Integrated Corridor Management

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

Post-Deployment Assessment Report

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Notice

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16. Abstract

The U.S. Department of Transportation Integrated Corridor Management (ICM) Initiative aims to advance the state of the practice in transportation corridor operations to manage congestion. Through the deployment of ICM at the two selected Demonstration Sites (Dallas, Texas and San Diego, California), this initiative thoroughly investigated and documented the impacts of the ICM deployments, especially in regards to improved agency coordination. Analysis, Modeling, and Simulation (AMS) efforts assisted corridor partners to optimize their ICM deployment, and supported the broader evaluation effort for the entire ICM Initiative. Using AMS enabled corridor partners to identify the strategies to include in their ICM System that would be most effective against their specific corridor congestion issues, by providing measureable results for multiple alternatives. The focus of this ICM Post-Deployment assessment is to investigate the impacts of the ICM system in its "as deployed" state on U.S.-75 in Dallas, using AMS tools and techniques developed and refined under both the current and previous phases of the program.

The localized ICM strategies deployed include improved multimodal traveler information, parking management system at park-and-ride facilities, interdependent incident response plans, route/mode shift/diversion, and increased transit capacity. A framework of the key activities required for post-deployment AMS, namely model enhancements, model calibration and validation, cluster analysis and incident matching, and alternatives analysis results, is presented in this report. Mobility performance results for the site indicate an expected annual savings of 22,004 person hours in peak directions of travel, while expected cumulative annual variability improvements for the northbound afternoon peak direction amounted to 20,145 hours.

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Executive Summary

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. In the context of this ICM initiative, a "corridor" refers to a largely linear geographic band defined by existing and forecasted travel patterns involving both people and goods. The corridor serves a particular travel market (or markets) that are affected by similar transportation needs and mobility issues. The corridor includes various combinations of facility type and mode, also known as networks (e.g., limited access facilities, surface arterials, transit, bicycle, pedestrian pathways, waterways, etc.) that provide similar or complementary transportation functions. Additionally, the corridor includes cross-network connections that permit the individual networks to be readily accessible from each other. The ICM initiative aims to pioneer innovative multimodal and multijurisdictional strategies and combinations of strategies that optimize existing infrastructure to help manage recurring and nonrecurring congestion in our nation's corridors.

Through the deployment of ICM at the two selected Demonstration Sites (Dallas, Texas and San Diego, California), this initiative thoroughly investigated and documented the impacts of the ICM deployments. Analysis, Modeling, and Simulation (AMS) efforts assisted corridor partners to optimize their ICM deployment and supported the broader evaluation effort for the entire ICM Initiative. Using AMS enabled corridor partners to identify the strategies to include in their Integrated Corridor Management System (ICMS) that would be most effective against their specific corridor congestion issues, by providing measureable results for multiple alternatives. A key benefit of using AMS is its ability to produce system level assessments of mobility and environmental impacts that cannot be observed directly from field data.

The focus of this ICM Post-Deployment assessment is to evaluate to what extent ICM technologies can efficiently and proactively manage the movement of goods and people in a major transportation corridor. Specifically, this project investigates the impacts of the ICM system in its "as deployed" state on U.S.-75 in Dallas, using AMS tools and techniques developed and refined under both the current and previous phases of the program. Results from traveler behavior surveys conducted in the vicinity of the U.S.-75 corridor by the Volpe Center were used to inform model assumptions and to enable more accurate representation of true driver behaviors on U.S.-75.

The U.S.-75 Corridor is a major north-south radial corridor connecting downtown Dallas with many of the suburbs and cities north of Dallas. The Corridor study area includes the freeway, continuous frontage roads, a light-rail line, transit bus service, park-and-ride lots, major regional arterial streets, toll roads, bike trails, and intelligent transportation systems.

The Dallas ICM deployment focuses on four ICM goals, including improve incident response, enable intermodal travel decisions, increase corridor throughput, and improve travel time reliability. The ICM strategies implemented in the "as-deployed" ICM system, which were replicated in the models used for post-deployment AMS include:

- Providing improved multimodal traveler information (pretrip, en-route), such as:
  - New 511 system (real-time information, including traffic incident information, construction information, traffic speeds, light rail transit (LRT) passenger loads, LRT vehicle locations, Red Line park-and-ride utilization).
  - My511 e-mail alerts.
  - ICM dynamic message signs (DMS) messages.
  - Social media.
  - Dallas Area Rapid Transit (DART) data feeds for third-party application development.
- Implementing a parking management system at Red Line park-and-ride facilities.
- Developing preapproved ICMS response plans.
- Developing a Decision Support System to support ICM strategy identification and selection.
- Diverting traffic to key frontage roads and arterials (Greenville Ave.) with coordinated and responsive traffic signal control.
- Encouraging travelers to use transit during major incidents on the freeway.
- Increasing utilization of Red Line capacity with the potential of additional train cars or decreased headways.

The AMS serves to assess the performance of various components of the ICM system under different operational conditions (e.g., time of day, direction of traffic, duration until the incident was cleared, etc.). Cluster analysis was used to group together workday travel characteristics between August 27, 2012 and April 30, 2013 in days where operational conditions were more similar to each other, than to those in other groups (clusters). Clusters were prioritized based on the total magnitude of expected incident impact for representative days in each cluster. The clusters in the northbound PM peak and southbound AM peak periods were of primary interest for ICM AMS because they represent peak period travel by direction. Field observed incidents that occurred in the year after ICM deployment were matched to high-impact clusters sharing similar operational conditions. Eight scenarios, representing the top eight high-impact clusters were analyzed "with" and "without" ICM. Two additional hypothetical scenarios were also analyzed in order to evaluate the impact of potential ICM strategies (i.e., operating the DSS during off-peak hours and diverting travelers to transit in the event of a severe incident).

Key Findings

Overall, the U.S.-75 corridor post-deployment AMS results show travel time improvements in the two peak directions as a result of ICM implementation. For the two peak directions (southbound AM and northbound PM), the expected daily travel time savings are 143 person hours of travel; expected annual savings are 22,004 person hours of travel. Travel time does not improve during the off-peak directions. Travel time reliability does not improve during the peak or off-peak directions. Travel time variability improves during the NB PM peak direction; expected cumulative annual variability improvements is 20,145 hours. Lastly, travel time benefits were concentrated in the vicinity of the incidents disrupting flow in the peak direction; travelers directly affected by the incident would experience the greatest benefits.

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- A hypothetical AMS exercise examined the potential benefit from extending the operation of the ICM DSS system for two additional hours until 8 PM. No mobility or emissions benefits were found in AMS resulting from this potential action.

- Another hypothetical AMS exercise looked into the potential benefit from engaging the ICM system during a severe incident on U.S.-75 (including diversion to frontage roads, Greenville Ave and transit). Such an incident did occur on May 2, 2014, but the ICM system was not operational during that day. The AMS results indicate that ICM would be beneficial to the traveling public during this scenario. The AMS indicates that transit ridership would increase by up to +5.5 percent during a severe incident.

- Overall, in 8 out of the 10 scenarios more travelers benefited from ICM, compared to the ones who did not.

Lessons Learned

The ICM methodology encourages transportation professionals to manage the transportation corridor as a multimodal system, as opposed to managing individual assets. The Dallas ICM demonstration involved the coordination of operations along the U.S.-75 corridor, including increased communication and coordination among partner agencies, facilitated by the deployment of an interagency-dependent DSS. AMS aids in the broader goals of ICM Evaluation by providing a framework that can be used to quantify potential and actual benefits of localized ICM strategies. Unlike traditional corridor studies, which often focus on a specific element of a corridor, ICM AMS is a comprehensive approach that analyzes different operational conditions across time and modes and across a large enough geographic area to absorb all impacts.

One major benefit of the ICM AMS methodology is that it instigated the use of performance measures (e.g., freeway and corridor travel time) to inform and refine the response plans. This allowed AMS to provide insights through measurable results, a major factor that can help agencies determine which transportation investments are worthwhile. AMS allows agencies to "see around the corner", producing simulations of possible future conditions, allowing agencies to react proactively. AMS offers the flexibility of trying different combinations of traffic mitigation strategies, opening up an envelope of potential benefits. Transportation professionals can integrate the AMS methodology with ICM decision support systems to facilitate predictive, real-time, and scenario-based operational decisionmaking. Overall, this helps agencies create a better, more informed product.

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Chapter 1. Introduction and Background

The objective of the *Integrated Corridor Management (ICM)* initiative is to demonstrate how intelligent transportation systems (ITS) technologies can efficiently and proactively manage the movement of people and goods in major transportation corridors. In the context of this ICM initiative, a "corridor" refers to a largely linear geographic band defined by existing and forecasted travel patterns involving both people and goods. The corridor serves a particular travel market (or markets) that are affected by similar transportation needs and mobility issues. The corridor includes various combinations of facility type and mode, also known as networks (e.g., limited access facilities, surface arterials, transit, bicycle, pedestrian pathways, waterways, etc.) that provide similar or complementary transportation functions. Additionally, the corridor includes cross-network connections that permit the individual networks to be readily accessible from each other. The ICM initiative aims to pioneer innovative multimodal and multijurisdictional strategies and combinations of strategies that optimize existing infrastructure to help manage both recurring and nonrecurring congestion in our nation's corridors. There are many corridors in the country with underutilized capacity in the form of additional transit capacity—bus, rail, bus rapid transit (BRT), etc.—under saturated parallel arterials, and inefficient utilization of principal facility resources. Each of these corridors could benefit from the application of ICM technologies and strategies.

The maturation of ITS technologies, growing availability of supporting data, and emerging multiagency institutional frameworks make ICM both practical and feasible. Several freeway, arterial, and transit optimization strategies are in widespread use across the United States, with most currently managed by individual local agencies on an asset-by-asset basis. For those that are managed by a larger regional agency, the approach is still generally uncoordinated and involves little or no integration among the different resources available on the corridor. By appropriately applying ICM strategies, the agencies responsible for managing these corridors can reduce severe congestion and improve overall productivity. Furthermore, providing travelers with relevant information on transportation alternatives can encourage a redistribution of trips to less congested routes, modes, or times of day, which further reduces congestion and affords travelers a greater mobility and increased safety.

Through the deployment of ICM at the two selected Demonstration Sites (Dallas, Texas and San Diego, California), this initiative thoroughly investigated and documented the impacts of the ICM deployments, especially in regards to improved agency coordination. Getting as many corridor partners and stakeholders (e.g., roadway agencies, transit agencies, law enforcement, planning organizations, fleet operations, project evaluators, corridor travelers, etc.) involved in the design of the ICM from the very beginning adds significant value to the project—from adding precision to the design and informing travel demand modelers, to proactively addressing agency regulations. The role of Analysis, Modeling, and Simulation (AMS) is to enable corridor partners to identify the strategies to include in their Integrated Corridor Management System (ICMS) that will be most effective against their localized corridor congestion issues, by providing measureable results for multiple alternatives.

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The AMS methodology was applied to the ICM deployments in both Dallas and San Diego. A key benefit of using AMS is its ability to focus on system level assessments of mobility and environmental impacts that cannot be observed directly from field data; this information will be used to support of the broader evaluation effort.

Based on the experience gained from the ICM deployments at the Dallas and San Diego Demonstration Sites, the ICM initiative developed an AMS methodology to assist corridor managers in forecasting and assessing the potential benefits and implications of ICM in their corridors of interest. The ICM AMS Guide has been incorporated into the Federal Highway Administration (FHWA) Traffic Analysis Toolbox (Volume XIII). The AMS approach is intended to be a flexible and iterative process adaptable to a wide variety of conditions, strategies, and situations. This flexibility is intended to provide practitioners with sufficient structure to enable a rigorous analysis suitable to complex strategies that at the same time is not so rigid as to limit the ability to restructure and rerun the analysis to address project contingencies as they occur. The AMS approach is designed to be implemented in conjunction with the ICM system development and design process and to provide a tool for continuous improvement of corridor performance as depicted in figure 1. This ICM implementation process is generally representative of the Systems Engineering process followed by the ICM Demonstration Sites. Regular periodic conduct of ICM AMS also supports continuous improvement of the supporting ICM system, and the analysis tools themselves.
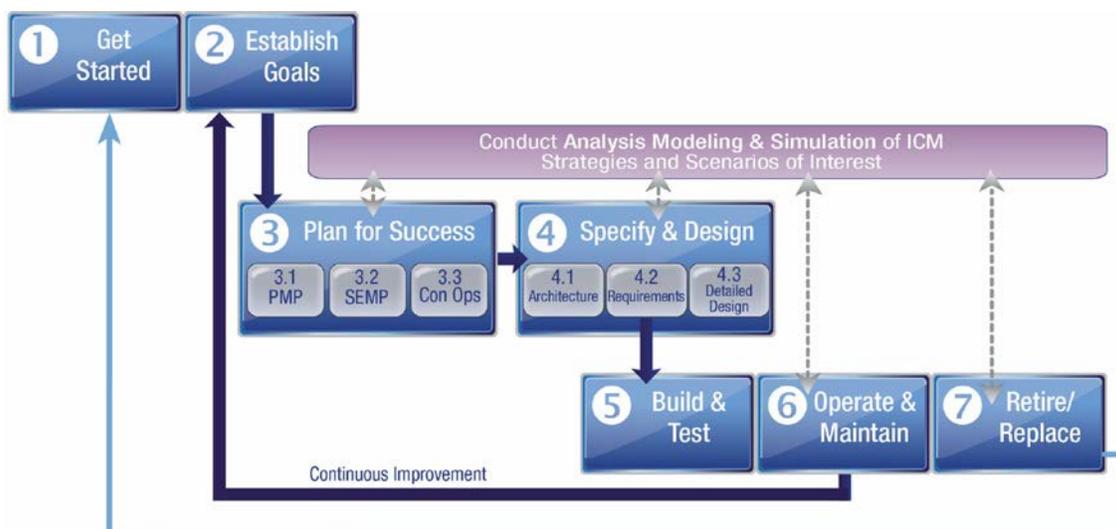
Figure 1. Flowchart. Integrated Corridor Management implementation process.
(Source: Office of the Assistant Secretary for Research and Technology, ITS JPO.)

The United States Department of Transportation (US DOT) has published multiple reports throughout the ICM initiative which can be used as references to aid transportation professionals in implementing their own ICM projects. In addition to the subset of reports listed below which are currently available, reports covering analytical and institutional lessons learned and the broader Evaluation Report will also be published.

- "Integrated Corridor Management Analysis, Modeling, and Simulation (AMS) Methodology."
- "Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software."

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- "Traffic Analysis Toolbox Volume XIII: Integrated Corridor Management Analysis, Modeling, and Simulation Guide."

- "Integrated Corridor Management: Implementation Guide and Lessons Learned."

- "Operations and Maintenance Plan for the U.S.-75 ICM, Dallas Integrated Corridor Management (ICM) Demonstration Project."

- "ICM Stage 2 Data Collection Plan for the US 75 Corridor in Dallas, Texas."

- "I-15 San Diego, California ICM AMS Analysis Plan."

- "U.S.-75 Dallas, Texas, ICM AMS Analysis Plan."

- "I-394 Minneapolis, Minnesota, ICM AMS Analysis Plan."

- "I-15 San Diego, California, Model Validation and Calibration Report."

- "U.S.-75 Dallas, Texas, Model Validation and Calibration Report."

- "I-394 Minneapolis, Minnesota ICM AMS Model Calibration and Validation Report."

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

- "Stage 3A Analysis, Modeling, and Simulation for the U.S.-75 Corridor in Dallas, Texas: Final Predeployment AMS Analysis Plan."

- "Analysis, Modeling, and Simulation for the U.S.-75 Corridor in Dallas, Texas Post-Deployment Analysis Plan."

- Integrated Corridor Management Initiative: Overview of the Dallas Traveler Response Panel Survey."

As the AMS process continues in parallel with the ICM system development and design process, it is likely that new strategies, alternatives and scenarios will emerge that will need to be evaluated within the AMS process; therefore, the flexibility to foresee and account for several iterations of analysis is critical. The design process may reveal new strategies or alternatives that may need to be analyzed in the AMS, prompting modifications to the AMS structure. Likewise, the AMS process may reveal parts of the concept of operations that are unworkable or uncover opportunities that may be leveraged that result in changes to the ultimate ICM design.

The advanced analysis capabilities of the AMS approach provides practitioners with enhanced opportunities to conduct detailed alternatives analysis to identify optimal combinations of strategies and to test and refine how the strategies may be most optimally implemented. Due to the complexity and resources required of the AMS, this level of analysis is typically most appropriate in the later planning stages after the preliminary screening of alternatives has winnowed out a smaller set of strategies and alternatives to be evaluated. The AMS will often continue through the design phase—being used to fine-tune strategies in an iterative function as the realities of the design process progress or to assess the impacts of sequencing the improvements to identify the optimal deployment phasing of the strategies.

The focus of this ICM Post-Deployment assessment is to evaluate to what extent ICM technologies can efficiently and proactively manage the movement of goods and people in a major transportation corridor. Initially, the discussion on performance-driven corridor management among the participating ICM Pioneer Sites was focused on measures derived from observed data. In the AMS phase of the

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effort however, attention turned to producing comparable measures derived from the outputs of different traffic simulation tools. This enabled hypothetical scenarios to be modeled, testing the impacts of potential ICM strategies before implementation and therefore reducing the chance of very expensive missteps in implementation.

This project investigates the impacts of the ICM system in its "as deployed" state in 2014 on U.S.-75 in Dallas, using AMS tools and techniques developed and refined under both the current and previous phases of the program. Results from traveler behavior surveys conducted in the vicinity of the U.S.-75 corridor by the Volpe Center were used to inform model assumptions and to enable more accurate representation of true driver behaviors on U.S.-75. The results of the post-deployment AMS were then used to assess and validate the estimated impacts resulting from the ICM deployment on U.S.-75 in Dallas.

The following is a summary of additional project objectives used to support these overall goals:

- Develop a post-deployment AMS Plan in collaboration with the ICM Demonstration Site staff to promote coordination of analysis efforts and coherent alignment of goals among this effort, the ICM Demonstration Site staff, and the ICM Evaluation team.

- Support the objective evaluation efforts of the Demonstration Site staff and enhance the ability of the modeling tools to accurately represent the deployed ICM strategies by identifying and facilitating improvements to AMS tools, techniques, and inputs.

- Manage the successful transition of modeling responsibilities from AMS Contractor to the ICM Demonstration Site staff and organizations, with workshops to promote the transfer of knowledge and technology.

- Support the integration of AMS tools and techniques into ongoing corridor management practices by the Demonstration Site staff.

- Provide technical documentation of AMS tool development, data sources, data processing methods, model calibration and validation procedures, and analysis techniques used to represent and evaluate ICM impacts.

One aspect of the ICM program is the enhancement of analytical techniques and tools to support ICM impact assessment. In an effort to advance ICM impact assessment, the main objective for the AMS team within the ICM Initiative was to refine AMS tools and strategies, assess the Pioneer Sites' data capabilities, conduct AMS for a subset of the ICM Pioneer Sites, and conduct pre- and post-demonstration evaluations using AMS tools.

