Integrated Corridor Management Initiative: Demonstration Phase Evaluation

Dallas Benefit-Cost Analysis Test Plan

www.its.dot.gov/index.htm
Final Report — August 17, 2012
Publication Number FHWA-JPO-13-052

U.S. Department of Transportation

Produced by Integrated Corridor Management Initiative: Demonstration Phase Evaluation
U.S. Department of Transportation
Research and Innovative Technology Administration
Federal Highway Administration
Federal Transit Administration

Notice

Technical Report Documentation Page

1. Report No. FHWA-JPO-13-052	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Integrated Corridor Management Initiative: Demonstration Phase Evaluation – Dallas Benefit-Cost Analysis Test Plan		5. Report Date August 17, 2012 6. Performing Organization Code
7. Author(s) Patrick Balducci, Battelle		8. Performing Organization Report No.
9. Performing Organization Name and Address Battelle 505 King Avenue Columbus, OH 43201		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-06-D-00007/ T.O. BA07081
12. Sponsoring Agency Name and Address U.S. Department of Transportation Research and Innovative Technology Administration Federal Highway Administration Federal Transit Administration 1200 New Jersey Avenue, S.E. Washington, DC 20590		13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report presents the test plan for conducting the Benefit-Cost Analysis (BCA) for the United States Department of Transportation (U.S. DOT) evaluation of the Dallas U.S. 75 Integrated Corridor Management (ICM) Initiative Demonstration. The ICM projects being deployed in Dallas include a suite of strategies aimed at balancing U.S. 75 corridor transportation supply and demand to promote overall corridor efficiency and safety. Operational strategies to be deployed in the Dallas U.S. 75 highway corridor include: simulations to predict travel conditions for improved incident response, interdependent response plans among agencies, traffic diversion to frontage roads and strategic arterials, traveler mode shift to the light rail system during major freeway incidents, and comparative travel time information to the public and operating agencies for freeway, HOV lanes, frontage roads, arterial streets, and light-rail transit lane. Technologies that will be used to carry out these strategies include a Decision Support System, a 511 traveler information system (telephone and website), a regional center-to-center information exchange network, dynamic message signs, parking management systems, transit signal priority and responsive traffic signals. This BCA Data Test Plan is based on the ICM Initiative Demonstration National Evaluation Framework. This test plan provides an overview of the BCA framework and describes the specific qualitative and quantitative data that will be collected to support the analysis. Data analysis methodologies as well as risks and mitigations associated with this evaluation analysis are also discussed in this test plan.

17. Key Word Integrated Corridor Management, ICM, benefit-cost analysis, evaluation, test plan	18. Distribution Statement		
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 52	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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ACKNOWLEDGEMENTS

Many individuals from the Dallas site team provided crucial input to the development of this test plan. We acknowledge and appreciate the assistance provided by Mr. Koorosh Olyai (Dallas Area Rapid Transit), Dr. Christopher Poe (Texas Transportation Institute) and Ms. Natalie Bettger (North Central Texas Council of Governments).

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LIST OF ABBREVIATIONS

AIS	Abbreviated injury scale
AMS	Analysis, Modeling and Simulation
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
BLS	Bureau of Labor Statistics
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DART	Dallas Area Rapid Transit
DSS	Decision Support Systems
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GUI	Graphical User Interface
HERS	Highway Economic Requirements System
HOT	High-Occupancy Tolling
HOV	High-Occupancy Vehicle
I-15	Interstate 15
I-635	Lyndon B. Johnson Freeway
ICM	Integrated Corridor Management
ICMS	Integrated Corridor Management System
ITS	Intelligent Transportation Systems
KTT	Knowledge and Technology Transfer
LRT	Light Rail Transit
MOE	Measure of Effectiveness
MOVES	Motor Vehicle Emissions Simulator
NCTCOG	North Central Texas Council of Governments

NO_x	Nitrogen Oxide
NTTA	North Texas Tollway Authority
O&M	Operations and Maintenance
OMB	Office of Management and Budget
$PM_{2.5}$	Particulate Matter that is 2.5 micrometers in diameter and smaller
RITA	Research and Innovative Technology Administration
SO_2	Sulfur Dioxide
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
U.S. DOE	U.S. Department of Energy
U.S. DOT	U.S. Department of Transportation
VMT	Vehicle-Miles Traveled
VOC	Volatile Organic Compounds
Volpe Center	John A. Volpe National Transportation System Center
VSL	Value of a Statistical Life
WTP	Willingness to Pay

1.0 INTRODUCTION

This report presents the plan for conducting the Benefit-Cost Analysis (BCA), one of seven analyses that comprise the United States Department of Transportation (U.S. DOT) national evaluation of the Dallas Integrated Corridor Management (ICM) Initiative demonstration phase. The ICM demonstration phase includes multimodal deployments in the U.S. 75 corridor in Dallas, Texas and the Interstate 15 (I-15) corridor in San Diego, California. Separate evaluation test plan documents are being prepared for each site. This document, which focuses on Dallas, is referred to as a "test plan" because, in addition to describing the specific data to be collected, it describes how that data will be used to test various evaluation hypotheses and answer various evaluation questions.

The primary thrust of the national ICM evaluation is to thoroughly understand each site's ICM experience and impacts. However, it is expected that various findings from the two sites will be compared and contrasted as appropriate and with the proper caveats recognizing site differences.

The remainder of this introduction chapter describes the ICM program and elaborates on the hypotheses and objectives for the demonstration phase deployments in Dallas and San Diego, as well as the subsequent evaluation analyses. The remainder of the report is divided into five sections. Chapter 2 summarizes the BCA overall. Chapters 3 and 4 describe the quantitative and qualitative data that will be used in this analysis. Chapter 5 describes how the data will be analyzed. Chapter 6 presents the risks and mitigations associated with BCA data.

1.1 ICM Program[1]

Congestion continues to be a major problem, specifically for urban areas, costing businesses an estimated $200 billion per year due to freight bottlenecks and drivers nearly 4 billion hours of time and more than 2 billion gallons of fuel in traffic jams each year. ICM is a promising congestion management tool that seeks to optimize the use of existing infrastructure assets and leverage unused capacity along our nation's urban corridors.

ICM enables transportation managers to optimize use of all available multimodal infrastructure by directing travelers to underutilized capacity in a transportation corridor—rather than taking the more traditional approach of managing individual assets. Strategies include motorists shifting their trip departure times, routes, or modal choices, or transportation managers dynamically adjusting capacity by changing metering rates at entrance ramps or adjusting traffic signal timing plans to accommodate demand fluctuations. In an ICM corridor, travelers can shift to transportation alternatives—even during the course of their trips—in response to changing traffic conditions.

[1] This section has largely been excerpted from the U.S. DOT ICM Overview Fact Sheet, "Managing Congestion with Integrated Corridor Management," http://www.its.dot.gov/icms/docs/cs_over_final.pdf, developed by SAIC for U.S. DOT. At the direction of U.S. DOT, some of the original text has been revised to reflect updates and/or corrections.

The objectives of the U.S. DOT ICM Initiative are:

- Demonstrate how operations strategies and Intelligent Transportation Systems (ITS) technologies can be used to efficiently and proactively manage the movement of people and goods in major transportation corridors through integration of the management of all transportation networks in a corridor.
- Develop a toolbox of operational policies, cross-network operational strategies, integration requirements and methods, and analysis methodologies needed to implement an effective ICM system.
- Demonstrate how proven and emerging ITS technologies can be used to coordinate the operations between separate multimodal corridor networks to increase the effective use of the total transportation capacity of the corridor.

The U.S. DOT's ICM Initiative is occurring in four phases:

- Phase 1: Foundational Research – This phase researched the current state of corridor management in the United States as well as ICM-like practices around the world; conducted initial feasibility research; and developed technical guidance documents, including a general ICM concept of operations to help sites develop their own ICM concept of operations.
- Phase 2: Corridor Tools, Strategies and Integration – U.S. DOT developed a framework to model, simulate and analyze ICM strategies, working with eight Pioneer Sites to deploy and test various ICM components such as standards, interfaces and management schemes.
- Phase 3: Corridor Site Development, Analysis and Demonstration – This phase includes three stages:
    1) Concept Development – Eight ICM Pioneer Sites developed concepts of operation and requirements documents.
    2) Modeling – U.S. DOT selected Dallas, Minneapolis and San Diego to model their proposed ICM systems.
    3) Demonstration and Evaluation – Dallas and San Diego will demonstrate their ICM strategies; data from the demonstrations will be used to refine the analysis, modeling and simulation (AMS) models and methodology.
- Phase 4: Outreach and Knowledge and Technology Transfer (KTT) – U.S. DOT is packaging the knowledge and materials developed throughout the ICM Initiative into a suite of useful multimedia resources to help transportation practitioners implement ICM.

An on-going ICM Initiative activity, AMS is very relevant to the evaluation. AMS tools were developed in Phase 2 and used by the sites to identify and evaluate candidate ICM strategies. In Phase 3, the proposed Dallas and San Diego ICM deployments were modeled. As sites further refine their ICM strategies, AMS tools continue to be used and iteratively calibrated and validated, using key evaluation results, in part. The AMS tools are very important to the evaluation for two reasons. First, the evaluation will produce results that will be used to complete validation of the AMS tools, e.g., assumptions related to the percentage of travelers who change routes or modes in response to ICM traveler information. Second, AMS tools will serve as a source of some evaluation data, namely the corridor-level, person-trip travel time and throughput measures that are difficult to develop using field data.

1.2 ICM Demonstration Phase Deployments[2]

This section summarizes the Dallas ICM deployment and briefly contrasts it with the San Diego deployment.

1.2.1 Overview of the Dallas ICM Deployment

The U.S. 75 ICM project is a collaborative effort led by Dallas Area Rapid Transit (DART) in collaboration with U.S. DOT; the cities of Dallas, Plano, Richardson, and University Park; the town of Highland Park; North Central Texas Council of Governments (NCTCOG); North Texas Tollway Authority (NTTA); and the Texas Department of Transportation (TxDOT).

