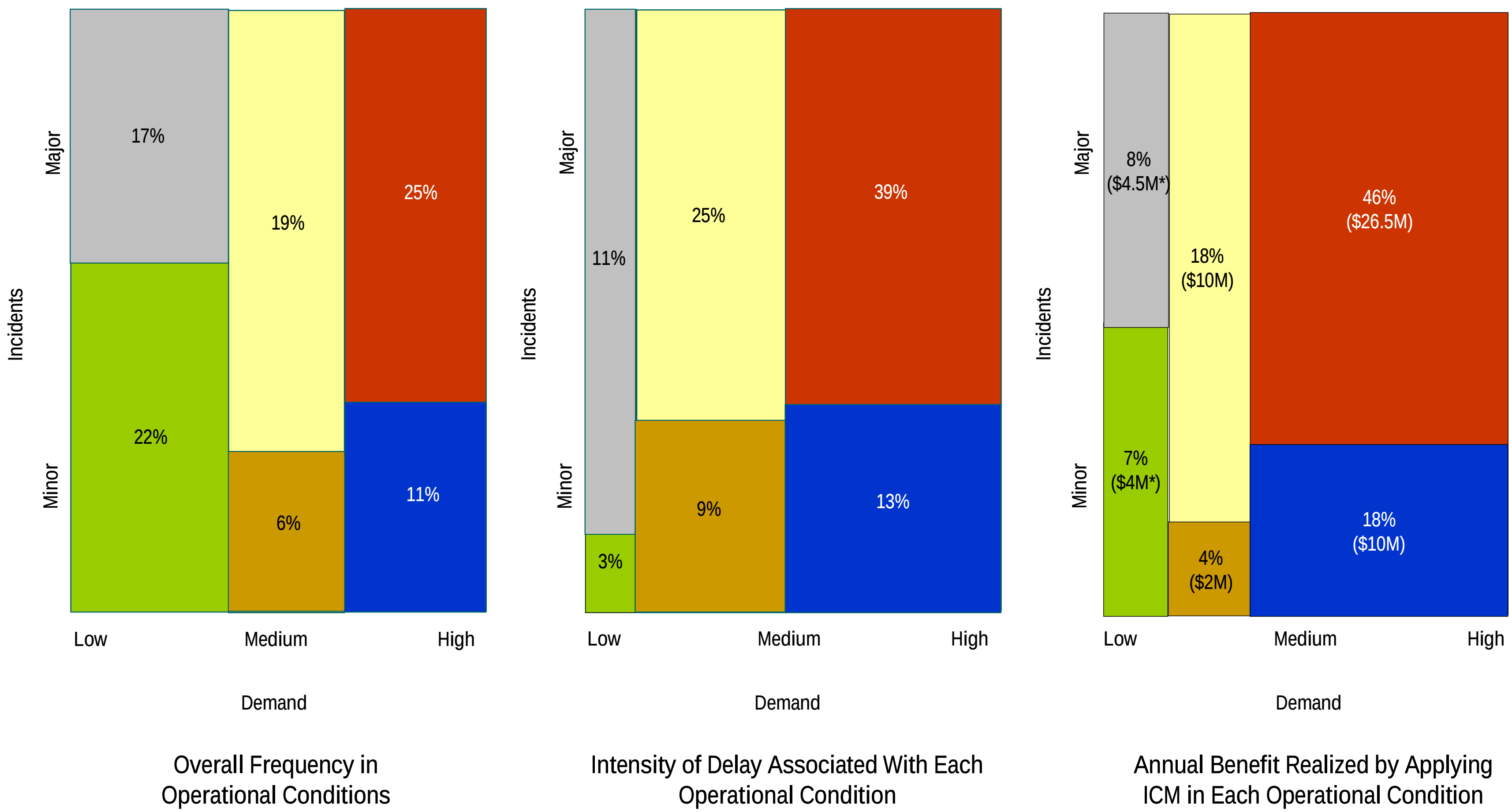
Figure 5.9 Benefits versus Costs
High Demand with Minor Incident



Overall, deployment of ICM on the Test Corridor produces a 10-year benefit of approximately $570 million. Summary findings include the following:

- Approximately one-half of ICM benefit is on high-demand/major incident days (representing 25 percent of commute days). This finding validates the hypothesis that ICM is most effective under the worst operational conditions, including heavy-demand and major incidents. The three parts of Figure 5.10 show: 1) the overall frequency in operational conditions for the Test Corridor (percentage of days in the year categorized by different incident and demand levels); 2) the intensity of delay associated with each operational condition; and 3) annual benefit realized by applying ICM in each operational condition and the percentage of total annual benefit resulting from the implementation of ICM on different operational conditions.
- A comparison of benefits across operational conditions reveals that the effectiveness of ICM strategies varies under different prevailing conditions. For example, an ICM strategy such as freeway ramp metering is shown to produce positive overall benefits under high travel demand, but may produce system disbenefits under medium 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.
- AMS results show that in the presence of a major incident (two freeway lanes blocked for 45 minutes), one to four percent of travelers affected by the incident shifted to transit. This result compares well against before-after studies of mode shift under nonrecurrent congestion.
- For the Test Corridor, the HOT lane and highway traveler information are consistently the most effective ICM investments in terms of both benefit-cost and net annual benefit. This finding will not necessarily apply to other corridors; different geometric, demand, and operational characteristics will result in different effectiveness of variable ICM strategies across different corridors.
- The test corridor modeling 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.

Figure 5.10   Test Corridor AMS – Overall ICM Benefit Under Different Operational Regimes



Benefits of Individual ICM Strategies

Test Corridor AMS results specific to benefits resulting from different ICM strategies are shown below.

HOT Lane

Conversion of the existing HOV lane to a **HOT lane** produces significant benefits – benefit-cost ratios range from 14 to 39, with **net** annual benefit of $50 million to $135 million. Net annual benefit is calculated by subtracting annual costs from annual benefits.

The analysis used an average value of time (VOT) of $14 per hour, which is standard for 2007 in the Bay Area and consistent with MTC assumptions. To model congestion pricing strategies, the analysis used dynamic traffic assignment where traveler expectations of potential time savings were equilibrated against the cost of using the HOT lane. The analysis used prespecified, time-dependent costs for the HOT lane. Also, $8.00 per trip was used as the maximum price for using the HOT lane (again based on local, Bay Area HOT lane studies for U.S. 101 and I-680). Diversion and mode shift parameters remained the same across all analyses, and all trips were assumed to occur in all alternatives analyzed to maintain consistency in the comparison (so no trips were lost or new trips generated across analysis alternatives).

Two improvements are recommended for consideration in the Pioneer Sites AMS:

1. It may be useful to vary VOT across travelers at different income levels, or across different zones, or vehicle classes – this could provide some additional sensitivity in the analysis results, especially as they relate to questions regarding equity.
2. Benefit estimation for a real-time decision support requires truly dynamic analysis based on short-term forecasts of traffic congestion. This capability is not currently available in simulation models.

Highway Traveler Information

Highway traveler information produces a large benefit, especially in the case of unexpected events such as a major incident – benefit-cost ratios range from 16 to 25, with net annual benefit of $37 million to $59 million. It is the presence of a major incident that renders traveler information effective; this is true for both medium- and high-demand with a major incident. In the case of a minor incident, traffic congestion does not produce significant enough incentives for drivers to shift routes/modes/time of travel.

Transit Traveler Information

Transit traveler information produces a benefit-cost ratio of 16 under different operational conditions, with net annual benefit of $33 million to $35 million. Up to four percent of travelers will mode-shift to transit in response to a major incident. These are positive benefits, and as highway congestion grows, transit traveler information benefits are expected to increase as well. Transit mode shift results are consistent with observed mode shift from previous evaluation studies: one to four percent mode shift in response to a major incident is consistent with observed mode shift. In the Test Corridor, there is good transit service to accommodate mode shifters; the estimated mode shift of one to four percent due to a major incident did not necessitate provision of additional transit or parking capacity. However, the GIS/pivot-point mode shift tool (developed for the Test Corridor AMS) does track **both** transit and parking supply required to accommodate additional demand for transit.

In the Test Corridor AMS, drivers were provided with real-time information both pretrip and en-route about incident conditions, expected delays, availability of transit and highway options, travel times for these options, and availability of parking. Probabilities of mode shift from highway to transit mode(s) were calculated based on each Origin-Intermediate-Destination travel times. These probabilities were applied to the number of trips to produce the number of trips diverted to transit. Parking searching times and walk times are added to transit mode utility equations. Based on all this, travelers shifted to transit if the combined (transit access/egress + transit trip) travel times provided travel time savings greater than one minute.

For the test corridor AMS the pivot point mode shift analysis initially used the same mode shift factors as in the locally available travel demand model. As identified in the AMS methodology report, the expectation was that long-term mode shift is more likely to occur than short-term mode shift in response to an incident. The limited available evidence of short-term dynamic mode choice indicated limited shift to transit – based on a review of a small number of available stated-preference studies on the subject, approximately one-half of a percent to two percent of commuters would switch to public transit in a major incident using pretrip or en-route traveler information.

After running the pivot point model in conjunction with the mesoscopic simulation model, the propensity of mode shift in the presence of a major incident (two out of four freeway lanes blocked for 45 minutes) was found to not differ from the propensity of mode shift in response to long-term congestion. In other words, the proportion of highway travelers shifting to transit is approximately the same under short- and long-term conditions. Other things being equal (such as availability of parking and quality of traveler information), the travel time difference between auto and transit seems to have the same proportional influence (as a determinant of mode shift) in the long run and the short run. This model finding was confirmed by anecdotal observations of mode shift during major incidents on I-880 and in the Bay Area.

This points to another finding from the Test Corridor AMS – generally, there is very little information on the impacts of incidents on short-term mode shift. Typically, transit agencies, state DOTs, and regional agencies do not collect such data nor do they conduct studies of such occurrences. For the Test Corridor, the AMS team used two sources of data, including: 1) data on BART ridership during known major incidents on I-880 (common timescale was the connecting factor); and 2) discussions with BART and AC Transit operations managers, MTC operations planners, and Caltrans Operations staff revolving around the expected mode shift in response to a major incident. Although it was difficult to make a statistical case through source 1 (day-to-day variation was greater than short-term mode shift), source 2 provided enough information to determine that one to four percent mode shift in response to a major incident was realistic.

Ramp Metering

Local adaptive ramp metering was tested in the Test Corridor AMS: 1) in high-demand days (36 percent of all workdays)benefit-cost ratios range from 6 to 12, with net annual benefit of $16 million to $36 million; 2) in medium-demand days, local adaptive ramp metering produces less (or even negative) benefit, because there is less congestion on the freeway to start with, and congestion created at on-ramps is more than congestion relieved on the freeway. This said, enhanced ramp metering strategies can produce even greater benefit: 1) corridor adaptive ramp metering can produce greater benefits than local adaptive ramp metering; and 2) ramp metering with ramp queue control can minimize the adverse effects of ramp metering on local streets and produce greater overall benefit.

Arterial Signal Coordination

In the high-demand scenarios, arterial signal coordination produces good benefit-cost ratios, ranging between 12 and 20. As expected, in the medium-demand scenarios, the benefit-cost ratio is less (ranging between 4 and 13), because there is less congestion and thus less incentive for drivers to divert to arterials. Net annual benefit of arterial signal coordination is $11 million to $63 million, depending on demand and incident conditions.

Combination of ICM Strategies

The combination of ICM strategies also produces significant benefit – benefit-cost ratios range from 7 to 25, with net annual benefits of $36 million to $132 million. The AMS framework applied to the Test Corridor has the capability to dynamically adjust the price of the HOT lane in response to changing traffic conditions, provide information to direct travelers to transit and other routes, update the ramp meters, and change arterial signal timings. The "combination" results take these dynamic relationships into account. For Pioneer Corridors AMS, the analysis will go into more detail in developing fully dynamic ICM strategies (such as corridor-adaptive ramp metering rather than only local-adaptive ramp metering). Lastly, a key finding in the Test Corridor AMS is that the combination of some ICM strategies may result in benefits that are less than the benefits produced by some individual strategies; in some circumstances, some ICM strategies may work across purposes. In other words, one ICM strategy, when used in combination, can hurt overall corridor goals under certain conditions. This is an important insight for the implementation of ICM strategies at Pioneer Corridors.

5.2 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.

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 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.

Component Cost Estimates

This section presents the cost estimates for various components currently planned or under consideration for this ICM project. Costs are presented for the following deployments:

- Advanced arterial signal control;
- Ramp metering;
- Highway traveler information;
- Transit traveler information;
- HOT lanes; and
- Combination of all of the above.

Table 5.2 shows a summary of annual lifecycle costs for each ICM deployment. It is worth noting that all of the above-mentioned deployments would need a traffic management center (TMC) and good detection coverage (every one-half-mile in urban areas such as the Test Corridor) as prerequisites.

Table 5.2 ICM Improvement Cost Estimates

	Annual Costs (in Million Dollars)
HOT Lane	2.1
Highway Traveler Information	1.0
Transit Traveler Information	0.7
Local Adaptive Ramp Metering	1.5
Arterial Traffic Signal Coordination	1.8
Common Infrastructure	1.4
Combination Annual Costs	7.5

Note: Average costs, consistent with ITS National Architecture. Annualized costs, including Capital and O&M costs.

To estimate the total cost of any specific deployment, the infrastructure and incremental costs are summed as shown below:

- Total Capital Costs = infrastructure capital cost + (# of units * incremental capital cost); and
- Annual O&M Costs = infrastructure O&M cost + (# of units * incremental O&M cost).

The annualized costs presented in the spreadsheets represent the amortized costs of deploying the capital equipment and redeploying the equipment, as necessary, to replace obsolete equipment. The annualized cost for any individual piece of equipment is estimated as follows:

- Annualized Cost = (Capital Cost/Useful Life) + O&M Cost.

The following method is used to estimate the total annualized cost of any specific deployment:

- Total Annualized Cost = annualized infrastructure cost + (# of units * annualized incremental cost).

It is important to note that these costs represent average cost figures. Individual ITS improvements may experience different costs or may require modified equipment inventories than specified here. Users of these cost estimates are encouraged to review the cost assumptions and equipment inventories for the ITS components before applying these costs to any individual planned deployment.

Significant cost savings may be realized through the sharing of equipment and integration of deployed components. An analysis of the equipment inventories also is encouraged to help identify cost allocation and funding responsibilities.

5.3 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 AMS for the Test Corridor proved the following:

- The test corridor modeling 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.
- The AMS methodology is able to analyze the individual and combination effect of ICM strategies under different operational conditions. The Test Corridor AMS validated the overall methodology in the sense that the analysis tools can model ICM strategies considered by Pioneer Sites.
- New analysis capabilities were successfully tested and produced intuitive results. These new capabilities include the analysis of: 1) mode shift to transit; 2) impacts of congestion pricing; and 3) impacts of traveler information.
- ICM performance measures were readily reported for all affected modes, facility types, and jurisdictions; and across all types of performance measures, including mobility, reliability, safety, emissions, fuel consumption and benefit-cost.

Test 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 Test Corridor produces a 10-year benefit of approximately $570 million.

- Approximately one-half of ICM benefit is on high demand/major incident days (representing 25 percent of commute days.) This finding validates the hypothesis that ICM is most effective under the worst operational conditions, including heavy demand and major incidents.
- A comparison of benefits across operational conditions reveals that the effectiveness of ICM strategies varies under different prevailing conditions. For example, an ICM strategy such as freeway ramp metering is shown to produce positive overall benefits under high travel demand, but may produce system disbenefits under medium 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.
- AMS results show that, in the presence of a major incident (two freeway lanes blocked for 45 minutes), one to four percent of travelers affected by the incident shifted to transit. This result compares well against before-after studies of mode shift under nonrecurrent congestion.
- For the Test Corridor, the HOT lane and highway traveler information are consistently the most effective ICM investments in terms of both benefit-cost and net annual benefit. This finding will not necessarily apply to other corridors; different geometric, demand, and operational characteristics will result in different effectiveness of variable ICM strategies across different corridors.

It should be noted, however, that the Test Corridor analysis compared annual benefits and costs for a number of ICM strategies (or combinations thereof) across a number of operational conditions, against the default case representing conventional transportation infrastructure with no ITS. This represents a measurement of "no ITS versus ICM" which is different than "pre-ICM versus post-ICM" that will be tested in Stage 2 AMS efforts.

In view of applying the AMS methodology to other Pioneer Corridors, the following lessons were learned from the application of the methodology to the Test Corridor:

- In Pioneer Corridor AMS, the analysis framework will require significant tailoring to account for the application of locally available software for macroscopic, mesoscopic, and microscopic modeling. Depending on the scope, complexity, and questions to be answered within a specific corridor, there may be more or less emphasis on each of the three general model types and their interaction.
- The emphasis of the AMS methodology has been to provide the greatest degree of flexibility and robustness in AMS support of Pioneer Sites. The methodology calls for different levels and forms of model integration of the macroscopic, mesoscopic, and microscopic models. Although the AMS

methodology has been designed in a way that is flexible to the availability of different types of models at Pioneer Sites, limitations in all three locally available software programs may present challenges.

- The Test Corridor modeling emphasizes using available data sources. Depending on the availability of data, accuracy of model calibration can be impacted.
- The methodology includes a simple pivot-point mode shift model and a transit travel-time estimation module to support comparison of network and modal alternatives, and facilitate the analysis of traveler shifts among different transportation modes. In this custom software local requirements have to be carefully specified to create a robust analysis.
- The methodology also includes linkage mechanisms required to establish consistency between the modeling resolutions of the AMS candidate tools. The interface was designed for the Test Corridor AMS, but with an eye towards flexibility to accommodate other Pioneer Site AMS. In these future efforts, interfaces will need to be customized to local Pioneer Site conditions.