The AMS methodology applied to the Dallas and San Diego Demonstration Sites were documented in FHWA's "Traffic Analysis Toolbox Volume XIII: Integrated Corridor Management Analysis, Modeling, and Simulation Guide". This guide is used to assist corridor managers in forecasting and assessing the potential benefits and implications of ICM in their corridors of interest. The ICM AMS methodology is rooted firmly in the US DOT's established modeling guidelines and frameworks, as defined in the FHWA Traffic Analysis Toolbox. Unlike traditional corridor studies, which often focus on a specific element of a corridor (i.e., a freeway or freeway and frontage road during a specific time of day), ICM AMS is a comprehensive approach that analyzes different operational conditions across time and modes and across a large enough geographic area to absorb all impacts.

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The following items outline the key roles of AMS in the ICM Program:

- Creating an analytics tool generates the buy-in from a large stakeholder group.
- Identifying when and where ICM strategies will be the most beneficial.
- Assisting in forecasting and assessing the potential implications of ICM.
- Developing methodologies that support the process for continuous improvement.
- Supporting the ICM Evaluation.
- Enabling agencies to understand system dynamics at the corridor level.
- Developing the analytical capital within each site so that the analyses can be conducted on a regular basis to support ICM decisionmaking (either in planning mode or Decision Support System (DSS) mode).

The post-deployment scope of work for the AMS team includes:

- Project Management and Program Support.
- Develop Analysis Plans.
- Enhance Tools to Reflect As-Deployed Corridor Management.
- Tool Calibration—Reasonableness Assessment.
- Conduct Post-Deployment Alternatives Analysis.
- Post-Deployment AMS Assessment Reports and Briefings.
- Support AMS Transfer to Site.
- Update AMS Guide.
- AMS Knowledge and Technology Transfer.

This *Post-Deployment ICM AMS Assessment Report for the U.S.-75 Corridor* outlines the core tasks associated with the realization of the project goals and objectives described earlier. The organization of this report is as follows:

- **Chapter 2** provides a brief description of the U.S.-75 Corridor in Dallas, Texas.
- **Chapter 3** describes the ICM strategies comprising the ICM deployment on the corridor.
- **Chapter 4** provides an overview of the incident response plans developed.
- **Chapter 5** describes the AMS methodology applied to the corridor.
- **Chapter 6** describes the performance measures used in the AMS.
- **Chapter 7** details the post-deployment AMS approach to model enhancements and model calibration and validation.
- **Chapter 8** summarizes main findings from alternatives analysis and highlights observations to further improve an ICM initiative and the significant benefits of AMS.

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Chapter 2. U.S.-75 Corridor Description

A 28 mile stretch of the U.S.-75 corridor in the Dallas-Fort Worth region (shown in figure 2) was selected as the demonstration site in Dallas (Source: Concept of Operations for the U.S. 75 Integrated Corridor, Dallas, Texas, March 2008). The Dallas-Fort Worth region was recently ranked as the 11th most congested region in the U.S. (Source: Schrank, D., B. Eisele, T. Lomax, and J. Bak. (2015). 2015 Urban Mobility Scorecard), with an expected population growth of one million every eight years. The U.S.-75 corridor is a major north-south radial corridor connecting downtown Dallas with many of the suburbs and cities north of Dallas. The U.S.-75 Corridor has been defined at two levels. The immediate corridor consists of the freeway, a light-rail line, and arterial streets within approximately two miles of the freeway. In addition, a full "travel shed" influence area has been defined that includes additional alternate modes and routes that may be affected by a major incident or event. The travel shed area is generally bound by downtown Dallas to the south, the Dallas North Tollway to the west, State Highway (SH) 121 to the north, and a combination of arterials streets and Dallas Area Rapid Transit (DART) Blue Line to the east.

U.S.-75 is Dallas' first major freeway, completed around 1950, and fully reconstructed with cantilevered frontage roads over the depressed freeway section and reopened in 1999 with a minimum of eight general-purpose lanes. The freeway mainlines carry more than 250,000 vehicles a day, with another 20,000 to 30,000 on the frontage roads. Although the peak direction of travel is southbound in the morning and northbound in the afternoon, the off-peak directions of travel experience significant travel volumes as well.

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

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

The U.S.-75 Corridor study area serves: 1) commuting trips into downtown Dallas, via the freeway, bus routes, light-rail line, and arterial streets; 2) a significant number of reverse commuters traveling to commercial and retail developments in the northern cities and neighborhoods; 3) regional traffic during off-peak periods; and 4) interstate traffic into Oklahoma, since the freeway is a continuation of Interstate 45. The corridor also is a major evacuation route and experienced significant volumes during the Hurricane Rita evacuation in 2005.

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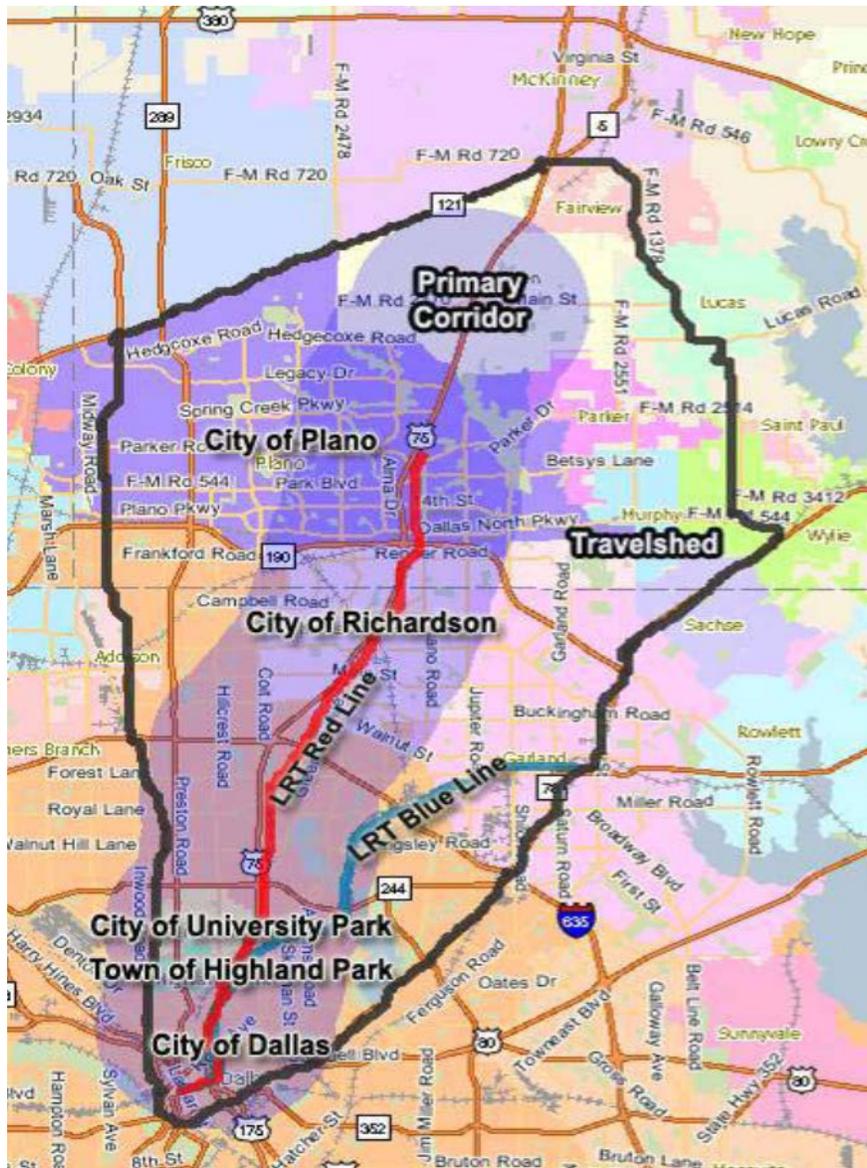
Figure 2. Map. Study area U.S.-75 Corridor in Dallas, Texas.
(Source: Dallas Area Rapid Transit.)

There are three major freeway interchanges in the corridor study area. In the southern section, U.S.-75 has an interchange with the downtown freeway network connecting to Interstate 45 and Interstate 35E. At midpoint there is a newly constructed interchange with Interstate 635, while in the northern section, there is an interchange with the President George Bush Turnpike (PGBT). Figure 2 illustrates the U.S.-75 Corridor, with the primary corridor study area highlighted, and the roadways included in the study area.

The inability to expand the freeways or arterials as a method to reduce delays caused by bottlenecks and incidents or improve travel time reliability created a need to explore alternative congestion reduction strategies. Several features of the corridor study area made it an ideal Integrated Corridor

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Management (ICM) testbed: eight-lane freeway with continuous frontage roads, a concurrent-flow, HOV lane, light-rail line, transit bus service, park-and-ride lots, major regional arterial streets within approximately two miles of the freeway, toll roads, bike trails, and intelligent transportation systems. The layout of the transportation network provided opportunities for strategic traffic diversion onto under-utilized frontage roads, arterials, or transit.

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Chapter 3. Integrated Corridor Management Strategies

The purpose of the U.S.-75 Integrated Corridor Management (ICM) project was to implement a system and organizational structure that will provide for the operation of the Corridor in a multimodal, integrated, efficient, and safe fashion. The ICM concept represented a shift for management and operations within the Corridor—from the prior partial coordinated operations between corridor networks and agencies, to an integrated and proactive operational approach that focuses on a corridor perspective rather than a collection of individual networks. (Please note, the contents of this chapter have been based on the "Operations and Maintenance Plan for the U.S. 75 ICM, Dallas Integrated Corridor Management (ICM) Demonstration Project," developed by the Dallas Area Rapid Transit (DART) and dated January 3, 2014.)

Agencies within the corridor had already taken actions to manage the transportation network and reduce congestion. The U.S.-75 ICM Project built upon these capabilities. Using cross—network operational strategies, the agencies capitalized on integrated network operations to manage the total capacity and demand of the system in real time in response to changing corridor conditions. With improved traveler information the public is better able to shift trip mode, route and time of day based on current conditions. New transportation operations and management systems allow agencies to better monitor current conditions and use capacity more efficiently.

The Dallas ICM deployment focuses on four ICM goals including: improve incident management, enable intermodal travel decisions, increase corridor throughput, and improve travel time reliability. ICM strategies in the "as-deployed" system used to achieve these goals include:

- Providing improved multimodal traveler information (pretrip, en-route), such as:
  - New 511 system (real-time information, including traffic incident information, construction information, traffic speeds, light rail transit (LRT) passenger loads, LRT vehicle locations, Red Line park-and-ride utilization).
  - My511 e-mail alerts.
  - ICM dynamic message signs (DMS) messages.
  - Social media.
  - Dallas Area Rapid Transit (DART) data feeds for third-party application development.
- Implementing a parking management system at Red Line park-and-ride facilities.
- Developing preapproved ICMS response plans.
- Developing a Decision Support System to support ICM strategy identification and selection.
- Diverting traffic to key frontage roads and arterials (Greenville Ave.) with coordinated and responsive traffic signal control.
- Encouraging travelers to use transit during major incidents on the freeway.

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- Increasing utilization of Red Line capacity with the potential of additional train cars or decreased headways.

In addition to the items listed above, the "as-planned" ICM system included a shuttle service to LRT private overflow parking, secured via public-private partnerships, and a valet service at the park-and-ride parking expansion lot. However, DART recently expanded the Parker Road and the President George Bush Turnpike (PGBT) Stations, which provides needed capacity for future ICM strategies, so the "as-deployed" ICM system did not implement the private parking or valet parking strategies. Some of the proposed Dallas ICM strategies were ahead of their time. For example, valet parking could have been a very effective strategy to encourage transit mode shifts if smartphones and rideshare services were more widely used at the time the Integrated Corridor Management System (ICMS) was initially designed.

The Dallas U.S.-75 ICM corridor approach to route diversion and mode shift follows this general concept: When an event (e.g., incident) causes nonrecurrent congestion and certain conditions are met, the traffic is first diverted to the frontage road. As the magnitude of the congestion grows, the DSS recommends the traffic to divert to both the frontage road and Greenville Avenue, a major arterial nearby. If the a major event occurs and congestion is not sufficiently averted, the DSS then recommends the travelers to park at several strategically located park-and-ride lots and switch to the Red Line to complete their trip.

The U.S.-75 ICM project includes the implementation of a number of technology systems and elements, including the following:

- A **Decision Support System** that monitors real-time data to assess current transportation network conditions, recommends preapproved strategies and response plans when events occur that affect corridor operations, analyzes and predicts response plan benefits, and evaluates response plan results.

- A **SmartNET Subsystem** which provides a graphical user interface that supports multiagency input and information sharing related to the transportation network including incidents, construction, and special events as well as the current status of devices and performance of the roadway and transit networks. It is also the means for communicating and monitoring response plans.

- A **SmartFusion Subsystem** which provides data collection, processing, fusion and dissemination functions for the system.

- A number of supporting projects and activities deployed in support of ICM such as a DART parking management system, traffic responsive signal control (i.e., not adaptive signal control) on key diversion arterials in the Cities of Richardson, and Plano and a regional 511 traveler information system.

- ICM operations were expected to be decentralized with the DalTrans Transportation Management Center (TMC) serving as the corridor's central coordination point. Field systems are expected to be operated by local agencies in accordance with ongoing agency operating capabilities, resources and procedures. In addition, there is a dedicated ICM Coordinator for the corridor, whose job is to review and accept appropriate Response Plans that are recommended by the DSS for review by local agency operators, insure the corridor agencies are responding to requests, and monitor the overall performance of the corridor.

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The systems involved in ICM operations fall into two categories:

1. **ICM System**. These are the technical systems that make up the ICMS including SmartNET, Smart Fusion and DSS.
2. **Agency Operations Systems.** These are agency systems that provide or support field operations needed to implement ICMS strategies and response plans, collect systems data, etc.

Figure 3 shows the major system components. The ICM System (shown in the yellow box), includes three subsystems (indicated by the orange boxes): 1) SmartFusion—where all the data is stored; 2) SmartNET—plan decision dialogue component and graphical user interface (GUI); and 3) DSS— includes expert rules, evaluation, and prediction components; the DSS is responsible for selecting response plans and sending them via SmartNET to agency operators. The red boxes represent the information sources which feed into the SmartFusion component (i.e., parking information, weather conditions, DART Automatic Vehicle Locator (AVL), center-to-center feed, etc.), while the green boxes specify information receivers (i.e., 511 Mobile, Social Media, Public Web, interactive trip planning systems, e-mail, center-to-center feed, etc.). Lastly, the blue boxes shown represent the end users of the ICM system: administrative users, AMS operators, agency users, model operators, and the ICM coordinator. The ICM coordinator was designed by request of the Dallas partners to be the "human element" of the Dallas ICM system and is responsible for evaluating the response plans generated by the DSS *before* they are implemented by the operating agencies.
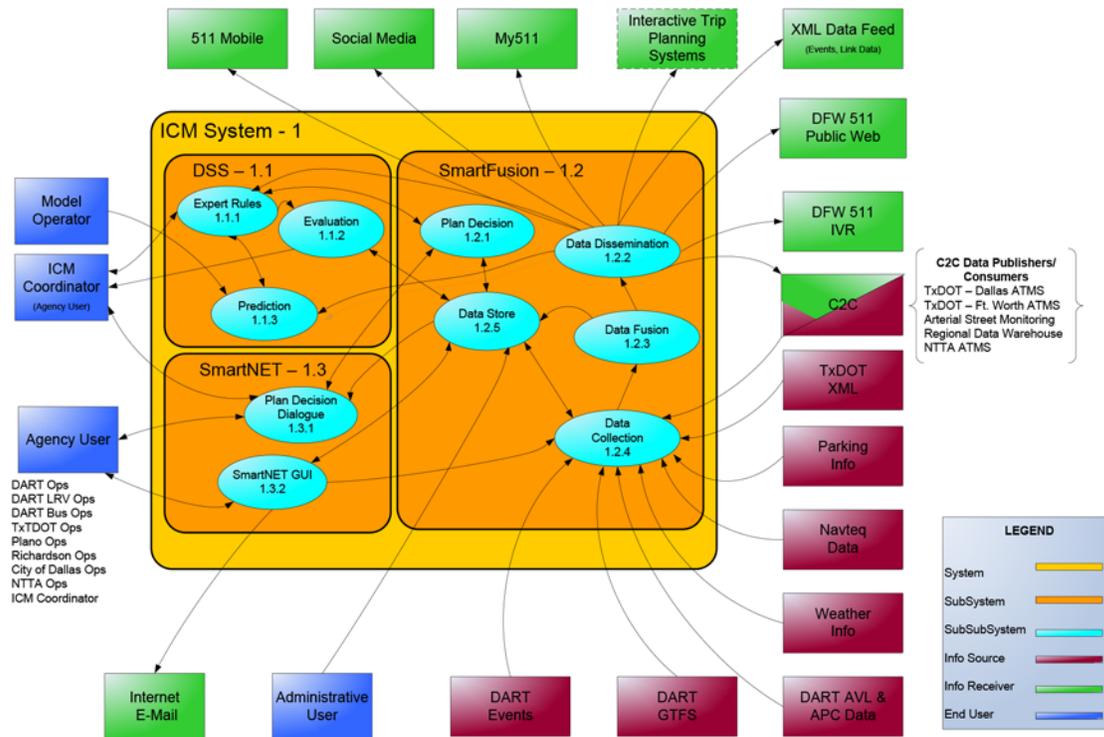
Figure 3. Diagram. High-level U.S.-75 Integrated Corridor Management conceptual diagram.
(Source: Dallas Area Rapid Transit, January 3, 2014.)

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Figure 4 outlines the role of the DSS in the ICMS. When an incident is identified, the details of the incident are entered into the SmartNet system, which in turn triggers the DSS to take action. The DSS evaluates the available capacity of alternate routes, transit capacity, park-and-ride-lot capacity, and response alternatives which are appropriate for addressing the incident at hand. Expert rules, aided by a 30-minute future forecast of traffic conditions are used to guide which of the pre-agreed-upon list of response plans are recommended by the DSS. The designated ICM Coordinator reviews the recommended response plans and chooses one (or none) for implementation. Once the solution has been implemented by the involved operating agencies, commuters will begin to receive actionable traveler information via a 511 system, agency Web sites, DMS, and social media. Meanwhile, the DSS continues to evaluate the solution based on the changing roadway conditions and incident status, making subsequent recommendations when needed.
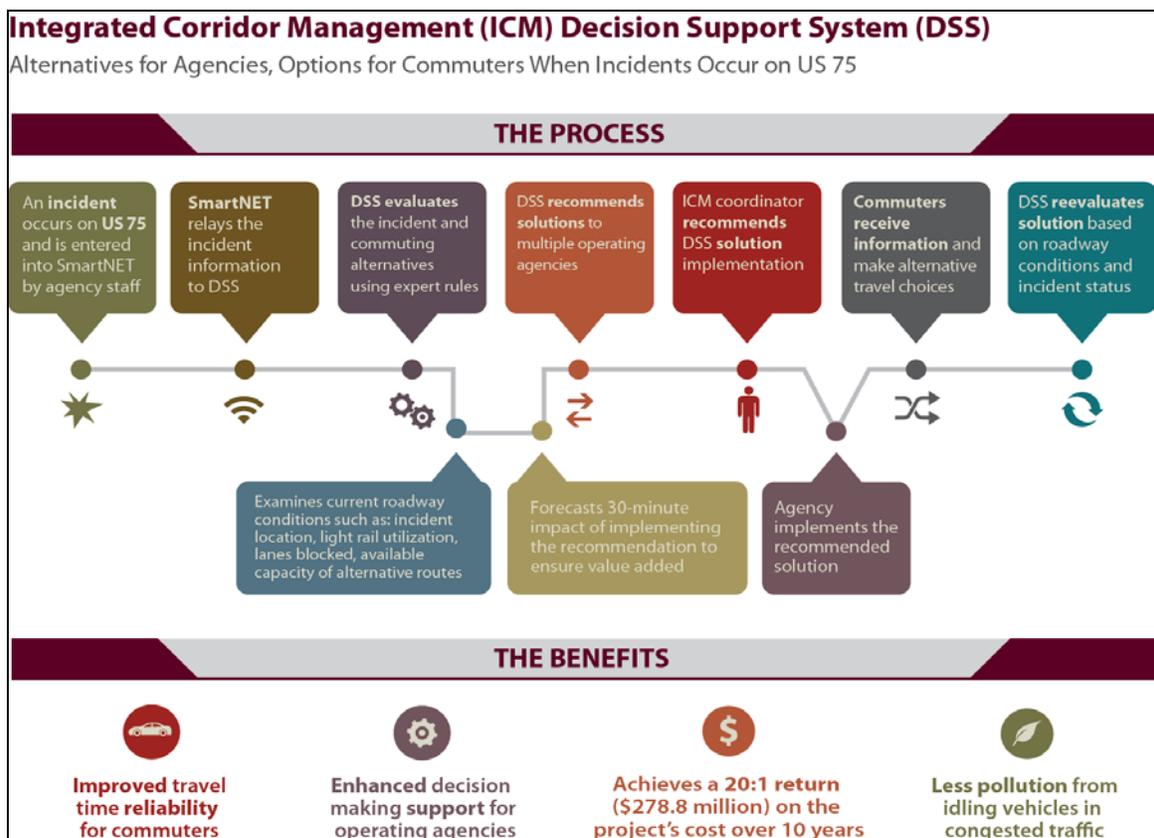
Figure 4. Flowchart. Integrated Corridor Management Decision Support System.
(Source: Dallas Area Rapid Transit, January 3, 2014.)