U.S. 75 is a north-south radial corridor that serves commuter, commercial, and regional trips, and is the primary connector from downtown Dallas to the cities to the north. Weekday mainline traffic volumes reach 250,000 vehicles, with another 30,000 vehicles on the frontage roads. The corridor (travelshed) has 167 centerline-miles (269 kilometers) of arterial roadways.

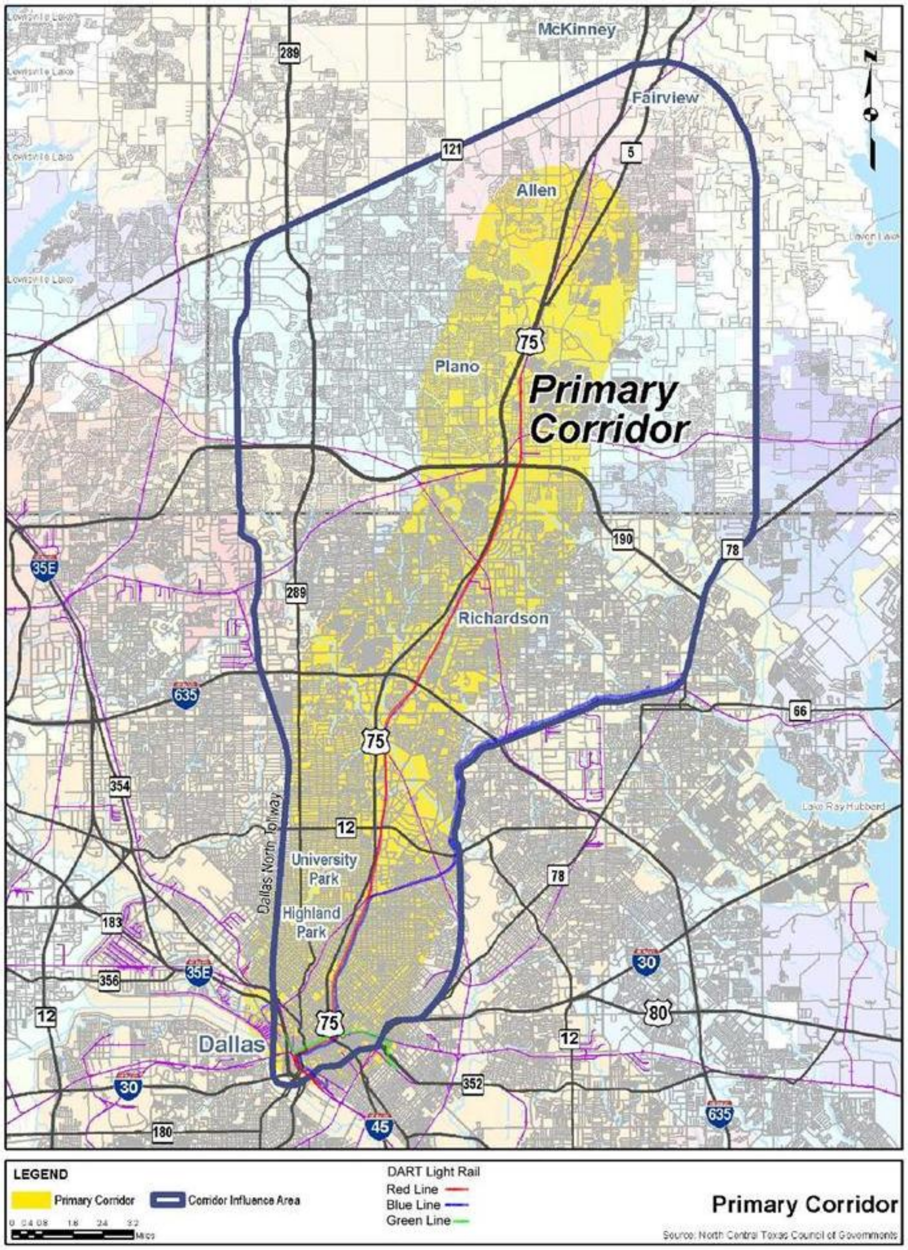
Exhibited in Figure 1-1, the U.S. 75 corridor has two concurrent flow-managed, high-occupancy vehicle (HOV) lanes, light rail, bus service, and park & ride lots. The corridor sees recurring congestion and a significant number of freeway incidents. Light rail on the DART Red Line is running at 75 percent capacity, and arterial streets are near capacity during peak periods and are affected by two choke points at the U.S. 75/Lyndon B. Johnson Freeway (I-635) interchange and U.S. 75/President George Bush Turnpike interchange.

DART and the regional stakeholders will contribute $3 million to the $8.3 million ICM deployment. The Dallas ICM deployment focuses on the four primary ICM goals shown in Table 1-1: improve incident management, enable intermodal travel decisions, increase corridor throughput, and improve travel time reliability. The Dallas site team intends to utilize a variety of coordinated, multimodal operational strategies to achieve these goals, including:

- Provide comparative travel times between various points of interest to the public via the 511 system for the freeway, arterial streets (i.e., Greenville Ave.), and light-rail transit line, as well as real-time and planned events status and weather conditions. Operating agencies plan to have real time status of all facilities within the ICM corridor.
- Use simulations to predict travel conditions for improved operational response
- Implement interdependent response plans among agencies.

[2] Information in this section has been excerpted from "Integrated Corridor Management," published in the November/December 2010 edition of Public Roads magazine. The article was authored by Brian Cronin (RITA), Steve Mortensen (FTA), Robert Sheehan (FHWA), and Dale Thompson (FHWA). With the consent of the authors, at the direction of U.S. DOT some updates or corrections have been made to this material.

- Divert traffic to strategic arterials and frontage roads with improved, event-specific traffic signal timing response plans.
- Shift travelers to the light-rail system during major incidents on the freeway.



DART and their ICM partners, June 30, 2010

Figure 1-1. U.S. 75 Corridor Boundaries of Dallas ICM Deployment

Table 1-1. Dallas ICM Project Goals

Goal #1	Improve Incident Management • Provide a corridor-wide and integrated approach to the management of incidents, events, and emergencies that occur within the corridor or that otherwise impact the operation of the corridor, including planning, detection and verification, response and information sharing, such that the corridor returns back to "normal."
Goal #2	Enable Intermodal Travel Decisions • Provide travelers a holistic view of the corridor and its operation through the delivery of timely, accurate and reliable multimodal information, to allow travelers to make informed choices regarding departure time, mode and route of travel. In some instances, the information will recommend travelers to utilize a specific mode or network. Advertising and marketing to travelers over time will allow a greater understanding of the modes available to them.
Goal #3	Increase Corridor Throughput • Agencies within the corridor have worked to increase throughput on their individual networks from supply and operations points of view, and will continue to do so. The ICM perspective builds on these network initiatives, managing delays on a corridor basis, utilizing any spare capacity within the corridor, and coordinating the junctions and interfaces between networks in order to optimize the overall throughput of the corridor.
Goal #4	Improve Travel Time Reliability • The transportation agencies within the corridor have done much to increase the mobility and reliability of their individual networks, and will continue to do so. The integrated corridor perspective builds on these network initiatives, managing delays on a corridor basis, utilizing any spare capacity within the corridor, and coordinating the junctions and interfaces between networks, thereby providing a multimodal transportation system that adequately meets customer expectations for travel time predictability.

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Technology investments that are being implemented as part of the ICM deployment in Dallas and which will be used to carry out ICM operational strategies include:

- A Decision Support System (DSS) that will utilize incoming monitoring data to assess conditions, forecast conditions up to 30 minutes in the future, and then formulate recommended response plans (including selecting from pre-approved plans) for consideration by operations personnel. Table 1-2 summarizes expected Dallas DSS functionality.
- Enhancement of the SmartNET regional information exchange network, a system that was recently implemented using non-ICM funding and which is being enhanced using ICM funding, including expanding the number of agencies able to exchange data through the system. SmartNET is a commercial data integration and dissemination tool with a common graphical user interface (GUI). SmartNet provides a conduit for input, fusion and shared, multi-agency access to a variety of transportation condition data.
- A 511 telephone and web-based traveler information system for the region.
- Development of new, event-specific traffic signal timing plans to support traffic diversions onto Greenville Avenue (termed the "Targeted Event Accelerated Response System," or TEARS).
- Arterial street monitoring system, including additional travel time detectors (Bluetooth).
- Using non-ICM funds, various supporting transit improvements including mobile data terminals and automatic vehicle location system replacement.
- Parking management systems for key park & ride lots.