A. Test Corridor ICM Costs

Table A.1 ICM Improvement Cost Estimates

	Annual Lifecycle Costs				TOTAL
Deployment	**Infrastructure**	**Incremental**	**Unit**	**Amount**	**ANNUAL COST**
Basic Needs					
Basic TMC Facilities	$ 633,333				**$ 633,333**
Hardware/Software for Traffic Surveillance	$ 15,000				**$ 15,000**
Loop Detector System Integration	$ 25,000				**$ 25,000**
Loop Detector (double set)		$ 3,350	ea ½-mi	120	**$ 402,000**
DS3 Communication Line		$ 2,700	ea ½-mi	120	**$ 324,000**
				TOTAL	**$ 1,399,333**
Advanced Arterial Signal Control					
Linked Signal System LAN	$ 3,850				**$ 3,850**
TMC Hardware for Signal Control	$ 6,500				**$ 6,500**
TMC Software/System Integration	$ 40,000				**$ 40,000**
Labor for Arterial Mgmt	$ 540,000				**$ 540,000**
Signal Controller Upgrade		$ 663	per int	160	**$ 106,000**
DS1 Communication Line		$ 6,638	per int	160	**$ 1,062,000**
				TOTAL	**$ 1,758,350**
Ramp Metering (Fixed or Adaptive)					
Ramp Meter (Signal, Controller)		$ 10,000	per ramp	90	**$ 900,000**
Loop Detectors (2)		$ 6,700	per ramp	90	**$ 603,000**
				TOTAL	**$ 1,503,000**
Highway Traveler Information					
TMC Hardware for Information Dissemination	$ 1,875				**$ 1,875**
TMC Software for Information Dissemination	$ 5,000				**$ 5,000**
TMC System Integration	$ 10,000				**$ 10,000**
DS3 Communication Line	$ 48,200				**$ 48,200**
Labor for Information Dissemination	$ 100,000				**$ 100,000**
Information Service Center Hardware	$ 3,150				**$ 3,150**
Info Center System Integration	$ 20,000				**$ 20,000**
Information Service Center Software	$ 34,375				**$ 34,375**
Map Database Software	$ 11,250				**$ 11,250**
Information Service Center Labor	$ 225,000				**$ 225,000**
DS0 Communication Line		$ 938	per CMS	32	**$ 30,000**
ChangeableMessage Sign		$ 9,025	per CMS	32	**$ 288,800**
Changeable Message Sign Tower		$ 6,525	per CMS	32	**$ 208,800**
				TOTAL	**$ 986,450**
Transit Traveler Information					
TMC Information Dissemination Hardware	$ 1,875				**$ 1,875**
TMC Information Dissemination Software	$ 5,000				**$ 5,000**
TMC System Integration	$ 10,000				**$ 10,000**
Labor for Traffic Information Dissemination	$ 100,000				**$ 100,000**
DS3 Communication Line	$ 48,200				**$ 48,200**
Transit Center Hardware	$ 2,250				**$ 2,250**
Transit Center Software/Integration	$ 49,750				**$ 49,750**
Transit Center Labor	$ 150,000				**$ 150,000**
DS3 Communication Line	$ 48,200				**$ 48,200**
Information Service Center Hardware	$ 3,150				**$ 3,150**
Info Center System Integration	$ 20,000				**$ 20,000**
Information Service Center Software	$ 41,225				**$ 41,225**
Map Database Software	$ 11,250				**$ 11,250**
Information Service Center Labor	$ 225,000				**$ 225,000**
				TOTAL	**$ 715,900**

Table A.1 ICM Improvement Cost Estimates (continued)

Deployment	Annual Lifecycle Costs Infrastructure	Annual Lifecycle Costs Incremental	Unit	Amount	TOTAL ANNUAL COST
HOT Lanes					
Electronic Toll Collection Software	$ 2,000				**$ 2,000**
Electronic Toll Collection Structure	$ 1,500				**$ 1,500**
Software for Dynamic Electronic Tolls	$ 13,700				**$ 13,700**
Integration for Dynamic Electronic Tolls	$ 22,000				**$ 22,000**
Labor for HOT Lanes Mgmt	$ 540,000				**$ 540,000**
Electronic Toll Reader		$ 2,000	ea ½-mi	120	**$ 240,000**
High-Speed Camera		$ 4,000	ea ½-mi	120	**$ 480,000**
DS1 Communication Line		$ 6,638	ea ½-mi	120	**$ 796,500**
				TOTAL	**$ 2,095,700**
Combination					
Basic TMC Facilities	$ 633,333				**$ 633,333**
Hardware/Software for Traffic Surveillance	$ 15,000				**$ 15,000**
Loop Detector System Integration	$ 25,000				**$ 25,000**
Loop Detector (double set)		$ 3,350	ea ½-mi	120	**$ 402,000**
DS3 Communication Line		$ 2,700	ea ½-mi	120	**$ 324,000**
Linked Signal System LAN	$ 3,850				**$ 3,850**
TMC Hardware for Signal Control	$ 6,500				**$ 6,500**
TMC Software/System Integration	$ 40,000				**$ 40,000**
Labor for Arterial Mgmt	$ 540,000				**$ 540,000**
Signal Controller Upgrade		$ 663	per int	160	**$ 106,000**
DS1 Communication Line		$ 6,638	per int	160	**$ 1,062,000**
Ramp Meter (Signal, Controller)		$ 10,000	per ramp	90	**$ 900,000**
Loop Detectors (2)		$ 6,700	per ramp	90	**$ 603,000**
TMC Information Dissemination Hardware	$ 1,875				**$ 1,875**
TMC Information Dissemination Software	$ 5,000				**$ 5,000**
TMC System Integration	$ 10,000				**$ 10,000**
Labor for Traffic Information Dissemination	$ 100,000				**$ 100,000**
DS3 Communication Line	$ 48,200				**$ 48,200**
Transit Center Hardware	$ 2,250				**$ 2,250**
Transit Center Software/Integration	$ 49,750				**$ 49,750**
Transit Center Labor	$ 150,000				**$ 150,000**
DS3 Communication Line	$ 48,200				**$ 48,200**
Information Service Center Hardware	$ 3,150				**$ 3,150**
Info Center System Integration	$ 20,000				**$ 20,000**
Information Service Center Software	$ 41,225				**$ 41,225**
Map Database Software	$ 11,250				**$ 11,250**
Information Service Center Labor	$ 225,000				**$ 225,000**
Electronic Toll Collection Software	$ 2,000				**$ 2,000**
Electronic Toll Collection Structure	$ 1,500				**$ 1,500**
Software for Dynamic Electronic Tolls	$ 9,120				**$ 13,700**
Integration for Dynamic Electronic Tolls	$ 14,650				**$ 22,000**
Labor for HOT Lanes Mgmt	$ 540,000				**$ 540,000**
Electronic Toll Reader		$ 2,000	ea ½-mi	120	**$ 240,000**
High-Speed Camera		$ 4,000	ea ½-mi	120	**$ 480,000**
DS1 Communication Line		$ 6,638	ea ½-mi	120	**$ 796,500**
				TOTAL	**$ 7,472,283**

HOT Lanes

Equipment	Useful Life	Capital Cost	O&M Cost	Annualized Cost
Basic Infrastructure Equipment				
Electronic Toll Collection Software	10	$ 20,000	$ -	$ 2,000
Electronic Toll Collection Structure	20	$ 30,000	$ -	$ 1,500
Software for Dynamic Electronic Tolls	5	$ 55,000	$ 2,700	$ 13,700
Integration for Dynamic Electronic Tolls	20	$ 220,000	$ 11,000	$ 22,000
Labor for HOT Lanes Mgmt	0	$ -	$ 540,000	$ 540,000
TOTAL Infrastructure Cost		***$ 325,000***	***$ 553,700***	***$ 579,200***
Incremental Deployment Equipment (per location)				
Electronic Toll Reader	10	$ 10,000	$ 1,000	$ 2,000
High-Speed Camera	10	$ 20,000	$ 2,000	$ 4,000
DS1 Communication Line	20	$ 750	$ 6,600	$ 6,638
TOTAL Incremental Cost		***$ 30,750***	***$ 9,600***	***$ 12,638***

Notes:

Labor costs assume: Operators (2 @ 50% of the time, at $100,000). Maintenance technicians (2 @ $75,000). Transportation Engineer (1 @ 50% of the time, at $100,000). Salary cost are fully loaded prices including base salary, overtime, overhead, benefits, etc.

Update timing plans ($2,000 per system per month for every 10 systems).

Does not include the cost of the traffic signal, or loop detectors.

Central Control Signal Coordination

Equipment	Useful Life	Capital Cost	O&M Cost	Annualized Cost
Basic Infrastructure Equipment				
Linked Signal System LAN	20	$ 55,000	$ 1,100	$ 3,850
TMC Hardware for Signal Control	5	$ 22,500	$ 2,000	$ 6,500
TMC Software/System Integration	5	$ 200,000	$ -	$ 40,000
Labor for Arterial Mgmt	0	$ -	$ 540,000	$ 540,000
TOTAL Infrastructure Cost		***$ 277,500***	***$ 543,100***	***$ 590,350***
Incremental Deployment Equipment (Per Intersection)				
Signal Controller Upgrade	20	$ 6,250	$ 350	$ 663
DS1 Communication Line	20	$ 750	$ 6,600	$ 6,638
TOTAL Incremental Cost		***$ 7,000***	***$ 6,950***	***$ 7,300***

Notes:

Labor costs assume: Operators (2 @ 50% of the time, at $100,000). Maintenance technicians (2 @ $75,000). Transportation Engineer (1 @ 50% of the time, at $100,000). Salary cost are fully loaded prices including base salary, overtime, overhead, benefits, etc.

Update timing plans ($2,000 per system per month for every 10 systems).

Does not include the cost of the traffic signal, or loop detectors.

Central Control Ramp Metering

Equipment	Useful Life	Capital Cost	O&M Cost	Annualized Cost
Basic Infrastructure Equipment				
TMC Hardware for Freeway Control	5	$ 22,500	$ 2,000	$ 6,500
TMC Software/Integration	5	$ 200,000	$ -	$ 40,000
TMC Labor		$ -	$ 250,000	$ 250,000
TOTAL Infrastructure Cost		***$ 222,500***	***$ 252,000***	***$ 296,500***
Incremental Deployment Equipment (Per Ramp Location)				
Ramp Meter (Signal, Controller)	5	$ 40,000	$ 2,000	$ 10,000
Loop Detectors (2)	5	$ 11,000	$ 4,500	$ 6,700
DS1 Communication Line	20	$ 750	$ 6,600	$ 6,638
TOTAL Incremental Cost		***$ 51,750***	***$ 13,100***	***$ 23,338***

Notes:

Labor costs assume: Operators (2 @ 50% of the time, at $100,000). Maintenance technicians (2 @ $75,000).
Salary cost are fully loaded prices including base salary, overtime, overhead, benefits, etc.

Kiosk-Based Traveler Information System

Equipment	Useful Life	Capital Cost	O&M Cost	Annualized Cost
Basic Infrastructure Equipment				
TMC Information Dissemination Hardware	5	$ 7,500	$ 375	$ 1,875
TMC Information Dissemination Software	5	$ 20,000	$ 1,000	$ 5,000
TMC System Integration	20	$ 100,000	$ 5,000	$ 10,000
Labor for Traffic Information Dissemination		$ -	$ 100,000	$ 100,000
DS3 Communication Line	20	$ 4,000	$ 48,000	$ 48,200
Transit Center Hardware	10	$ 22,500	$ -	$ 2,250
Transit Center Software/Integration	20	$ 815,000	$ 9,000	$ 49,750
Transit Center Labor		$ -	$ 150,000	$ 150,000
DS3 Communication Line	20	$ 4,000	$ 48,000	$ 48,200
Information Service Center Hardware	20	$ 45,000	$ 900	$ 3,150
Info Center System Integration	5	$ 100,000	$ -	$ 20,000
Information Service Center Software	20	$ 412,000	$ 20,625	$ 41,225
Map Database Software	2	$ 22,500	$ -	$ 11,250
Information Service Center Labor		$ -	$ 225,000	$ 225,000
TOTAL Infrastructure Cost		***$ 1,552,500***	***$ 607,900***	***$ 715,900***
Incremental Deployment Equipment (Per Kiosk Location)				
Informational Kiosk	7	$ 35,000	$ 4,500	$ 9,500
Informational Kiosk Integration w/ System	7	$ 11,000	$ -	$ 1,571
TOTAL Incremental Cost		***$ 46,000***	***$ 4,500***	***$ 11,071***

Notes:

Does not include the cost of traffic surveillance or data collection.

Traffic Surveillance - CCTV

Equipment	Useful Life	Capital Cost	O&M Cost	Annualized Cost
Basic Infrastructure Equipment				
Hardware/Software for Traffic Surveillance	20	$ 150,000	$ 7,500	$ 15,000
System Integration	20	$ 250,000	$ 12,500	$ 25,000
TOTAL Infrastructure Cost		***$ 400,000***	***$ 20,000***	***$ 40,000***
Incremental Deployment Equipment (Per Intersection)				
Video Camera	10	$ 12,250	$ 1,150	$ 2,375
Camera Tower	20	$ 6,500	$ 475	$ 800
DS3 Communication Line	20	$ 4,000	$ 2,500	$ 2,700
TOTAL Incremental Cost		***$ 22,750***	***$ 4,125***	***$ 5,875***

Notes:

B. Organization of DynaSmart-P Model Runs

All data and models used in the Test Corridor AMS are located in the DVDs accompanying this report. The DynaSmart-P version used in this analysis was DynusT Version 2.0. There are four main folders, including the following:

- The ICM_RUNS folder, including: a) the HIGH-DEMAND folder holds all the model runs corresponding to the high demand operational condition; and b) the MEDIUM-DEMAND folder holds all the model runs corresponding to the medium-demand level.
- The UTILITIES folder holds all the required pre- and post-processing tools.
- The CALIBRATION folder holds the Dynasmart-P calibration tool.
- The TRAVEL_DEMAND_MODEL folder includes the travel demand model and the pivot-point mode choice model.

HIGH-DEMAND Scenarios (Folder)

The following scenarios (folders) were run under this demand-level: folder = F:\ICM_DVD\ICM_RUNS\HIGH-DEMAND:

- BASE_CASE;
- HIGHWAY_INFORMATION;
- HOT;
- RAMP_METERING;
- SIGNAL_COORDINATION;
- TRANSIT_INFORMATION;
- COMBO_I – [HOT + TravInfo (Hwy & Transit)];
- COMBO_II – [HOT + TravInfo + Signal Coord + RM]; and
- COMBO_III – [HOT + Signal Coord + RM].

BASE_CASE

This folder includes the following:

- **BASE_LINE –** This is the baseline scenario that is computed by solving for the User Equilibrium (UE) flow pattern using the high-demand matrices.

- **BASE_LINE_INCI –** This is the baseline plus a major incident scenario. This scenario is computed by creating a major incident with the appropriate characteristics while loading the UE flow pattern. Please see the Dynasmart-P user's guide for instructions to set up the incident.dat file or use the Dynasmart-P Graphical User Interface (GUI).

HIGHWAY_INFORMATION

This folder includes the following:

- **H – INCI – info – iter –** This is the solution to different classes of drivers following different information provision strategies. Please see the Dynasmart-P user's guide for instructions about how to model different classes of drivers or use the GUI.
- **H – INCI – info –** This is a one shot simulation loading the above flow pattern. This is so as to be consistent with the baselines (isolating effects) by using the same loading mechanism.

HOT

This folder includes the following:

- **HOT_BASE –** This scenario corresponds to solving for a new flow pattern under the presence of HOT lanes in the network. Please see the Dynasmart-P user's guide for instructions to set up the toll.dat file or use the GUI.
- **HOT_BASE_INCI –** This scenario corresponds to creating a major incident and loading the above flow pattern.

RAMP_METERING

This folder includes the following:

- **RAMP_BASE –** This scenario implies solving for a new flow pattern under the presence of ramp meters. Please see the Dynasmart-P user's guide for instructions to set up the ramp.dat file or use the GUI.
- **RAMP_BASE_INCI –** This scenario corresponds to creating a major incident and loading the above flow pattern.

SIGNAL_COORDINATION

This folder includes the following:

- **COORDINATION –** This scenario implies optimizing (coordinating) the signal settings a priori and solving for a new flow pattern based on the optimized new settings. Please see the Dynasmart-P user's guide for instructions to set up the control.dat file or use the GUI.
- **COORDINATION_INCI –** This scenario corresponds to creating a major incident and loading the above flow pattern.

TRANSIT_INFORMATION

This folder includes the following:

- **MS – INPUT – BASE – INCI – H –** This folder houses all the inputs required by the mode-shift model.
- **MS – INPUT – BASE – INCI – H – ppmm –** This folder holds all the outputs from the mode-shift model.
- **BASE_LINE_INCI _ MS –** This scenario corresponds to the transit information scenario where the routes of the vehicles shifting to transit are adjusted to represent the mode shift effects. Details about how to model this scenario are provided in a separate document.

COMBO_I

This folder includes the following results for the combination of the HOT lane, highway traveler information, and transit traveler information:

- **MS – INPUT – COMBO_I – H –** This folder houses all the inputs required by the mode-shift model.
- **COMBO_I-H-ppmm –** This folder holds all the outputs from the mode-shift model.
- **H – INCI – iter –** This scenario solves for the flow pattern under the presence of HOT lanes and highway information provision. Please see the Dynasmart-P user's guide for instructions to set up the toll.dat file or use the GUI.
- **H – INCI – MS –** This scenario loads the above flow pattern after the vehicular paths have been adjusted to represent the transit information effects.

COMBO_II

This is the analysis scenario for which "Combination" results were reported for the Test Corridor AMS. This folder includes the following results for the combination of the HOT lane, highway traveler information, transit traveler information, arterial signal coordination, and local-adaptive ramp metering:

- **MS – INPUT – COMBO_II – H –** This folder houses all the inputs required by the mode-shift model.
- **COMBO_II-H-ppmm –** This folder holds all the outputs from the mode-shift model.
- **H – INCI – iter –** This scenario solves for the flow pattern under the presence of HOT lanes, highway information, traffic signal coordination, transit traveler information, and ramp metering. Please see the Dynasmart-P user's

guide for instructions to set up the toll.dat, control.dat, and ramp.dat files or use the GUI.

- **H – INCI – MS –** This scenario loads the above flow pattern after the vehicular paths have been adjusted to represent the transit information effects.

COMBO_III

This folder includes the following results for the combination of the HOT lane, arterial signal coordination, and local-adaptive ramp metering:

- **H – iter –** This scenario solves for the flow pattern under the presence of HOT lanes, traffic signal coordination, and ramp metering. Please see the Dynasmart-P user's guide for instructions to set up the toll.dat, control.dat, and ramp.dat files or use the GUI.
- **H – INCI –** This is a one shot simulation loading the above flow pattern. This is so as to be consistent with the baselines (isolating effects) by using the same loading mechanism.

MEDIUM-DEMAND Scenarios (Folder)

Ten model runs were conducted for each of the analysis scenarios under the medium-demand level. This was designed so as to model the randomness associated with day-to-day variability in the system. There are three factors that create the difference among the 10 model runs as follows:

1. Demand variation;
2. Traffic flow modeling variations; and
3. Random seed number variations.

The average model run is the run designated with the label "RUN-1-1234 – OK."

The following scenarios (folders) were run under this demand-level:

- Folder = F:\ICM_DVD\ICM_RUNS\MEDIUM-DEMAND:
  - BASE_CASE;
  - HIGHWAY_INFORMATION;
  - HOT;
  - RAMP_METERING;
  - SIGNAL_COORDINATION; and
  - TRANSIT_INFORMATION.

- Folder = F:\ICM_RUNS\MEDIUM-DEMAND
  - COMBO_I;
  - COMBO_II; and
  - COMBO_III.

BASE_CASE

This folder includes the following:

- **BASE_LINE –** Just as in the high-demand scenario, this is the baseline scenario for the medium-demand level. Hence, it is computed by solving for the User Equilibrium (UE) flow pattern using the medium-demand matrices.
- **BASE_LINE_INCI –** This is the baseline plus a major incident scenario. This scenario is computed by creating a major incident with the appropriate characteristics while loading the UE flow pattern. Please see the Dynasmart-P user's guide for instructions to set up the incident.dat file or use the Dynasmart-P GUI.

HIGHWAY_INFORMATION

This folder includes the following:

- **M – INCI – info – iter –** This is the solution to different classes of drivers following different information provision strategies. Please see the Dynasmart-P user's guide for instructions about how to model different classes of drivers or use the GUI.
- **M – INCI – info –** This is a one shot simulation loading the above flow pattern. This is so as to be consistent with the baselines (isolating effects) by using the same loading mechanism.

HOT

This folder includes the following:

- **HOT_BASE –** This scenario corresponds to solving for a new flow pattern under the presence of the HOT lane in the network. Please see the Dynasmart-P user's guide for instructions to set up the toll.dat file or use the GUI.
- **HOT_BASE_INCI –** This scenario corresponds to creating a major incident and loading the above flow pattern.

RAMP_METERING

This folder includes the following:

- **RAMP_BASE –** This scenario implies solving for a new flow pattern under the presence of ramp meters. Please see the Dynasmart-P user's guide for instructions to set up the ramp.dat file or use the GUI.
- **RAMP_BASE_INCI –** This scenario corresponds to creating a major incident and loading the above flow pattern.

SIGNAL_COORDINATION

This folder includes the following:

- **COORDINATION –** This scenario involves optimizing (coordinating) the signal settings a priori and solving for a new flow pattern based on the optimized new settings. Please see the Dynasmart-P user's guide for instructions to set up the control.dat file or use the GUI.
- **COORDINATION_INCI –** This scenario corresponds to creating a major incident and loading the above flow pattern.

TRANSIT_INFORMATION

This folder includes the following:

- **MS – INPUT – BASE – INCI – M –** This folder houses all the inputs required by the mode-shift model.
- **MS – INPUT – BASE – INCI – M – ppmm –** This folder holds all the outputs from the mode-shift model.
- **BASE_LINE_INCI_MS –** This scenario corresponds to the transit information scenario where the routes of the vehicles shifting to transit are adjusted to represent the mode shift effects. Details about how to model this scenario are provided in a separate document.

COMBO_I

This folder includes the following results for the combination of the HOT lane, highway traveler information, and transit traveler information:

- **MS – INPUT – COMBO_I – M –** This folder houses all the inputs required by the mode-shift model.
- **COMBO_I-M-ppmm –** This folder holds all the outputs from the mode-shift model.
- **M – INCI – MS –** This scenario loads the flow pattern after the vehicular paths that result from solving for HOT lanes and highway information provision have been adjusted to represent the transit information effects.

COMBO_II

This is the analysis scenario for which "Combination" results were reported for the Test Corridor AMS. This folder includes results for the combination of the HOT lane, highway traveler information, transit traveler information, arterial signal coordination, and local-adaptive ramp metering:

- **MS – INPUT – COMBO_II – M –** This folder houses all the inputs required by the mode-shift model.
- **COMBO_II-M-ppmm –** This folder holds all the outputs from the mode-shift model.
- **M – INCI – iter –** This scenario solves for the flow pattern under the presence of HOT lanes, highway information, transit traveler information, and traffic signal coordination. Please see the Dynasmart-P user's guide for instructions to setup the toll.dat, control.dat, and ramp.dat files or use the GUI.
- **M – INCI – MS –** This scenario loads the above flow pattern after the vehicular paths have been adjusted to represent the transit information effects.