The U.S.-75 ICM project is a collaborative effort led by DART in collaboration with the United States Department of Transportation (US 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).

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Chapter 4. Development of Response Plans

The Dallas U.S.-75 Integrated Corridor Management System (ICMS) integrated various regional and municipal systems and operations using a decentralized approach. Through wireless and web-based alerts, as well as dynamic message signs, travelers received increased access to real-time information on traffic conditions, travel times, public transit schedules, and parking availability, which can help them plan their routes and make adjustments as needed in response to changing conditions. (Please note, the contents of this chapter have been based on the "Technical Memorandum—Development of TEARS Incident Signal Timing Plans," developed by Kimley-Horn and Associates Inc. (Kimley-Horn) and dated March 25, 2014.)

One component of the process was to deploy adjusted traffic signal timing as a means of mitigating congestion when on-freeway incidents cause traffic to divert to the arterial street network. Freeway incidents occur at various locations, directions and times of the day. Incidents have widely differing severity, duration and resulting impact on traffic. In order to determine the incident types most in need of having predeveloped signal timing adjustment strategies, Texas A&M Transportation Institute (TTI) performed a clustering method of historical traffic events along U.S.-75 within the project area. This analysis used parameters such as crash severity (e.g. number of lanes affected and duration), direction, time of day, weather, and U.S.-75 traffic demand. TTI also modeled the probable traffic shifts that would occur as a result of these frequently occurring incident types using Dynamic Intermodal Routing Environment for Control and Telematics (DIRECT), the Integrated Corridor Management (ICM) mesoscopic model developed by Southern Methodist University (SMU).

Targeted Event Accelerated Response System (TEARS) is the U.S.-75 ICM component that includes the implementation of traffic signal timing changes to mitigate specific incident types. TEARS signal timing plans were developed using the time-of-day dependent clusters (i.e., AM, mid-day, PM periods) resulting from TTI's analysis, which were prioritized based on their delay impact on U.S.-75 and the surrounding roadway network. The plans were tuned with help from AMS in the form of probable traffic volume changes modeled by SMU's DIRECT model.

The expert rules outlined in table 1 serve as a filtering mechanism to select the appropriate response plan from the set number of preapproved response plans. The values used for implementation were determined based on the consensus of the operational stakeholders. At the time these criteria were developed it was recognized that "Established criteria values can be subject to change based on experience and post implementation analysis." Many crashes will never meet all of the conditions required to recommend a multiagency action plan. Once a crash meets the criteria for coordinated action across agencies, a recommendation is sent to the ICM Coordinator and the affected agencies, and the ICM Coordinator initiates field implementation, as appropriate.

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For example, an incident is classified as a minor incident with short diversion to frontage road if it affects one or more general purpose and/or high-occupancy vehicle (HOV) lanes, *and* has a queue length between 0.5 mile to 0.99 mile; defined as average speed of the consecutive U.S.-75 links upstream of incident (same direction) is greater than 30 miles per hour, *and* the average speed of the frontage road links (same direction) between first available on-ramp downstream of incident to one-mile upstream of the incident is greater than 20 miles per hour, *and* prediction measures of performance (MOPs) is <0% for U.S.-75 (same direction) and <2% for the entire network. However, if the U.S.-75 queue length is > one-mile *and* all other conditions are the same then it is classified as a major incident with long diversion to frontage road.

Table 1. Expert rules for response plan recommendation.

| Strategies | No. Affected Lanes General Purpose and HOV | Main Lanes | | Speed FR (on Diversion Route) (mph) | Speed GV (on Diversion Route) (mph) | Prediction Δ MOP Plan versus Do Nothing | Park and Ride Utilization | Light Rapid Transit Utilization |
		Speed (mph)	Queue Length Derived from Avg. Speed (mi.)					
Minor Incident: Short Diversion to FR.	≥ 1	< 30	0.5 < Q <1	> 20	N/A	< 0%, < 2%	N/A	N/A
Major Incident: Long Diversion to FR.	≥ 1	< 30	Q ≥ 1	> 20	N/A	< 0%, < 2%	N/A	N/A
Major Incident: Diversion to FR. GV.	≥ 2	< 30	Q ≥ 1	< 20	> 20	< 0%, < 2%	N/A	N/A
Major Incident: Diversion to FR. & GV., Transit	≥ 2	< 30	Q > 4	< 20	< 20	< 0%, < 2%	< 85%	< 85%
Major Incident: Diversion to FR. and GV., Stop Transit Diversion (No DMS action)	≥ 2	< 30	Q > 4	< 20	< 20	< 0%, < 2%	> 85%	> 85%

(Source: Texas A&M Transportation Institute.)

When an incident occurs along the Dallas U.S.-75 ICM corridor which fulfills the criteria to recommend a DSS plan (otherwise known as an Implementable DSS Plan), the ICM Coordinator evaluates the response plan and approves it for the operating agencies to recommend. The plan consists of one or more of the following actions: dynamic message sign message (e.g., "Try Greenville Ave."), traffic signal timing adjustment, added rail capacity, or parking utilization. Simultaneously, information regarding the incident is made available via 511, agency Web sites, social media, etc., which is also available for incidents that did not generate an Implementable DSS plan (also known as Information Only Plans).

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Figures 5 and 6 provide examples of an Implementable DSS Plan and the actions required of each agency involved. Each Flex Group number corresponds to a specific signal timing scheme for a specified set of traffic signals. Each impacted city (e.g., Richardson, Plano, etc.) is responsible for activating the correct Flex Group plan and monitoring traffic every 15 minutes to determine if the response plan is clearing the congestion caused by the incident.
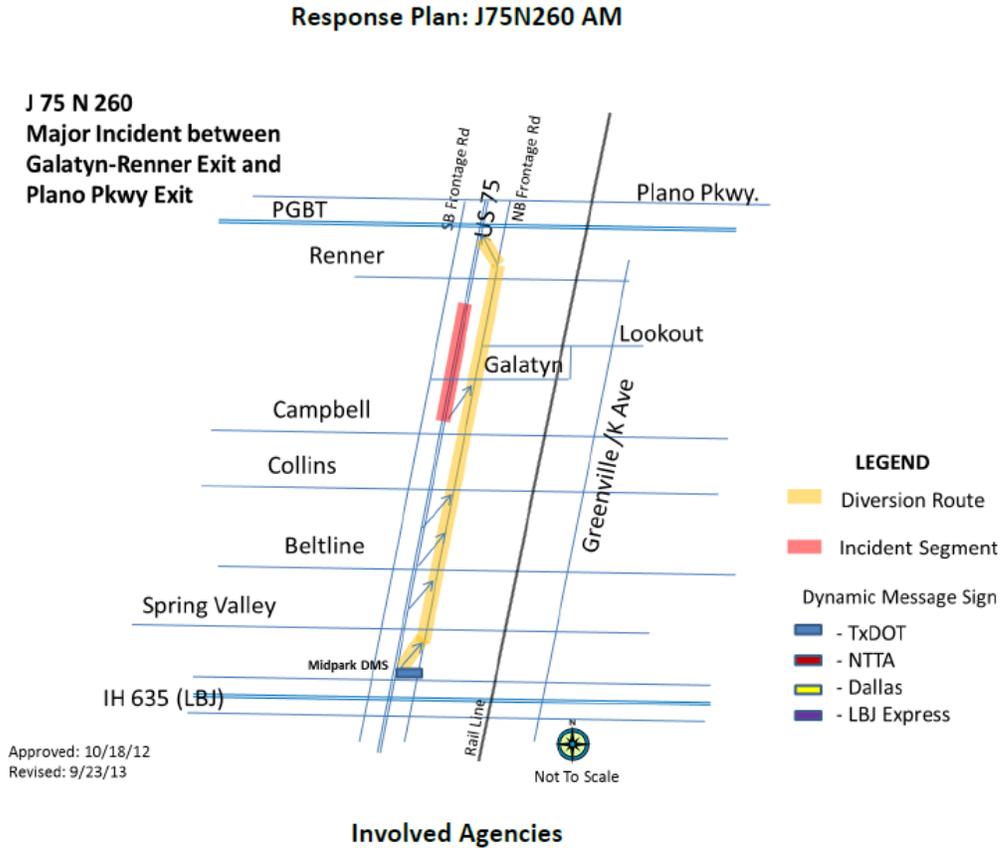
Figure 5. Diagram. Response plan J75N260 AM—diversion plan.
(Source: Implementable Response Plans for Stage 3,
Texas A&M Transportation Institute, 11/18/13, p. 84, unpublished.)

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Required Actions

Richardson

- Activate Flex Group 19 and monitor every 15 min. Applicable only during AM Peak Period (6-9am).

Plano

- Activate Flex Group 19 and monitor every 15 min. Applicable only during AM Peak Period (6-9am).

No.	Signal	TEARS/ DIRECT ID	CITY	Flex Group	SmartNet ID
1	Arapaho @ US 75 NBFR	4227	RIC	19	1010154650
2	Arapaho @ US 75 SBFR	182	RIC	19	1010154640
3	Campbell @ US 75 NBFR	4355	RIC	19	1010139300
4	Campbell @ US 75 SBFR	4352	RIC	19	1010139290
5	Renner @ US 75 NBFR	4303	RIC	19	1010154860
6	Renner @ US 75 SBFR	4306	RIC	19	1010154850
7	Plano Rd @ Renner	4300	RIC	19	1010154870
8	Park Blvd @ Republic	17	PLA	19	1010147320

TxDOT

- DMS:

Message ID	Name	SmartNet ID
1	HOV 75_NB Midpark	5074890

Figure 6. Table. Response plan J75N260 AM—required actions.
(Source: Implementable Response Plans for Stage 3,
Texas A&M Transportation Institute, 11/18/13, p. 85, unpublished.)

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Chapter 5. Analysis, Modeling, and Simulation Methodology

The Analysis, Modeling, and Simulation (AMS) methodology applied to the Dallas Demonstration Site was documented in the Federal Highway Administration's (FHWA) "Traffic Analysis Toolbox Volume XIII: Integrated Corridor Management, Analysis, Modeling, and Simulation Guide", a guide designed to help corridor stakeholders implement the Integrated Corridor Management (ICM) AMS methodology successfully and effectively. This guide provides a framework for developing an effective analysis plan to support selection and application of available tools and models specifically conducive to ICM.

Every tool type represents a tradeoff between geographic scope and level of resolution (scale versus complexity). Figure 7 shows the different types of analysis tools that can be incorporated into AMS. Less detailed tool types are tractable for large networks, while more detailed tool types are restricted to smaller networks. Depending on corridor size and the types of analyses required, all tool types are potentially valuable for ICM AMS. Microscopic simulation models, for example, are effective at analyzing system optimization strategies, such as freeway ramp metering and arterial traffic signal coordination, while mesoscopic simulation models are less effective, and travel demand models do not have this analysis capability. Travel demand models are better at estimating mode shift, but microscopic and mesoscopic simulation models are better at estimating route shifts. Mesoscopic tools can estimate regional dynamic diversion of traffic, while microscopic tools can estimate route shift at a smaller geographic scale. Finally, mesoscopic simulation tools are better at analyzing traveler responses to congestion pricing. The ICM AMS offers corridor managers greater capability than is available in any single existing tool.

Modeling Components

Existing candidate AMS tools for the Dallas-Fort Worth region were evaluated for their ability to model ICM strategies. The following sections provide an overview of the various modeling components utilized in the AMS modeling framework for the U.S.-75 Corridor.

Travel Demand Forecasting Model

Travel demand models estimate demand based on projections of household and employment characteristics and predict preferences in activity location, time of day, mode, and route choice. The North Central Texas Council of Governments (NCTCOG), Dallas' metropolitan planning organization, maintains the regional travel demand model in TransCAD. The static nature of NCTCOG's travel demand model is not entirely compatible with the dynamic nature of travel choices during an incident situation. Dynamic Intermodal Routing Environment for Control and Telematics (DIRECT), the selected mesoscopic model and used for AMS for the U.S.-75 Corridor study area, models the diversion to different routes or modes during simulation run time, thus circumventing the need to feed

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back to the travel demand model and providing a more realistic view of the traveler decisions and their impact to network conditions.
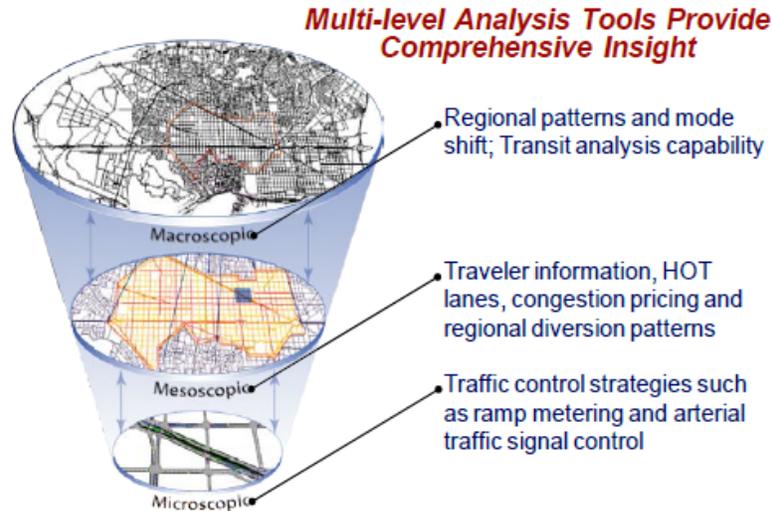
Figure 7. Illustration. The Integrated Corridor Management Analysis, Modeling, and Simulation methodology blends up to three classes of modeling tools for comprehensive corridor-level modeling and analysis.
(Source: Cambridge Systematics, Inc., September 2009.)

The NCTCOG model was used as the primary source for the vehicular trip tables and networks. Available coefficients (e.g., value of time, operating cost per mile, etc.) and variables from the travel demand model were reviewed and adjusted for incorporation into the generalized cost equation within the simulation model. While travel demand subarea procedures allowed for the extraction of the vehicular demand for the U.S.-75 Corridor study area, similar procedures were not available for the transit component. Therefore, the Dallas AMS team utilized the Dallas Area Rapid Transit (DART) on-board survey to develop an estimate of the transit origin-destination (OD) trip table. It is a known limitation of existing travel demand forecasting models to generate trip tables which accurately reflect real travel conditions. However, the AMS for this Demonstration Site uses the same trip table in both with-ICM and without-ICM scenarios, so the impact of the Integrated Corridor Management System (ICMS) is more accurately captured and analyzed.

Mesoscopic Simulation Model

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

For the analysis of the U.S.-75 Corridor, the mesoscopic model DIRECT developed by the Southern Methodist University (SMU) was used. DIRECT supports the analysis of the dynamic impact of ICM strategies, such as route shifts, mode shifts, and corridor-specific traveler information (pretrip and en-route). Figure 8 shows the model network used in post-deployment AMS overlayed onto the pre-

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deployment AMS area. The AMS area boundaries were reduced in post-deployment AMS to achieve improved operational efficiency in the Decision Support System (DSS) model. Model network link types include arterials, collectors, freeway, high-occupancy vehicle (HOV), rail, and ramps.
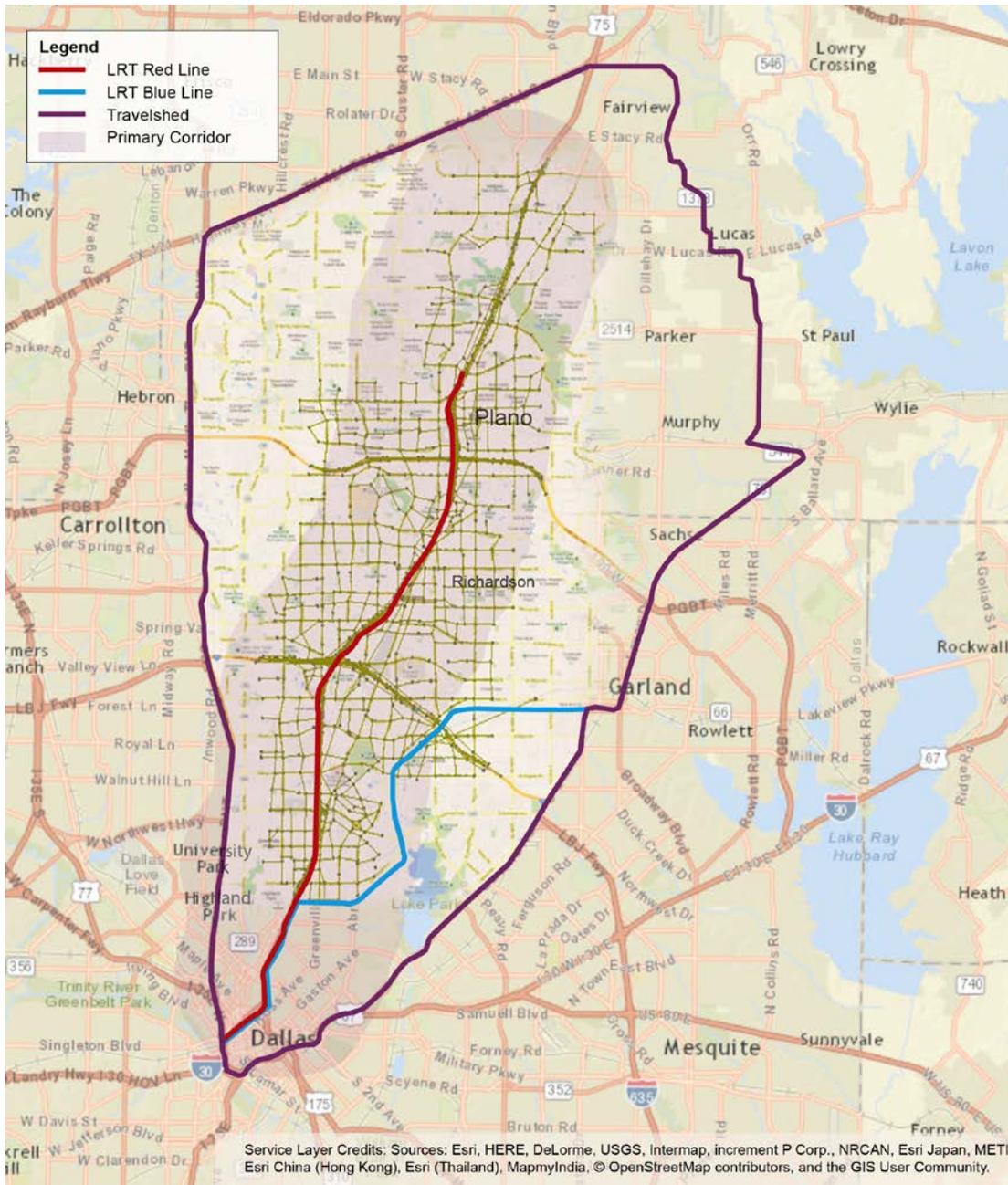
Figure 8. Map. Model network U.S.-75 for post-deployment Analysis, Modeling, and Simulation overlayed onto pre-deployment Analysis, Modeling, and Simulation area boundaries.
(Source: Integrated Corridor Management Analysis, Modeling, and Simulation for the U.S.-75 Corridor in Dallas, Texas Post-Deployment Analysis Plan, FHWA-JPO-16-392, p. 9 (model network image).)