Table 1-2. Summary of Dallas DSS Functionality

Functionality	Summary
Modularization of Response Plan Recommendation Functionality and Predictive Functionality	Dallas has explicitly separated the functionality required to select candidate response plans based on real-time conditions from the functionality associated with predicting future conditions. The former functionality resides in the Expert System DSS subsystem and the latter resides in the Prediction subsystem. These functions have been modularized so that the DSS will still be able to recommend response plans in the event that the mesoscopic traffic model used in the Prediction sub-system is not able to run faster than real-time, that is, to not only monitor current conditions but also to forecast conditions X minutes into the future. Dallas is anticipating their Predictive subsystem will ultimately be capable of running faster than real-time but they need to complete the design and testing phases of Stage 3. The decision to separate response plan selection functionality from prediction functionality was also based on prediction accuracy considerations. Another important part of the DSS Expert System module is the periodic (most likely monthly or if feasible every 2 weeks) post-review of action plans implemented and modifying them as needed.
Real-time Monitoring of Transportation System Conditions	The real-time data is collected by the ICMS Data Fusion subsystem. The Expert System subsystem of the Dallas DSS will monitor conditions from the Data Fusion subsystem in real-time and, based on key real-time system performance indicators, select one or more pre-defined, proposed response plans for consideration by the ICM Coordinator.
Prediction and Prioritization of Emerging Transportation System Problems	The Dallas ICMS will continuously monitor conditions. When events such as significant changes in demand, incidents (planned or not planned), or inclement weather occur, the Dallas DSS will initiate an analysis for possible operational strategies to improve corridor operation. The analysis of operational strategies is planned to include a prediction of future conditions under possible strategies. The Dallas ICMS is not currently planned to continuously predict future conditions. The Predictive subsystem is only executed as part of an evaluation of possible strategies. Although it is possible that the Dallas ICMS may be used in such a capacity at some point within or beyond the evaluation period, it is not an explicit design objective of the Dallas DSS to continuously predict conditions or anticipate developing problems. The Dallas ICMS, will however, have to account for multiple events occurring in the corridor and be able to prioritize which events need to be addressed or assess the interaction of strategies to different events.
Prediction of the Impact/Performance of Response Plans	The Prediction subsystem of the Dallas DSS will be capable of being used at regular time intervals or "on the fly" during an event to determine whether the net impacts/benefits of a candidate response plan recommended to the ICM Coordinator by the Expert System will be positive given current transportation system conditions and expected travel demand X minutes into the future. That is, prediction of the impacts of a response plan will be used in the decision of whether to recommend a candidate response plan by the Expert System. Further, if it is found that the Prediction subsystem is able to operate in faster-than-real-time mode—that is predict conditions X minutes into the future—the recommendation of response plans by the Expert System subsystem (and potentially the refinement or re-selection of response plans over the course of a long event) will incorporate predictions of transportation conditions and/or response plan impacts X minutes into the future.

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It is expected that the various Dallas ICM system capabilities and strategies will be utilized in several different contexts and timeframes. These contexts and timeframes are expected to become more definitive and elaborated as the sites proceed with the design and implementation of their systems. Further, these uses are expected to evolve as the sites work through their six-month "shakedown" periods following the initial system go-live dates, and possibly, continuing to some extent into the 12-month post-deployment data collection period. Currently, it is expected that the ICM systems will be applied in at least the following general contexts and timeframes:

1. In "real time" (or near real time), in association with an unplanned event like a traffic incident.
2. In advance, e.g., pre-planned:
    a. Anticipating a specific, atypical event, such as major roadway construction or a large sporting event; and
    b. Periodic or cyclical (e.g., seasonal) adjustments to approaches based on lessons learned and evolution of the ICM strategies and/or in response to lasting changes in transportation conditions. These lasting changes may be either directly related to ICM strategy utilization (e.g., drivers who may have switched to transit during a specific ICM-supported traffic incident choosing to continue to use transit on a daily basis) or to other, non-ICM related changes such as regional travel demand.

1.2.2 Dallas ICM Deployment Schedule

Table 1-3 presents the latest, formal, U.S. DOT-approved Dallas ICM deployment schedule. As is often the case with large, complex technology deployments, it is quite possible that this schedule may slip over time. The schedule of data collection and analysis activities presented throughout this test plan reflect the latest schedule but they will be adjusted as necessary in response to any future changes in the deployment schedule.

As indicated in Table 1-3, individual components of the deployment will be completed in a phased manner, with full ICM system operations currently scheduled to commence in early April 2013. The Dallas site team has indicated that they do expect, to at least some degree, to begin using individual components and associated ICM strategies as they become available prior to the overall system go-live. The approach to this analysis attempts to take that phasing into consideration. Since both the completion dates of the individual ICM components and the Dallas site team's utilization of them are expected to evolve as the ICM system design, implementation and shakedown period progress, the approach presented in this test plan may flex somewhat in response.

Table 1-3. Dallas ICM Deployment Schedule

Activity	Completion Date
Complete Planning Phase	December 2010
Complete Design Phase	February 2012
Build Phase (complete unit testing):	
Arterial Street Monitoring System	April 2012
Mobile Web	April 2013
511 Interactive Voice Response (phone)	
My 511 (Web)	
Social Networking	
Transit Signal Priority	August 2012
Event Specific Traffic Signal Timing Plans (Targeted Event Accelerated Response System)	September 2012
Parking Management Information	October 2012
DART Data Portal	
Video Sharing	
SmartNET/Smart Fusion (including all integration of new ICM data) IT Infrastructure	
Decision Support System	November 2012
Complete Integration Testing	January 2013
Complete Acceptance Testing/Operations Go Live	April 8, 2013
Complete Shakedown Period	October 8, 2013
Complete Evaluation One Year Operational Period	October 7, 2014

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1.2.3 Comparison to the San Diego ICM Deployment

The overall objectives of the Dallas ICM deployment are similar to those in San Diego and many of the same general operational strategies are planned, focusing on improving the balance between travel supply and demand across multiple modes and facilities, including highways, arterial streets and transit. The major distinctions in the ICM strategies to be utilized by each site generally flow from the differences in their transportation systems:

- The Dallas U.S. 75 corridor includes the Red Line light rail transit (LRT) service whereas the I-15 in San Diego corridor will include extensive bus rapid transit (being implemented separately from and immediately prior to ICM).
- The Dallas U.S. 75 corridor includes concurrent flow HOV lanes whereas the San Diego corridor includes concurrent flow high-occupancy tolling (HOT)/managed lanes:
  - The San Diego corridor includes a recently expanded four-lane managed lane system in the I-15 median that is variably priced high occupancy tolling and includes two reversible center lanes. The San Diego site team does not expect

ICM to impact their variable pricing decisions but it will impact their use of the four configurable managed lanes.
    - The Dallas U.S.-75 corridor includes access-controlled, HOV lanes located in the median, although, like San Diego with the HOT lanes, they do not expect ICM to impact their occupancy requirement decisions.
    - Both sites currently lift HOV restrictions during major incidents.

- Both sites include major arterials that run parallel with the freeways. However, while the arterial in Dallas is continuous for the length of the corridor, there is no single continuous arterial running parallel to I-15 in San Diego; Black Mountain Road, Pomerado Road, and Centre City Parkway are parallel arterials in the I-15 corridor.
- The Dallas corridor includes an extensive frontage road system, while the San Diego I-15 corridor includes auxiliary lanes between most freeway interchanges that function similarly, though with less capacity.
- The San Diego corridor includes ramp meters on I-15 and so their traffic signal timing strategies include ramp meter signals. Dallas does not use ramp meters.
- Both sites include responsive traffic signal control. Dallas is not upgrading any traffic signal controllers, but has responsive traffic signal control along the major parallel arterial, Greenville Avenue, through the Cities of Dallas, Richardson and Plano. The San Diego deployment includes responsive traffic signal control along Black Mountain and Pomerado Roads, both of which are major arterials that parallel I-15.

1.3 National Evaluation Objectives and Process

This section summarizes key aspects of the overall ICM national evaluation. A more comprehensive discussion is contained in the National Evaluation Framework document and the details of individual analyses are documented in this and other test plans.

1.3.1 U.S. DOT Hypotheses

The U.S. DOT has established the testing of eight "hypotheses" as the primary objective and analytical thrust of the ICM demonstration phase evaluation, as shown in Table 1-4. There are a number of cause-effect relationships among the U.S. DOT hypotheses; for example, enhanced response and control is dependent on enhanced situational awareness. These relationships will be examined through the evaluation in addition to testing the individual hypotheses. Another important relationship among the hypotheses is that DSS is actually a component of enhanced response and control and, depending on the specific role played by the DSS, may also contribute to improved situational awareness.

Table 1-4. U.S. DOT ICM Evaluation Hypotheses

Hypothesis	Description
The Implementation of ICM will:	
Improve Situational Awareness	Operators will realize a more comprehensive and accurate understanding of underlying operational conditions considering all networks in the corridor.
Enhance Response and Control	Operating agencies within the corridor will improve management practices and coordinate decision-making, resulting in enhanced response and control.
Better Inform Travelers	Travelers will have actionable multimodal (highway, arterial, transit, parking, etc.) information resulting in more personally efficient mode, time of trip start, and route decisions.
Improve Corridor Performance	Optimizing networks at the corridor level will result in an improvement to multimodal corridor performance, particularly in high travel demand and/or reduced capacity periods.
Have Benefits Greater than Costs	Because ICM must compete with other potential transportation projects for scarce resources, ICM should deliver benefits that exceed the costs of implementation and operation.
The implementation of ICM will have a positive or no effect on:	
Air Quality	ICM will affect air quality through changes in Vehicle Miles Traveled (VMT), person throughput, and speed of traffic, resulting in a small positive or no change in air quality measures relative to improved mobility.
Safety	ICM implementation will not adversely affect overall safety outcomes, and better incident management may reduce the occurrence of secondary crashes.
Decision Support Systems*	Decision support systems provide a useful and effective tool for ICM project managers through its ability to improve situational awareness, enhance response and control mechanisms and provide better information to travelers, resulting in at least part of the overall improvement in corridor performance.

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* For the purposes of this hypothesis, the U.S. DOT considers DSS functionality to include both those carried out by what the sites have labeled their "DSS" as well as some related functions carried out by other portions of the sites' ICM systems.

1.3.2 Evaluation Analyses

The investigation of the eight U.S. DOT evaluation hypotheses have been organized into seven evaluation "analyses." Table 1-5 associates six of those seven analyses with specific U.S. DOT hypotheses; the seventh analysis not shown in Table 1-5 investigates institutional and organizational issues and relates to all of the hypotheses since the ability to achieve any intended ICM benefits depends upon successful institutional coordination and cooperation.

Table 1-5. Relationship Between U.S. DOT Hypotheses and Evaluation Analyses

U.S.DOT Hypotheses	Evaluation Analysis Area
• Improve Situational Awareness • Enhance Response and Control	Technical Assessment of the Capability to Monitor, Control, and Report on the Status of the Corridor
• Better Inform Travelers	Traveler Response (also relates to Enhance Response and Control)
• Improve Corridor Performance	Quantitative Analysis of the Corridor Performance – Mobility
• Positive or No Impact on Safety	Quantitative Analysis of the Corridor Performance – Safety
• Positive or No Impact on Air Quality	Air Quality Analysis
• Have Benefits Greater than Costs	Benefit-Cost Analysis
• Provide a Useful and Effective Tool for ICM Project Managers	Evaluation of Decision Support Systems

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The evaluation features a "logic model" approach in which each link in the cause-effect sequence necessary to produce the desired impacts on transportation system performance is investigated and documented, beginning with the investments made ("inputs"), the capabilities acquired and their utilization ("outputs") and traveler and system impacts ("outcomes").