COMBO_III

This folder includes the following results for the combination of the HOT lane, arterial signal coordination, and local-adaptive ramp metering:

- **M – iter –** This scenario solves for the flow pattern under the presence of HOT lanes and traffic signal coordination. Please see the Dynasmart-P user's guide for instructions to set up the toll.dat and control.dat files or use the GUI.
- **M – INCI –** This is a one shot simulation loading the above flow pattern. This is so as to be consistent with the baselines (isolating effects) by using the same loading mechanism.

UTILITIES (Folder)

A detailed description of the software in this folder (F:\ICM_DVD\UTILITIES) is provided in the next Appendix describing two tools developed the ICM AMS project, including 1) the Pivot Point Mode Shift model and 2) Dynasmart-P post-processors. This folder includes the following utilities:

- ICM_summarized pretrip shift_modified.mxd => Pivot-point mode shift model.
- icmFiles.exe and icmFilesII.exe => disaggregates Dynasmart-P output for the mode shift model.
- GenerateODTT.py => generates the input for the mode-shift model.
- icm transit shift.exe => adjusts the paths of the shifting vehicles.

- ICMExtract.exe => post-processes Dynasmart-P results.
- Summary_Mean.xls = > aggregates information from Dynasmart-P runs and generates corridor-level, facility type statistics, and important MOEs based on the simulation results.
- Spatial_Plot.xls => generates corridor-level speed contours.

CALIBRATION (Folder)

Folder = F:\ICM_DVD\CALIBRATION

This folder includes the calibration tool developed by the University of Arizona at Tucson. The objective of this tool is to adjust the travel demand so as to minimize the difference between actual and simulated link traffic counts. The tool is a MATLAB script that solves a least square minimization problem. It uses a commercial optimization solver (MOSEK) to find the solution to the minimization problem. The solution method is based on an iterative approach that uses realizations of dynamic traffic assignment equilibrium solutions. To post-process these solutions, the calibration tool uses Python code. This code also is included in the calibration folder.

TRAVEL_DEMAND_MODEL (Folder)

Folder = F:\ICM_DVD\TRAVEL_DEMAND_MODEL

This folder contains the TP+ application of the ACCMA travel demand model. This model is based on the MTC Baycast-90 model. The scripts used for the different steps of the model (trip generation, trip distribution, mode choice, and assignments) and the inputs and outputs from each of the steps are contained in the respective folders. The steps for running the model are outlined in detail in the "Set TP+ variable path.doc" document. The trip generation procedure is developed for different trip purposes, home-based work, home-based shop, home-based social/recreation, and nonhome-based, which are segmented into four income quartiles. The transit skimming process is carried out for the different transit modes, BART, commuter rail, LRT, express bus, and local bus. The mode choice models use different nesting structures for each trip purpose, and hence were developed separately. The scripts for post-processing of results and determination of peak spreading factors also are located in this folder.

C. Tools Developed Under ICM AMS

Pivot-Point Mode Shift Model

(ICM_summarized pretrip shift_modified.mxd, icmFiles.exe, and icmFilesII.exe)

This is the software used to calculate the probabilities of travelers shifting modes in response to incidents or in response to the deployment of ICM strategies. It is a script that works under GIS software such as ArcGIS. Inputs required by the pivot point mode shift model include the following:

- Under the ICM analysis framework, transit information is provided to drivers in the event of an incident. The incident location layer is one of the inputs required by this software.
- The probabilities of mode shift are computed at the traffic zone (TAZ) level, and thus the TAZ boundary layer is another required input.
- In addition, demand modeling and simulation-based data are required inputs. Demand modeling data include mode share information and the coefficients used by the utility maximization model, which is part of the pivot-point mode shift model. Simulation data include time-dependent demand and travel times for each origin-destination pair.

Instructions for Using the Pivot Point Mode Shift Model

Step 1 – Copy icmFiles.exe and icmFilesII.exe into a folder containing the travel demand and travel time data output from Dynasmart-P.

Step 2 – Open the Windows Command Prompt.

- **Step 2.1 –** Go to folder where you copied the icmfiles.exe and icmfilesII.exe files.
- **Step 2.2 –** Type ICMfiles filename.dat (filename is the name of the file with the travel time output from Dynasmart-P.
- **Step 2.3 –** Type icmfilesII filename1.dat (filename1 is the name of the file with the travel demand output from Dynasmart-P).

Step 3 – Open the ICM_summarized pretrip shift_modified.mxd file with ArcGIS and click the tool “pivot-point mode shift model.”

Step 4 – In the pop-up window, click open, and browse to corresponding travel demand and travel time files. Then, click “OK.”

Step 5 – Designate the format for the output file. Then click “OK.”

Step 6 – The output files from the pivot-point modes shift model are the files named icmouthov_*probability.csv and icmoutsov_* probability.csv. Here, * represents a time period.

Dynasmart-P Post-Processors

ICMExtract.exe

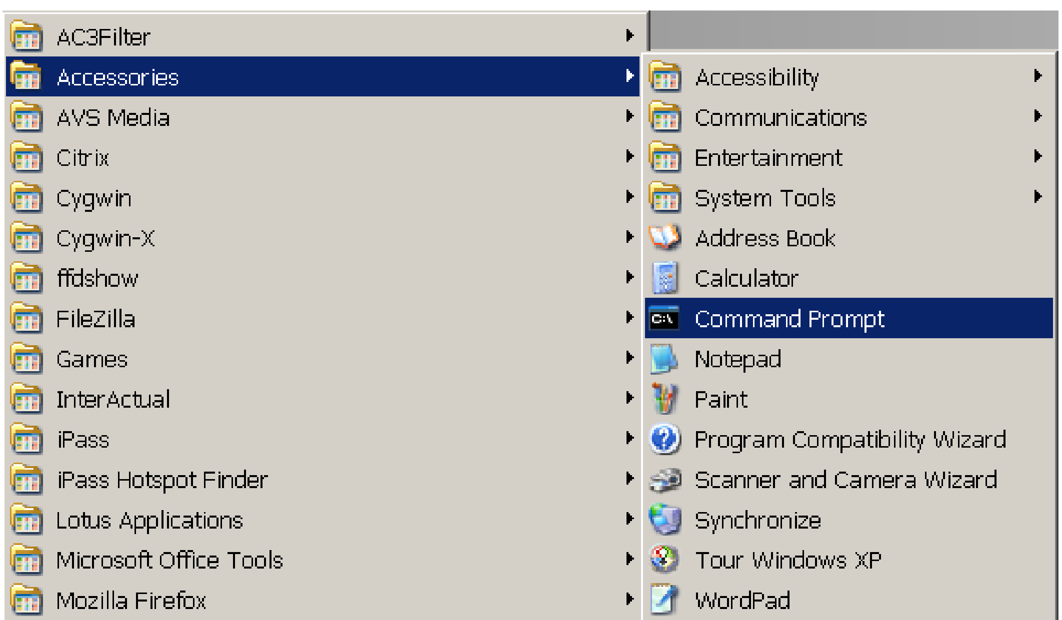
This is the software used to aggregate the time-dependent information associated with the vehicle trajectories generated by Dynasmart-P. It has the capability to generate either time-dependent link travel times or the average link travel times for the entire simulation period.

- The inputs for this software are: 1) VehTrajectory.dat; 2) network.dat; 3) movement.dat; and 4) SummaryStat.dat.
- The outputs are time-dependent and aggregate link travel times that later can be loaded into another tool (Summary_Mean.xls) to generate various performance measures.

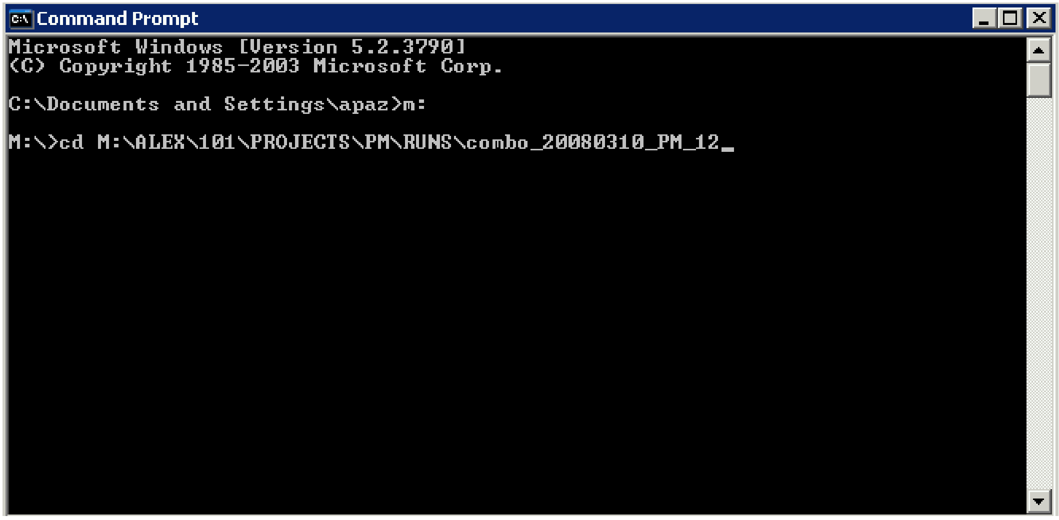
Instructions for Using ICMExtract.exe

Step 1 – Copy ICMExtract.exe to the folder containing your Dynasmart-P outputs.

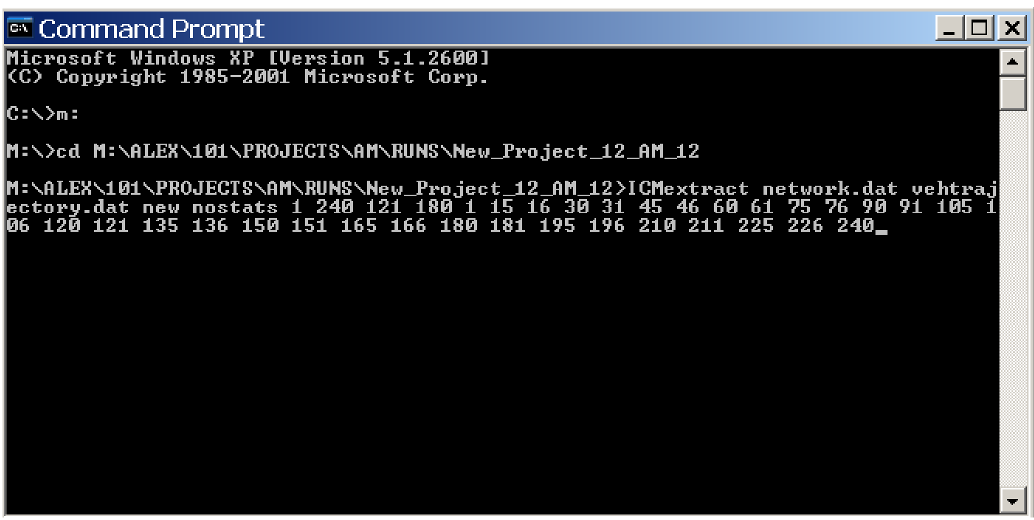
Step 2 – Open the Windows Command Prompt



- **Step 2.1 –** Go to folder where you copied ICMExtract.exe. For example, if your data is in: M:\ALEX\101\PROJECTS\AM\RUNS\New_Project_12_AM_12. Type: M: and press enter, and then type: M:\ALEX\101\PROJECTS\AM\RUNS\New_Project_12_AM_12 and press enter.



Step 2.2 – Type ICMextract movement.dat vehtrajectory.dat 1 240 121 180 1 15 16 30 31 45 46 60 61 75 76 90 91 105 106 120 121 135 136 150 151 165 166 180 181 195 196 210 211 225 226 240 and press enter.



The argument "new" is used when the Dynasmart-P output corresponds to the new version of Dynasmart-P. Otherwise use "old." The argument "stats" is used to print vehicle-type-level statistics, such as emissions, fuel consumption, and travel times. The numeric arguments are used to request time-depending statistics. In our example, since there are the arguments 1 240, the post-processor will compute statistics for the time interval 1 to 240 minutes. Similarly, the post-processor will compute output for the interval 121 to 180 minutes, 1 to 15 minutes, and so on.

Step 3 – The output(s) of ICMExtract.exe are the files which names contain "vehtrajectoryOut," followed by the corresponding time period. The output(s) will be in the same folder as your network files.

Summary_Mean.xls

This spreadsheet is used to load average time-dependent and aggregated link travel times to generate segment- and corridor-level statistics for the peak and peak-hour period. It computes statistics such as average speeds, travel times, vehicle-miles traveled, and estimated number of crashes. The inputs for this software are: 1) network.dat; 2) movement.dat; 3) SummaryStat.dat; and 4) the various vehtrajectoryOut-int.dat files, where “int” denotes different time intervals. The outputs generated by this software are within different Excel sheets included in the Summary_Mean.xls file.

Instructions for Using Summary_Mean.xls

Step 1 – Create a folder called “Post-Processing” in the folder with your network files, and copy the following files into the newly created folder:

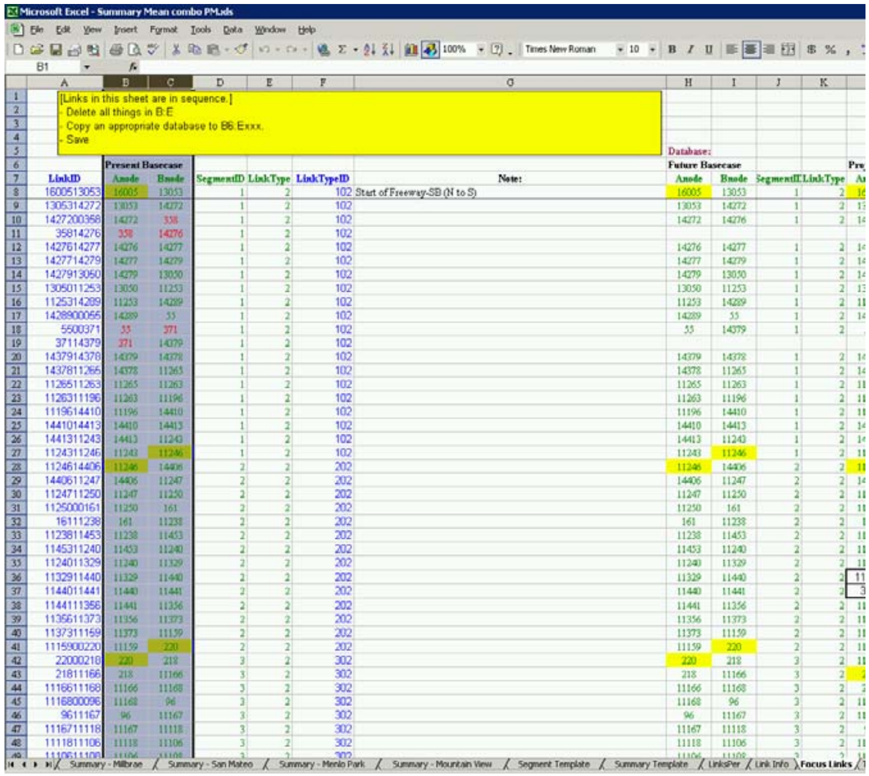
- All of the “vehtrajectoryOut” files generated by ICMExtract.exe;
- network.dat;
- movement.dat;
- SummaryStat.dat; and
- Summary_Mean.xls and Spatial_Plot.xls files.

Step 2 – Rename the Summary_Mean.xls and Spatial_Plot.xls files to reflect a name corresponding to the scenario under analysis.

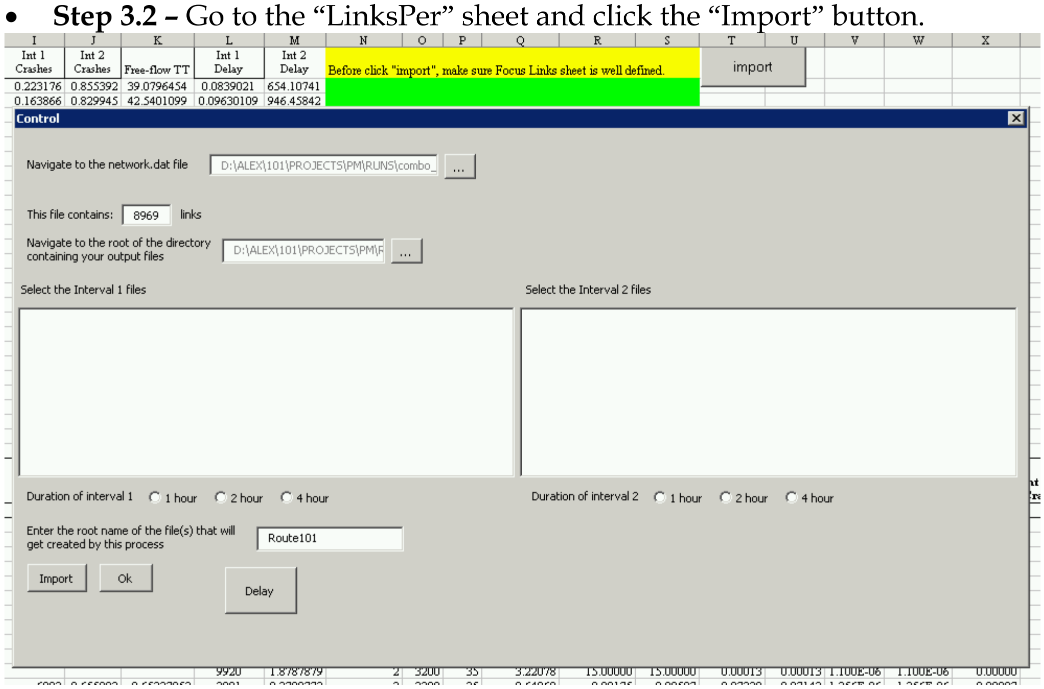
Step 3 – Open Summary_Mean.xls

- **Step 3.1 –** Go to the “Focus Links” sheet, and check that the freeway nodes listed in Columns B and C are correct.

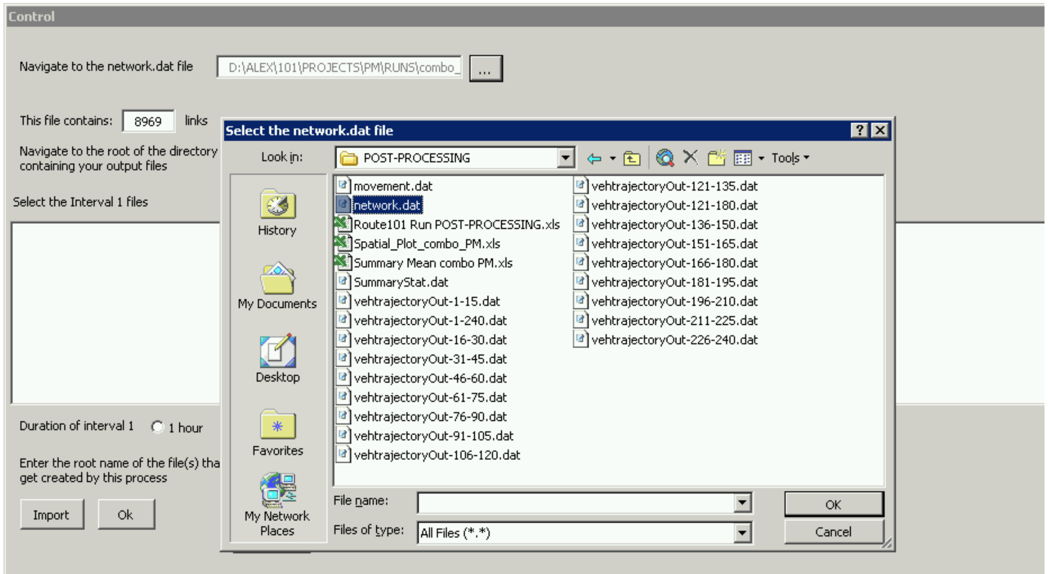
Here SegmentID is used to indicate to the spreadsheet what links to use to compute the segment-level statistics (e.g., travel times). LinkType denotes the type of link (e.g., five for arterials; see Dynasmart-P User’s guide for a description of the different link types).