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In DIRECT, the traveler's mode and route are generated so that each traveler is assigned to a route-mode option that: 1) minimizes the traveler's generalized cost; and 2) matches the traveler's mode preference options which are influenced by the willingness to carpool and to use transit. The high-level DIRECT modeling framework is diagrammed in figure 9.

As part of the model input, each origin-destination pair is assigned a value to represent the percentage of travelers who are willing to use transit (i.e., considering transit in their mode choice set either as pure mode or combined with private car) or carpool. An estimate of the willingness to use transit was obtained as the ratio of the number of transit travelers recorded in the DART on-board transit survey over the total number of travelers estimated for each origin-destination pair.

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

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

- Set I—Routes for Single-Occupant Vehicles (SOVs) (drive-alone).
- Set II—Routes for HOVs (carpool).
- Set III—Routes for park-and-ride (excluding carpool).
- Set IV—Routes for transit (pure transit).

The set of route and mode options available for each traveler is diagramed in figure 10. For example, if the traveler is not willing to use transit and not willing to carpool, then the traveler will choose an option from Set I. On the other hand, if the traveler is willing to use transit and not willing to carpool, then the traveler will choose from Sets I, III, or IV. Another case could be that the traveler is not willing to use transit but is willing to carpool, then the traveler will choose from Sets I or II.

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

- Departing from the same origin zone.
- Departing within a given time window (10 minutes).
- Going to the same destination zone.
- Willing to car pool.
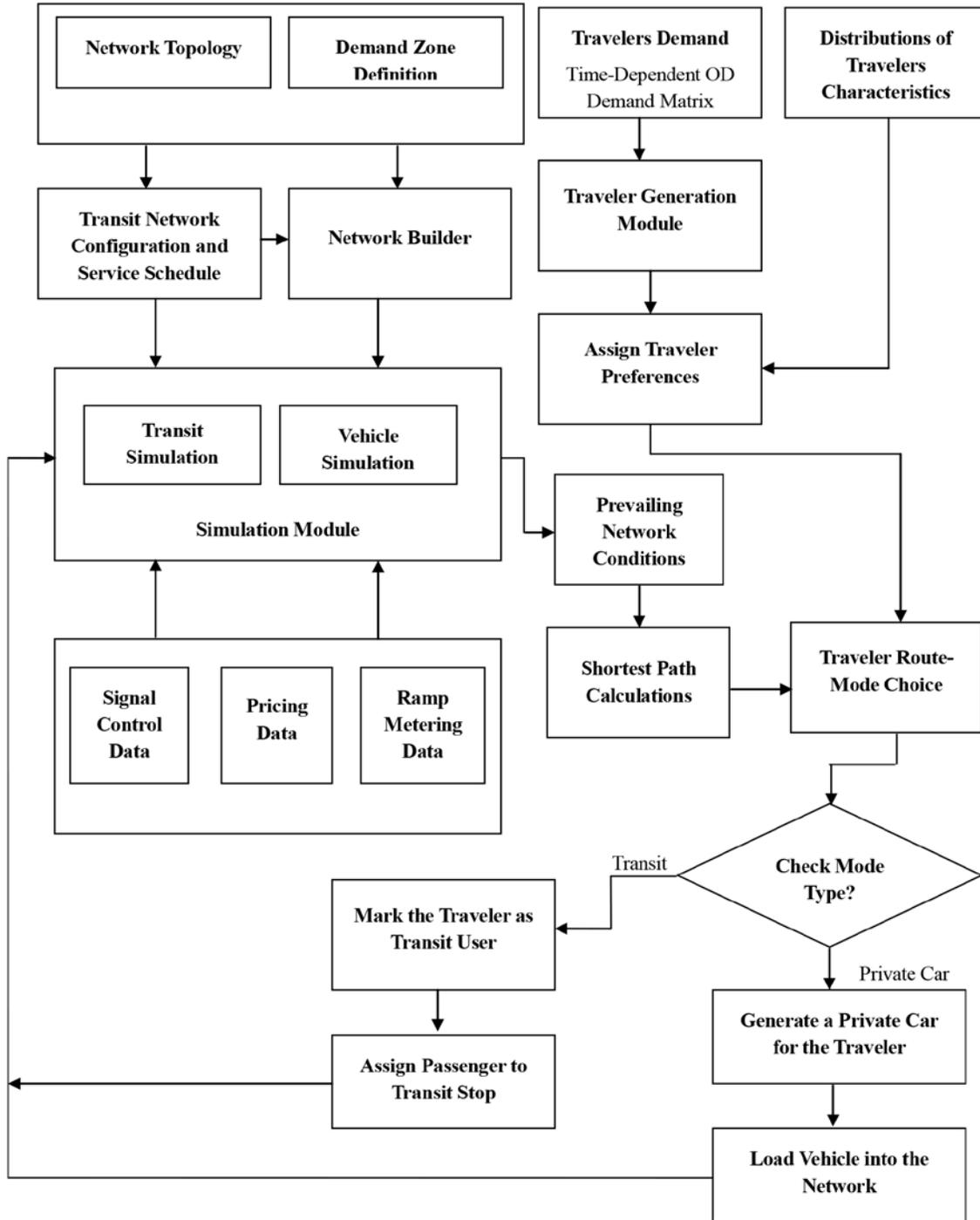
Figure 9. Flowchart. Dynamic Intermodal Routing Environment for Control and Telematics modeling framework.
(Source: Dallas US 75 - Post-Deployment Analysis, Modeling, and Simulation (AMS) Reasonableness Assessment and Tool Modification Technical Memorandum—Final, Cambridge Systematics, Texas A&M Transportation Institute, and Southern Methodist University, 3/12/15, p. 27, unpublished.)

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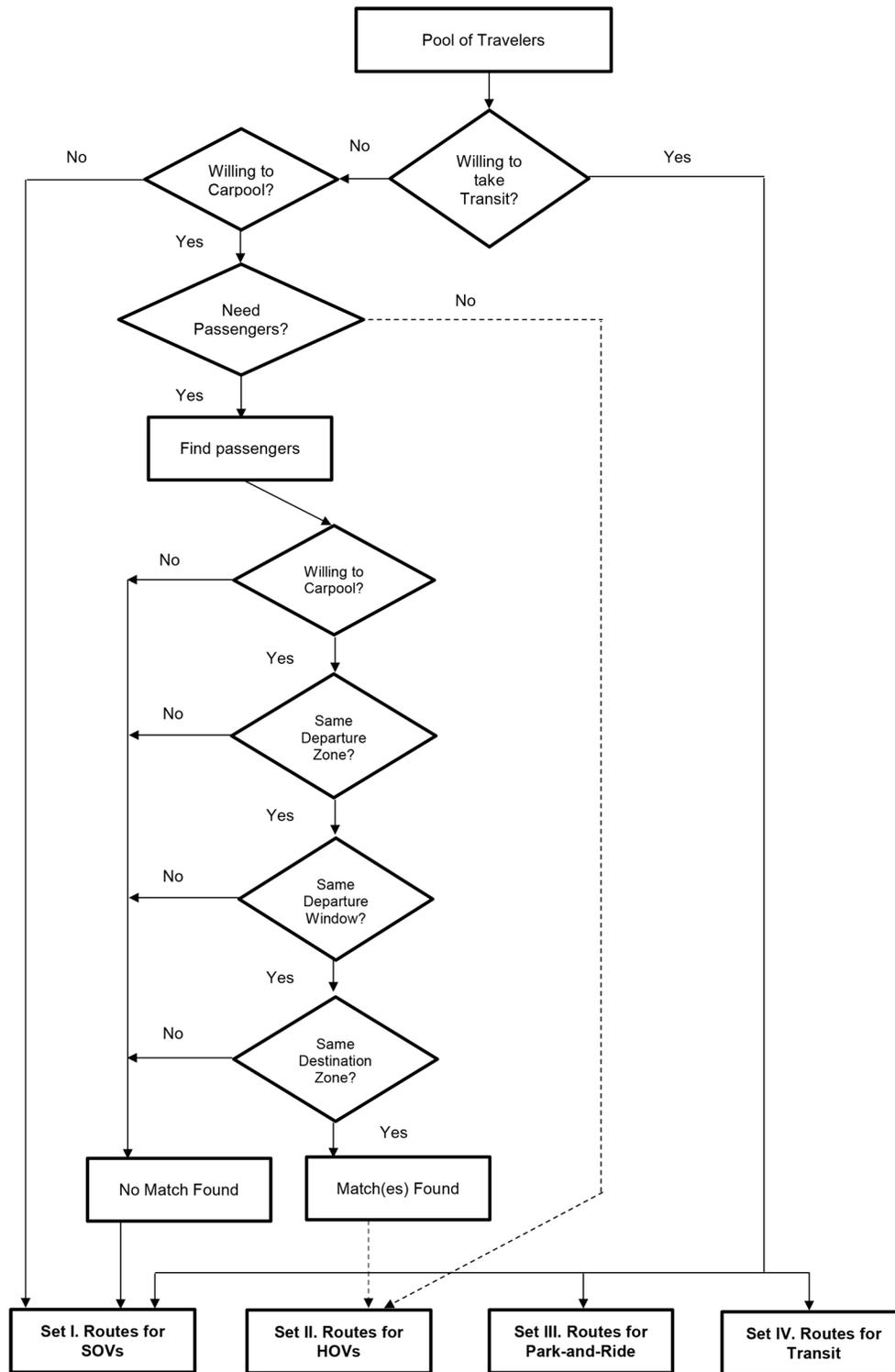
Figure 10. Flowchart. Traveler route-mode choice.
(Source: Cambridge Systematics, Inc., 2016.)

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

The travelers' mode and route choice is done simultaneously and is a function of the congestion evolution in the network. DIRECT utilizes a multiobjective shortest path algorithm coupled with an incremental all-or-nothing, rather than a dynamic user equilibrium, assignment. Travel times along a route are reflective of the link travel times when the traveler is generated (instantaneous travel times), rather than the link travel times at the time the traveler enters the link (experienced travel times). DIRECT assigns each traveler to the shortest vehicular, transit, or park-and-ride path, calculated every five minutes.

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

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

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

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

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

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

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

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

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

During an incident, travelers follow their long-term established mode-route choices ("historical routes") unless they encounter freeway/arterial congestion or receive and consider pretrip or en-route information that may identify a more attractive mode-route option compared to the "historical route." Pretrip information could be in the form of a TV announcement, an e-mail alert, or information provided by a web site. En-route information could be in the form of a radio announcement, a dynamic message sign (DMS), or live traffic updates via a Global Positioning System (GPS) receiver.

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

Travelers with no-information follow their "historical routes." Travelers with pretrip information have the option to update their routes and/or mode of transportation at the origin of their trips. Travelers with

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access to en-route information could receive updates through their devices at any node along their routes, including their trip origin. Therefore, a portion of them could be considered as travelers with access to pretrip information as well. As such, for modeling purposes, Group B considers travelers with access to pretrip information ONLY, while Group C considers travelers that have access to pretrip, as well as en-route information.

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

Finally, any traveler associated with Groups A, B, or C could pass a DMS and be eligible to respond to the available information. As such, travelers passing a DMS constitute Group DMS. In the deployed Dallas ICM system, DMSs are activated if a response plan calls for their activation and stay activated until termination of the response plan.

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

- **DMS Diversion**—This type of diversion is only applicable to travelers in Group DMS. DMSs are only activated if they are part of a coordinated response plan and only from the time the response plan is implemented to termination of the plan. Travelers responding to a DMS compare the generalized cost of the updated route, from the downstream node of the current link to the final destination, with the generalized cost of the corresponding section of the originally assigned route. Diversion occurs only if the generalized cost savings between the updated and originally assigned route, compared to the generalized cost of the originally assigned route, is more than 10 percent.

- **Pretrip Diversion**—This type of diversion is applicable to travelers in Group B. Travelers with access to pretrip information at their origin, compare the generalized cost of the suggested mode-route option to their destination with the generalized cost of their "historical route." Diversion occurs only if the generalized costs savings between the updated and originally assigned route, compared to the generalized cost of the originally assigned route, is more than 10 percent.

- **En-Route Diversion**—This type of diversion is applicable to travelers in Group C. Travelers equipped to receive en-route information compare the generalized cost of the updated route, from the downstream node of the current link to the final destination, with the generalized cost of the corresponding section of the originally assigned route. Diversion occurs only if the generalized costs savings between the updated and originally assigned route (or drivers' perceptions of costs savings), compared to the generalized cost of the originally assigned route, is more than 10 percent. Paths of travelers in this group are recalculated at time of departure and at every intermediate node in the network. More specifically, the optimized path (based on the lowest generalized cost) is calculated every 5 minutes for every node to every destination (generation or intermediate node). When a traveler is generated, that path is assigned to the traveler. If the traveler is receiving en-route information (Group C) a path from the downstream node to the destination is assigned from the latest optimized path calculation.

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- **Congestion Diversion**—This type of diversion is only applicable to travelers in Group R. When the congestion diversion is triggered, the shortest freeway or arterial path (based on travel time and the current interval shortest path calculation) initiating from the first downstream exit (ramp or intersection) is assigned to the traveler. As such, Group R travelers' decisions are neither multimodal nor comparative.

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

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

While DMS is a form of en-route information, it presents a special case in the current version of DIRECT, it is assumed that 100 percent of the travelers have access to the information presented in the DMS.

Modeling Integrated Corridor Management Strategies

The following list identifies the ICM strategies implemented as part of the U.S.-75 ICM system:

- Travel time information (pretrip and en-route).
- Incident signal retiming plans for arterials.
- Incident signal retiming plans for frontage roads.
- LRT information on parking availability.
- Red/Orange Line capacity increase.

The strategies listed above are discussed in more detail in the ensuing sections.

Traveler Information

Multimodal information dissemination includes travel times for freeway, arterial, and transit to provide travelers with information on the best routes and modes. The information also includes park-and-ride availability. As a result, more travelers will be able to choose the best option (alter route, mode, and/or departure time) that reflects the optimal travel time. The travel time information is distributed pretrip and en-route. In post-deployment AMS the parameters related to awareness and use of traveler information before and after the ICMS was deployed (pre-ICM and post-ICM) in the U.S.-75 ICM

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corridor are based on findings from the Volpe Center's "Integrated Corridor Management Initiative: Overview of the Dallas Traveler Response Panel Survey" report. Assumptions used for these parameters in pre-deployment AMS are listed below so as to enable comparisons between pre- and post-deployment AMS.

The Volpe Center used a panel survey approach, whereby the same individuals were surveyed both before and after the deployment of ICM to more realistically capture behavioral data for travelers (i.e., changes in peak period mode, route, time of travel, changes in awareness of traveler information sources; changes in reported utilization of traveler information sources) in the study area of the U.S.-75 corridor. Results from the survey were used to update the model parameters for: 1) "awareness" or "market penetration" (traveler access to real-time information); 2) "use" reflecting an upper bound on the percent of travelers who might divert as a response to the information; and 3) "compliance" reflecting actual travelers making a change in their trip making as a result of traveler information.

Pretrip Traveler Information

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

As shown in table 2, 94 percent of travelers were considered to have access to pretrip traveler information pre-ICM. *Awareness* increased by two percent post-ICM, as 511 and more valuable traveler information were made available. *Compliance* to pretrip information also increased by two percent post-ICM to 18.4 percent.

En-Route Traveler Information

One of the U.S.-75 ICM strategies intends to proactively disseminate en-route information via 511, radio/TV, agency Internet sites, smart phones, etc. The analysis modeled the impact of en-route information available to travelers to assess:

- **Change in Route Choice**—This relates to real-time change in route choice of drivers based on travel time or congestion updates they receive via radio, 511, GPS devices, or information provided by a DMS sign.

- **Change in Mode En-Route**—The possibility of changing mode while en-route has potential on the U.S.-75 Corridor, considering the availability of a number of park-and-ride facilities. An SOV traveler may receive en-route traveler information of congested conditions on U.S.-75 and park-and-ride availability at the stations along the DART Red or Orange lines. Proposed DMS message information is simple with incident information and recommendation to "Try DART light rail", while other media may provide more detail about the incident, actual number of park-and-ride lots spaces available, and comparative travel time information.

Note: "Use" does not necessarily result in an action, unless the proposed mode-route option is more attractive than the "historical route," based on the diversion rules. Therefore, "use" reflects an upper bound on the percent of travelers who might divert as a response to the information, with the actual percentage dependent on the attractiveness of the new route and referred to as "compliance."

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As shown in table 2, *awareness* of en-route traveler information increased from 92 percent pre-ICM to 95 percent post-ICM. *Use* levels increased by a little over one percent post-ICM, from 28.3 percent to 29.5 percent, indicating an increase in the relevance of en-route information, while *compliance* levels increased by two percent post-ICM, from 26 percent to 28 percent.

Table 2 provides a summary of modeling assumptions used in pre- and post-deployment AMS regarding awareness, use, and compliance to pretrip and en-route traveler information for both pre- and post-ICM implementation.

Table 2. Modeling assumptions regarding awareness, use, and compliance to traveler information.

	Pretrip (Agency Web Sites, 511, Public Access TV, Local Radio, etc.)			En-Route (DMS, Radio, 511, GPS Devices, etc.)		
	Awareness	**Use**	**Compliance**	**Awareness**	**Use**	**Compliance**
Pre-deployment: *Based on findings from 2005 Perception Tracking survey conducted in Minneapolis.*						
Pre-ICM	60%	10%	1%	50%	20%	10%
Post-ICM	80%	20%	4%	60%	30%	18%
Post-Deployment: *Based on overall findings from panel surveys of U.S.-75 corridor users, conducted by the Volpe Center (not pulse surveys).*						
Pre-ICM	94%	17.4%	16.4%	92%	28.3%	26%
Post-ICM	96%	19.2%	18.4%	95%	29.5%	28%

(Source: Integrated Corridor Management Analysis, Modeling, and Simulation for the U.S.-75 Corridor in Dallas, Texas Post-Deployment Analysis Plan, FHWA-JPO-16-392, p. 34 and Overview of the Dallas Traveler Response Panel Survey - Draft, Volpe Center, 5/18/16.)