Collectively, the results of the eight evaluation analyses will provide a comprehensive understanding of the ICM demonstration phase experience:

- What ICM program-funded and other key, ICM-supporting investments did the Dallas and San Diego site teams make, including hardware, software, and personnel (inputs)?
- What capabilities were realized through those investments; how were they exercised and to what extent did they enhance previous capabilities (outputs)?
- What were the impacts of the ICM deployments on travelers, transportation system performance, safety and air quality (outcomes)?
- What institutional and organizational factors explain the successes and shortcomings associated with implementation, operation and effectiveness (inputs, outputs and outcomes) of ICM and what are the implications for U.S. DOT policy and programs and for transportation agencies around the country (Institutional and Organizational Analysis)?
- How well did the DSS perform (DSS Analysis)?
- What is the overall value of the ICM deployment in terms of benefits versus costs (Benefit-Cost Analysis)?

1.3.3 Evaluation Process and Timeline

Figure 1-2 shows the anticipated sequence of evaluation activities. The evaluation will collect 12 months of baseline (pre-ICM deployment) data and, following a 6-month shakedown period, 12 months of post-deployment data.

The major products of the evaluation are two interim technical memoranda after the end of the baseline and post-deployment data collection efforts and a single final report documenting the findings at both sites as well as cross-cutting results. Two formal site visits are planned by the national evaluation team to each site: as part of evaluation planning during national evaluation framework development and test planning-related visits. Additional data collection trips will be made by various members of the national evaluation team during baseline and post-deployment data collection.

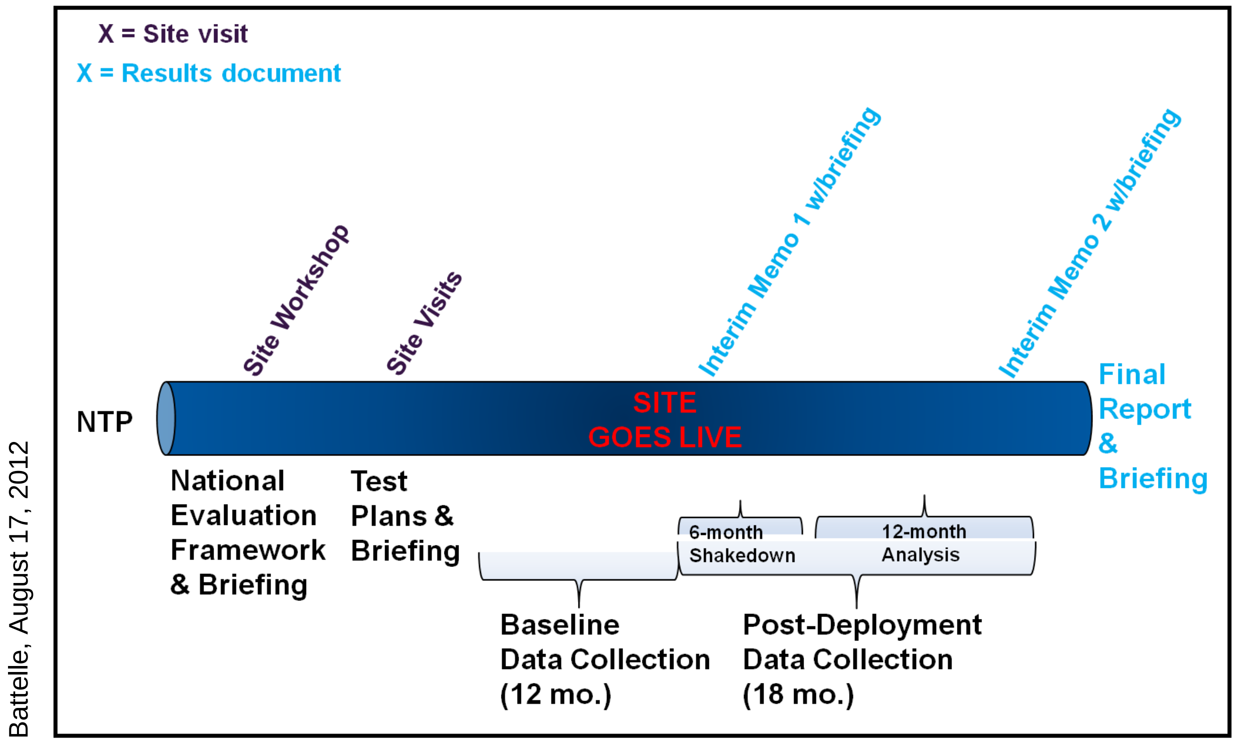

Figure 1-2. Sequence of Evaluation Activities

Based on current deployment schedules for both Dallas and San Diego, the anticipated schedule for major evaluation activities is as follows:

- Finalize test plans – Summer 2012
- Collect baseline (pre-ICM deployment) data – Spring 2012 through Spring 2013
- Complete Interim Technical Memorandum on baseline data – Spring 2013
- Collect post-deployment data – Summer 2013 – Fall 2014
- Complete Interim Technical Memorandum on evaluation results – Fall 2014
- Complete Final Report – Spring 2015

1.3.4 Roles and Responsibilities

The U.S. DOT ICM Management Team is directing the evaluation and is supported by the Volpe National Transportation Systems Center (Volpe Center), Noblis and ITS America. The national evaluation team is responsible for leading the evaluation consistent with U.S. DOT direction and is responsible for collecting certain types of evaluation data—namely partnership documents and conducting workshops and interviews. The national evaluation team is also responsible for analyzing all evaluation data—including that collected by the national evaluation team as well as the Volpe Center and the Dallas site team—preparing reports and presentations documenting the evaluation results, and archiving evaluation data and analysis tools in a data repository that will be available to other researchers. The Dallas site team is responsible for providing input to the evaluation planning activities and for collecting and transmitting to the national evaluation team most of the evaluation data not collected directly by the national evaluation team. The Volpe Center is providing technical input to the evaluation and will carry out the traveler survey activities discussed in the Traveler Response Test Plan. The U.S. DOT Analysis, Modeling and Simulation contractor, Cambridge Systematics, will provide key AMS modeling results to the evaluation, namely person-trip measures that cannot be feasibly collected in the field, and will utilize certain evaluation outputs, such as those related to traveler response, to calibrate the AMS tools post-ICM deployment. In the case of Dallas, the Dallas site team will execute the model runs that will generate the performance measures provided by Cambridge Systematics.

2.0 ANALYSIS OVERVIEW

This chapter provides a high-level overview of the approach to the BCA, including a discussion of the evaluation hypothesis to be tested and measures of effectiveness (MOEs).

ICM strategies generate outcomes that can be monetized and used in the BCA. ICM strategies, including adding transit capacity and en-route traveler information systems, will collectively generate economic benefits through travel time savings, enhanced travel time reliability, reduced motor fuel costs, lower emissions, and reductions in the number and severity of crashes. The BCA is largely derivative in that it relies on the data/findings associated with other evaluation tasks (e.g., air quality, traveler response) to quantify those benefits.

An overview of the BCA approach is summarized graphically in Figure 2-1. Figure 2-1 identifies the primary data sources and evaluation methods for the BCA, and notes that the analysis will include a “with” and “without ICM” component to ensure that the marginal impact of ICM technologies are evaluated. Further, the BCA will examine a 10-year analysis time horizon, which corresponds to the life of most ICM technologies. The BCA data sources, design, and evaluation methods are explored in more detail in the remainder of this section.

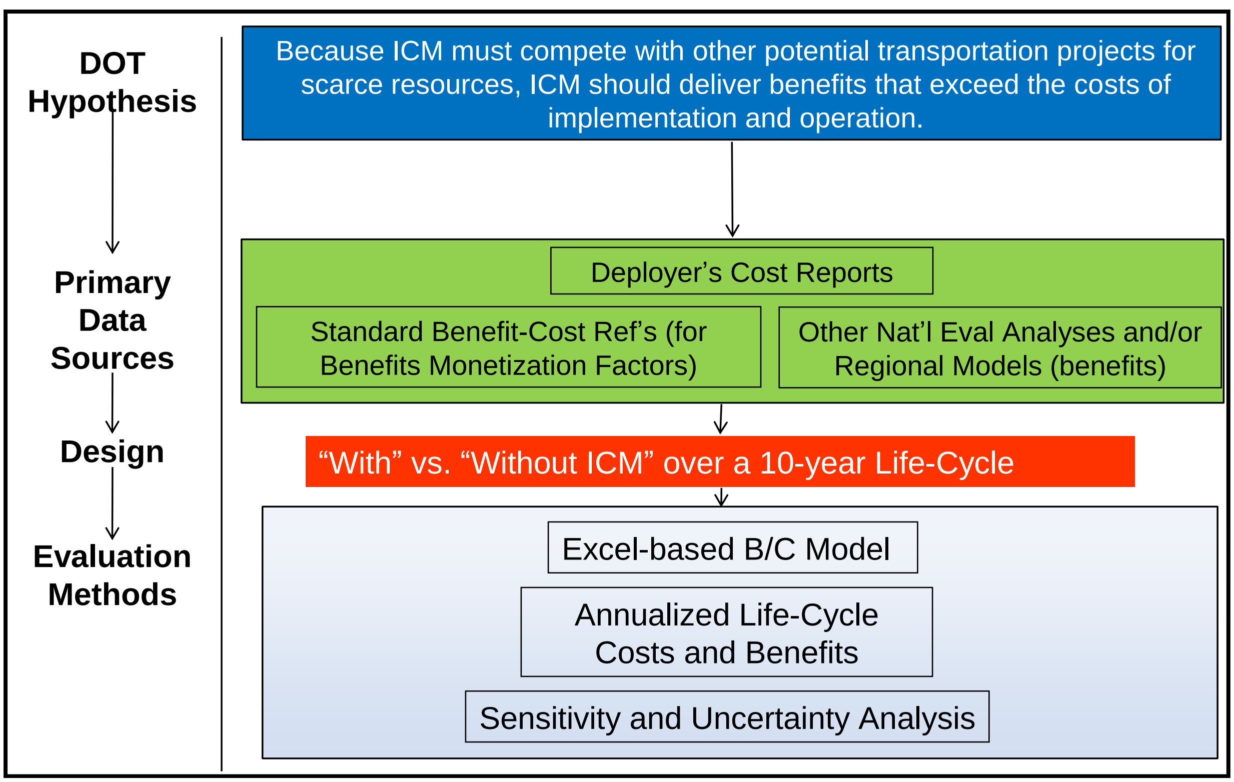

Figure 2-1. Overview of Benefit-Cost Analysis

The examination of a broad spectrum of benefit and cost elements is considered a key objective of the benefit-cost analysis. Figure 2-2 depicts the major benefit and cost elements, and illustrates the general methods used to combine these factors to yield benefit-cost ratios (BCRs). The procedures and data used to support this analysis are detailed later in this section.