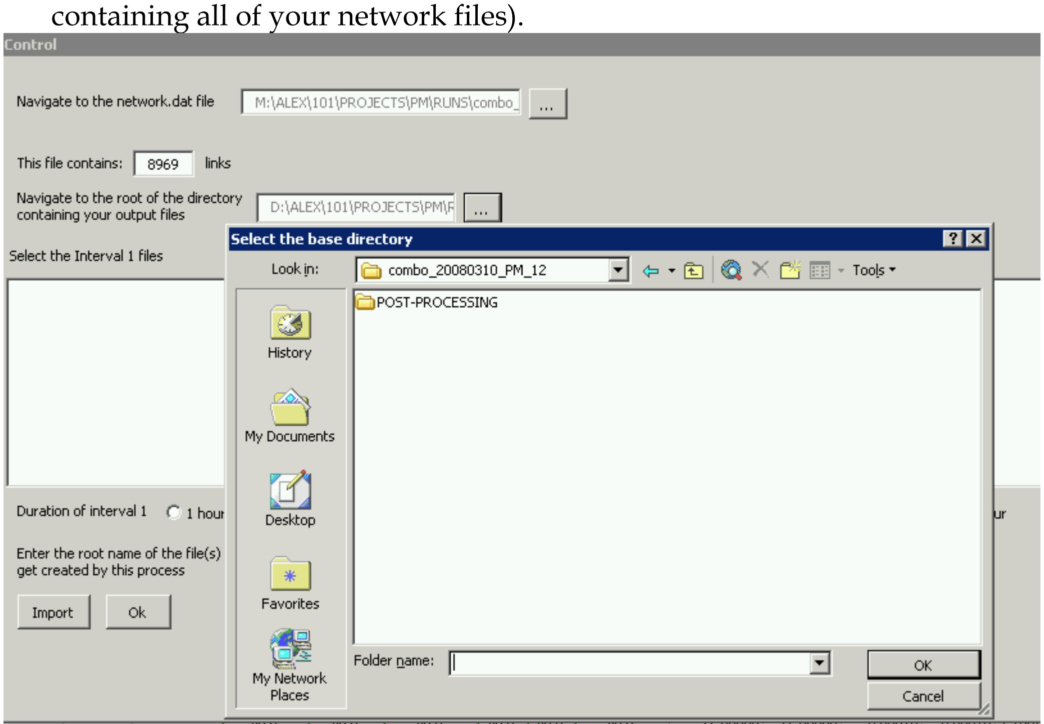
- **Step 3.2 –** Go to the "LinksPer" sheet and click the "Import" button.



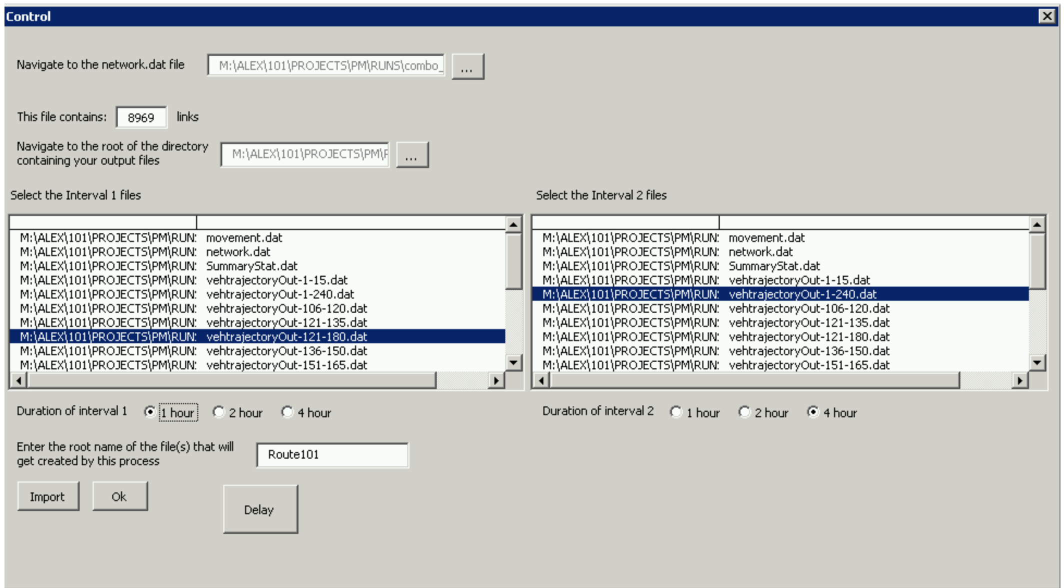
- **Step 3.3 –** Click on the "…" button after "Navigate to the network.dat file" and select the network file.



- **Step 3.4 –** Once the network is loaded, click on the "…" button after "Navigate to the root directory containing your output files," and select the folder one level up from the "Post-Processing" folder (i.e., the folder containing all of your network files).

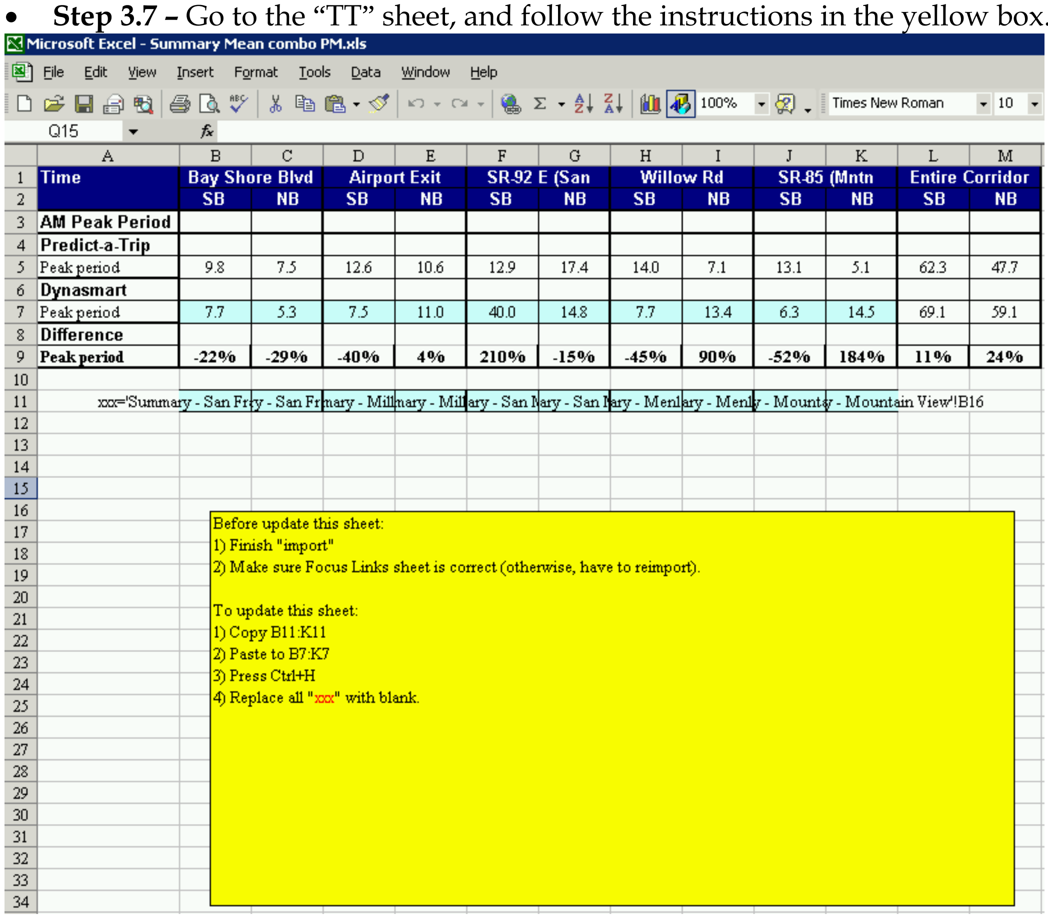


- **Step 3.5 –** Select the files you want for the 1st and 2nd intervals, and select the durations of each interval.



- **Step 3.6 –** Click the "Import" button. If necessary, click ok after the import of data is finished. Here the "Delay" button is optional to recalculate the spreadsheet without reimporting the data.

- **Step 3.7 –** Go to the "TT" sheet, and follow the instructions in the yellow box.



Time	Bay Shore Blvd		Airport Exit		SR-92 E (San		Willow Rd		SR-85 (Mntn		Entire Corridor	
	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB	SB	NB
AM Peak Period												
Predict-a-Trip												
Peak period	9.8	7.5	12.6	10.6	12.9	17.4	14.0	7.1	13.1	5.1	62.3	47.7
Dynasmart												
Peak period	7.7	5.3	7.5	11.0	40.0	14.8	7.7	13.4	6.3	14.5	69.1	59.1
Difference												
Peak period	**-22%**	**-29%**	**-40%**	**4%**	**210%**	**-15%**	**-45%**	**90%**	**-52%**	**184%**	**11%**	**24%**

xxx='Summary - San Fr y - San Fr mary - Mill mary - Mill ary - San ary - San ary - Men ary - Men y - Mount y - Mountain View'!B16

Before update this sheet:
1) Finish "import"
2) Make sure Focus Links sheet is correct (otherwise, have to reimport).

To update this sheet:
1) Copy B11:K11
2) Paste to B7:K7
3) Press Ctrl+H
4) Replace all "xxx" with blank.

It is important to copy and paste the correct B to K cells. They also are denoted by the light blue color.

Spatial_Plot.xls

This spreadsheet is used to generate corridor-level speed contour plots. The speed contours can be used to graphically assess corridor-level performance and identify bottleneck locations. The inputs for this software are: 1) network.dat; 2) movement.dat; 3) SummaryStat.dat; and 4) the various vehtrajectoryOut-int.dat files, where "int" denotes different time intervals. The outputs generated by this software are speed contour plots located in the "Plots" sheet within the Spatial_Plot.xls file.

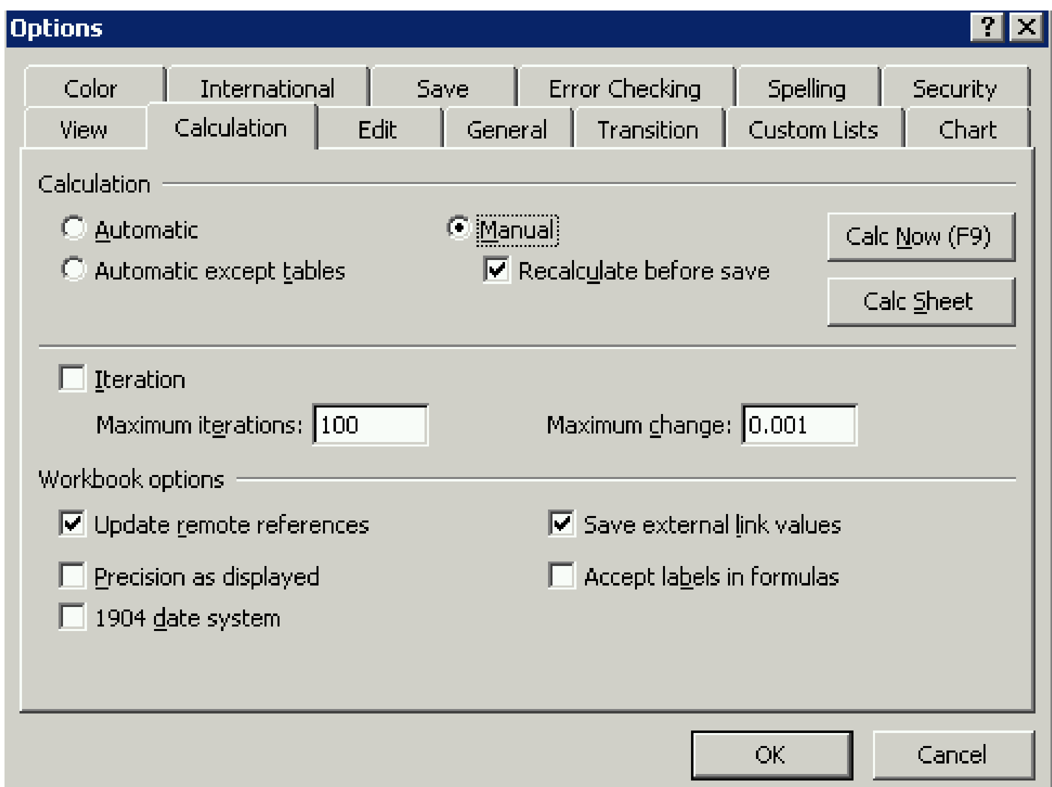
Instructions for Using Spatial_Plot.xls

Note: Steps 1 and 2 under **Instructions for Using Summary Mean.xls** need to have been completed in order to use Spatial_Plot.xls.

Step 1 – Open the renamed Spatial_Plot.xls file.

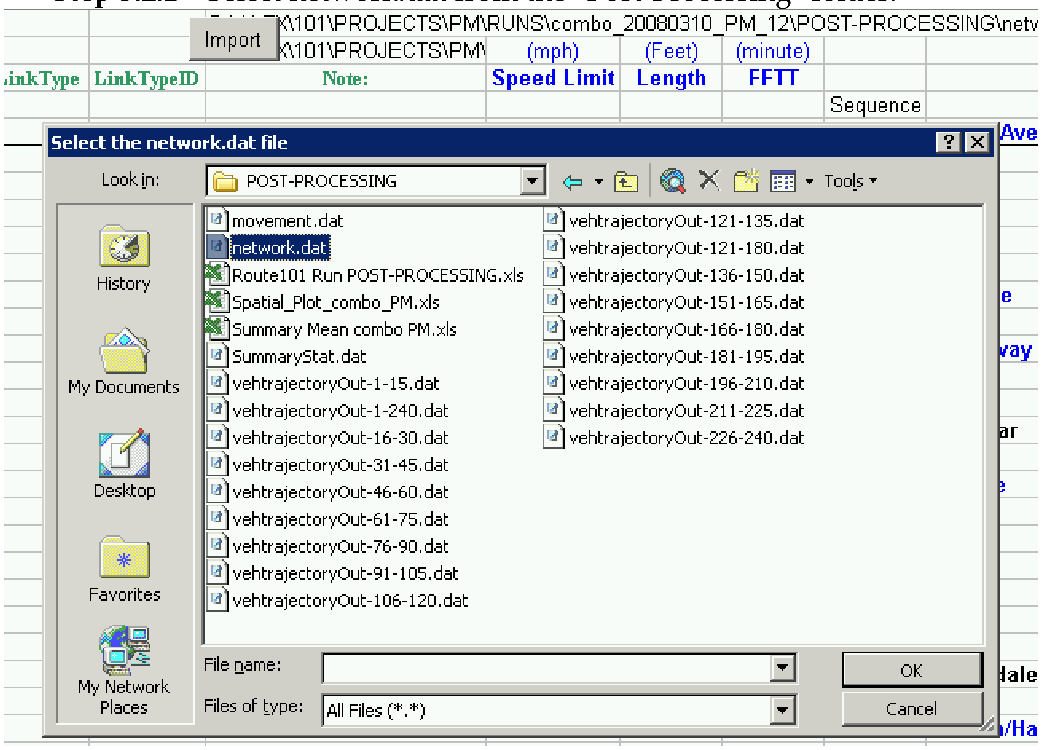
Step 2 – In the menu "Tools/Options" set cell calculation to "Manual" (so you're not waiting for Excel to finish calculating cells each time you make a change).

- **Step 2.1 –** Go to Tools → Options.
- **Step 2.2 –** Go to "Calculation" tab, select "Manual" and check the "Recalculate before save" box.



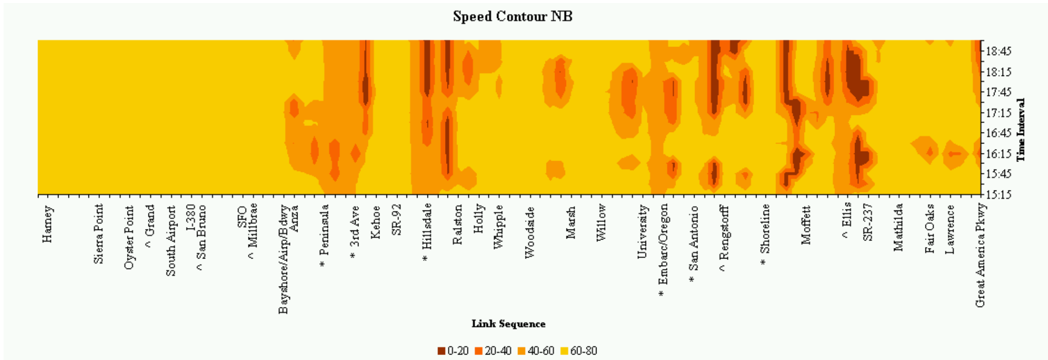
Step 3 – Go to the “Sum” sheet.

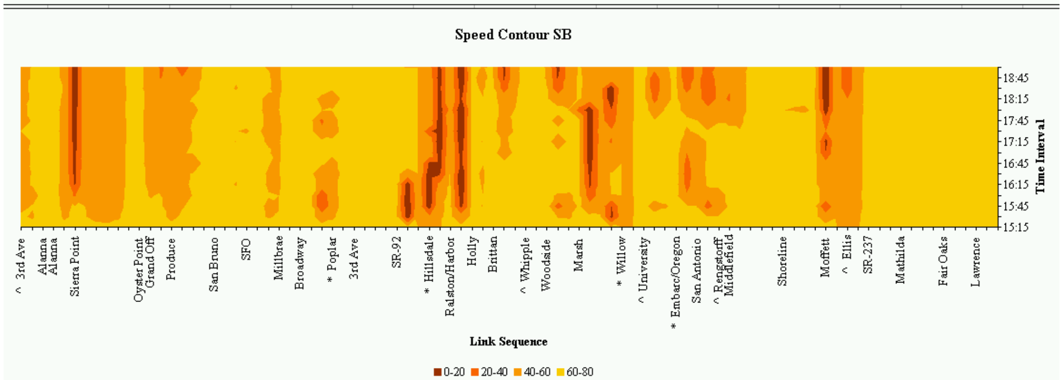
- **Step 3.1 –** Make sure the freeway nodes are correct.
- **Step 3.2 –** Click the “import” button.
- **Step 3.2.1 –** Select network.dat from the “Post-Processing” folder.



- **Step 3.2.2 –** Select the “Post-Processing” folder.
- **Step 3.3 –** To double-check that the files have been imported, look at cells G1 and G2 (they should show the location of your network.dat and the location of the “Post-Processing” folder, respectively).
- **Step 3.4 –** To check that there are no errors, scroll down and make sure that none of the cells say “#N/A.”
- **Step 3.5 –** Check that you have the correct plot labels (Column L and Cells M4:AB4 and M101:AB101).

The speed contour plot is in sheet “plots.”





GenerateODTT.py

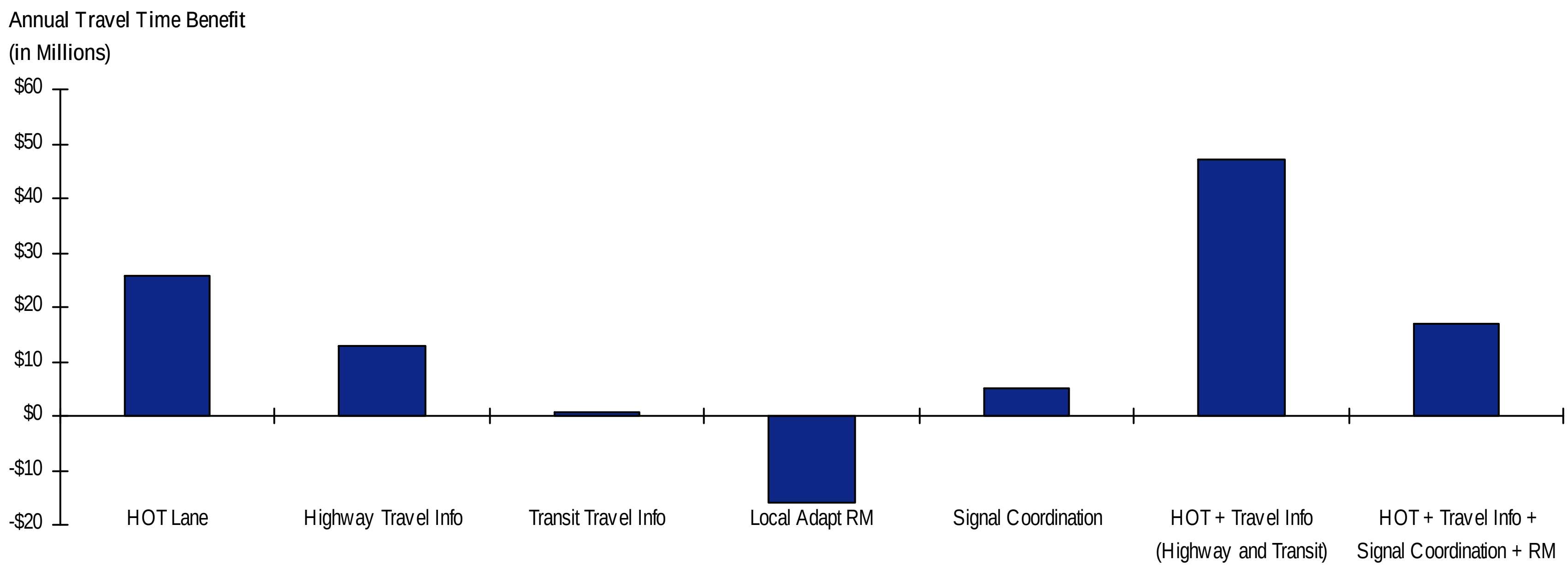
This is the software used to post-process the Dynasmart-P output and generate the input for the mode-shift model. Hence, the inputs for this software are the Dynasmart-P outputs and the software outputs are the inputs required by the mode-shift model. To run the software, the user needs to specify the input and output folders in GenerateODTT.py. Then push F5.