Incident Signal Retimings

As part of the ICM deployment, the U.S.-75 ICM stakeholders developed 'flush' signal timing plans to increase arterial throughput and decrease arterial travel time during an incident. The increase in throughput was reflected in DIRECT in the form of signal retiming. Generally, southbound or northbound phases had the green time increased to allow for more throughput along those routes.

Frontage Road Signal Retiming

For a minor incident, signal retiming adjustments may suffice on the frontage roads only. By giving more green time to the southbound or northbound movements on the frontage road, freeway travelers can detour to the frontage road upstream of an incident and return to the freeway downstream of the incident.

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Arterial Street Signal Retiming/Coordination

In addition to the frontage road signal retiming, signal retiming and signal coordination to a strategic arterial may increase corridor throughput. The stakeholders identified Greenville Avenue as the primary arterial for diverted freeway traffic, since it runs parallel to U.S.-75 for nearly the entire length of the freeway corridor, and it also is the closest major arterial with available capacity. This strategy generally included increasing green time to the southbound or northbound movements along Greenville Avenue and sometimes also along the frontage roads.

Parking Availability at Red Line Park-and-Ride Lots

For the mode shift strategies, parking at the Red Line light rail transit (LRT) park-and-ride lots is critical to encourage changes in travelers' behavior. The DART park-and-ride lots toward the north end of the Red Line have been in past years at capacity, with station parking often taking place on adjacent city streets. However, DART recently expanded the Parker Road and the President George Bush Turnpike (PGBT) Stations, which provided the needed capacity for these ICM strategies.

The parking strategy was to implement Smart Parking systems at each of the DART park-and-ride lots on the Red Line along U.S.-75. This is a basic system that continuously collects vehicle counts entering and leaving the lot, and records the number of parking spots available. The first transit-based smart parking field operational test in the U.S. occurred in late 2004 (Source: Rodier, C. J., S. Shaheen, and C. Kemmerer. (2008). Smart Parking Management Field Test: A Bay Area Rapid Transit (BART) District Parking Demonstration; Final Report. *Institute of Transportation Studies*), making this parking strategy an innovative concept at the time it was incorporated into the initial ICM Concept of Operations.

By disseminating information regarding park-and-ride lot availability, traveler's confidence in transit is expected to increase, and potential modal shifts may occur during incidents. Internet, TV, and radio information may include more detail about the actual number of park-and-ride lots spaces available at each station. With ICM and Smart Parking, DIRECT allows the lot to reach full capacity before the park-and-ride lot paths are excluded from the route and mode selection.

Red/Orange Line Capacity Increase

DART has the capability of adding capacity to the Red/Orange Lines through additional train cars or through decreased headways during the off-peak periods only. During peak periods, the frequency of the trains are already operating with the minimum headway required between trains. Under major corridor incidents, it may be beneficial to decrease headways of the Red/Orange Line to increase the person carrying capacity of the LRT system.

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Chapter 6. Performance Measures

This chapter provides an overview of the performance measures used in the Analysis, Modeling, and Simulation (AMS) of Integrated Corridor Management (ICM) strategies for the U.S.-75 Corridor.

The performance measures analyzed by the AMS team focused on the following key areas.

Mobility

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

- **Travel time**—This is defined as the average travel time for the entire length of the corridor or segment within the corridor by facility type (e.g., mainline, high-occupancy vehicle (HOV) lanes, and surface streets), mode, link, individual traveler, and by direction of travel. Travel times were computed for each peak period analyzed.

- **Delay**—This is defined as the total observed travel time less the travel time under uncongested conditions, and is reported both in terms of vehicle-hours and person-hours of delay. Delays were calculated for freeway mainline and HOV facilities, transit, and surface streets, for all travelers individually and cumulatively, in all analysis scenarios.

- **Throughput**—Throughput is measured by comparing the total number of vehicles entering the network and reaching their destination within the simulation time period. The measure ensures that the throughput of the entire system can be utilized as a performance measure for all the scenarios. The corresponding Vehicle Miles Traveled (VMT), Person Miles Traveled (PMT), Vehicle Hours Traveled (VHT), and Person Hours Traveled (PHT) were reported as a macroscopic measure of the general mobility of the corridor.

Reliability and Variability of Travel Time

Reliability and variability capture the relative predictability of the public's travel time. Unlike mobility, which measures how many people are moving at what rate, the reliability and variability measures focus on how much mobility varies from day to day. Travel time reliability was reported in terms of changes in the Planning Time Index, while travel time variability was reported in terms of changes in the standard deviation of average travel time. Since a deterministic mesoscopic model was used (Dynamic Intermodal Routing Environment for Control and Telematics or DIRECT), the AMS team used post-processors to calculate the impacts on the reliability/variability of travel time. Appendix B describes the methodology that was used in calculating reliability and variability impacts.

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Other Measures

Emissions and Fuel Consumption

The U.S.-75 Corridor AMS also produced model outputs for use by the Evaluation Contractor to estimate emissions and fuel consumption, associated with the deployment of ICM strategies. The emissions analysis methodology incorporated reference values to identify the emissions and fuel consumption rates based on variables, such as facility type, vehicle mix, speed ranges, and acceleration ranges. The emissions and fuel consumption rates were based on available sources. Emissions that are principal pollutants of concern include nitrogen oxides (NO_x), particulate matter (PM), hydrocarbons (HC), volatile organic compounds (VOCs), carbon monoxide (CO), sulfur dioxide (SO_2), hazardous air pollutants (toxics), and greenhouse gases (CO_2). Emissions are generally measured in terms of kilograms of output and computed by pollutant, mode, and facility type. Fuel consumption is typically computed by fuel type, mode, and facility type. Fuel consumption is generally measured in terms of gallons of fuel consumed. The broader Evaluation Report will contain the results on the specific measures used to evaluate the impact of ICM strategies on emissions and fuel consumption.

Cost Estimation

For the identified ICM strategies and based on input by the Evaluation Contractor, planning-level cost estimates will be prepared by the Evaluation team for life-cycle costs (capital, operating, and maintenance costs) and therefore, were not a part of this analysis. Typically, analyzed scenarios representing different operating conditions will be combined together, weighted by the probability of occurrence to arrive at a total annual benefit, net annual benefit, and benefit-cost. Please refer to the full Evaluation Report for the final benefit-cost assessment.

Safety

Although safety is an important performance measure to consider, currently, available safety analysis methodologies are not sensitive to ICM strategies. At best, available safety analysis methods rely on crude measures, such as a volume-to-capacity ratio (V/C), and cannot take into account ICM effects on smoothing traffic flow. Clearly, this is an area deserving of new research and as such, no explicit safety analysis was conducted as part of this effort.

Summary of Performance Measures

Table 3 provides a summary of the mobility, reliability, and variability performance measures used to analyze the impacts of ICM. Performance measures which are typically used in evaluating emissions, fuel consumption, and cost estimation are listed.

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Table 3. Summary of performance measure categories and operational characteristics for analysis.

Category	Performance Measure
Mobility	Travel time: average travel time
	Delay: vehicle-hours of delay, person-hours of delay
	Throughput: vehicle miles traveled, person miles traveled, vehicle hours traveled, person hours traveled
Reliability	Planning Time Index
Variability	Changes in the standard deviation of average travel time
Emissions	Kilograms of Nitrogen oxides (NO_x), particulate matter (PM), hydrocarbons (HC), volatile organic compounds (VOCs), carbon monoxide (CO), sulfur dioxide (SO_2), hazardous air pollutants (toxics), and greenhouse gases (CO_2)
Fuel Consumption	Gallons consumed for each fuel type
Cost Estimation	Infrastructure costs and incremental costs for capital costs, operating costs, and maintenance costs
Operational Characteristics	
Facility Type	Mainline, High-Occupancy Vehicle (HOV) lanes, Surface Streets
Mode Type	Drive, Transit
Direction of Travel	Northbound, Southbound
Time of Day	AM peak period, PM peak period, PM off-peak period
Scenarios	with-ICM, without ICM

(Source: Cambridge Systematics, Inc., 2016.)

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Chapter 7. Post-Deployment Analysis, Modeling, and Simulation Approach

Pre-deployment Analysis, Modeling, and Simulation (AMS) activities were associated with AMS support prior to the deployment and activation of Integrated Corridor Management (ICM) systems. Pre-deployment AMS activities focused on the expected impacts and benefits of ICM associated with "as planned" ICM strategies prior to deployment. Pre-deployment AMS activities were intended to both refine and prepare AMS capabilities to represent the "as planned" ICM strategies and to inform an ICM evaluation regarding the type, location, and intensity of potential benefits.

Post-Deployment AMS activities focus on identifying impacts and benefits of the "as-deployed" ICM system. The "as-deployed" ICM strategies may differ from "as-planned" ICM strategies. The differences could include ICM strategies that are not successfully deployed, ICM strategies that are deployed differently from planned because of technical issues, and ICM strategies that are deployed differently to take advantage of enhancements or impacts not anticipated pre-deployment. Further, Post-Deployment AMS activities took full advantage of site-specific traveler behavior and response characterization efforts conducted by the ICM Evaluation team. This includes the refinement of parameters and methods in tools to most accurately reflect traveler behavior in response to ICM strategies.

This chapter describes the post-deployment AMS activities that supported the ICM system for the U.S.-75 corridor. During post-deployment AMS, the tools and methodologies developed in previous AMS efforts were revisited and further evaluated in order to improve the capability of the site-specific tools to represent and evaluate the ICM system. The key objectives of post-deployment AMS include the following:

- Identify and facilitate further enhancements to tools, data, and methods developed from previous AMS activities.

- Conduct modeling analysis using enhanced tools in order to assess the impacts of the ICM strategies deployed in the corridor.

- Provide guidance for the site's ICM deployment and support for the integration of the AMS tools and methods developed with their ongoing corridor management practices.

- Support Demonstration Site-Specific ICM Demonstration Evaluation efforts.

- Manage the successful transition of modeling leadership responsibilities from the AMS contractor to the ICM Demonstration site staff and organizations.

- Provide technical documentation of ICM AMS tool development, data collection and analysis, model calibration and validation methods, and analytical methods deployed to both represent and evaluate ICM impacts.

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To achieve these objectives, post-deployment AMS included the following tasks in order to evaluate the impacts and readiness of the deployed ICM system. Subsequent sections provide further detail on each of the following tasks:

- Enhance tools to reflect as-deployed corridor management. Adjust tools and methods to differentiate the "as-deployed with-ICM" and "without-ICM" alternatives in analytical tools—this was accomplished by modifying model inputs, assumptions, and analytical approaches to reflect as deployed ICM strategies and observed traffic conditions.

- Conduct post-deployment alternatives analysis using most impactful scenarios from cluster analysis and incident matching.

Model Enhancements

This section describes the task items related to coordination and support of the alteration of tool inputs, analytical methodology, and enhancements to analytical software to reflect post-deployment corridor management technologies and strategies. The AMS team coordinated with the U.S.-75 ICM team and the Evaluation team to confirm, refine, and validate the parameters and assumptions that serve as the basis for modeling traveler responses and impacts related to ICM strategies currently present in the models used in the real-time decision support efforts. Dallas Area Rapid Transit (DART) and local stakeholders reviewed the model parameter assumptions to ensure that they sufficiently capture travel characteristics for the corridor and system response times according to the capabilities of their transportation management systems.

Post-deployment AMS work captured the nature of the as-deployed system, including a good representation of traveler responses to ICM strategies, based on site-specific measurements of traveler responses and reactions, conducted in other parts of the ICM program. The AMS team coordinated with both the ICM Demonstration Site and the Evaluation team to clearly identify whether the deployed capability matched the assumptions made for modeling and simulation.

The model enhancements were classified into three categories, including: 1) the model input data; 2) the logic used to model traffic control and travelers' behavior; and 3) other model enhancements.

The input data changes included:

- The travelshed area of the corridor was reduced in post-deployment AMS. This decision was made by the Dallas AMS team after the completion of pre-deployment AMS to better cover the spatial scope of response plans and also facilitate the use of the model as a real-time prediction tool for the Decision Support System (DSS). The network was modified to better represent the travelshed area of the corridor including the strategic diversion routes. Figure 8 provides a depiction of the pre- and post-deployment AMS travelsheds.

- As the model was proposed to support the DSS and the Targeted Event Accelerated Response System (TEARS) analysis, the analysis horizon was extended for the entire day. As such, the demand table was extended to cover the entire day (as opposed to only the AM peak period in pre-deployment AMS).

- The origin-destination demand matrix was adjusted using a select-link analysis to better match the 2014 U.S.-75 and arterial volumes; the Federal Highway Administration (FHWA)

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Traffic Analysis Tools publication titled "Level of Effort Guide for Traffic Analysis" contains a chapter providing step-by-step information on Origin-Destination Matrix Estimation (ODME).

- As part of the model reasonableness assessment effort the Dallas AMS team modified: 1) the travel demands at different model zones, and b) any model network geometries that may have impacts on the results of the Reasonableness Assessment. The first step in adjusting the travel demands was to identify the model links with large volume differences compared to observed volumes. After these links were identified, the next step was to determine how much to adjust the volumes by and where these changes needed to be applied.

- In pre-deployment AMS, the model was used to model the morning peak period with one signal timing plan that covered that period. As the model was extended to cover the entire day, the model input was modified to include multiple signal timing plans that cover different periods of the day.

- The percentage of travelers with access to pretrip and en-route information was modified based on the survey data collected by the Volpe Center team.

The modifications of the model's logic included:

- The model logic was modified to be able to represent multiple signal plans that vary from one period to another.

- As the model's simulation logic was extended to cover a full day of operations, the logic was modified to allow the model to switch from one signal timing plan to another based on the time of day.

- The model logic was modified to have the ability to activate and deactivate a certain response plan as recommended by the DSS.

- The logic was modified to better represent the travelers' route choice under nonrecurrent congestion to allow diversion based on their perception of the congestion ahead and also to allow the diversion to occur at multiple exit ramps upstream of the incident.

- In pre-deployment AMS, the model provided a performance measure summary for the entire period. The performance measures (average travel time, average delays, etc.) were being produced by averaging over all simulated travelers for the entire simulation horizon. As the model was enhanced to support real-time operations, this was changed to produce performance measures based on a moving temporal window. At each five-minute roll, the performance measure statistics were generated for a 30 minute back horizon.

Other model enhancements included:

- The Dynamic Intermodal Routing Environment for Control and Telematics (DIRECT) model used for pre-deployment AMS did not have the ability to calculate impacts on the reliability of travel time, emissions and fuel consumption. The AMS team used post-processors which transformed the DIRECT model outputs into performance measures such as travel time, travel time reliability, and throughput. The post processors also produced inputs to the Evaluation Contractor's impact analysis, including emissions and fuel consumption impacts.

Model enhancements are described in further detail in the following sections.

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Ensure U.S.-75 Integrated Corridor Management System is Accurately Represented in the Model

To more precisely model the operation of the ICM system and evaluate its benefits, the AMS team used ICM operational data to model the timeline from incident detection to ICM response implementation. This allowed the DIRECT model to estimate impacts of the implemented response plans and approximate the DSS process, including resulting "timeline" and "thresholds" used in the actual operation of the system. In addition to calibrating the model for a typical day the Dallas team also conducted a reasonableness assessment for an incident day. The selected real incident occurred on September 24, 2014 and generally blocked two lanes on northbound U.S.-75 at Galatyn between 4 and 5 PM. This day was chosen because it had a major U.S.-75 incident that met DSS criteria for a major incident response plan. This plan had an associated TEARS timing and was implemented during the PM peak in one of the most congested sections of U.S.-75. U.S.-75 detector data were available for that day, along with data for several arterial locations. The Dallas team modeled the incident features at the same location and blocked two lanes for the same amount of time in the northbound direction of U.S.-75. The AMS team conducted a detailed review of model assumptions and code elements to make sure the model accurately represented the operation of the implemented ICM system.

DIRECT Model Better Represents Signal Timings and Phasings

The DIRECT model was modified to improve the way multiphase signal timings were represented in the model so that they closely represent actual field signal operations. DIRECT is now capable of modeling dynamic signal control in which the timing plan could vary by time of day following a known schedule, or due to implementing a specific traffic management plan in response to a nonrecurrent congestion situation. Existing timing plans were collected from Dallas, Richardson, and Plano and then simplified to two-phase timing plans (i.e. approximating split phases, lead/lag left turn phases, etc.). For each timing plan, the phases are defined in terms of permissible maneuvers and the green/red time split. Lanes associated with each permissible maneuver were also defined. In each simulation interval, if a lane is serving a movement that is part of the green phase, the saturation flow rate for this lane was used to discharge the vehicles in that lane. As the phase changed to red, a queue would start to form and incoming vehicles were assumed to join this queue.

The DIRECT model adopted a mesoscopic simulation logic for vehicle movements on links and at the intersections. The simulation interval used by the model is six seconds. The model can still capture the average capacity assigned to the different approaches and translate the capacity reduction during the red intervals into delays on the links, which consequently affect the path travel times and associated traffic assignment results. There will always be a tradeoff between reducing the length of simulation interval and maintaining the model's computational tractability to facilitate modeling a large network.

For normal operations, the schedule for these timing plans followed the local morning, mid-day, and evening timing operation. A new timing plan is activated when the clock time reaches one of these operational periods. The cycle length and phasing data for all intersections were updated according to this timing plan. Similarly, a new timing plan can be activated as part of a deployed response scheme. Once the response scheme is deactivated due to the clearance of the incident, the original timing plan is resumed or the next scheduled plan is activated if its starting time has been reached while the response scheme was active.

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DIRECT Model Represents the Full Peak Periods

Previously, the DIRECT model used the travel demand trip table for a typical morning peak period (6:30 AM to 11:00 AM) with a time step of 15-minutes. The model was enhanced to represent an entire day including continuous peak periods for both AM and PM in both directions. This task involved:

- Developing a time-dependent origin-destination (OD) demand matrix for the entire day. The resolution of this matrix was one hour (i.e., 24 intervals). The demand pattern for each peak period (AM or PM) can be extracted from this model, and can be broken into 15 min intervals, if needed.

- Making sure that no travel demand is "lost" by extending the analysis period as necessary so that no trips that originated their travel in the peak period did not finish their travel in the same peak period.

- Creating the flexibility to extend the analysis period beyond the four-hour period until there is no severe congestion in the model.

After these enhancements, DIRECT can now be used in the offline mode to simulate peak periods considering different combinations of operational conditions and traffic network management strategies.

Traveler Information Sensitivity Analysis

One of the major efforts to enhance the post-deployment model was refining model parameters and structure by modifying traveler information availability to better represent route diversion and mode shift based on Volpe Center surveys. The Volpe Center gathered behavioral data for travelers in the area of the U.S.-75 ICM project through panel surveys. The ICM Evaluation team collected and analyzed field data for the post-deployment period, and the AMS team modeled different operating scenarios (with and without ICM) using post-deployment data as well. Collaboration between efforts were needed to ensure that any major events (i.e., incidents) that occur on the corridor were properly captured/analyzed by all three teams. Furthermore, traveler information parameters and assumptions were collected by both the Volpe Center travel surveys and by the ICM evaluation effort.