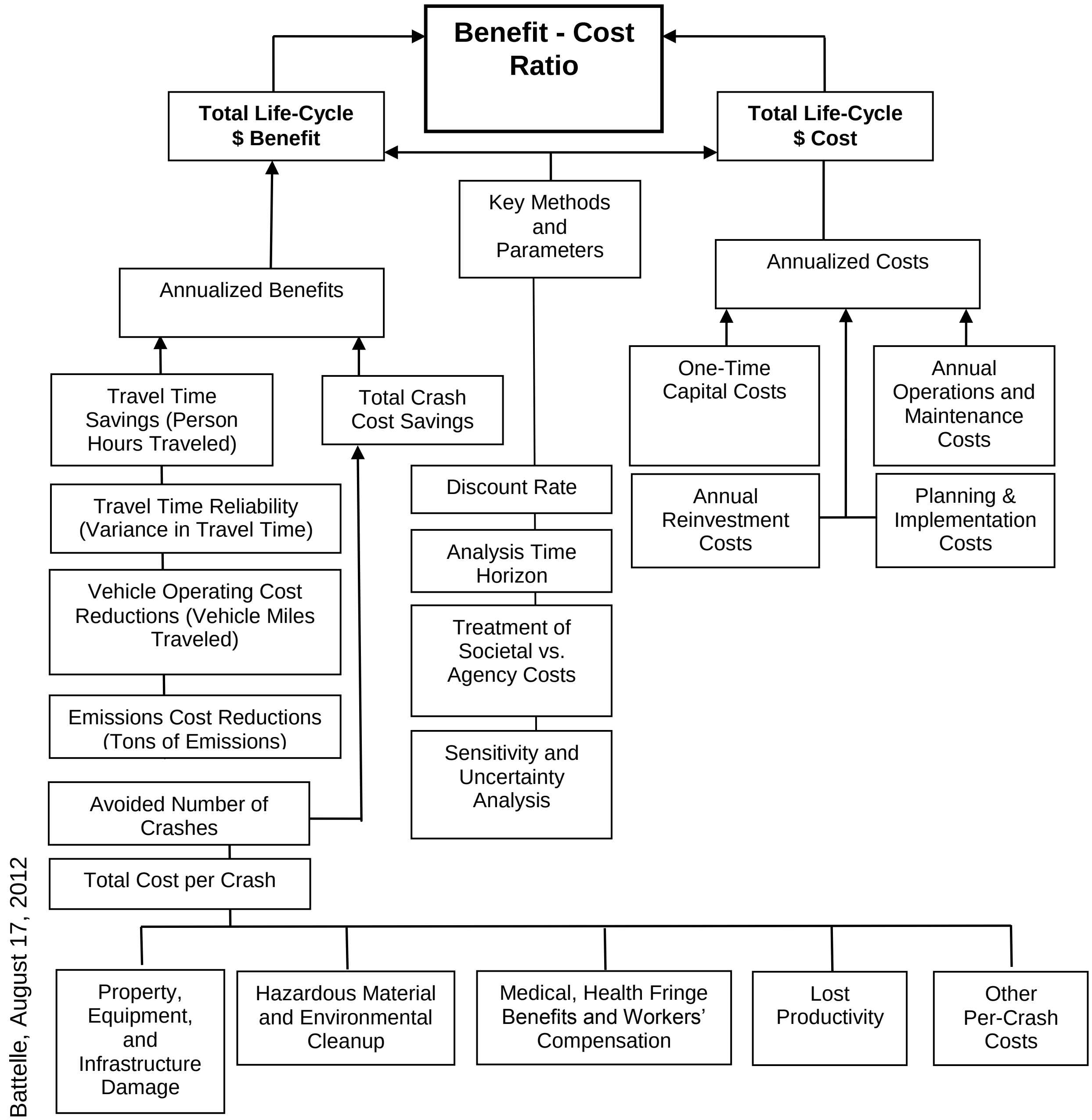

Figure 2-2. Framework for Estimating ICM Benefits and Costs

Because ICM must compete with other potential transportation projects for scarce resources, ICM should deliver benefits that exceed the costs of implementation and operation. More specifically, the hypothesis being tested in this analysis is that present value benefits of ICM deployment will exceed present value costs over the study time horizon.

The key MOE for the BCA is that ICM strategies will generate benefits that exceed costs. The BCRs represent the MOE for ICM strategies and are calculated by dividing the total present value of benefits by the total present value of costs. The BCA will also examine several ICM scenarios. A scenario as used in this instance is defined by varying key parameters (e.g., strategy, motor fuel prices, emissions values, discount rates) and is not a reference to operational scenarios. The ability to determine benefits for individual ICM strategies or groups of strategies will depend on the capacity of the other evaluation analyses to measure ICM impacts. The findings of the other evaluation analyses will therefore provide the benefits information required for the BCA.

This BCA analysis will not directly assess nor report benefits and costs under various transportation system operating conditions, e.g., major incidents, recurring congestion, etc. Rather, this analysis will examine costs and benefits on an annualized basis. Benefits will be annualized based on information provided through the other evaluation analyses identifying what proportion of the year various operating conditions were present.

Expected ICM outcomes (documented through the other evaluation analyses) that, if identified, will be monetized in the BCA include (evaluation analysis source identified in parentheses):

- Change in travel times (Corridor Performance – Mobility)
- Change in travel time reliability (Corridor Performance – Mobility)
- Change in number and severity of crashes (Corridor Performance – Safety)
- Change in emissions levels (Air Quality)
- Change in transit ridership (Traveler Response)

Table 2-1 presents an overview of the primary benefit and cost categories considered in this analysis, specific data elements, and the source(s) of data required to estimate each element. The remainder of this document describes the approaches for estimating benefits and costs of ICM deployment and presents a more detailed assessment of data requirements.

Table 2-1. Benefit-Cost Analysis Data Elements and Relation to MOEs and Hypotheses

Data Element		MOE	Hypothesis
Quantitative Data			
1. Decision Support Systems	1.1 Implementation Cost	ICM strategies will generate present value benefits that exceed costs.	Dallas ICM strategies generate positive net benefits (benefits minus costs).
	1.2 Operations and Maintenance Costs		
	1.3 Reinvestment Costs		
2. SmartNET Regional Information Exchange Network	2.1 Implementation Cost		
	2.2 Operations and Maintenance Costs		
	2.3 Reinvestment Costs		
3. Traffic Signal Systems	3.1 Implementation Cost		
	3.2 Operations and Maintenance Costs		
	3.3 Reinvestment Costs		
4. Arterial Street Monitoring System	4.1 Implementation Cost		
	4.2 Operations and Maintenance Costs		
	4.3 Reinvestment Costs		
5. Parking Management Systems	5.1 Implementation Cost		
	5.2 Operations and Maintenance Costs		
	5.3 Reinvestment Costs		
6. Regional 511 System	6.1 Implementation Cost		
	6.2 Operations and Maintenance Costs		
	6.3 Reinvestment Costs		
7. Administrative, Planning, and Marketing Activities	7.1 Implementation Cost		
	7.2 Operations and Maintenance Costs		
	7.3 Reinvestment Costs		
8. Travel Time Savings	8.1 Personal Vehicle Travel Time Savings		
	8.2 Commercial Vehicle Travel Time Savings		
	8.3 Transit Rider Travel Time Savings		
	8.4 Commercial Vehicle Percentage of Regional VMT		

Table 2-1. Benefit-Cost Analysis Data Elements and Relation to MOEs and Hypotheses (Continued)

Data Element		MOE	Hypothesis
Quantitative Data			
9. Vehicle Operating Cost Savings	9.1 Personal Vehicle Operating Costs		
	9.2 Commercial Vehicle Operating Costs		
	9.3 Transit Vehicle Operating Costs		
	9.4 Motor Fuel Prices		
10. Air Quality Improvements	10.1 Reductions in Emissions		
	10.2 Emissions Values		
11. Safety Improvements	11.1 Changes in the Number and Severity of Crashes		
	11.2 Crash Costs		
12. Travel Time Reliability	12.1 Change in Buffer Index		
	12.2 Travel Time Values		
13. Travel Cost Changes due to Mode Shift	13.1 Changes in Mode Split		
	13.2 Transit Fares		
	13.3 Changes in Personal Travel Times		
Qualitative Data			
This test plan utilizes no qualitative data			

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3.0 QUANTITATIVE DATA

This chapter identifies the quantitative data elements to be used in the BCA. The BCA will rely on four primary sources of data:

- ICM-related cost data from the Dallas site team that are responsible for capital expenditures, operations and maintenance (O&M) and reinvestment in ICM equipment
- Quantified outcomes from the ICM Corridor Performance (mobility and safety portions), Air Quality, and Traveler Response Analyses
- Literature used to monetize certain benefit elements
- Federal, state and regional government guidance.