D. ICM AMS Results

Table D.1 *ICM Analysis Scenarios*

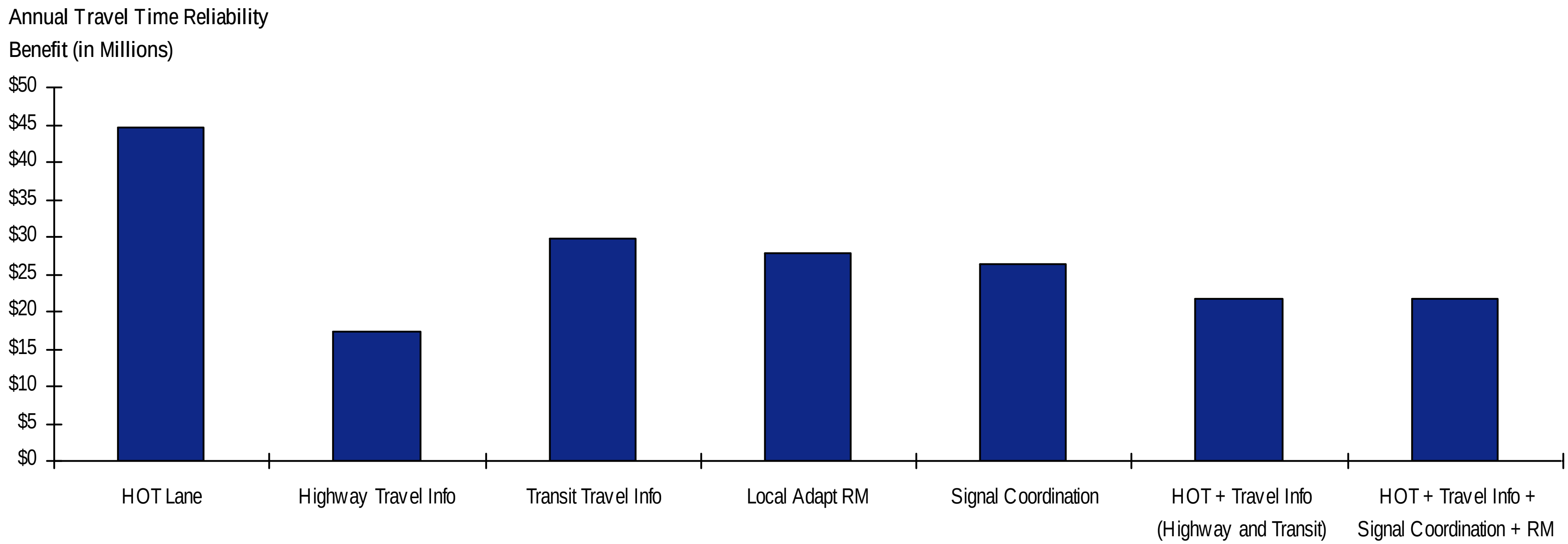
ICM Strategy	Description and Models Used
Zero ITS Baseline	Combinations of medium/high travel demand and presence (or not) of incident with no existing ITS. Incident is a two-lane blockage (50% reduction in capacity) for 45 minutes.
Highway Traveler Information	Pretrip and en-route traveler information at 20% market penetration + Variable Message Signs; DynaSmart-P (DSP).
Transit Traveler Information	Impact of incident information on mode shift; Travel demand model, DSP, pivot-point mode choice model.
HOT Lane	Conversion of existing HOV lane to HOT lane; DSP, pivot-point mode choice model.
Ramp Metering	Local adaptive ramp metering; Not corridor-adaptive ramp metering; DSP.
Arterial Signal Coordination	157 traffic signals were optimized for medium demand/no incident; Synchro, DSP.
Combination	All models.

Figure D.1 Annual Travel Time Benefits – Medium Demand With Major Incident
Value of Time = $14 per Hour



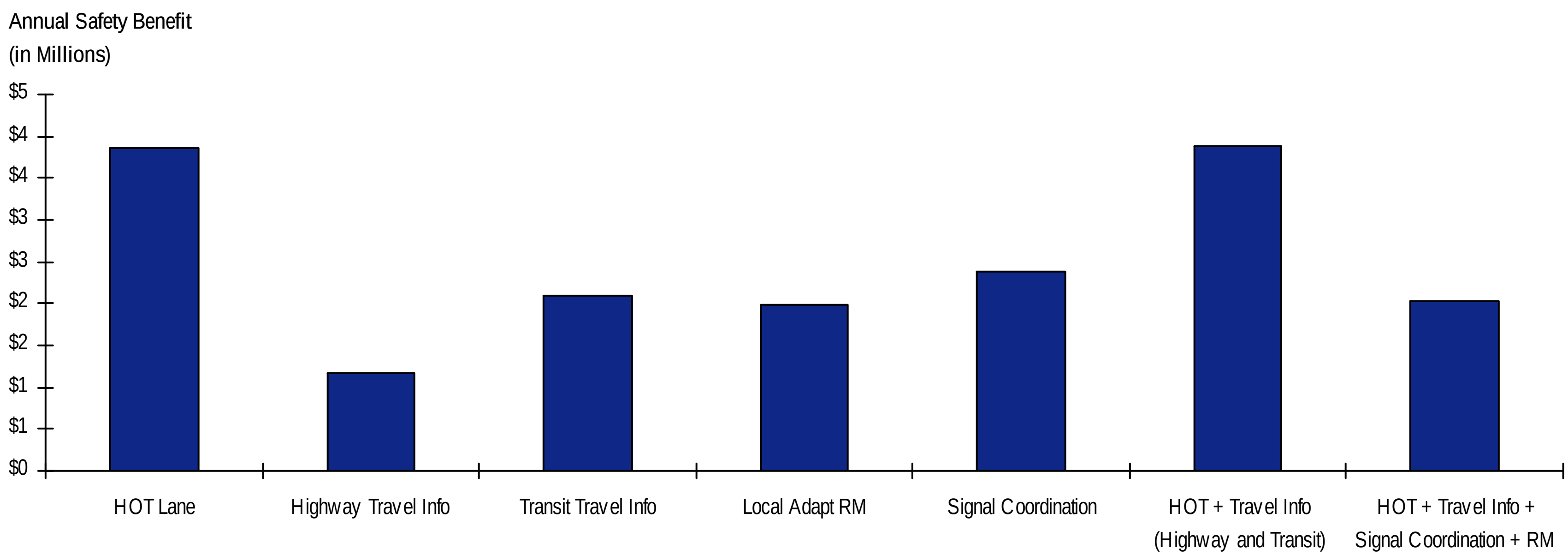
Annual Benefit (in Million-Hours of Delay Saved)	HOT Lane	Highway Travel Info	Transit Travel Info	Adapt RM	Signal Coordination	HOT + Travel Info	Combo
	1.9	0.9	0.1	-1.2	0.4	3.4	1.2

Figure D.2 Annual Travel Time Reliability Benefits – Medium Demand With Major Incident
Value of Time Reliability Improvement = $14 per Hour



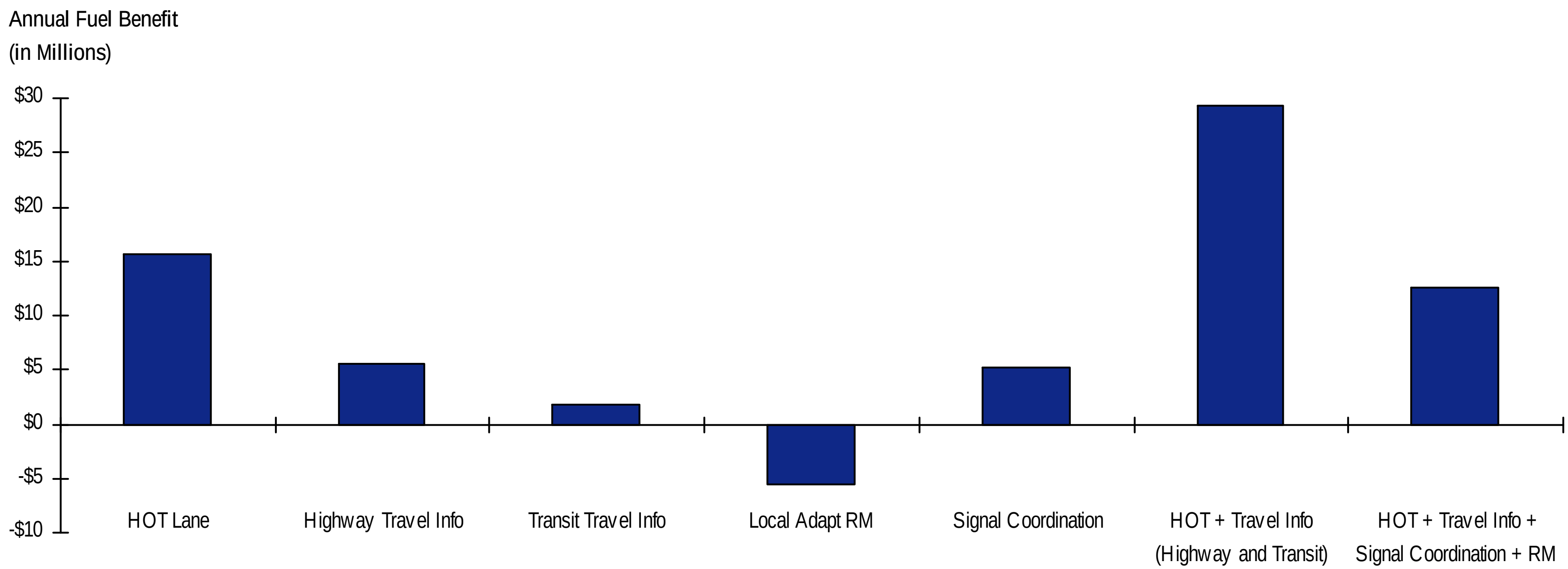
Annual Benefit (in Million-Hours of Delay Saved)	HOT Lane	Highway Travel Info	Transit Travel Info	Adapt RM	Signal Coordination	HOT + Travel Info	Combo
	3.3	1.3	2.2	2.0	1.9	1.6	1.6

Figure D.3 Annual Safety Benefits – Medium Demand With Major Incident
Average Loss from Each Crash = $55,000



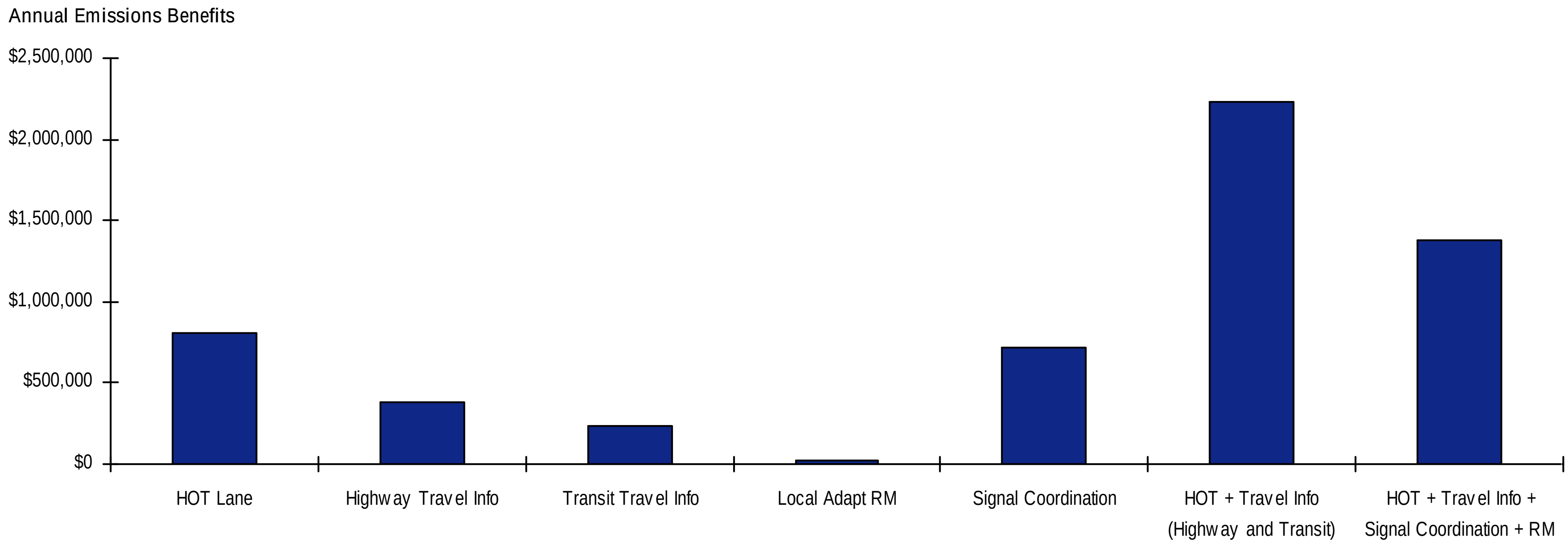
Annual Benefit (in Crashes Prevented)	HOT Lane	Highway Travel Info	Transit Travel Info	Adapt RM	Signal Coordination	HOT + Travel Info	Combo
	70	21	38	36	43	70	37

Figure D.4 Annual Fuel Benefits – Medium Demand With Major Incident
Value of Gallon of Gasoline = $4.00



Annual Benefit (in Million-Gallons of Fuel Saved)	HOT Lane	Highway Travel Info	Transit Travel Info	Adapt RM	Signal Coordination	HOT + Travel Info	Combo
	3.9	1.4	0.4	-1.4	1.3	7.3	3.1

Figure D.5 Annual Emissions Benefit
MDMAI



Annual Benefit (in thousands of tons of emissions reduced)	HOT Lane	Highway Travel Info	Transit Travel Info	Adapt RM	Signal Coordination	HOT + Travel Info	Combo
	12.2	5.7	3.7	0.58	10.8	33.3	20.8

Figure D.6 Summary of Benefits
Medium Demand with Major Incident

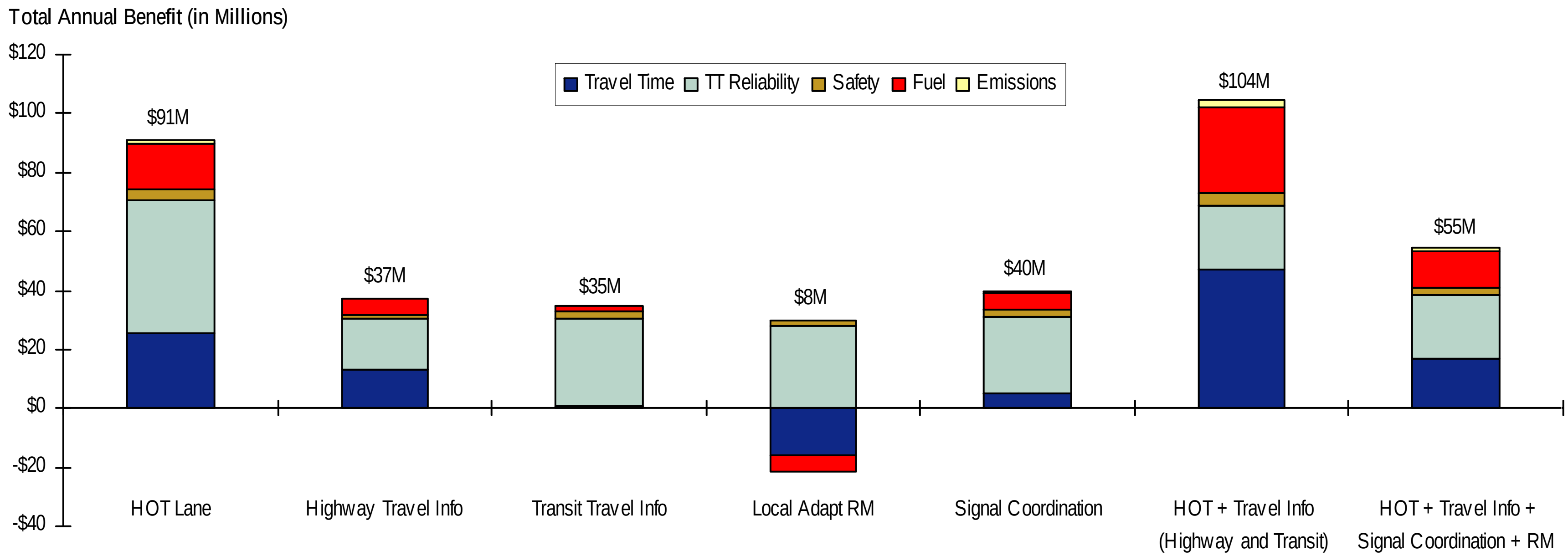
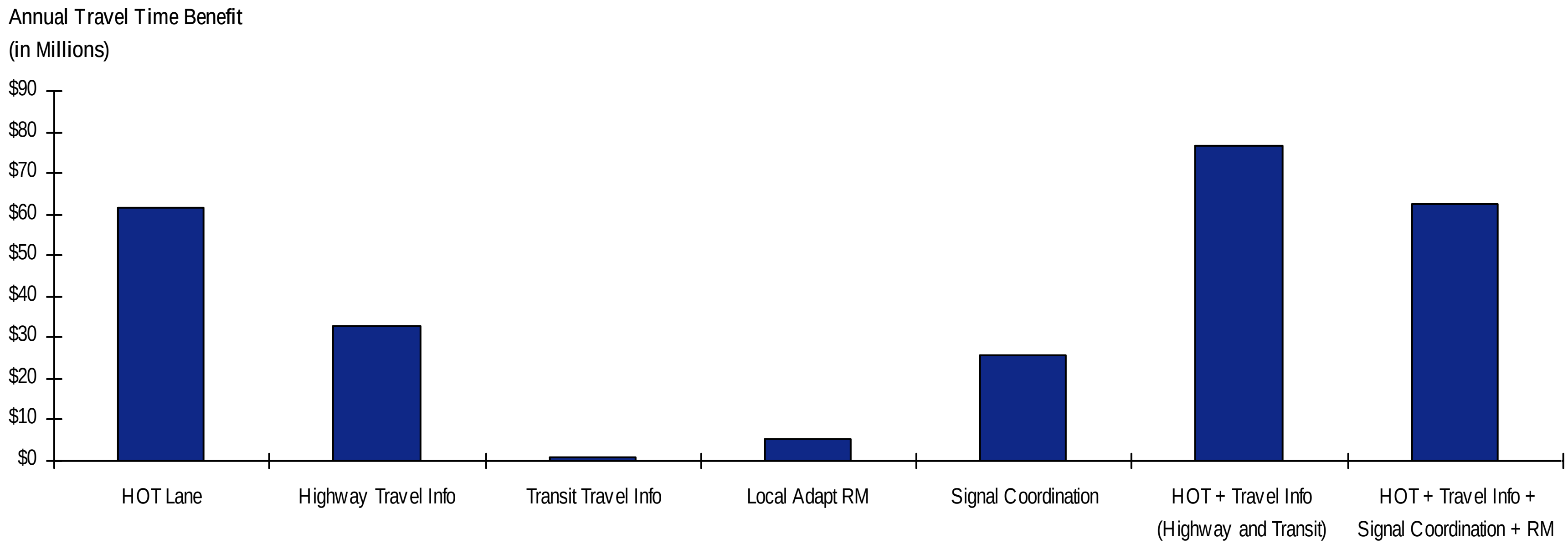


Figure D.7 Annual Travel Time Benefits – High Demand With Major Incident
Value of Time = $14 per Hour



Annual Benefit (in Million-Hours of Delay Saved)	HOT Lane	Highway Travel Info	Transit Travel Info	Adapt RM	Signal Coordination	HOT + Travel Info	Combo
	4.5	2.4	0.1	0.4	1.9	5.6	4.6