The following Volpe survey measures were used in the AMS analysis:

- Percent travelers who made a travel change based on pretrip information (percent of travelers who changed time of departure, route, mode, destination, or decided not to make trip).

- Percent travelers who made a change to their trip (en-route) based on information (percent of travelers who changed route, mode, and destination).

In order to make the DIRECT model better represent vehicle diversion, a panel survey approach was selected whereby the same individuals are surveyed both before and after the deployment of ICM. Since the impacts of ICM are expected to be greatest during incident conditions, the methodology included a series of "pulse" surveys that were administered immediately following incidents in each of the corridors. This enabled the measurement of trip-specific behavior during incident conditions.

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The study population included "regular" users of the main facility in the U.S.-75 corridor. In order to qualify for the survey, individuals had to travel on the facility three or more weekdays per week in either the AM peak period (6-10 AM) and/or the PM peak period (3-7 PM). The study population was constrained in this way for two reasons:

1. Regular users are familiar with the performance of the facility and are likely to be more sensitive to any changes in corridor performance.
2. In order to successfully conduct the pulse surveys, the Volpe Center required a panel of travelers who are regularly on the facility (particularly at congested times of the day, such as the AM and PM peak), so that they maximize the pool of respondents who are eligible to be pulsed for any given incident (and thus increase the likelihood of obtaining responses to the pulse surveys).

The purpose of the survey was to measure the impacts of ICM on travelers in each of the corridors. More specifically, the survey addresses:

- Changes in peak period travel behavior (mode, route, timing, frequency, etc.) due to conditions in the corridor and due to improved traveler information.
- Changes in satisfaction regarding travel/trip experiences in the corridor.
- Ability of travelers to detect improvement in the quality of service in the corridor.
- Changes in awareness of traveler information sources.
- Changes in reported utilization of (frequency, method, timing, etc.) traveler information sources.
- Changes in satisfaction regarding traveler information/sources.

These measures were identified for comparable incidents in the pre- and post-ICM periods (and when a response plan was implemented in the post-ICM period). The "Post-Deployment" section of table 2 outlines the model parameter values derived for awareness and use, based on real data collected from traveler surveys.

Summary of Analysis Settings

The ICM strategies implemented in the "as-deployed" U.S.-75 ICM system, and replicated in the models used for post-deployment AMS include:

- Providing improved multi\modal traveler information (pretrip, en-route) such as:
  - New 511 system (real-time information, including traffic incident information, construction information, traffic speeds, light rail transit (LRT) passenger loads, LRT vehicle locations, Red Line park-and-ride utilization).
  - My511 e-mail alerts.
  - ICM dynamic message sign (DMS) messages.
  - Social media.
  - DART data feeds for third-party application development.
- Implementing a parking management system at Red Line park-and-ride facilities.
- Developing preapproved ICMS response plans.
- Developing a Decision Support System to support ICM strategy identification and selection.

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- Diverting traffic to key frontage roads and arterials (Greenville Ave.) with coordinated and responsive traffic signal control.

- Shifting travelers to transit during major incidents on the freeway.

- Increasing utilization of Red/Orange Line capacity with the potential of additional train cars or decreased headways.

Based on the Volpe Center traveler surveys, the "Post-Deployment" section of table 2 presents the parameters that were used in the AMS related to the travelers' awareness, use and compliance to traveler information:

- "Awareness" represents the portion of travelers who have access to information. For awareness the AMS used the percentages from the Volpe Center's baseline/endline surveys, and they are both in the mid 90-percent range.

- "Use" represents a traveler's intent to take action, but does not necessarily result in an action, unless the proposed mode-route option is more attractive than the "historical route," based on the model's diversion rules. Therefore, "use" reflects an upper bound on the percent of travelers who might divert as a response to the information, with the actual percentage dependent on the attractiveness of the new route and referred to as "Compliance." For better linearity of model functions (nonjumpiness across steps) the model uses this convention, where "compliance"="awareness" * "use".

- This AMS effort (as reported in the "Post-Deployment" section of table 2) used the compliance numbers reported in the pulse summary tables provided by the Volpe Center on June 22, 2015. These are the combined compliance numbers across AM and PM pretrip and en route (unweighted). These traveler responses excluded responses recorded after a major pedestrian fatality incident, because the overall team considered this event as an outlier.

Table 4 shows the analysis settings used for conducting Post-Deployment AMS for the Dallas U.S.-75 corridor.

Table 4. Dallas U.S.-75 Corridor—*summary of post-deployment analysis settings.*

Parameter	Value	Comment
Analysis year	2014	The analysis year was derived from the anticipated completion of design, testing, and deployment of ICM.
Time period of analysis	AM peak period (6 AM to 10 AM) PM peak period (3 PM to 7 PM)	Several incidents that occurred in days representative of different clusters, and for which response plans were activated, were selected to be represented in both AM and PM peak periods. Also, two hypothetical scenarios were selected for analysis, including 1) an incident that occurred between 6 and 8 PM, and 2) a severe incident that occurred between 6 AM and 7 PM that would have triggered a transit mode shift response.
Simulation period	4 hours in each peak period	6-10 AM and 3-7 PM were selected to represent the AM and PM analysis periods.
Freeway incident locations and durations	Based on cluster analysis and presented in table 8-3	These locations experienced incidents, offered the potential for route diversion, had a response plan activated, and had a high impact on corridor travel.

(Source: Integrated Corridor Management Analysis, Modeling, and Simulation for the U.S.-75 Corridor in Dallas, Texas Post-Deployment Analysis Plan, FHWA-JPO-16-392, p. 34.)

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Model Calibration and Reasonableness Assessment

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. 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. Calibration improves the ability of the model to accurately reproduce local traffic conditions. The calibration efforts conducted as part of the ICM initiative exceeded standard calibration efforts by introducing innovative methods such as having specific calibration criteria for incident days and transit. The key steps in model calibration include:

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

Available data on bottleneck locations, traffic flows, and travel times were used for calibrating the simulation model for the analysis of the U.S.-75 corridor. The U.S.-75 Corridor calibration strategy was based on the three-step strategy recommended in the FHWA (US DOT) Guidelines for Applying Traffic Microsimulation Modeling Software (Source: Dowling, R., A. Skabardonis, and V. Alexiadis, *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*, U.S. DOT-HRT-04-040, Federal Highway Administration, July 2004.):

- **Capacity calibration**—An initial calibration is 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 first performed, followed by link-specific fine-tuning. The capacity calibration for the U.S.-75 Corridor was performed utilizing volume data collected by Texas A&M Transportation Institute (TTI) on the corridor freeway, frontage roads and parallel arterials, and from the Texas Department of Transportation (TxDOT) database.
- **Route choice calibration**—Because the U.S.-75 corridor includes parallel arterial streets, route choice calibration plays a significant role in the overall calibration effort. After capacity calibration, this second calibration process is performed with the route choice parameters. A global calibration is first performed, followed by link-specific fine-tuning.
- **System performance calibration**—Finally, the overall model estimates of system performance (travel times and congestion patterns) is compared to the field measurements for travel times and congestion patterns. Fine-tuning adjustments are made to enable the model to better match the field measurements.

Post-Deployment Analysis, Modeling, and Simulation Tool Reasonableness Assessment

Full recalibration of the model system was not expected to be required in the Post-Deployment AMS Phase. However, a Reasonableness Assessment was conducted, where the model inputs and parameters were modified as necessary so that the model can reasonably match Post-Deployment field conditions, including location, extent, and severity of bottleneck locations. The objective of the

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Reasonableness Assessment was to review the post-deployment simulation model, and modify the model inputs accordingly in order to ensure that the model sufficiently replicates and simulates observed travel conditions and congestion patterns on the field during the post-deployment stage of ICM.

The U.S.-75 corridor has seen continued growth north of Plano and more recent developments and growth related to the new State Farm's regional office in Richardson (late 2014), Toyota's US headquarters in Plano (2015), and FedEx Corporate Campus (2015). After 2011, U.S.-75 volumes have increased accordingly, particularly during the peak periods. Thus in the AMS work, the origin-destination demand matrix was adjusted using a select-link analysis to better match the 2014 U.S.-75 and arterial volumes.

Methodology

The Reasonableness Assessment Methodology involved the comparison of the U.S.-75 model volumes, travel times, and speeds (including bottleneck locations) with field observed data from 2014. In order to perform this assessment, the methodology included four steps, as detailed in the following sections.

Step 1. Data Collection

The first step in the Reasonableness Assessment was to obtain the necessary data inputs, including field observed volumes and speeds along the freeway mainline and ramps of the U.S.-75 Corridor, and arterials in the overall corridor area. Such data were being collected and archived as part of the ICM deployment on U.S.-75 and as part of the evaluation effort. Since pre-deployment, TxDOT installed several more Daltrans detectors north of Lyndon B Johnson (LBJ) Freeway. This allowed the Dallas Team to perform volume and bottleneck checks for the entire corridor as opposed to just south of LBJ as in pre-deployment AMS. This was done by adjusting the demand and the speed-flow relationships on selected links until the model sufficiently replicated the temporal and geographical extents of bottlenecks along the corridor.

Volume and speed data were collected in September 2014. Nineteen weekdays were used to define a "typical" day with no major incident response plans recommended by the DSS. The days with major DSS-recommended response plans were filtered out so long as there was enough remaining data to provide reasonable hourly volume averages. Data were generally collected at five-minute intervals but aggregated to hourly volumes and 15-minute speeds, as needed. Volumes were aggregated to hourly target flows and speeds were aggregated to 15-minute contour plots.

Step 2. Reasonableness Assessment Criteria

The Reasonableness Assessment methodology employed similar elements of the model calibration criteria detailed in the United States Department of Transportation (US DOT) "Guidelines for Applying Traffic Microsimulation Modeling Software", including two types of data comparisons:

1. **Volume comparison—**The first part of the assessment determined whether the 2014 U.S.-75 post-ICM deployment model reasonably replicated observed year 2014 volume data. The criteria for comparing flows between model and observed values are summarized in table 5. Note the peak-periods were defined as 6:00 AM to 10:00 AM, and 3:00 PM to 7:00 PM.

2. **Travel speeds and bottlenecks—**The reasonableness of the model's speeds were assessed based on a visual audit comparing speed contour diagrams from observed data with model speed data. Speed contour diagrams depict typical weekday speeds along the

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U.S.-75 Corridor for a 24-hour typical day period. Bottleneck formation and dissipation was verified by matching the field and simulated flow breakdown rate (capacity) at bottleneck locations, verifying bottleneck queues are generally beginning at the same location and time of day in the simulation as in the field, shockwave speeds are consistent between the field and simulation, and queue dissipation and the end of queue are consistent between the field and simulation data.

Table 5. Reasonableness Assessment criteria and acceptance targets.

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

(Source: U.S.-75 Dallas, Texas, Analysis Plan, FHWA-JPO-10-035, p. 37.)

Step 3. Model versus Observed Data Comparison

The third step of the Reasonableness Assessment involved comparing the 2014 model outputs and performance measures against field volume and bottleneck data along the U.S.-75 Corridor. The criteria established in Step 2 were then be utilized to determine whether the model results adequately replicate the field data.

Step 4. Travel Demand and Network Adjustments

Based on the results of the initial comparison conducted in Step 3, additional work was needed in order to adjust: 1) the travel demands at different model zones, and 2) any model network geometries that may have impacts on the results of the Reasonableness Assessment. The first step in adjusting the travel demands was to identify the model links with large volume differences against observed volumes. After these links were identified, the next step was to determine how much to adjust the volumes by and where these changes needed to be applied.

Step 5. Incident Day Model Assessment

For an incident day, the following criteria were used within the context of the model calibration reasonableness assessment:

- **Freeway bottleneck locations.** Should be on a modeled segment that is consistent with the location, design, and attributes of the representative roadway section.

- **Duration of incident-related congestion.** Duration where observable within 25 percent.

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- **Extent of queue propagation**. Should be within 20 percent.

Results—Typical Day

Link Count Comparisons

A total of 40 and 44 freeway mainline (northbound and southbound, respectively) and 40 arterial and frontage road link counts were compared against the modeled count output from the simulation runs for a typical day with no incident. All of the U.S.-75 freeway links and only two frontage road links had volumes higher than 8,000 vehicles (equivalent of 2,000 vph) during both AM and PM 4-hour peak periods. A total of 86 link counts (40 northbound plus 44 southbound plus 2 frontage road) that exceeded the equivalent of 2,000 vph were used in the link count comparisons.

Table 6 summarizes the overall counts from simulation and from field measurements, for all arterial and U.S.-75 locations above the following volume thresholds:

- Average hourly flow of at least 2,000 vph for U.S.-75.
- Average hourly flow of at least 1,000 vph for arterials.

Table 6. Count comparison for all U.S.-75 and arterial locations above vehicle per hour threshold.

Model		Observed		Differences		Percent Error	
6-10 AM	3-7 PM	6-10 AM	3-7 PM	6-10 AM	3-7 PM	6-10 AM	3-7 PM
1,013,998	1,077,412	1,020,291	1,077,829	-6,293	-417	-1%	0%

(Source: Dallas US 75 - Post-Deployment Analysis, Modeling, and Simulation (AMS) Reasonableness Assessment and Tool Modification Technical Memorandum—Final, Cambridge Systematics, Texas A&M Transportation Institute, and Southern Methodist University, 3/12/15, p. 5, unpublished.)

Refer to "Dallas U.S.-75—Post-Deployment Analysis, Modeling, and Simulation (AMS) Reasonableness Assessment and Tool Modification Technical Memorandum—Final" for the detailed observed versus modeled link counts for U.S.-75 northbound, U.S.-75 southbound, and arterial streets.

The summary of link count reasonableness assessment results for a typical, no incident day include:

- About 68 of the 86 links (79 percent) met the 15 percent comparison criterion described in table 5 if all links were considered as equal regardless of their actual volumes. However, when taking into account the volume- or count-weighted impact of different links on the model calibration effort, Criterion 1 is met for individual links for the AM and PM peak periods, individually and combined. Also, the AMS team conducted some additional volume comparisons along key screenlines in the corridor. Link count differences and percent differences are also shown in this table. Overall, 11 out of 12 screenlines (more than 85 percent) showed differences of less than 15 percent between the sums of observed and modeled link volumes. Criterion 1 was also met for screenlines.

- The sum of all model link flows across both peak periods was 1,959,476 while the sum of observed link counts was 1,959,452. These volume sums were well within five percent and thus Criterion 2 was met for the two combined peak periods.

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- The sum of all model link flows in the AM peak period was 911,074 while the sum of observed link counts was 907,721. These volume sums were within five percent and thus Criterion 2 was met for the AM peak period.

- The sum of all model link flows in the PM peak period was 1,048,402, while the sum of observed link counts was 1,051,731. These volume sums were within five percent and thus Criterion 2 was met for the PM peak period.

Delay, Speed, and Bottleneck Comparisons

Another component of the reasonableness assessment criteria is the visual audit of model speeds and bottlenecks. Model versus field-observed speeds and bottlenecks were compared using speed contour diagrams. Figures 11 and 12 compare the speed contour diagrams from simulation and field measurements for southbound and northbound U.S.-75 during a typical day generated using detector speed data versus model outputs.

Comparisons of the detector and model speed contour plots showed that the model was able to sufficiently represent the bottleneck temporal and spatial extents for both southbound and northbound U.S.-75. The one exception to this is the fact that the northbound U.S.-75 speed contour plot using field measurements shows a bottleneck between Legacy Drive and North Parker Road in the afternoon peak period which is not represented in the speed contour plot using simulated data. It is likely that State Highway Spur 399, which is located north of the AMS area and not included in the AMS model, was the cause for that bottleneck. Overall, modeled congestion was well within 10 percent of the observed temporal and spatial extents of observed congestion on the U.S.-75 freeway.

Results—Incident Day

In addition to calibrating the model for a typical day, the Dallas team also conducted a reasonableness assessment for an incident day. The selected real incident occurred on September 24, 2014 and generally blocked two lanes on northbound U.S.-75 at Galatyn between 4 and 5 PM. This day was chosen because it had a major U.S.-75 incident that met DSS criteria for a major incident response plan. This plan has an associated TEARS signal timing plan and was implemented during the PM peak in one of the most congested sections of U.S.-75. U.S.-75 detector data and data at several arterial locations were available for that day as well. The Dallas team modeled the incident features at the same location and blocked two lanes for the same amount of time in the northbound direction of U.S.-75.

Figures 13 and 14 compare the speed contours of northbound U.S.-75 during an incident day generated using detector speed data versus model outputs. Comparisons of the detector and model speed contour plots show that the model was able to sufficiently represent the bottleneck temporal and spatial extents for northbound U.S.-75 during an incident day. Modeled congestion was well within 25 and 20 percent of the observed temporal and spatial extents respectively of observed incident congestion on the U.S.-75 freeway.

Overall Conclusion

Verifying that the model accurately represents the current traffic conditions in the field is an important component of the Reasonableness Assessment. This effort helps to ensure that the post-ICM deployment baseline model is capable of accurately representing road geometries, demands, and

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operational conditions in the year 2014 after the ICM system was deployed. The changes made and the lessons learned through this assessment contribute to the continuous improvement of the AMS approach throughout the various stages of the ICM Initiative.

Through the Reasonableness Assessment, new and more current field data were collected and several network and demand adjustments were completed in order to improve the baseline model. Some network edits were made to better reflect current roadway network. The biggest adjustment to the network was updating all signal timings to the new time-of-day timings as discussed in the "Dallas US 75 Post-Deployment Site AMS Tool Modification Technical Memorandum". The presence of additional information therefore allowed for a more accurate observed dataset to be compared to the model outputs.

The presence of additional detectors and more up-to-date information also allowed the Dallas Team to make the appropriate adjustments to the forecasted demands (such as the select link analysis and the different growth adjustments for U.S.-75 sections). Such adjustments enabled the Dallas Team to identify areas experiencing demand growth/decline as well as other errors that may impact the accuracy of the demand forecasts. The revised demands allow for the model to better represent the post-ICM travel demand and traffic conditions in year 2014.

In order to validate these adjustments, model volumes were compared to field counts. For a typical day with no incident the overall comparison of total model link flows against the aggregate field volumes showed that the model generally meets the suggested link count model calibration criteria. Plus, the overall results of the speed contour comparisons showed that the model was able to sufficiently represent the bottleneck temporal and spatial extents for both southbound and northbound U.S.-75 Corridor. For an incident day the model was also able to sufficiently represent the bottleneck temporal and spatial extents during an incident. Therefore, the Dallas AMS team believed that the model is capable of adequately representing the post-deployment corridor operational conditions and corridor management strategies in the U.S.-75 Corridor.