Each benefit and cost element will be monetized with data input into the benefit-cost model. Table 3-1 summarizes the data requirements for the BCA Test Plan. The details associated with the source, timing, and other elements are discussed in the sections that follow. Note that changes in the road network, services provided, work zone activity, and other non-ICM factors that may affect traffic speeds or demand will be documented and controlled for, to the extent feasible, in the ICM corridor performance (mobility and safety portions), air quality and traveler response analyses.

3.1 ICM Technology Cost Data

ICM technology costs include all those related to implementation, operations and maintenance, and reinvestment costs. Implementation costs are all those related to the design and installation of ICM equipment, including hardware and software costs, labor, and engineering/design costs. Operations and maintenance costs are the marginal costs associated with ongoing repair and maintenance of ICM equipment, including all related labor. Reinvestment costs are those related to equipment replacement planned during the 10-year post-deployment time horizon. All cost data will be obtained quarterly from the Dallas site team and provided through the Texas Transportation Institute (TTI), which serves as the Dallas site team's evaluation support contractor and who will serve as a cost data clearinghouse. Data collection will begin when the first ICM-related expenditure is made and will end at the conclusion of the 12-month post-deployment data collection period (October 2014). The before ICM period, therefore, begins with the decision to engage in ICM and would include all design costs. Data will be collected and transmitted quarterly over the April 2013-October 2014 time period.

Table 3-1. Quantitative Data Summary

Data Element	Location		Data Collection Frequency	Data Collection Period		Data Collection Responsible Party	Data Transmittal
	Start	End		Start	End		
Decision Support System							
1.1 Implementation Cost	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
1.2 Operations and Maintenance Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
1.3 Reinvestment Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
SmartNET Regional Information Exchange Network							
2.1 Implementation Cost	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
2.2 Operations and Maintenance Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
2.3 Reinvestment Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
Traffic Signal Systems							
3.1 Implementation Cost	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
3.2 Operations and Maintenance Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
3.3 Reinvestment Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)

Table 3-1. Quantitative Data Summary (Continued)

Data Element	Location Start	Location End	Data Collection Frequency	Data Collection Period Start	Data Collection Period End	Data Collection Responsible Party	Data Transmittal
Arterial Street Monitoring System							
4.1 Implementation Cost	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
4.2 Operations and Maintenance Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
4.3 Reinvestment Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
Parking Management Systems							
5.1 Implementation Cost	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
5.2 Operations and Maintenance Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
5.3 Reinvestment Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
Regional 511 System							
6.1 Implementation Cost	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
6.2 Operations and Maintenance Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
6.3 Reinvestment Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
Administrative, Planning, and Marketing Activities							
7.1 Implementation Cost	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
7.2 Operations and Maintenance Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)
7.3 Reinvestment Costs	N/A	N/A	Quarterly	Apr 2013	Oct 2014	TTI	Apr 2013 – Oct 2014 (Email to National Evaluation Team)

Table 3-1. Quantitative Data Summary (Continued)

Data Element	Location Start	Location End	Data Collection Frequency	Data Collection Period Start	Data Collection Period End	Data Collection Responsible Party	Data Transmittal
Travel Time Savings							
8.1 Personal Vehicle Travel Time Savings	Data will come from the national evaluation team's Corridor Performance Analysis (see that test plan for details of that data collection)						Jan 2015
8.2 Commercial Vehicle Travel Time Savings							Jan 2015
8.3 Transit Rider Travel Time Savings							Jan 2015
8.4 Commercial Vehicle Percentage of Regional VMT	N/A	N/A	One Time	--	Oct 2014	NCTCOG	Nov 2014 (Email to National Evaluation Team)
Vehicle Operating Cost Savings							
9.1 Personal Vehicle Operating Costs	N/A	N/A	One Time	--	Oct 2014	NCTCOG	Nov 2014 (Email to National Evaluation Team)
9.2 Commercial Vehicle Operating Costs	N/A	N/A	One Time	--	Oct 2014	NCTCOG	Nov 2014 (Email to National Evaluation Team)
9.3 Transit Vehicle Operating Costs	N/A	N/A	One Time	--	Oct 2014	DART	Nov 2014 (Email to National Evaluation Team)
9.4 Motor Fuel Prices	N/A	N/A	One Time	--	Oct 2014	NCTCOG	Nov 2014 (Email to National Evaluation Team)
Air Quality Improvements							
10.1 Reductions in Emissions	Data will come from the national evaluation team's Air Quality Analysis (see that test plan for details of that data collection)						Jan 2015
10.2 Emissions Values	N/A	N/A	One Time	--	Oct 2014	Battelle	Nov 2014 (Will Obtain from Current Literature)

Table 3-1. Quantitative Data Summary (Continued)

Data Element	Location		Data Collection Frequency	Data Collection Period		Data Collection Responsible Party	Data Transmittal
	Start	End		Start	End		
Safety Improvements							
11.1 Changes in the Number and Severity of Crashes	Data will come from the national evaluation team's Corridor Performance Analysis (see that test plan for details of that data collection)						Jan 2015
11.2 Crash Costs	N/A	N/A	One Time	--	Oct 2014	Battelle	Nov 2014 (Will Obtain from Current Literature)
Travel Time Reliability							
12.1 Change in Buffer Index	Data will come from the national evaluation team's Corridor Performance Analysis (see that test plan for details of that data collection)						Jan 2015
12.2 Travel Time Values	N/A	N/A	One Time	--	Oct 2014	NCTCOG	Nov 2014 (Email to National Evaluation Team)
Travel Cost Changes due to Mode Shift							
13.1 Changes in Mode Split	Data will come from the national evaluation team's Traveler Response Analysis (see that test plan for details of that data collection)						Jan 2015
13.2 Transit Fares	N/A	N/A	One Time	--	Oct 2014	DART	Nov 2014 (Email to National Evaluation Team)
13.3 Changes in Personal Travel Times	Data will come from the national evaluation team's Corridor Performance Analysis (see that test plan for details of that data collection)						Jan 2015

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3.2 Travel Time Savings

Personal travel time savings, which are a result of improvements in traffic conditions from reduced congestion experienced by motor carriers, motorists, and transit riders, will be generated in the ICM Corridor Performance Analysis. Travel time reductions when combined with travel time values will be used to estimate the avoided costs resulting from ICM-related reductions in congestion. The ICM BCA will use local travel time values for personal and commercial operators provided by the NCTCOG. Travel time savings from various transportation operating conditions will be weighted to provide an annualized estimate. The ICM Corridor Performance Analysis (mobility portion) will not distinguish travel time savings between personal and commercial operators. Therefore, the national evaluation team will take the additional step of obtaining the commercial vehicle percentage of peak and off-peak regional VMT from NCTCOG, and will use these values as the bases for assigning corridor travel time savings to vehicle classes.

3.3 Vehicle Operating Cost Savings

Vehicle operating cost savings include both fuel and non-fuel operating cost savings realized due to congestion reduction. Operating cost savings result from reductions in wasted time and fuel experienced by operators during congested periods. ICM impacts on congestion will be estimated by Battelle in the Corridor Performance Analysis (mobility portion) and weighted to represent a full year. Battelle will use NCTCOG-estimated commercial vehicle VMT shares to assign corridor operating cost savings to vehicle classes. ICM impacts on motor fuel consumption will be estimated by Battelle in the ICM air quality analysis. The ICM BCA will use local values for fuel costs, minus taxes, provided by the NCTCOG. Motor fuel price data, though collected at a single point in time, will include a time series of historic prices registered over the study time period. Motor fuel prices will not be forecast. Rather, Battelle will assume that in real terms, motor fuel prices remain constant. Non-fuel costs will also be supplied by NCTCOG. Transit vehicle operating costs will be supplied by DART. All data will be collected in October 2014 and transmitted in November 2014.

3.4 Air Quality Impacts

Air quality improvements are tied to the benefits realized from improved traffic throughput and reductions in carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NOx), fine particulate matter ($PM_{2.5}$), and sulfur dioxide (SO_2), as estimated using the Environmental Protection Agency (EPA) Motor Vehicle Emission Simulator (MOVES) model. An annual estimate of emissions impacts will be developed by extrapolating and weighting the MOVES output for specific operating conditions by the estimated percentage of the year when these conditions prevail, as determined based on data collected through the Corridor Performance Analysis. The ICM BCA will rely on U.S. Department of Energy (U.S. DOE), U.S. DOT, and EPA-recommended values for estimating the health and other welfare-related damage costs associated with emissions. This procedure uses what could be considered average values to estimate the health and other costs associated with emissions. It does not evaluate impacts in real time given climate or local air quality conditions. Rather, it uses average health and other emissions-related costs across average fuel mixes to approximate the costs of emissions. These average proxy values are then used to monetize the changes in several pollutants realized due to ICM deployments.

3.5 Safety Impacts

The impact of ICM investments on the number and severity of crashes will be estimated as part of the national evaluation Corridor Performance Analysis. That analysis will report crash impacts on an annual basis. To monetize these impacts, Battelle will use technical guidance from U.S. DOT on the treatment of the economic value of a statistical life (VSL) published at http://ostpxweb.dot.gov/policy/reports/VSL%20Guidance%20031809%20a.pdf. U.S. DOT guidance, which is updated periodically, monetizes the VSL and injuries varied by the abbreviated injury scale (AIS). While the U.S. DOT guidance does not include the value of other economic benefits not tied to VSLs, it does note that these values can be combined with the fatality and injury-related values to determine the total economic costs of vehicular crashes. These other economic costs (e.g., property damage, travel delay) will be monetized for each AIS level using data presented in Blincoe et al (2002).[3]

3.6 Travel Time Reliability

The benefits associated with the willingness to pay (WTP) by motorists to improve the predictability regarding trip durations will be measured based on the change in the buffer index as measured in the Corridor Performance Analysis (mobility portion). The buffer index along with other relevant indices will be discussed in greater detail in Section 5.6. Local values of travel time will be provided to the national evaluation team by NCTCOG.