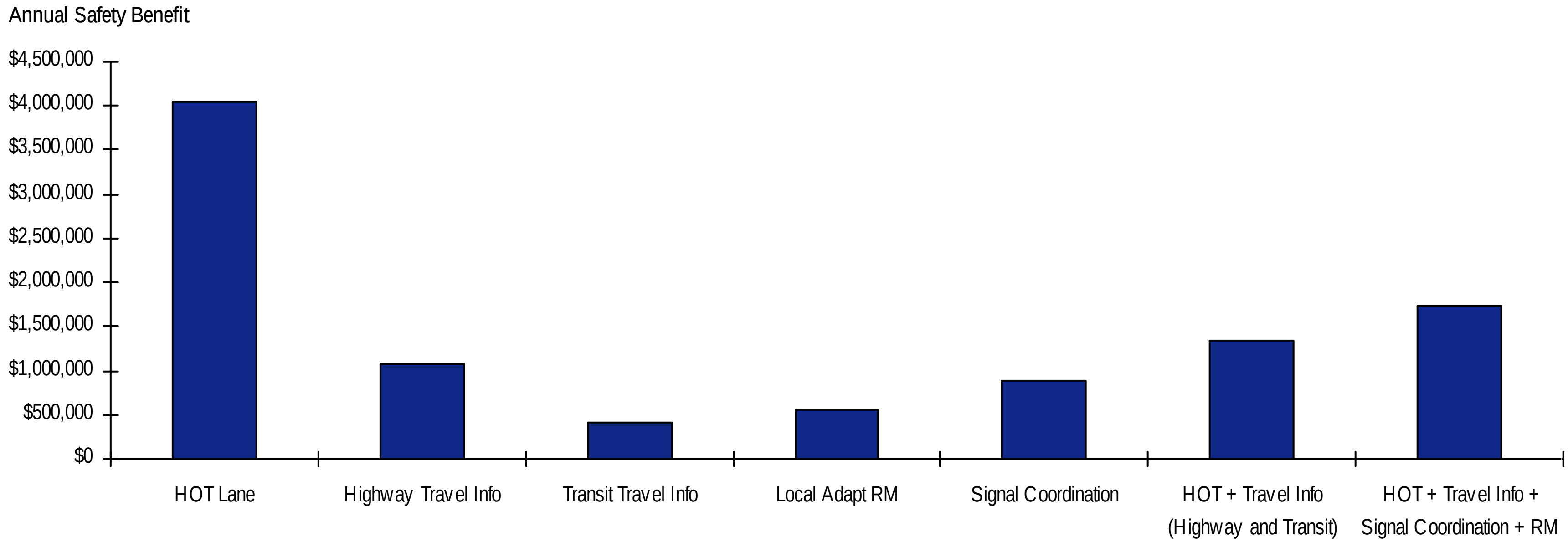
Table D.2 Annual Travel Time Reliability Benefits – High Demand With Major Incident

Value of Time Reliability Improvement = $14 per Hour
(In Million Hours of Delay Saved)

HOT Lane	Hwy Trav Info	Transit Trav Info	Adapt RM	Signal Coord	HOT + Trav Info	Combo
3.3	1.3	2.2	2.0	1.9	1.6	1.6

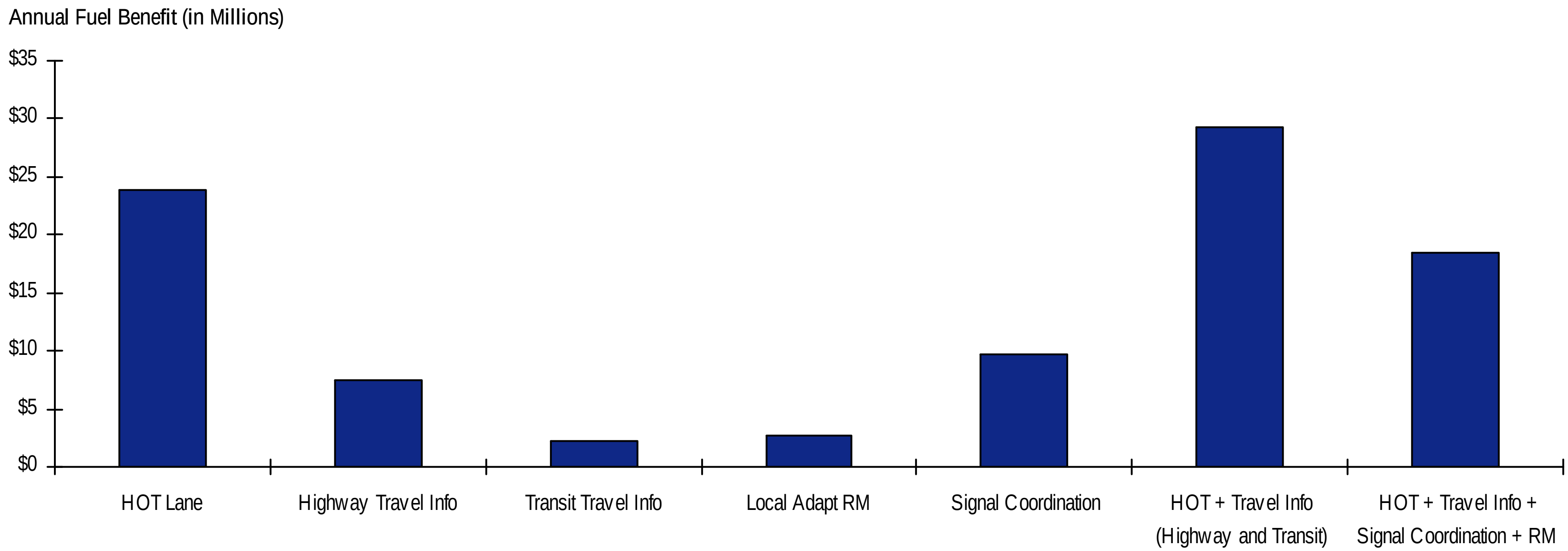
Conservatively assumed that under high demand, improvement in travel time reliability is the same as in medium demand.

Figure D.8 Annual Safety Benefits – High Demand With Major Incident
Average Loss from Each Crash = $55,000



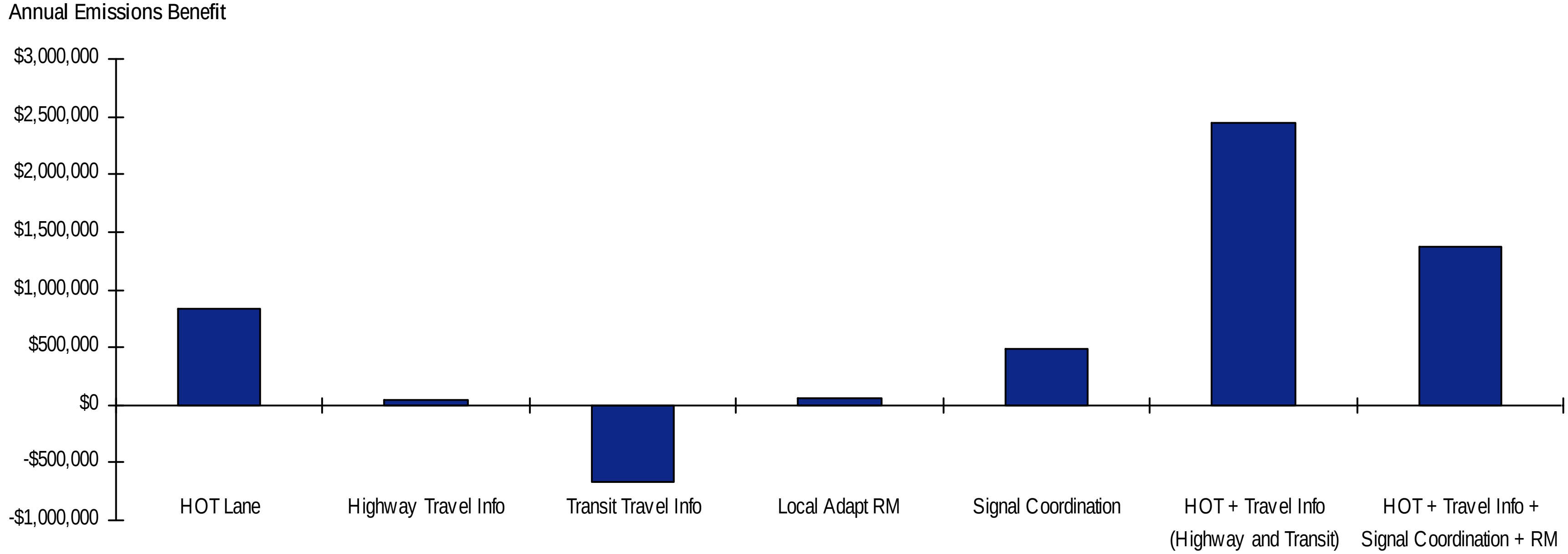
Annual Benefit (in Crashes Prevented)	HOT Lane	Highway Travel Info	Transit Travel Info	Adapt RM	Signal Coordination	HOT + Travel Info	Combo
	73	20	7	10	16	24	32

Figure D.9 Annual Fuel Benefits – High Demand With Major Incident
Value of Gallon of Gasoline = $4.00



Annual Benefit (in Million-Gallons of Fuel Saved)	HOT Lane	Highway Travel Info	Transit Travel Info	Adapt RM	Signal Coordination	HOT + Travel Info	Combo
	6.0	1.9	0.6	0.7	2.4	7.3	4.6

Figure D.10 Annual Emissions Benefit – High Demand with Major Incident



Annual Benefit (in thousands of tons of emissions reduced)	HOT Lane	Highway Travel Info	Transit Travel Info	Adapt RM	Signal Coordination	HOT + Travel Info	Combo
	11.8	0.6	-10.2	1.0	7.3	36.5	20.4

Figure D.11 Summary of Benefits
High Demand with Major Incident

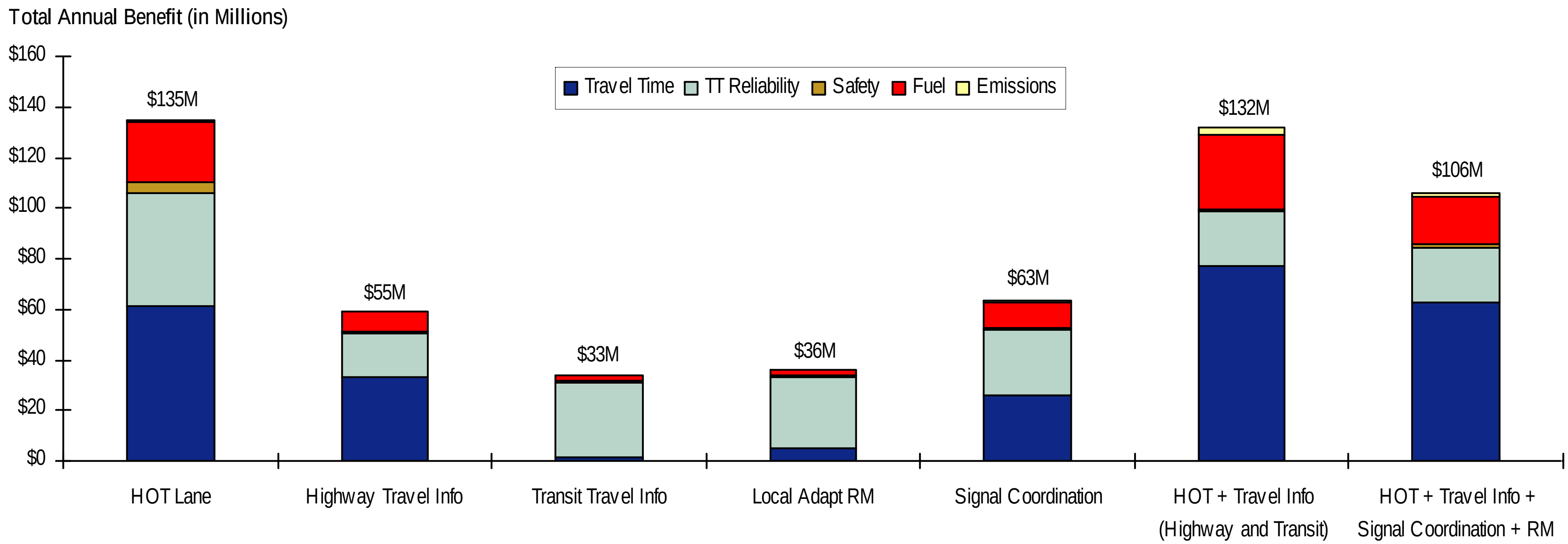
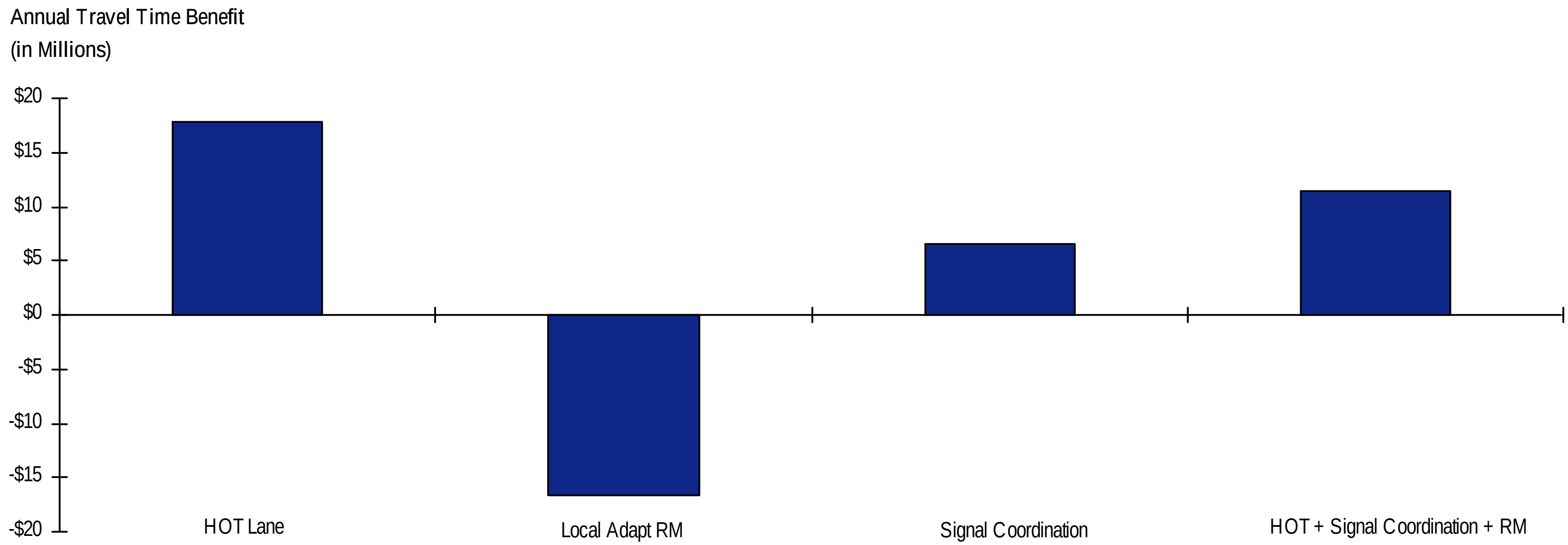
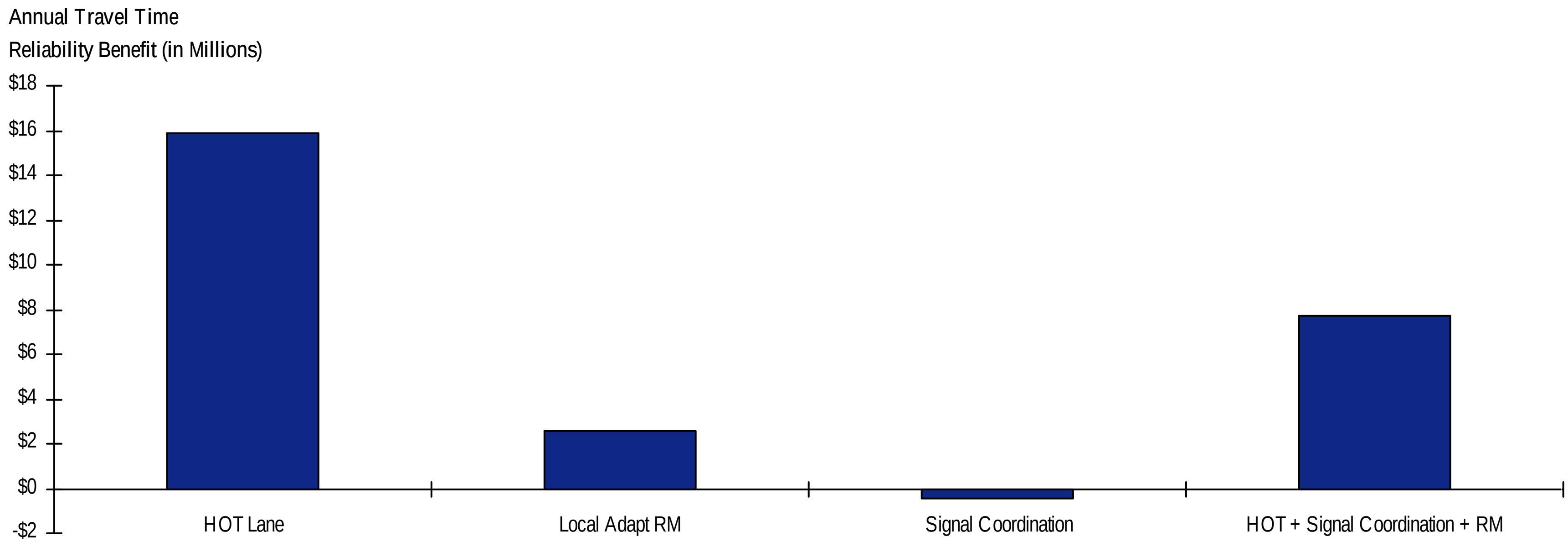


Figure D.12 Annual Travel Time Benefits – Medium Demand With Minor Incident
Value of Time = $14 per Hour



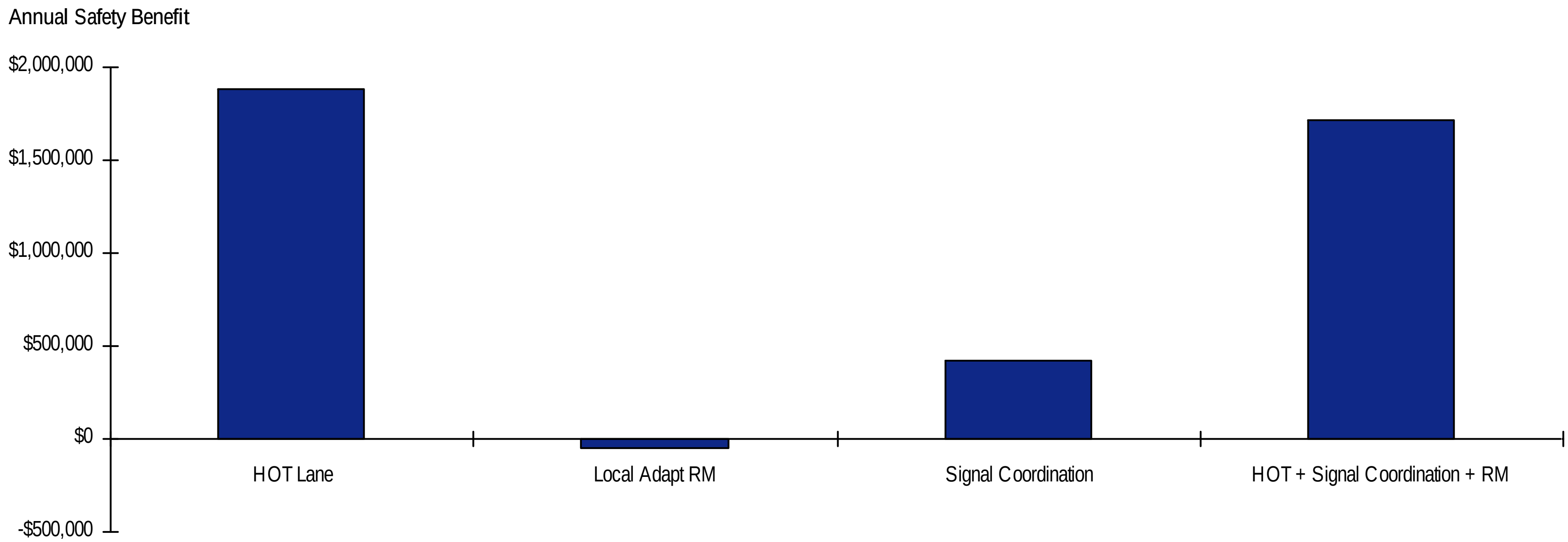
Annual Benefit (in million-hours of delay saved)	HOT Lane	Adapt RM	Signal Coordination	HOT + Signal Coordination + RM
	1.3	-1.2	0.5	0.8