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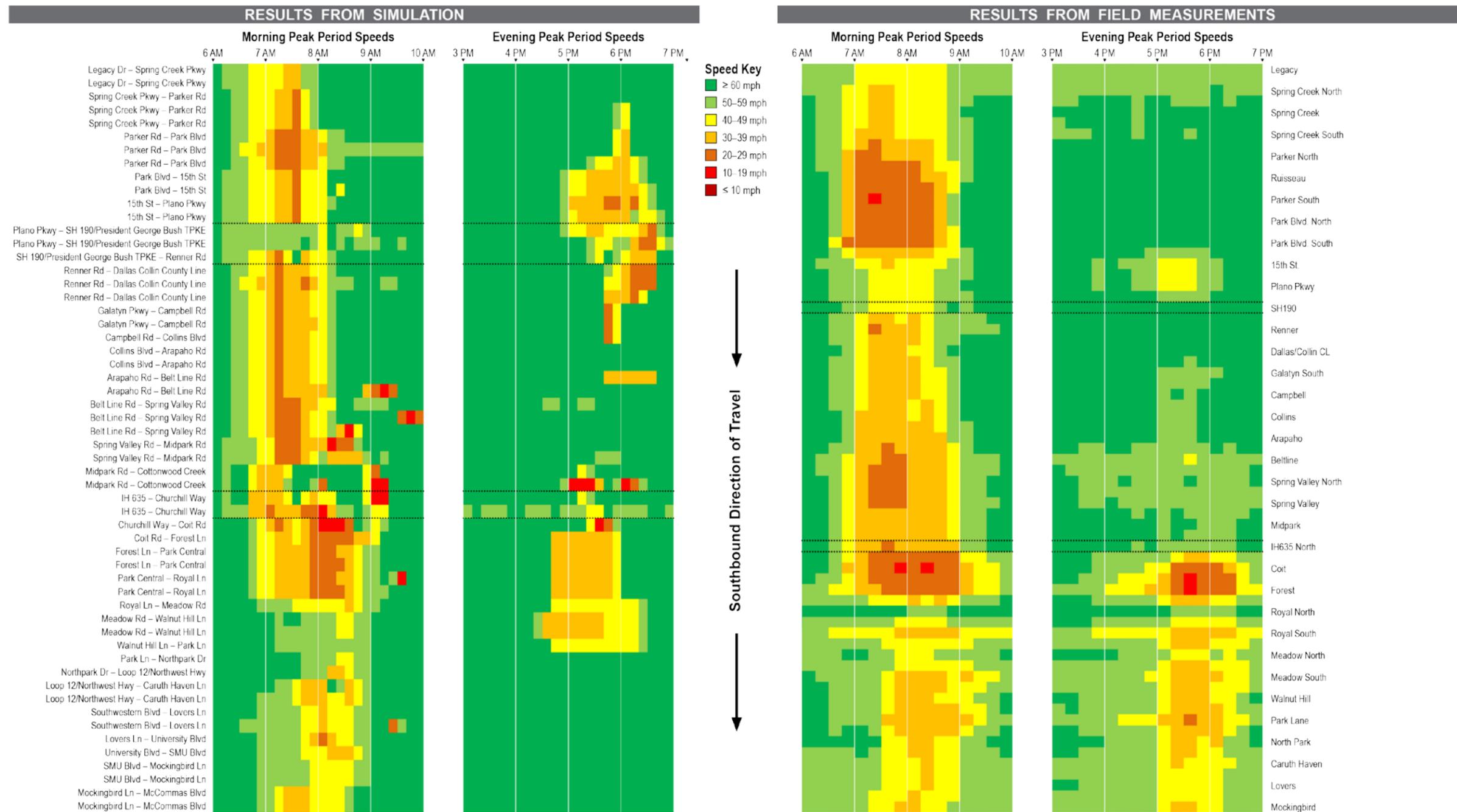
Figure 11. Heatmap. Southbound U.S.-75 modeled and observed speed contours—typical day.
(Source: Dallas US 75 - Post-Deployment Analysis, Modeling, and Simulation (AMS) Reasonableness Assessment and Tool Modification Technical Memorandum—Final, Cambridge Systematics, Texas A&M Transportation Institute, and Southern Methodist University, 3/12/15, p. 14, unpublished.)

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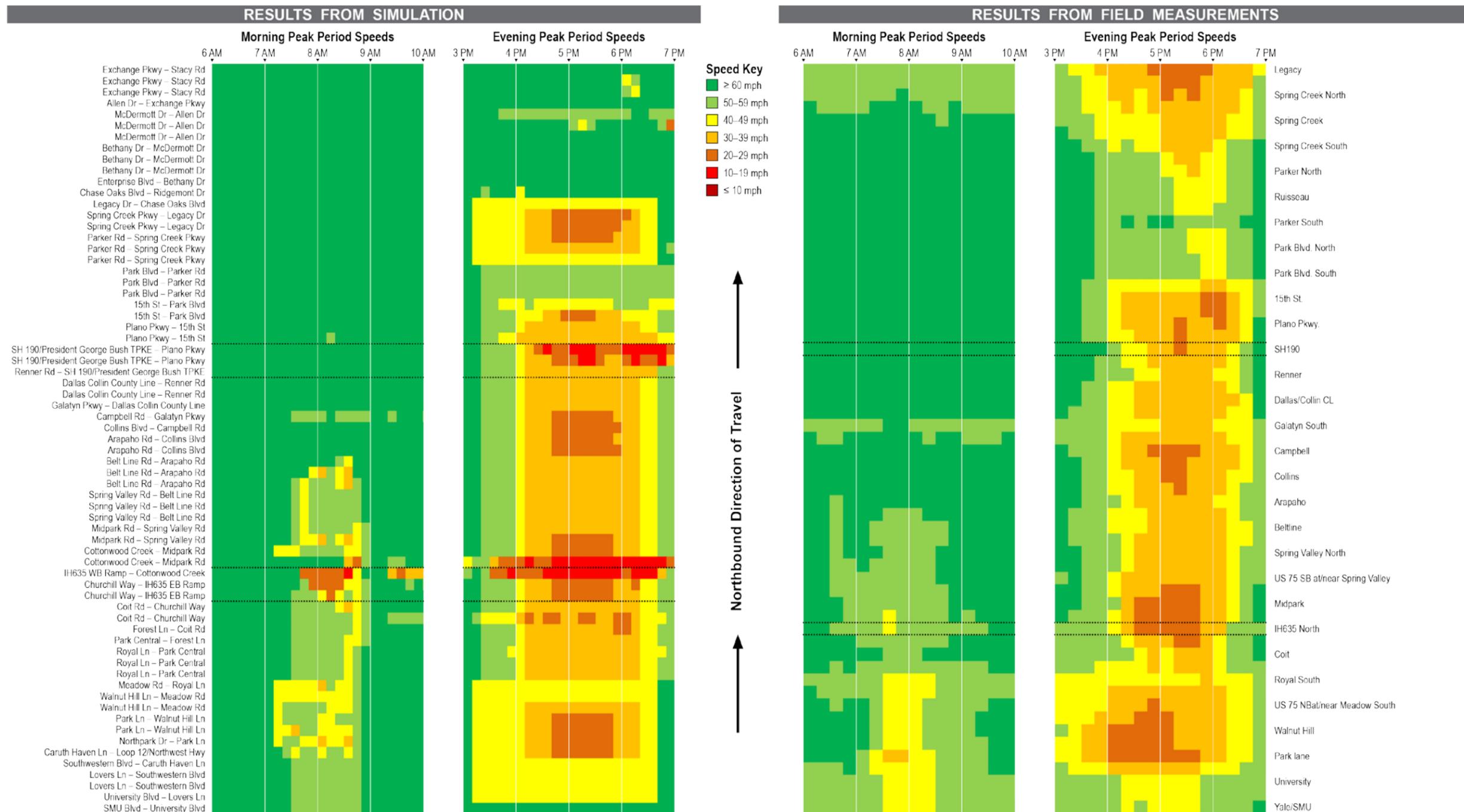
Figure 12. Heatmap. Northbound U.S.-75 modeled and observed speed contours—typical day.
(Source: Dallas US 75 - Post-Deployment Analysis, Modeling, and Simulation (AMS) Reasonableness Assessment and Tool Modification Technical Memorandum—Final, Cambridge Systematics, Texas A&M Transportation Institute, and Southern Methodist University, 3/12/15, p. 15, unpublished.)

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Detector	2:45 PM	3:00 PM	3:15 PM	3:30 PM	3:45 PM	4:00 PM	4:15 PM	4:30 PM	4:45 PM	5:00 PM	5:15 PM	5:30 PM	5:45 PM	6:00 PM	6:15 PM	6:30 PM	6:45 PM	7:00 PM	7:15 PM	7:30 PM	7:45 PM	8:00 PM
US 75 NB at/near Legacy	50.0	54.0	34.0	25.0	30.0	27.0	38.0	52.0	51.0	31.0	26.0	25.0	25.0	22.0	28.0	24.0	25.0	25.0	43.0	54.0	54.0	59.0
	54.5	55.0	40.0	28.0	30.5	27.5	46.0	56.5	55.5	37.0	26.0	27.0	28.5	27.0	33.0	23.0	24.5	27.0	47.5	56.0	55.5	59.0
US 75 NB at/near Spring Creek North	59.0	56.0	46.0	31.0	31.0	28.0	54.0	61.0	60.0	43.0	26.0	29.0	32.0	32.0	38.0	22.0	24.0	29.0	52.0	58.0	57.0	59.0
	60.0	58.5	47.5	30.5	27.0	31.0	59.0	62.0	59.0	44.0	31.0	29.5	30.0	32.5	35.0	25.5	22.0	33.0	53.5	59.0	59.5	59.5
US 75 SB at/near Spring Creek	61.0	61.0	49.0	30.0	23.0	34.0	64.0	63.0	58.0	45.0	36.0	30.0	28.0	33.0	32.0	29.0	20.0	37.0	55.0	60.0	62.0	60.0
	64.5	64.5	55.0	35.5	30.0	44.5	67.5	65.0	61.5	53.5	29.5	26.5	29.5	33.0	31.0	27.0	22.0	33.5	56.0	62.5	65.5	64.5
US 75 SB at/near Spring Creek South	68.0	68.0	61.0	41.0	37.0	55.0	71.0	67.0	65.0	62.0	23.0	23.0	31.0	33.0	33.0	25.0	24.0	30.0	57.0	65.0	69.0	69.0
	64.5	62.0	46.5	33.5	30.0	38.0	48.5	43.0	41.0	38.5	17.5	21.5	25.0	25.5	24.0	23.0	27.0	35.0	59.5	62.5	65.5	65.0
US 75 NB at/near Parker North	61.0	56.0	32.0	26.0	23.0	21.0	26.0	19.0	17.0	15.0	12.0	20.0	19.0	18.0	18.0	21.0	30.0	40.0	62.0	60.0	62.0	61.0
	64.0	60.5	46.5	44.0	37.0	43.0	47.0	42.0	38.0	32.5	33.0	32.5	33.0	30.0	32.0	31.5	30.0	43.0	63.0	61.5	63.5	63.5
US 75 SB at/near Ruisseau	67.0	65.0	61.0	62.0	51.0	65.0	68.0	65.0	59.0	57.0	53.0	45.0	47.0	42.0	46.0	42.0	30.0	46.0	64.0	63.0	65.0	66.0
	68.0	66.0	64.0	63.5	57.5	67.0	69.0	67.5	63.0	59.5	58.5	52.5	51.0	46.5	54.5	50.5	35.5	53.0	65.0	66.0	67.0	67.0
US 75 SB at/near Parker South	69.0	67.0	67.0	65.0	64.0	69.0	70.0	70.0	67.0	62.0	64.0	60.0	55.0	51.0	63.0	59.0	41.0	60.0	66.0	69.0	69.0	68.0
	67.0	65.5	65.0	64.0	62.5	67.0	68.0	68.0	63.5	60.5	62.0	59.0	54.0	52.0	60.0	58.0	46.0	59.5	64.5	66.0	66.5	66.0
US 75 NB at/near Park Blvd. North	65.0	64.0	63.0	63.0	61.0	65.0	66.0	66.0	60.0	59.0	60.0	58.0	53.0	53.0	57.0	57.0	51.0	59.0	63.0	63.0	64.0	64.0
	64.0	64.0	62.0	61.5	60.0	66.0	66.0	65.5	59.0	58.0	58.0	56.0	52.0	52.0	54.5	54.5	55.5	58.5	62.0	64.0	64.5	63.5
US 75 SB at/near Park Blvd. South	63.0	64.0	61.0	60.0	59.0	67.0	66.0	65.0	58.0	57.0	56.0	54.0	51.0	51.0	52.0	52.0	60.0	58.0	61.0	65.0	65.0	63.0
	64.5	63.5	63.0	53.0	51.5	65.5	67.0	65.5	53.0	42.0	42.0	40.5	40.5	40.0	45.0	46.0	61.0	59.5	62.0	64.5	64.5	64.5
US 75 NB at/near 15th St.	66.0	63.0	65.0	46.0	44.0	64.0	68.0	66.0	48.0	27.0	28.0	27.0	30.0	29.0	38.0	40.0	62.0	61.0	63.0	64.0	64.0	66.0
	65.5	63.5	64.0	51.5	49.5	65.0	69.0	66.5	47.0	25.5	29.5	27.5	31.5	28.0	39.0	42.0	62.5	60.5	62.0	64.5	64.5	67.5
US 75 SB at/near Plano Pkwy.	65.0	64.0	63.0	57.0	55.0	66.0	70.0	67.0	46.0	24.0	31.0	28.0	33.0	27.0	40.0	44.0	63.0	60.0	61.0	65.0	65.0	69.0
	65.5	64.0	63.5	60.0	59.0	67.0	69.5	67.5	48.0	23.5	26.5	26.0	30.0	27.5	37.5	49.0	62.5	60.5	62.5	64.0	65.0	67.5
US 75 NB at/near SH190	66.0	64.0	64.0	63.0	63.0	68.0	69.0	68.0	50.0	23.0	22.0	24.0	27.0	28.0	35.0	54.0	62.0	61.0	64.0	63.0	65.0	66.0
	65.5	65.0	65.5	63.5	64.0	68.0	69.0	70.0	51.5	26.0	25.0	25.0	30.0	30.5	37.5	54.5	63.0	61.0	64.0	64.5	66.5	66.5
US 75 SB at/near Renner	65.0	66.0	67.0	64.0	65.0	68.0	69.0	72.0	53.0	29.0	28.0	26.0	33.0	33.0	40.0	55.0	64.0	61.0	64.0	66.0	68.0	67.0
	66.0	64.5	64.5	62.0	64.0	64.0	66.5	67.0	53.5	25.5	26.5	29.0	29.5	28.0	38.5	49.5	63.5	61.0	64.5	66.0	67.5	67.5
US 75 NB at/near Dallas/Collin CL	67.0	63.0	62.0	60.0	63.0	60.0	64.0	62.0	54.0	22.0	25.0	32.0	26.0	23.0	37.0	44.0	63.0	61.0	65.0	66.0	67.0	68.0
	61.5	62.0	59.5	57.0	52.0	35.5	37.0	36.0	47.0	26.5	29.0	37.5	29.5	24.0	38.5	48.0	60.0	58.0	62.5	64.5	63.5	65.0
US 75 NB at/near Galatyn South	56.0	61.0	57.0	54.0	41.0	11.0	10.0	10.0	40.0	31.0	33.0	43.0	33.0	25.0	40.0	52.0	57.0	55.0	60.0	63.0	60.0	62.0
	59.0	60.5	58.0	56.0	45.5	10.5	10.0	9.0	34.0	36.0	40.5	44.5	32.5	27.5	35.5	52.0	56.0	55.0	60.0	62.5	61.5	61.0
US 75 NB at/near Campbell	62.0	60.0	59.0	58.0	50.0	10.0	10.0	8.0	28.0	41.0	48.0	46.0	32.0	30.0	31.0	52.0	55.0	55.0	60.0	62.0	63.0	60.0
	63.0	61.5	60.5	59.0	53.0	10.5	9.0	8.0	25.5	49.0	54.5	51.5	32.0	28.0	30.5	54.5	57.5	57.0	60.5	62.5	63.5	61.0
US 75 NB at/near Collins	64.0	63.0	62.0	60.0	56.0	11.0	8.0	8.0	23.0	57.0	61.0	57.0	32.0	26.0	30.0	57.0	60.0	59.0	61.0	63.0	64.0	62.0
	63.0	61.5	60.5	60.0	58.0	10.0	6.5	6.5	23.0	55.5	58.0	56.5	35.5	32.5	31.0	56.0	58.0	57.5	60.0	62.5	62.5	61.5
US 75 NB at/near Arapaho	62.0	60.0	59.0	60.0	60.0	9.0	5.0	5.0	23.0	54.0	55.0	56.0	39.0	39.0	32.0	55.0	56.0	56.0	59.0	62.0	61.0	61.0
	61.0	61.0	60.0	60.5	60.0	19.5	10.5	11.5	19.0	36.0	36.0	42.0	37.5	40.0	35.0	47.0	46.5	51.5	56.5	62.0	61.0	61.5
US 75 NB at/near Beltline	60.0	62.0	61.0	61.0	60.0	30.0	16.0	18.0	15.0	18.0	17.0	28.0	36.0	41.0	38.0	39.0	37.0	47.0	54.0	62.0	61.0	62.0
	61.0	62.5	61.0	60.5	60.0	35.0	14.5	13.5	11.5	17.0	15.0	22.0	34.5	36.0	37.0	33.5	35.5	42.0	57.5	62.0	62.5	62.0
US 75 NB at/near Spring Valley North	62.0	63.0	61.0	60.0	60.0	40.0	13.0	9.0	8.0	16.0	13.0	16.0	33.0	31.0	36.0	28.0	34.0	37.0	61.0	62.0	64.0	62.0
	61.0	61.0	60.5	59.0	60.5	38.0	15.5	12.5	13.5	18.0	15.0	17.0	30.0	26.5	30.5	27.0	29.5	32.5	60.0	61.5	64.0	62.5
US 75 SB at/near Spring Valley	60.0	59.0	60.0	58.0	61.0	36.0	18.0	16.0	19.0	20.0	17.0	18.0	27.0	22.0	25.0	26.0	25.0	28.0	59.0	61.0	64.0	63.0
	60.5	57.0	50.0	46.5	50.0	36.5	26.0	22.5	21.5	18.0	18.5	18.5	21.0	21.5	26.5	32.0	31.5	34.0	56.5	59.5	63.0	62.0
US 75 NB at/near Midpark	61.0	55.0	40.0	35.0	39.0	37.0	34.0	29.0	24.0	16.0	20.0	19.0	15.0	21.0	38.0	38.0	40.0	54.0	58.0	62.0	61.0	
	60.0	56.5	48.0	46.0	48.0	43.5	29.5	21.5	18.0	15.5	16.5	15.0	17.0	20.5	25.0	31.5	36.0	45.0	56.0	58.5	62.5	60.5
US 75 NB at/near IH635 North	59.0	58.0	56.0	57.0	57.0	50.0	25.0	14.0	12.0	15.0	13.0	11.0	19.0	20.0	22.0	25.0	34.0	50.0	58.0	59.0	63.0	60.0
	60.0	59.5	58.0	56.0	56.0	43.0	32.5	18.5	17.0	15.5	17.5	14.0	20.0	22.5	26.5	33.0	36.5	51.5	59.0	61.5	62.0	61.5
US 75 NB at/near Coit	61.0	61.0	60.0	55.0	55.0	36.0	40.0	23.0	22.0	16.0	22.0	17.0	21.0	25.0	31.0	41.0	39.0	53.0	60.0	64.0	61.0	63.0
	57.0	57.0	49.0	46.0	49.5	38.0	40.0	29.5	25.0	18.5	24.0	20.5	22.5	30.0	34.0	40.5	39.0	47.0	51.0	59.0	57.0	59.5
US 75 NB at/near Royal South	53	53	38	37	44	39	40	36	28	21	26	24	24	35	37	40	39	41	42	54	53	56
	57.0	54.0	39.0	36.0	41.5	38.0	37.0	32.5	26.0	18.5	23.0	21.5	19.5	28.0	32.5	39.0	38.5	40.5	48.0	56.0	57.5	58.5
US 75 NBat/near Meadow South	61.0	55.0	40.0	35.0	39.0	37.0	34.0	29.0	24.0	16.0	20.0	19.0	15.0	21.0	28.0	38.0	38.0	40.0	54.0	58.0	62.0	61.0
	63.0	52.5	34.5	30.5	33.0	30.5	32.5	29.5	24.5	17.5	17.0	18.0	15.5	21.0	28.0	37.5	36.0	36.0	53.5	60.0	63.0	62.5
US 75 NB at/near Walnut Hill	65.0	50.0	29.0	26.0	27.0	24.0	31.0	30.0	25.0	19.0	14.0	17.0	16.0	21.0	28.0	37.0	34.0	32.0	53.0	62.0	64.0	64.0
	63.0	53.0	30.5	26.0	25.0	22.5	28.5	24.5	21.0	17.0	13.0	18.5	17.5	19.5	23.0	29.0	32.0	36.0	57.5	61.0	63.0	62.5
US 75 NB at/near Park lane	61.0	56.0	32.0	26.0	23.0	21.0	26.0	19.0	17.0	15.0	12.0	20.0	19.0	18.0	18.0	21.0	30.0	40.0	62.0	60.0	62.0	61.0
	60.0	57.0	45.5	42.0	40.5	39.5	38.0	35.5	35.0	31.0	19.5	31.5	23.0	28.0	30.0	34.0	44.0	49.5	60.5	56.5	59.0	56.0
US 75 NB at/near University	59.0	58.0	59.0	58.0	58.0	58.0	50.0	52.0	53.0	47.0	27.0	43.0	27.0	38.0	42.0	47.0	58.0	59.0	59.0	53.0	56.0	51.0
	59.5	59.0	60.0	59.0	59.0	60.0	52.5	52.5	52.0	47.0	29.5	42.0	35.5	38.5	40.5	42.5	58.0	59.5	59.0	54.0	56.0	52.5
US 75 NB at/near Yale/SMU	60.0	60.0	61.0	60.0	60.0	60.0	55.0	53.0	51.0	47.0	32.0	41.0	44.0	39.0	39.0	38.0	58.0	60.0	59.0	55.0	56.0	54.0

Figure 13. Heatmap. Northbound U.S.-75 observed speed contours—incident day.
(Source: Dallas US 75 - Post-Deployment Analysis, Modeling, and Simulation (AMS) Reasonableness Assessment and Tool Modification Technical Memorandum—Final, Cambridge Systematics, Texas A&M Transportation Institute, and Southern Methodist University, 3/12/15, p. 16, unpublished.)