3.7 Travel Cost Changes due to Mode Shifts

Person-based travel time changes resulting from shifts in mode from highway to transit will be estimated using the AMS model as part of the Corridor Performance Analysis. These estimates will be used in combination with vehicle operating cost data provided by NCTCOG and fare data obtained from DART to estimate traveler cost changes due to mode shifts.

[3] Blincoe, L., A. Seay, E. Zaloshnja, T. Miller, E. Romano, S. Luchter, and R. Spicer. The Economic Impact of Motor Vehicle Crashes, 2000. Prepared for the U.S. Department of Transportation, National Highway Traffic Safety Administration. May 2002. Washington D.C.

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4.0 QUALITATIVE DATA

The BCA will utilize no qualitative data.

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5.0 DATA ANALYSIS

This section describes how the gathered BCA data will be analyzed. Specifically, for each benefit and cost element relevant to the BCA, the approach to gathering and using the data will be discussed. This section begins with a general discussion of the BCA framework and concludes with a discussion of each data element.

The benefit-cost methodology will demonstrate how the various data collected to support this evaluation will be combined to determine the relevant BCRs. The analysis time period used in this evaluation will begin when the first expenditure is made in an ICM technology by a participating agency and conclude 10 years following ICM deployment. The BCA time horizon was determined based on the economic lives of the ICM technologies deployed.

Future benefit and cost streams will be compressed into net present value terms using a real discount rate of 7 percent. The discount rate selected for this analysis was included in the Office of Management and Budget (OMB) Circular A-94, which provides guidelines for conducting BCAs of Federal programs.[4] Future benefits will be assumed to be the same as those identified through the various evaluation analyses for post-deployment year 1. Use of the AMS model for forecasting future benefits was discussed with U.S. DOT and it was mutually agreed that, given the inherent uncertainties in such forecasts, the value would not warrant the significant modeling expense.

Battelle will develop a detailed benefit-cost model for ICM. The model will be designed to enable the user to change general study parameters – including those related to crash-reduction rates, mobility impacts, and ICM cost elements – and view the output of the model on a single worksheet. Due to its combined input-output page and embedded notes, the BCA spreadsheet-based model, once completed, could be operated without viewing study data or possessing any specific foreknowledge of the model's design.

In conducting the BCA, the national evaluation team will construct with and without ICM scenarios to determine the marginal impact of ICM technology deployment on the benefit and cost elements examined in the BCA. These elements will form the foundation of the BCA and are detailed in the remainder of this section of the report. To the extent that the other national evaluation analyses are able to identify the benefits of various individual ICM strategies or groups of ICM strategies, the BCA will be able to monetize and report those separately.

5.1 ICM Technology Cost Data

The national evaluation team has prepared a cost reporting framework, which was presented in Table 3-1. In the framework, detailed cost categories include the DSS, enhancement of the SmartNET regional information exchange network, upgrades to traffic signal systems, the arterial street monitoring system, parking management systems for park & ride lots, and the

[4] U.S. Office of Management and Budget (OMB). Circular A-94: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs. October 1992. Washington D.C.

regional 511 system. For each cost category data will include implementation costs, O&M costs, and reinvestment costs.

The study time frame has been set to account for the full life cycle of most ICM technologies. Data collection will begin on the date that the first ICM-related expenditure takes place and will conclude one full year post-ICM deployment. As noted in Section 3.1, the before ICM period begins with the decision to engage in ICM and would include all design costs. To the extent that a technology's useful life extends beyond the 10-year post ICM deployment time horizon or the technology is expected to be replaced during the post deployment time horizon (e.g., after seven years) and will have some residual life remaining at the end of 10 years, the national evaluation team will estimate the salvage value of the equipment using the methodology outlined at http://www.dot.state.mn.us/planning/program/benefitcost.html, calculated as follows:

$$\text{Salvage Value} = \frac{(1+r)^n \times \left[\left(\frac{(1+r)^L - 1}{r(1+r)^L} \right) - \left(\frac{(1+r)^n - 1}{r(1+r)^n} \right) \right]}{\left(\frac{(1+r)^L - 1}{r(1+r)^L} \right)}$$

Where r = the discount rate (0.07)

n = number of years in the analysis period (10)

L = useful life of the asset

The national evaluation team will also, to the extent feasible, attempt to report full agency costs. In so doing the national evaluation team will work with the Dallas site team to determine the agency costs that extend beyond the purchasing, installation, and O&M of ICM technologies. These administrative cost categories, including planning and training costs, may be difficult to isolate and quantify; however, the national evaluation team will work with TTI to identify the number of hours or FTE spent within each partner agency engaged in these activities and will use relevant labor categories in Bureau of Labor Statistics (BLS) data to monetize these administrative costs.

5.2 Travel Time Savings

Cost savings associated with reductions in travel time as a result of congestion reductions resulting from ICM deployment will be measured in the Corridor Performance Analysis in terms of person hours traveled. The value of travel time savings will be calculated for motor carriers, motorists, and among transit users as follows:

- For freight transportation, travel cost savings depend on the opportunity cost of lost productivity associated with congestion. The value of lost productivity will be based on standard data reported by the NCTCOG. The value of time for freight transportation was reported by NCTCOG at $17 per hour in 2007 dollars. The final value used in the BCA will be prepared in June 2014 following ICM deployment.

- For personal travel, including both automobile and transit modes, cost savings depend on travel time saved and the NCTCOG value of travel times, reported at $14 per hour in 2007 dollars. As used for freight transportation, NCTCOG reported values in November 2014 will be used in the BCA.
- Travel time savings will be estimated using facility-, trip-, and person-based travel times. Shifts in mode choice will be measured in the Traveler Response Analysis with changes in travel time by mode assessed in the Corridor Performance Analysis. Trip- or person-based travel times will be estimated in the Corridor Performance Analysis using AMS. Mode shifts that impact travel times will be identified and the associated travel time gains or losses will be monetized using the NCTCOG reported travel time values in 2014.
- Data collected through the Corridor Performance Analysis will not enable the national evaluation team to vary the cost of travel by activity (e.g., waiting at a transit stop, traveling in a transit vehicles, operating a motor vehicles). Further, it will not differentiate travel time savings between personal and commercial vehicles. Thus, the national evaluation team will rely on NCTCOG-estimated commercial vehicle VMT shares to assign corridor travel time savings to vehicle classes.

5.3 Vehicle Operating Cost Savings

Vehicle operating cost savings include the fuel and non-fuel-related O&M costs associated with driving. The computation of fuel cost depends on fuel prices in the local area, fuel efficiencies under various driving speeds, and miles driven. Data from the ICM air quality analysis will be used to determine ICM-related fuel savings. Motor fuel prices, minus taxes, will be obtained from NCTCOG in 2014, and these values will be used to monetize the costs of fuel savings realized due to the impacts of ICM investments. In June 2011, NCTCOG reported motor fuel prices were $3.55 per gallon (http://www.nctcog.org/trans/data/gasprices/Gasoline_Initial.asp?id_measure=1). Non-fuel costs (maintenance and tire costs) will also be obtained from NCTCOG. Currently, NCTCOG estimates these costs at 15 cents per mile in 2007 dollars.

5.4 Air Quality Impacts

The benefits associated with air quality impacts will depend on the change in emissions attributed to ICM and the cost per ton assigned to each pollutant. The impact of ICM deployments on CO, CO_2, volatile organic compounds (VOC), NOx, $PM_{2.5}$, and SO_2 emissions will be estimated using the EPA MOVES model in the Air Quality Analysis. Scenario-based data prepared in the ICM air quality analysis will be weighted based on day/time and used to estimate overall air quality impacts.

The current values per ton presented in Table 5-1 were derived from EPA estimates of quality of life and health damages associated with emissions. These values are recommended for FHWA analyses. Forecast values were presented in Highway Economic Requirements System (HERS) documentation.[5] ICM benefits will be calculated as the product of the emissions reductions estimated in the ICM Air Quality Analysis and the values presented in Tables 5-1 and 5-2.

Table 5-1. Current Values of Reduced Emissions

Pollutant	Cost (2007 $)
Carbon Monoxide (CO)	$486 per ton[6]
Carbon Dioxide (CO_2)	$21 per metric ton[7]
Volatile Organic Compounds (VOC)	$1700 per ton[8]
Nitrogen Oxides (NO_X)	$4,000 per ton
Particulate Matter ($PM_{2.5}$)	$168,000 per ton
Sulfur Dioxide (SO_2)	$16,000 per ton

U.S. Department of Energy (2010), Battelle (2011),
U.S. Department of Transportation (2009), and Litman (2006).

Table 5-2. Future Values of Reduced Emissions (in 2007 $)

Pollutant	Cost in 2015	Cost in 2020
CO	$555 per ton	$602 per ton
CO_2	$24 per metric ton	$26 per metric ton
VOC	$1,200 per ton	$1,300 per ton
NO_X	$4,900 per ton	$5,300 per ton
$PM_{2.5}$	$270,000 per ton	$290,000 per ton
SO_2	$28,000 per ton	$31,000 per ton

Battelle (2011).

[5] Battelle. Seattle/Lake Washington Corridor Urban Partnership Agreement National Evaluation: Cost Benefit Analysis Test Plan. Prepared for the United States Department of Transportation. January 2011. Columbus, OH.

[6] CO estimates are derived from Litman, Todd, Air Pollution Costs Spreadsheet, Victoria Transport Policy Institute, November 2006. Victoria, Canada. Future year values were assumed to grow commensurate with those forecast for CO^2.

[7] The CO_2 estimates are derived from the U.S. Department of Energy. Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866. April 2010. Washington D.C. http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/sem_finalrule_appendix15a.pdf

[8] VOC estimates are derived from U.S. DOT, NHTSA. Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks. March 2009. http://www.nhtsa.gov/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/CAFE_Final_Rule_MY2011_FRIA.pdf

5.5 Safety Impacts

The reduction in the number of incidents by incident type, as measured in the ICM Corridor Performance Analysis will determine crash cost savings. Crashes result in property damage, lost productivity (e.g., crash investigation, lost wages, recruitment and training replacement workers), medical costs, travel delay, legal and court costs, emergency services, insurance costs, and other costs to employers. The costs associated with crashes are differentiated based on crash severity, ranging from no injury to fatality.