Figure D.13 Annual Travel Time Reliability Benefits – Medium Demand With Minor Incident
Value of Time Reliability Improvement = $14 per Hour



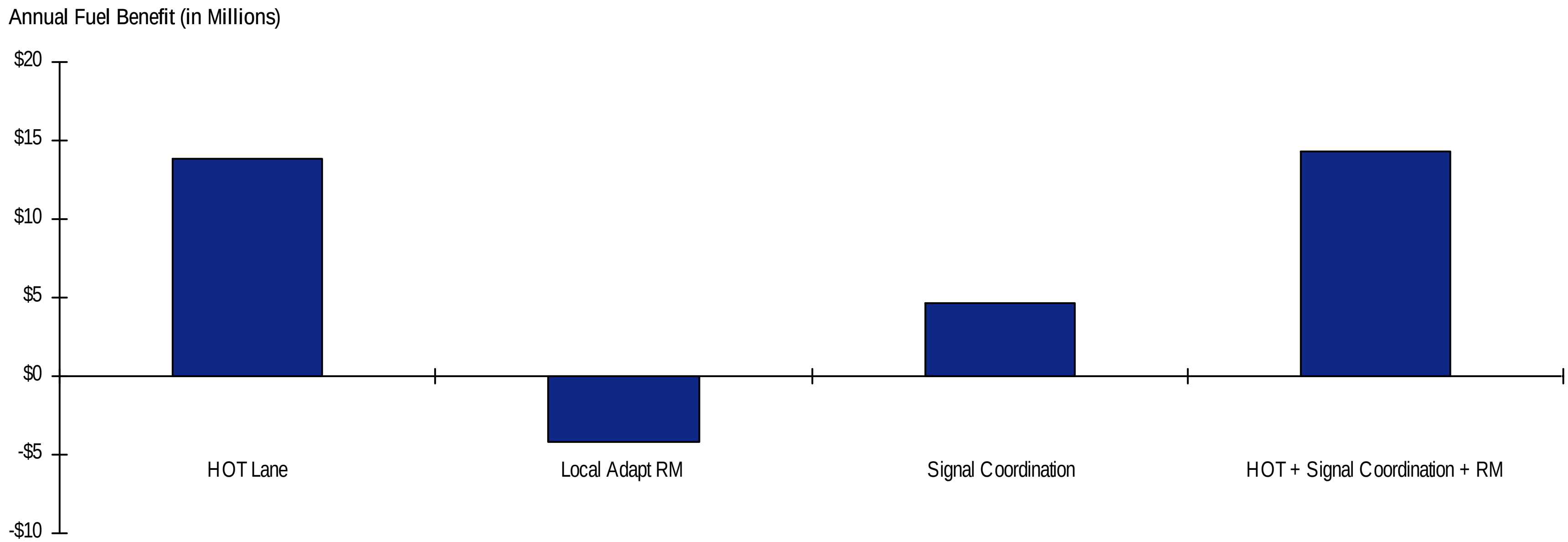
Annual Benefit (in million-hours of delay saved)	HOT Lane	Adapt RM	Signal Coordination	HOT + Signal Coordination + RM
	1.15	0.19	-0.03	0.56

Figure D.14 Annual Safety Benefits – Medium Demand With Minor Incident
Average Loss from Each Crash = $55,000



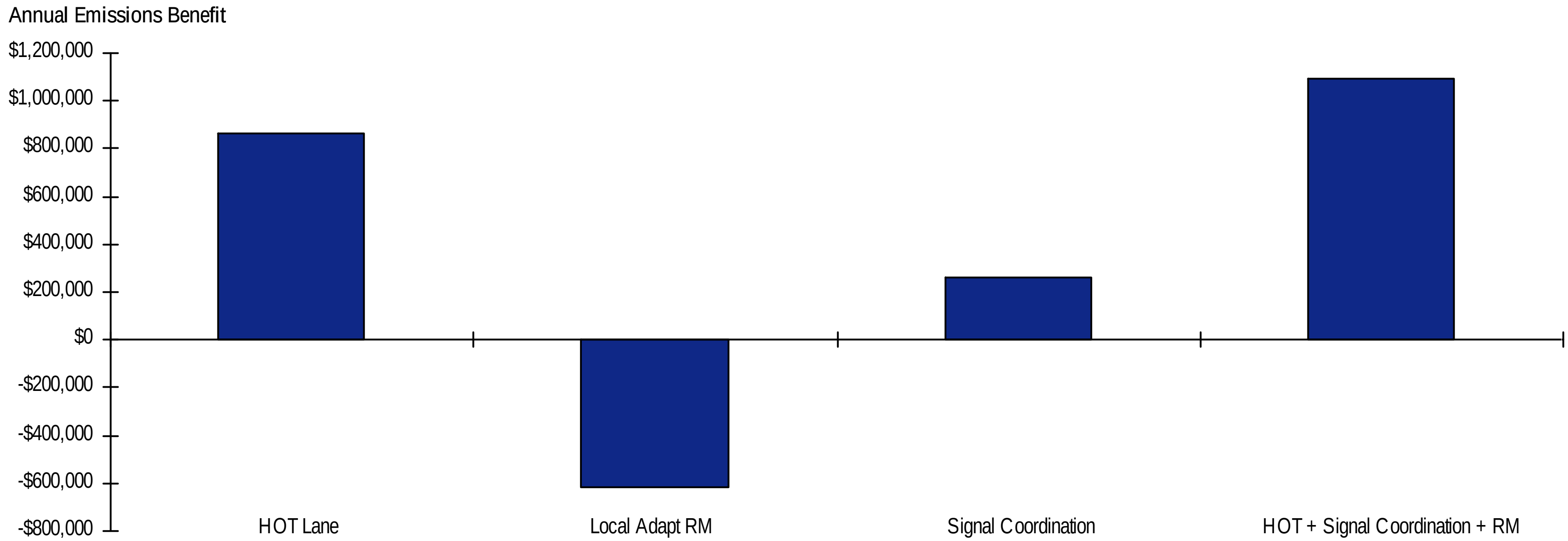
Annual Benefit (in Crashes Prevented)	HOT Lane	Adapt RM	Signal Coordination	HOT + Signal Coordination + RM
	34	-1	8	31

Figure D.15 Annual Fuel Benefits – Medium Demand With Minor Incident
Value of Gallon of Gasoline = $4.00



Annual Benefit (in million-gallons of fuel saved)	HOT Lane	Adapt RM	Signal Coordination	HOT + Signal Coordination + RM
	3.5	-1.0	1.2	3.6

Figure D.16 Annual Emissions Benefit – Medium Demand with Minor Incident



Annual Benefit (in thousands of tons of emissions reduced)	HOT Lane	Adapt RM	Signal Coordination	HOT + Signal Coordination + RM
	13.1	-9.2	4.0	16.3

Figure D.17 Summary of Benefits
Medium Demand with Minor Incident

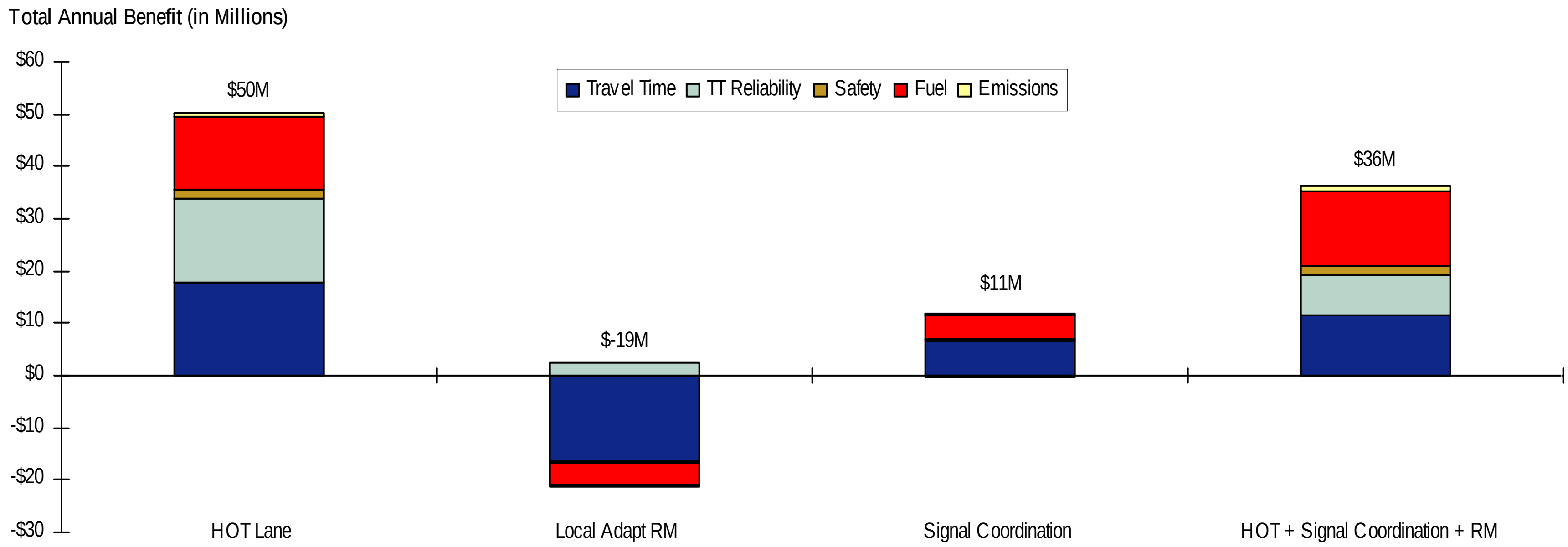
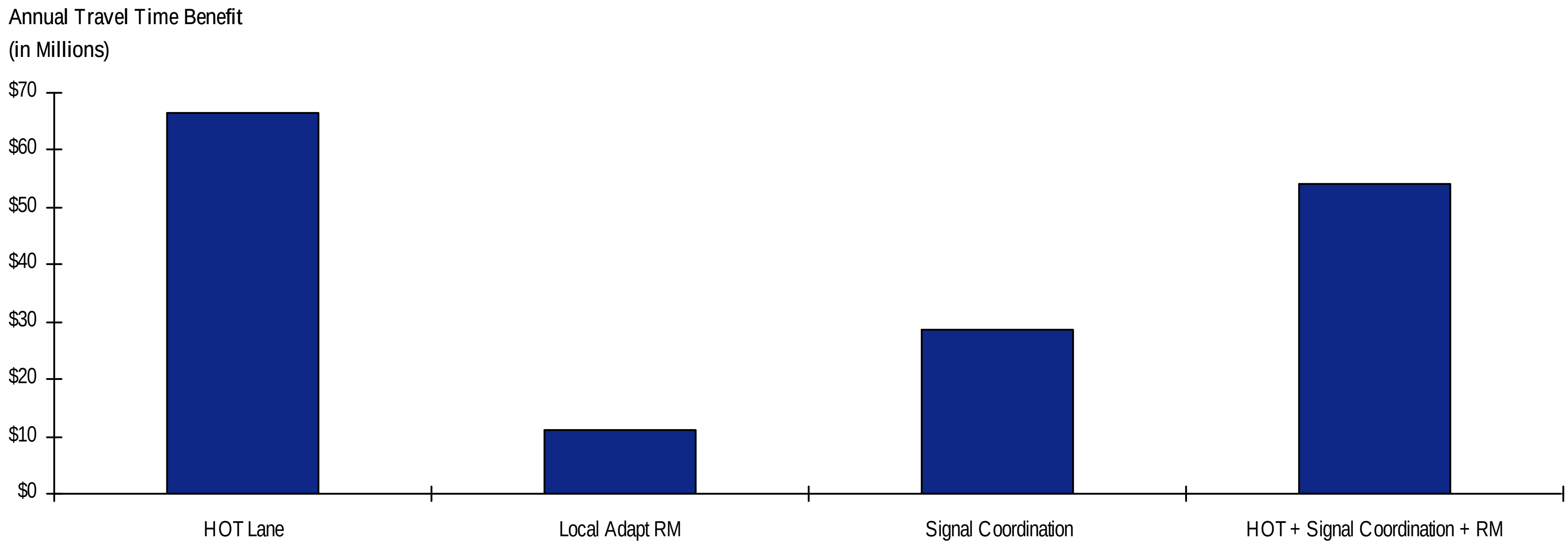


Figure D.18 Annual Travel Time Benefits – High Demand with Minor Incident
Value of Time = $14 per Hour



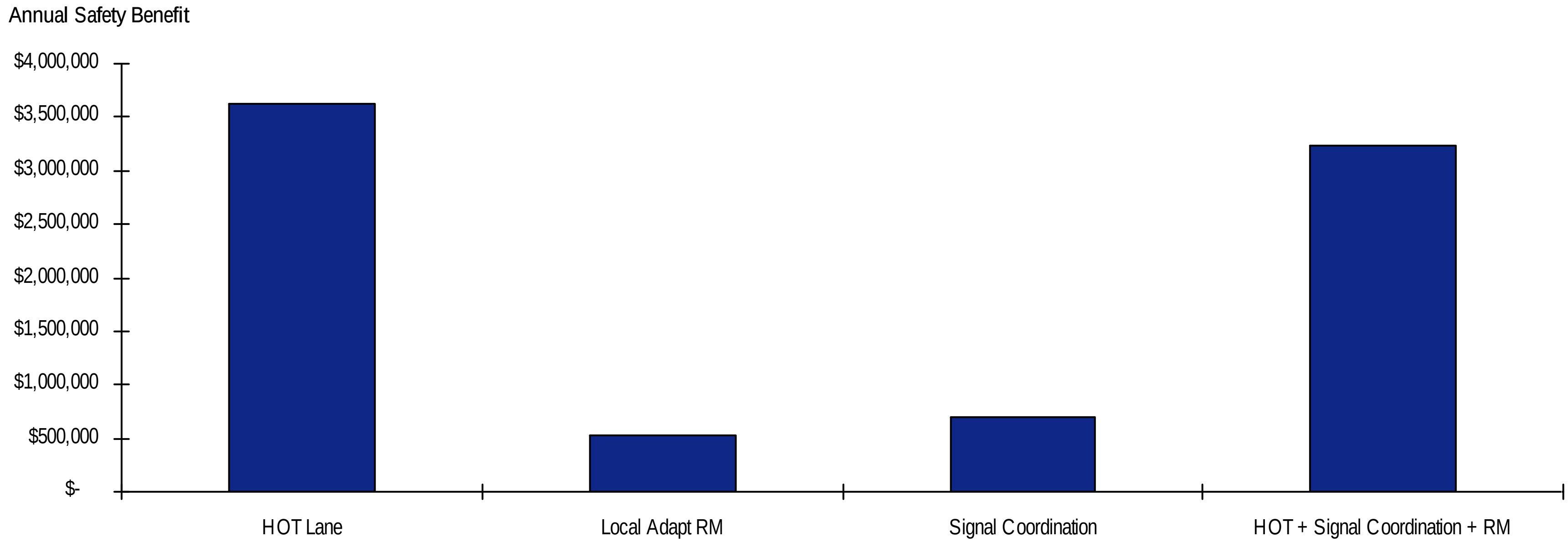
Annual Benefit (in million-hours of delay)	HOT Lane	Adapt RM	Signal Coordination	HOT + Signal Coordination + RM
	4.8	0.8	2.1	3.9

Table D.3 Annual Travel Time Reliability Benefits – High Demand with Minor Incident
Value of Time Reliability Improvement = $14 per Hour
(In Million-Hours of Delay Saved)

HOT Lane	Adapt RM	Signal Coord	HOT + Signal Coord + RM
1.15	0.19	-0.03	0.56

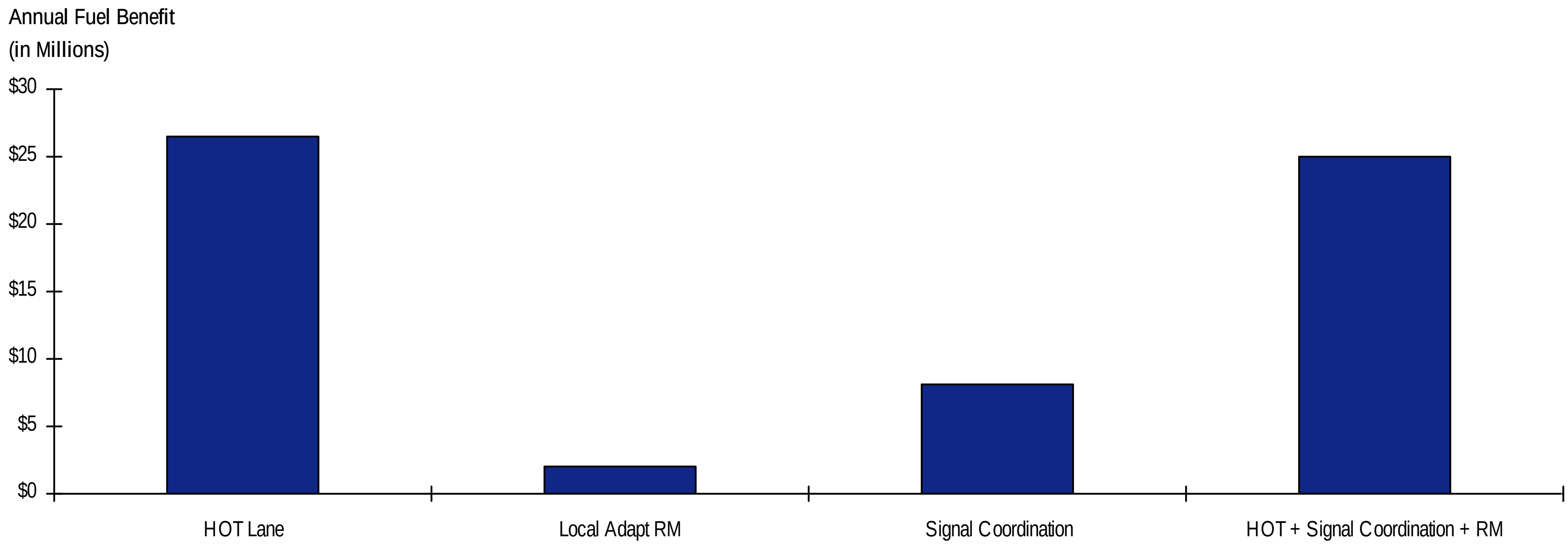
Conservatively assumed that under high demand, improvement in travel time reliability is the same as in medium demand.

Figure D.19 Annual Safety Benefits – High Demand With Minor Incident
Average Loss from Each Crash = $55,000



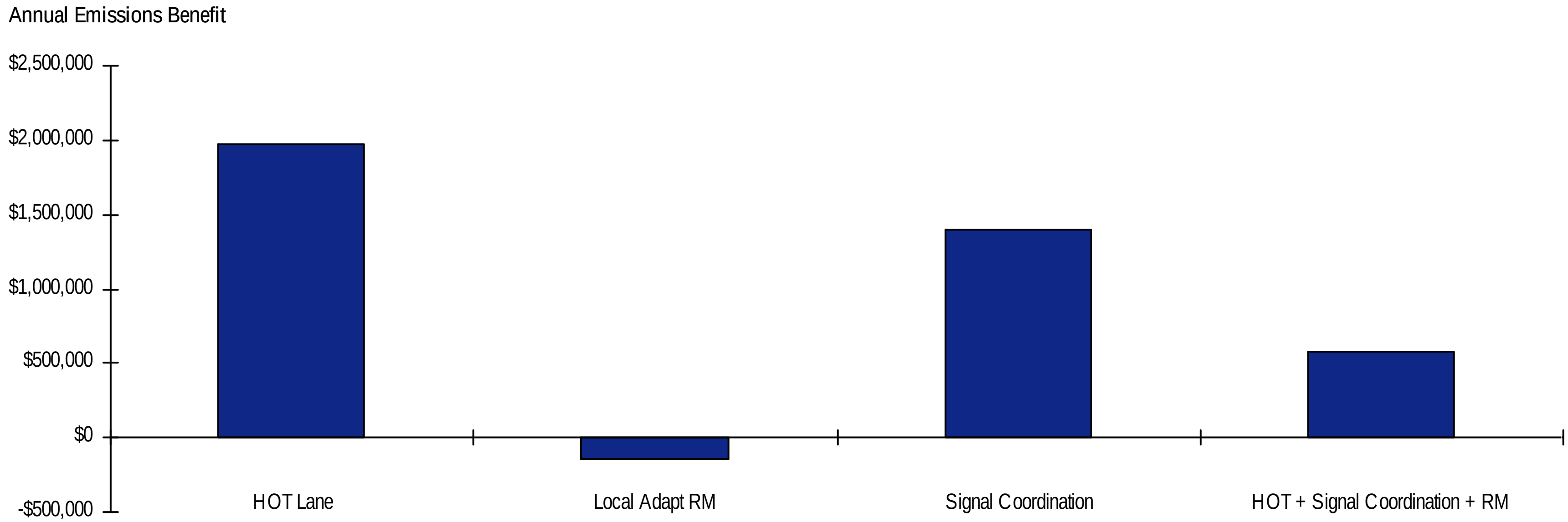
Annual Benefit (in crashes prevented)	HOT Lane	Adapt RM	Signal Coordination	HOT + Signal Coordination + RM
	65	10	13	58

Figure D.20 Annual Fuel Benefits – High Demand with Minor Incident
Value of Gallon of Gasoline = $4.00



Annual Benefit (in million-gallons of fuel saved)	HOT Lane	Adapt RM	Signal Coordination	HOT + Signal Coordination + RM
	6.6	0.5	2.0	6.3

Figure D.21 Annual Emissions Benefit – High Demand with Minor Incident



Annual Benefit (in thousands of tons of emissions reduced)	HOT Lane	Adapt RM	Signal Coordination	HOT + Signal Coordination + RM
	29.0	-2.2	21.1	8.4

Figure D.22 Summary of Benefits
High Demand with Minor Incident

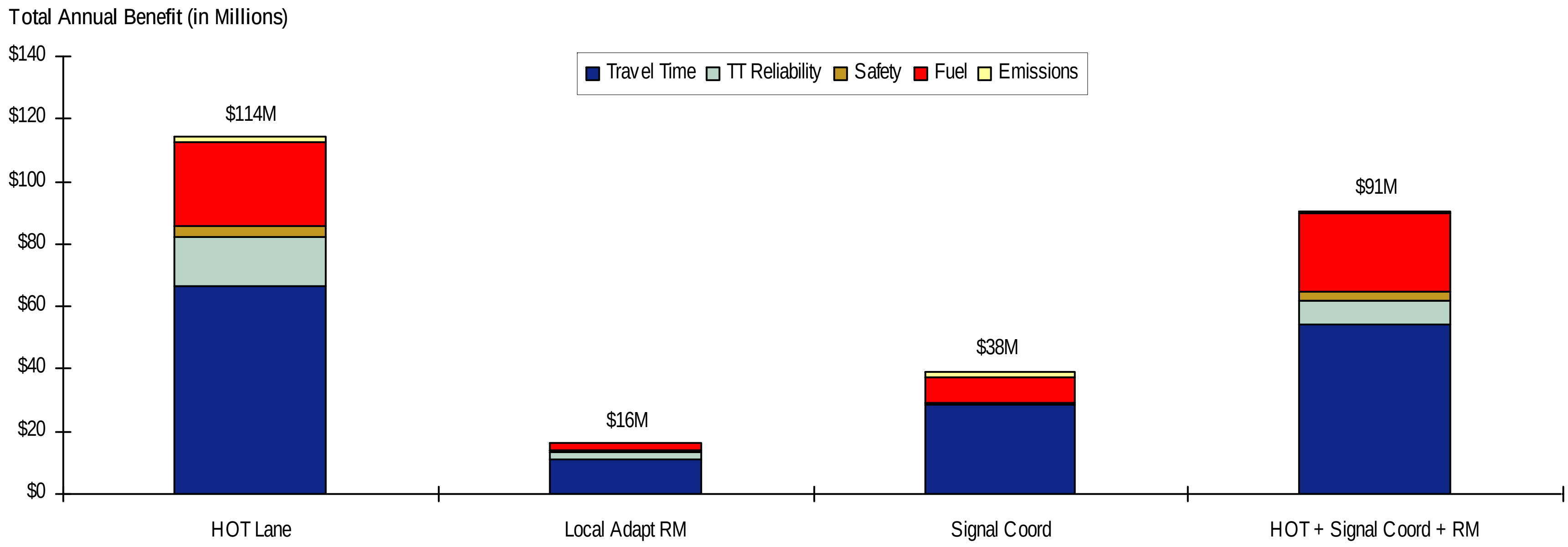


Figure D.23 Test Corridor Operational Conditions
Incident Patterns and Travel Demand Considered Jointly

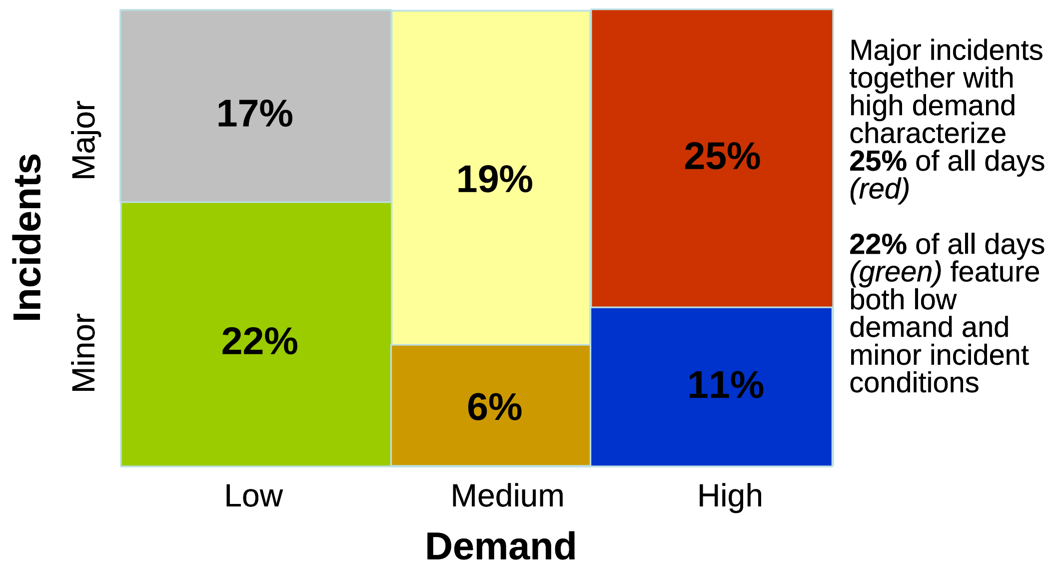


Figure D.24 Test Corridor Total System Delay
Share of Annual Delay

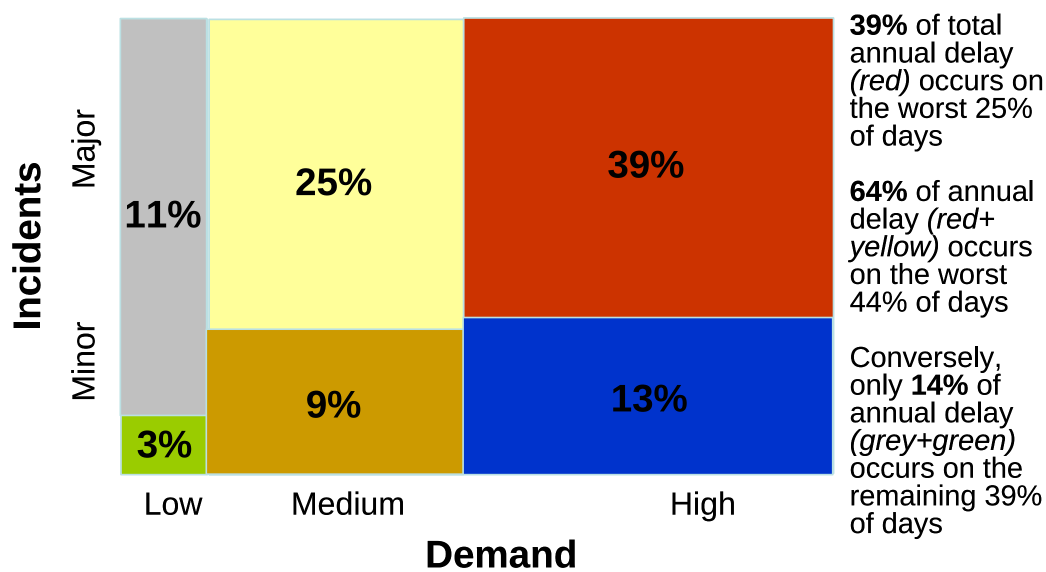
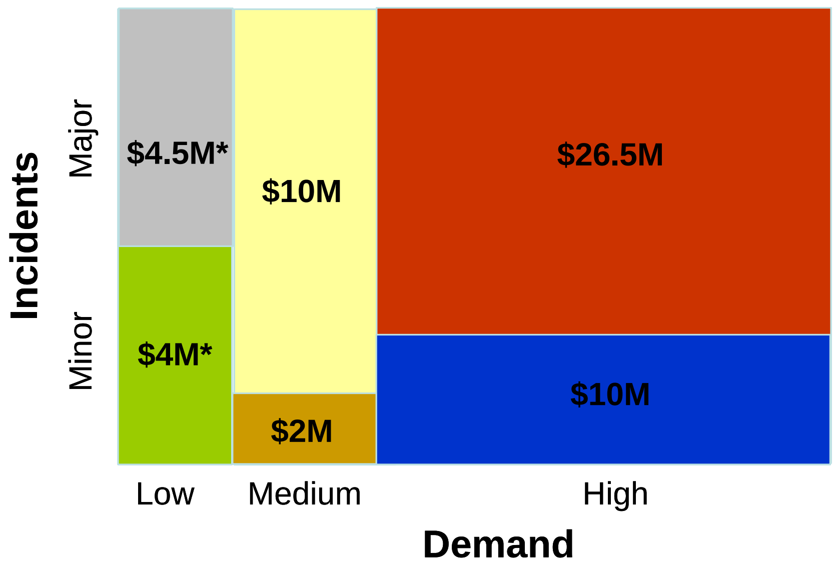


Figure D.25 Test Corridor AMS
Overall ICM Benefit under Different Operational Regimes



Total Test Corridor benefit in a typical year is **$57M**

Approximately half of ICM benefit is on high demand/major incident days

* Assume that low demand benefits are half of normal demand

Figure D.26 Summary of Benefits versus Costs
Medium Demand with Major Incident

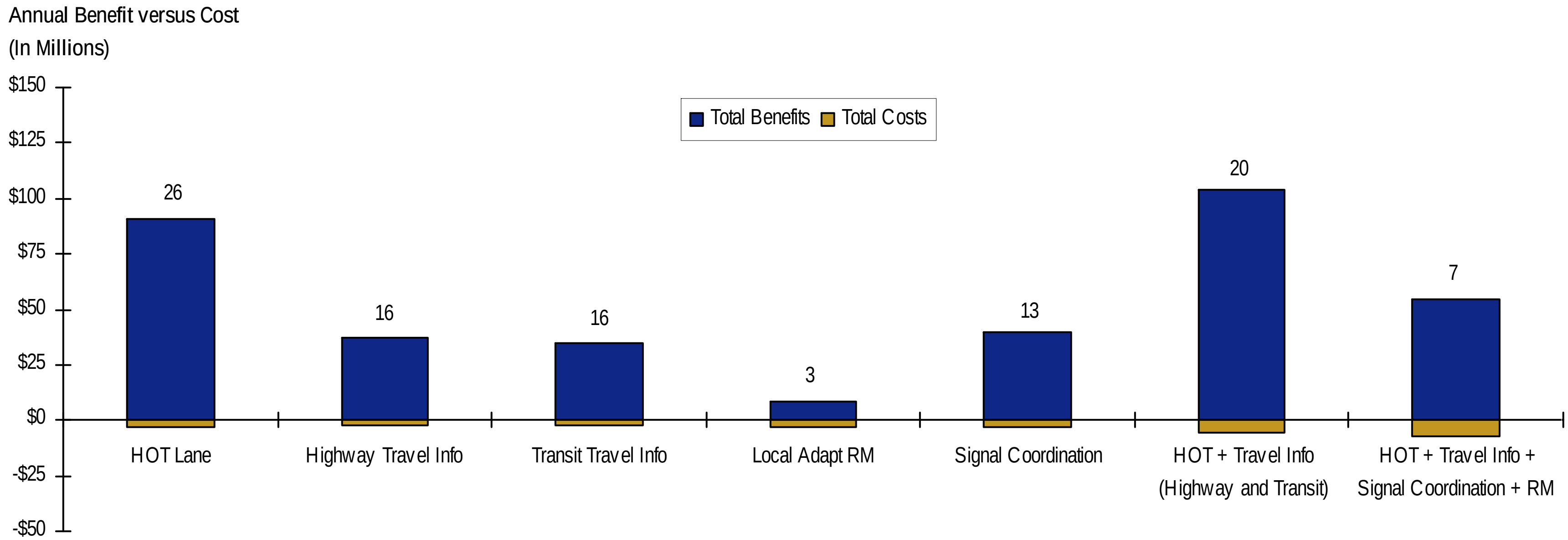


Figure D.27 Summary of Benefits versus Costs
High Demand with Major Incident

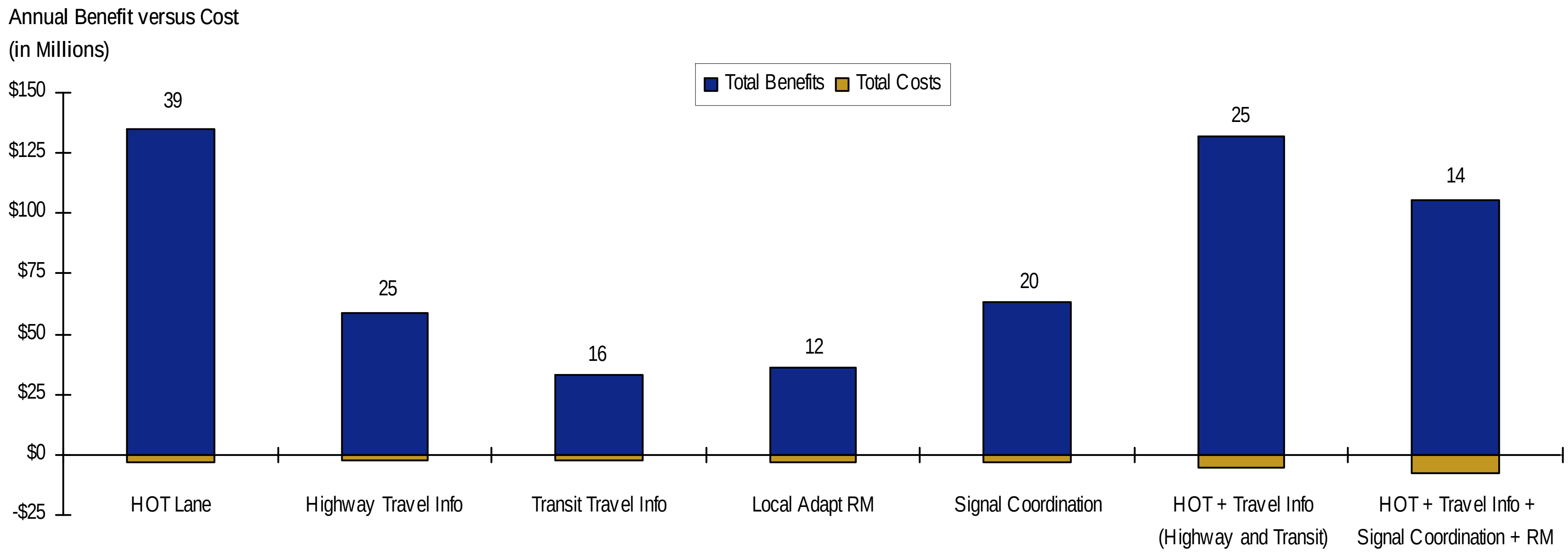


Figure D.28 Summary of Benefits versus Costs
Medium Demand with Minor Incident

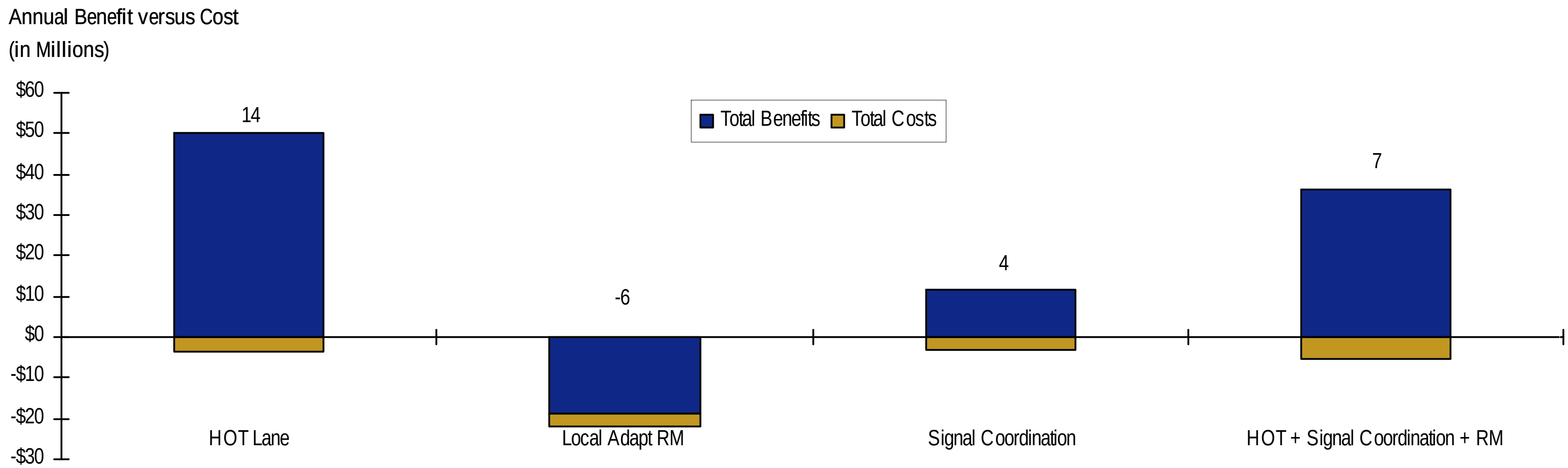


Figure D.29 Summary of Benefits versus Costs
High Demand with Minor Incident

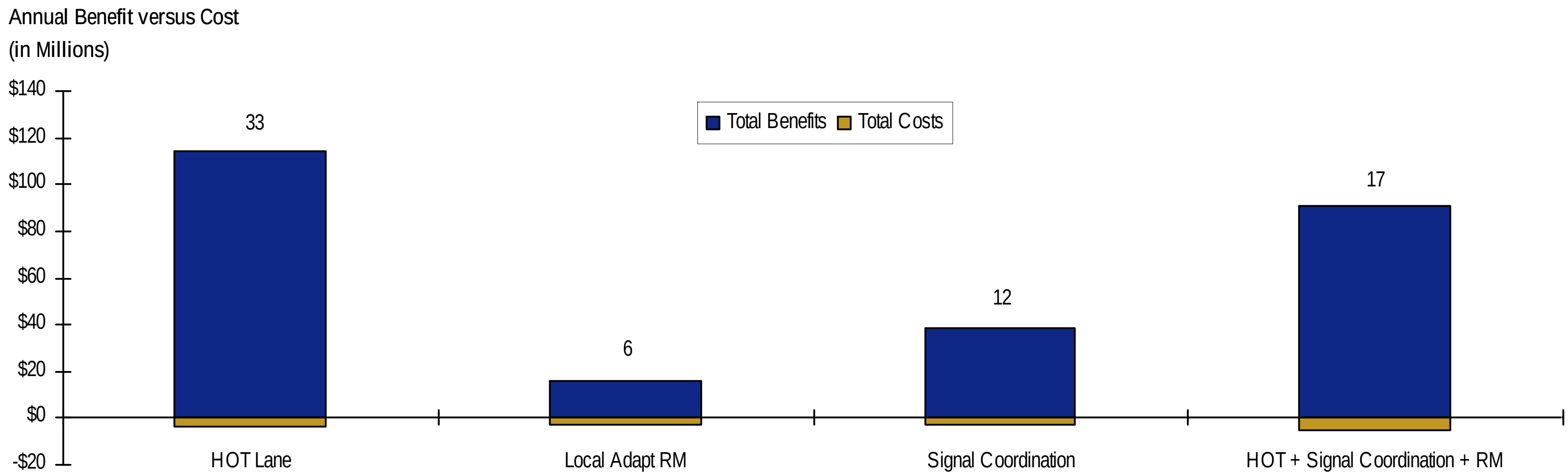


Table D.4 Effectiveness of ICM Strategies under Different Operational Regimes (B-C)

	Medium Demand w/Major Incident	High Demand w/Major Incident	Medium Demand w/Minor Incident	High Demand w/Minor Incident
HOT Lane	26	39	14	33
Hwy Trav Info	16	25		
Transit Trav Info	16	16		
Local Adapt RM	3	12	-6	6
Art Signal Coord	13	20	4	12
Best Combo	20	25	7	17

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