Guidelines for estimating the VSL or value of a statistical life in departmental analyses were established by U.S. DOT and are updated periodically. The VSL was estimated at $6 million in 2009 based on an extensive review and assessment of relevant literature. Non-fatal injury costs are estimated based on the fraction of a VSL suffered in terms of pain, suffering, reduced income and loss of quality of life. These VSL fractions were estimated for each injury severity based on input from panels of experienced physicians who were asked to relate each injury severity to a quality of life adjustment. VSL fractions are presented in Table 5-3.

Table 5-4 presents estimated crash costs associated with each injury severity using the aforementioned U.S. DOT guidance and estimated non-injury costs (e.g., property damage and travel delay) presented in Blincoe et al. (2002), adjusted to 2011 dollars using the CPI-U. These cost estimates will be updated using 2014 CPI-U data prior to use in the ICM BCA.

Table 5-3. Relative Disutility Factors by Injury Severity Level

Injury Severity	Maximum Abbreviated Injury Scale Level	Fraction of the Value of a Statistical Life
Minor	1	0.0020
Moderate	2	0.0155
Serious	3	0.0575
Severe	4	0.1875
Critical	5	0.7625
Fatal	6	1.0000

Battelle (2011)

Table 5-4. Estimated Costs of Vehicular Crashes by Injury Severity Level ($2011)

Injury Severity	Maximum AIS Level	Injury Costs	Non Injury Costs	Total Costs
No-Injury	0	-	2,348	2,348
Minor	1	12,600	6,054	18,654
Moderate	2	97,650	6,288	103,938
Serious	3	362,250	10,138	372,388
Severe	4	1,181,250	14,190	1,195,440
Critical	5	4,803,750	24,358	4,828,108
Fatal	6	6,300,000	25,442	6,325,442

Battelle (2011) and Blincoe (2002)

5.6 Travel Time Reliability

There are benefits tied to travel time reliability that have been well documented in recent economic literature. While there is no definitive guidance from U.S. DOT on the treatment of travel time reliability, recent literature indicates a willingness to pay on the part of motorists who desire greater predictability regarding trip durations. Travel time reliability values can be computed based on the calculation of a reliability ratio that relates the value of travel time reliability to known travel time values. The reliability ratio can be calculated as follows:

$$RR = \frac{VOR}{VOT}$$

Where:

RR = reliability ratio
VOR = value of travel time reliability
VOT = value of travel time

A study conducted recently by Carrion and Levinson (2012) examined the findings of 17 travel time reliability studies completed since 1993 using both stated preference and revealed preference techniques. While the findings of the 17 studies varied widely with reliability ratios ranging from 0.1 to 2.51, several studies conducted since 2007 appear to be converging on an average reliability ratio of roughly 1.0.[9] Therefore, the national evaluation team intends to employ a reliability ratio of 1.0 in this analysis.

The reliability ratio equation can be modified to demonstrate how travel time reliability will be monetized using local travel time values for Dallas as follows:

$$VOR = RR * VOT * \Delta TR$$

or

$$VOR = 1.0 * \$14 * \Delta TR$$

Where:

RR = reliability ratio
VOR = value of travel time reliability
VOT = value of travel time
$\Delta\ TR$ = change in travel time reliability

[9] Carrion, C. and D. Levinson. Value of Travel Time Reliability: A Review of Current Evidence. Presented at the 2012 Transportation Research Board Annual Meeting. January 26, 2012. Washington, D.C.

To complete the analysis, the national evaluation team must establish a measure for estimating changes in travel time reliability. There are several measures typically used to examine travel time reliability, including:

- 90^{th} or 95^{th} percentile travel times. This measure reports the travel time delays on specific routes during the most congested traffic days each year as measured in minutes.
- Buffer index. The buffer index measures the extra time required for a traveler to build into their estimated travel time to ensure an on-time arrival 95 percent of the time. Thus, if the average travel time is 30 minutes and the buffer index is 20 percent, the motorist must build a six minute buffer (0.2 x 30) to ensure an on-time arrival.
- Planning time index. The planning time index represents a measure of the total time required to ensure on-time arrival. Thus, if the planning time index is 1.6 and the average trip time is 15 minutes, the planning time would be 24 minutes (15 x 1.6) to ensure an on-time arrival.

While any of these measures could be used to measure travel time reliability, the national evaluation team plans to use the buffer index as it is the most direct measure of travel time reliability. The buffer index also has an advantage over some of the other methods used to measure reliability (e.g., changes in standard deviation) in that it shows the additional time required to ensure on-time arrival and does not include the effects of trips that take less time than planned.

The ICM Corridor Performance Analysis (mobility portion) will be reporting the travel time index, 95^{th} percentile travel time, planning time index, and buffer index. These values combined with the local NCTCOG values of travel time will be used to monetize the benefits associated with enhanced travel time reliability resulting from ICM deployment.

5.7 Sensitivity Analysis

In addition to the risk mitigation strategies outlined in Chapter 6, the national evaluation team will conduct sensitivity analysis, including varying assumptions relating to:

- Discount rates
- Motor fuel prices (vary rates using U.S. Department of Energy [U.S. DOE], AAA, and other values as appropriate, and consider high motor fuel growth rate scenarios based on assumptions underlying the High Oil Prices case used in the U.S. DOE's Annual Energy Outlook)
- Value of a statistical life
- Vehicle crash costs
- Travel time costs
- Emissions values (vary rates using values proposed by various Federal agencies and for emissions allowance and reduction credits traded by Evolution Markets and the Chicago Climate Exchange)

- High/low (25 percentile / 75 percentile) values generated by the other evaluation analyses, to the extent the data allow
- Other elements as deemed necessary by U.S. DOT.

The risk and uncertainty analysis will be designed to determine the sensitivity of BCA results to small changes in key variables. Varying a single assumption or combinations of assumptions will enable the national evaluation team to determine how robust the results are to changes in key parameters. The economic model developed by Battelle will allow for easy "what if" adjustments to various inputs and assumptions.

6.0 RISKS AND MITIGATIONS

Table 6-1 identifies the risks associated with this analysis and the national evaluation team's response plan for each risk. The remainder of this section documents the primary risks to successfully completing the ICM BCA and discusses mitigation strategies.

The first risk outlined in Table 6-1 relates to risks in data collection and analysis. Due to overlapping technologies and enabling systems, there are risks embedded in the data collection process due to inconsistencies, duplication, delays, and the inability to separate out ICM from non-ICM benefits and costs. This issue as it relates to costs will be addressed through the cost reporting framework presented in Table 3-1. With respect to benefits elements, risks in data collection and analysis are being addressed in the other national evaluation analysis test plans.

The second risk outlined in Table 6-1 pertains to the treatment of ICM-enabling technologies. ICM systems do not operate in isolation and, in fact, build on existing traffic management, transit, and other ITS systems. Thus, the BCRs generated from this BCA cannot be applied at other sites without more knowledge of asset requirements and existing on-site systems. From the standpoint of this BCA, former investments in any ICM-enabling systems (e.g., the initial implementation of the pre-ICM SmartNET system that was not funded by ICM) will be considered sunk costs and the focus of the analysis will be on the marginal benefits and costs associated with ICM-funded investments. To mitigate the risk associated with misattributing costs to ICM-enabling technologies, Battelle will perform a detailed review of the buildup to the ICM system to isolate sunk enabling technology costs and distinguish them from those related to ICM deployment. Mitigation strategies related to the ICM benefit elements are being addressed in the other national evaluation analysis test plans.

Table 6-1. Risks and Mitigations

Risk	Mitigation Strategy
1. Risks in Data Collection/Analysis	Detailed Cost Reporting Framework and Reliance on Other ICM Analyses
2. Treatment of ICM-Enabling Technologies	Detailed Historical Review of ICM Technology Development
3. Forecasting benefits over 10-year time horizon.	Assume Benefits Measured During 12-Month Post-Deployment Period Extend to 10-Year Analysis Time Horizon
4. Estimating ICM-Related Agency Costs	Detailed Cost Reporting Framework, Periodic Meetings, and Quarterly Data Collection and Review

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The third risk outlined in Table 6-1 is tied to the risks associated with forecasting benefits over a 10-year post ICM deployment time horizon. The BCA envisioned for this study is not static inasmuch as benefits and costs are measured over an extended time horizon. To forecast benefits and costs, the national evaluation team had considered using local regional models or AMS models; however, after further discussion with the Dallas site team and U.S. DOT, it was determine that using the regional or AMS models to forecast benefits over the 10-year post-ICM deployment time horizon would be speculative and could introduce uncertainty into the estimation process. Thus, the determination was made to fall back to the position that benefits experienced in the year following full ICM deployment would continue throughout the analysis time horizon.

The fourth, and final, risk outlined in Table 6-1 addresses the risk associated with estimating ICM-related agency costs. The BCA analysis will require a breakdown of capital, O&M, planning, training, and reinvestment costs by year from the date of first expenditure to the end of the 10-year post ICM deployment time horizon. The national evaluation team will also experience difficulty in measuring full agency costs, including those related to training staff to use ICM technologies and ICM deployment planning. To mitigate these risks, the national evaluation team will, if requested by the Dallas site team, further refine the cost reporting framework outlined in Table 3-1 and will work with TTI to identify the number of hours or FTE used to plan and implement ICM technologies that are not captured in ICM-related budget documents. Finally, the national evaluation team will collect cost data on a quarterly basis and will be available for periodic meetings to address questions and concerns raised by the Dallas site team.

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Toll-Free "Help Line" 866-367-7487
www.its.dot.gov

Publication Number FHWA-JPO-13-052

U.S. Department of Transportation