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Link\Time	02:50 PM	03:00 PM	03:10 PM	03:20 PM	03:30 PM	03:40 PM	03:50 PM	04:00 PM	04:10 PM	04:20 PM	04:30 PM	04:40 PM	04:50 PM	05:00 PM	05:10 PM	05:20 PM	05:30 PM	05:40 PM	05:50 PM	06:00 PM	06:10 PM	06:20 PM	06:30 PM	06:40 PM	06:50 PM	07:00 PM	07:10 PM	07:20 PM	07:30 PM	07:40 PM	07:50 PM	08:00 PM
US 75 N Legacy Dr TO Chase Oaks Blvd	65	65	46	46	46	46	46	46	35	35	35	35	35	35	35	35	34	34	35	35	40	39	40	35	49	64	65	65	65	65	65	65
US 75 N Spring Creek Pkwy TO Legacy Dr	65	65	46	46	46	46	46	46	35	35	35	35	35	35	35	35	32	32	35	35	38	39	40	35	41	62	65	65	65	65	65	65
US 75 N Spring Creek Pkwy TO Legacy Dr	65	65	46	46	46	46	46	46	35	35	35	35	35	35	35	35	35	35	34	35	40	40	40	35	50	65	65	65	59	52	51	56
US 75 N Parker Rd TO Spring Creek Pkwy	65	65	46	46	46	46	46	46	35	35	35	35	35	35	35	35	35	35	35	35	40	40	40	35	65	65	65	65	65	65	65	65
US 75 N Parker Rd TO Spring Creek Pkwy	65	65	46	46	46	46	46	46	54	54	54	54	44	35	35	30	28	28	33	35	40	40	40	53	50	51	51	51	65	65	61	51
US 75 N Parker Rd TO Spring Creek Pkwy	65	65	65	59	54	54	54	54	54	54	54	54	54	54	45	45	45	45	45	45	54	54	54	54	59	65	65	65	65	65	65	65
US 75 N Park Blvd TO Parker Rd	65	65	65	59	54	54	54	54	54	54	54	54	54	54	45	45	45	45	45	45	54	54	54	54	59	65	65	65	65	65	65	65
US 75 N Park Blvd TO Parker Rd	65	65	65	59	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	59	65	65	65	65	65	65	65
US 75 N Park Blvd TO Parker Rd	65	65	65	59	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	59	65	65	65	65	65	65	65
US 75 N 15th St TO Park Blvd	65	65	65	59	54	46	43	43	53	54	54	54	54	54	45	38	36	36	36	36	43	52	54	45	54	65	61	55	51	51	51	50
US 75 N 15th St TO Park Blvd	65	65	65	59	54	54	54	54	35	35	35	35	35	35	34	22	18	17	16	14	24	40	40	50	59	65	58	60	63	42	32	57
US 75 N Plano Pkwy TO 15th St	65	65	65	59	54	54	50	46	35	35	35	35	35	35	35	35	33	31	28	27	35	40	40	52	59	65	65	65	65	65	84	65
US 75 N Plano Pkwy TO 15th St	65	65	65	59	52	45	41	41	35	35	35	35	35	35	45	35	30	30	30	30	34	34	34	45	54	64	64	64	64	64	64	64
US 75 N SH 190/President George Bush TPKE TO Plano Pkwy	65	65	65	59	54	54	54	46	35	35	35	35	35	35	35	44	28	27	27	27	27	27	27	27	45	63	63	63	63	63	63	63
US 75 N SH 190/President George Bush TPKE TO Plano Pkwy	65	65	65	59	54	54	50	46	35	35	35	35	35	35	45	51	46	41	28	27	27	27	27	27	45	63	63	63	63	63	63	63
US 75 N Renner Rd TO SH 190/President George Bush TPKE	65	65	65	59	54	54	50	46	35	35	35	35	35	35	45	40	34	34	34	34	21	14	11	10	12	38	63	63	63	63	63	63
US 75 N Dallas Collin County Line TO Renner Rd	65	65	65	59	54	54	54	49	46	35	35	35	35	35	35	33	33	34	34	31	23	23	11	10	12	39	64	65	65	65	65	65
US 75 N Dallas Collin County Line TO Renner Rd	65	65	65	59	54	54	50	46	35	35	35	35	35	35	35	30	24	19	18	16	25	20	10	11	17	18	26	52	65	65	65	65
US 75 N Galatyn Pkwy TO Dallas Collin County Line	65	65	65	59	54	54	50	20	12	10	10	10	10	10	11	14	12	14	12	16	16	15	20	36	45	62	65	65	65	65	65	65
US 75 N Campbell Rd TO Galatyn Pkwy	64	65	65	59	54	54	50	20	16	10	10	10	10	11	20	39	32	32	35	17	33	45	51	45	49	55	64	65	65	65	65	65
US 75 N Collins Blvd TO Campbell Rd	65	65	65	59	54	54	50	20	17	15	11	10	10	11	18	31	32	32	32	21	25	35	46	54	59	65	65	65	65	65	65	65
US 75 N Arapaho Rd TO Collins Blvd	65	65	65	59	54	54	50	20	17	17	17	10	10	11	18	31	32	56	43	30	29	49	54	54	59	65	65	65	65	65	65	65
US 75 N Arapaho Rd TO Collins Blvd	65	65	65	59	54	54	50	20	17	17	17	16	10	11	19	31	37	35	35	35	36	38	39	54	59	65	65	65	65	65	65	65
US 75 N Belt Line Rd TO Arapaho Rd	65	65	65	59	54	54	50	20	17	17	17	17	13	11	18	40	36	35	35	34	40	40	40	53	59	65	65	65	65	65	65	65
US 75 N Belt Line Rd TO Arapaho Rd	65	65	65	59	54	54	50	20	18	17	17	18	17	12	10	26	35	35	35	35	40	40	40	54	59	65	65	65	65	65	65	65
US 75 N Belt Line Rd TO Arapaho Rd	65	65	65	59	54	54	50	20	18	18	18	18	18	17	21	33	35	34	34	35	40	40	40	53	59	65	65	65	65	65	65	65
US 75 N Spring Valley Rd TO Belt Line Rd	65	65	65	59	54	54	50	19	17	17	17	17	16	17	21	34	35	35	35	34	40	40	40	52	59	65	65	65	64	65	65	65
US 75 N Spring Valley Rd TO Belt Line Rd	65	65	65	59	54	54	50	20	17	18	17	18	18	18	22	34	35	35	35	35	40	40	40	53	59	65	65	65	65	65	65	65
US 75 N Spring Valley Rd TO Belt Line Rd	65	65	62	59	54	54	50	20	18	18	18	17	17	19	31	35	34	34	35	40	40	40	54	59	65	65	65	65	65	65	65	65
US 75 N Midpark Rd TO Spring Valley Rd	65	65	65	59	54	54	50	46	30	19	17	17	17	17	17	22	27	30	34	35	46	50	54	54	59	65	65	65	65	65	65	65
US 75 N Midpark Rd TO Spring Valley Rd	65	65	65	59	54	54	50	46	30	20	18	18	18	18	18	22	26	31	34	35	46	50	54	54	59	65	65	65	65	65	65	65
US 75 N Cottonwood Creek TO Midpark Rd	65	65	65	59	54	54	50	46	30	20	18	18	17	18	18	22	27	30	34	35	46	50	54	54	59	65	65	65	65	65	65	65
US 75 N Cottonwood Creek TO Midpark Rd	65	51	59	55	38	25	19	25	18	16	15	13	14	13	13	14	13	16	16	16	34	33	33	65	65	65	65	65	65	65	65	65
US 75 N IH635 WB Ramp TO Cottonwood Creek	64	58	64	58	34	25	33	37	24	17	13	14	16	14	13	13	13	12	11	32	32	32	65	65	65	65	65	65	65	65	65	65
US 75 N Churchill Way TO IH635 EB Ramp	65	65	65	59	52	54	54	50	46	30	19	16	17	17	16	16	21	22	22	32	24	37	32	33	31	56	65	65	65	65	65	64
US 75 N Churchill Way TO IH635 EB Ramp	65	65	65	59	53	54	54	50	46	30	19	17	17	17	17	17	20	19	31	34	33	51	55	54	59	65	65	65	65	65	65	65
US 75 N Coit Rd TO Churchill Way	65	65	65	59	54	54	50	46	29	19	17	17	17	17	18	21	26	30	34	34	45	50	54	54	65	65	65	65	65	65	65	65
US 75 N Coit Rd TO Churchill Way	50	64	64	47	43	50	50	40	25	18	16	16	15	16	15	19	26	30	27	27	45	50	54	53	59	65	65	65	61	55	62	
US 75 N Forest Ln TO Coit Rd	48	65	65	59	54	54	50	46	37	21	18	18	18	18	19	26	33	39	42	40	40	40	54	59	65	65	65	65	65	65	65	65
US 75 N Park Central TO Forest Ln	65	65	65	59	54	54	50	46	43	37	32	26	19	17	15	17	22	24	24	24	28	31	33	45	53	62	64	65	65	65	65	65
US 75 N Royal Ln TO Park Central	65	56	57	59	54	54	46	46	43	36	29	26	20	17	16	19	22	24	23	26	27	31	32	40	51	61	62	54	64	65	65	57
US 75 N Royal Ln TO Park Central	65	65	65	59	54	54	50	46	43	35	32	26	20	16	15	17	22	23	26	30	29	31	32	45	51	61	64	65	65	65	65	65
US 75 N Royal Ln TO Park Central	65	65	65	59	54	54	50	46	43	37	32	26	20	16	15	18	22	25	26	27	28	31	32	44	53	61	64	65	65	65	65	65
US 75 N Meadow Rd TO Royal Ln	55	46	46	46	46	46	46	46	43	37	32	26	20	18	18	20	23	25	26	29	29	31	32	45	52	61	64	65	65	65	65	65
US 75 N Walnut Hill Ln TO Meadow Rd	55	46	46	46	46	46	46	46	43	37	32	26	20	17	17	20	23	25	27	30	29	31	33	44	54	61	64	65	65	65	65	65
US 75 N Walnut Hill Ln TO Meadow Rd	55	46	46	46	46	46	37	28	25	23	20	17	15	15	19	22	25	26	29	29	30	33	45	54	61	65	65	65	65	65	65	65
US 75 N Park Ln TO Walnut Hill Ln	58	46	46	46	46	46	37	29	28	26	24	22	20	19	19	21	22	23	25	26	30	32	33	47	56	66	70	70	70	70	70	70
US 75 N Park Ln TO Walnut Hill Ln	58	46	46	46	46	46	37	29	28	26	24	21	20	19	19	21	22	23	25	26	30	32	33	46	56	66	70	70	70	70	70	70
US 75 N Northpark Dr TO Park Ln	55	46	46	46	46	46	37	29	27	25	23	21	18	16	17	19	21	22	24	25	31	36	41	45	52	61	64	65	65	65	65	65
US 75 N Caruth Haven Ln TO Loop 12/Northwest Hwy	55	46	46	45	46	46	40	34	34	34	31	31	34	34	35	34	34	34	34	34	45	50	54	54	59	65	65	65	65	64	65	64
US 75 N Southwestern Blvd TO Caruth Haven Ln	65	65	65	59	54	54	44	34	35	35	34	34	33	35	35	34	35	35	34	34	35	46	50	54	54	59	65	65	65	65	65	65
US 75 N Lovers Ln TO Southwestern Blvd	65	65	65	59	54	54	44	34	35	35	35	35	35	35	35	35	35	35	35	35	46	50	54	54	59	65	65	65	65	65	65	65
US 75 N Lovers Ln TO Southwestern Blvd	65	65	65	59	54	54	44	35	35	35	35	35	35	35	35	35	35	35	35	35	46	50	54	54	59	65	65	65	65	65	65	65
US 75 N University Blvd TO Lovers Ln	70	70	70	62	54	54	44	35	35	35	35	35	35	35	35	35	35	35	35	35	46	50	54	54	62	70	70	70	70	70	70	70
US 75 N SMU Blvd TO University Blvd	65	65	65	59	54	54	54	54	44	46	46	46	46	46	46	46	46	54	54	54	54	54	54	59	65	65	65	65	65	65	65	65
US 75 N Mockingbird Ln TO SMU Blvd	65	65	65	59	54	54	54	54	46	46	46	46	46	46	46	46	46	54	54	54	54	54	54	59	65	65	65	65	65	65	65	65
US 75 N Mockingbird Ln TO SMU Blvd	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65

Figure 14. Heatmap. Northbound U.S.-75 modeled speed contours—incident day.
(Source: Dallas US 75 - Post-Deployment Analysis, Modeling, and Simulation (AMS) Reasonableness Assessment and Tool Modification Technical Memorandum—Final, Cambridge Systematics, Texas A&M Transportation Institute, and Southern Methodist University, 3/12/15, p. 17, unpublished.)

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Chapter 8. Alternatives Analysis and Results

This section provides an overview of the analysis, modeling, and simulation (AMS) efforts associated with the Post-Deployment Alternatives Analysis. The alternatives analysis serves to assess the performance of various components of the Integrated Corridor Management (ICM) system under different operational conditions (e.g., time of day, direction of traffic, duration until the incident was cleared, etc.). The methodologies, tools, and strategies incorporated into the Post-Deployment Alternatives Analysis are documented in this section, including information regarding the alternative scenarios identified for analysis. This AMS work follows the United States Department of Transportation (US DOT)-approved Post-Deployment AMS Plan.

Several facets of analysis results are presented. The pulse survey results from the Volpe Center reveals the percentage of travelers along the U.S.-75 Corridor who made travel changes based on pretrip or en-route traveler information. Main findings from mobility, reliability, and variability performance measures are highlighted and compared against estimated travel time benefits from pre-deployment AMS of the "as-planned" ICM system. Lastly, the ICM AMS methodology is reviewed as a whole, with several takeaways summarized for future improvements.

Analysis Scenarios

Once the models were refined using the enhancements presented in the previous chapter, they were used for testing and analysis that served to assess the impacts of the implemented ICM deployment While ICM is designed to address both recurrent and nonrecurrent events, the evaluation of the Dallas Integrated Corridor Management System (ICMS) focused solely on incident-related events. The potential ICM deployment-related alternatives were identified using cluster analysis that grouped together incidents that occurred under operational conditions (e.g., time of day, direction of traffic, length of time until the incident was cleared, etc.) which were more similar to each other, than to those in other groups (clusters). These clusters were then prioritized based on total delay impact. Field observed incidents that occurred in the year after ICM deployment were matched to high-impact clusters sharing similar operational conditions. Feedback and input from the site coordinators and local agencies were used to select the final eight scenarios included in alternatives analysis, along with two additional hypothetical scenarios. (Please note, the contents of this chapter have been based on a set of memos from the Evaluation Contractor to FHWA titled "ICM Evaluation—Dallas Cluster Analysis—Revised", dated May 19, 2015; and "ICM Evaluation—Dallas Incident Matching—Revised," dated November 13, 2015.)

The AMS team focused on identifying and then representing the "as deployed" system. This includes linking the assumptions in chapter 5 about how the "with" and "without" cases are differentiated and modeled with the cluster analysis. Alternatives analysis were performed primarily by staff from the

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Dallas ICM Demonstration Site (Southern Methodist University and Texas A&M Transportation Institute) in conjunction with Cambridge Systematics, the AMS contractor for the US DOT.

Cluster Analysis

A coordinated cluster analysis was conducted by the Evaluation and AMS teams that characterizes different operational conditions in the U.S.-75 corridor, as well as the frequency of occurrence of these conditions. As a follow up to the clustering analysis done in October, 2014, the Dallas pre-deployment traffic data from August 27, 2012 to April 30, 2013 were reexamined for clustering. In this case, rather than treating each incident on its own, data were collapsed by the day on which the incident occurred, separating incidents according to the period at which the incident took place (6:00-9:59 a.m.—AM; 10:00 a.m.-2:59 p.m.—Midday; and 3:00-7:00 p.m.—PM) and the direction in which the traffic was moving (North or South). In addition, weekends and holidays were not included in the clustering.

Based on expected impact magnitude, proposed clusters of operational conditions were identified using the following variables:

- The day on which an incident occurred.
- The time at which the incident occurred (AM, Midday, PM).
- The direction the traffic was traveling (North or South).
- The number of lanes that were closed during the incident.
- The duration (in minutes) until the incident was cleared.
- The flow of traffic that was traveling during the given time and direction.
- The average number of inches of precipitation that fell on that day.
- The average travel time in minutes.

Data sources for the variables listed above include the Regional Integrated Transportation Information System (RITIS) and the National Weather Service (NOAA).

Table 7 presents a summary of identified clusters for the U.S.-75 corridor. Single incident delay impact is the difference of average travel time and the free flow travel time of 21.24 minutes in the corridor. Total cluster delay impact for each cluster is calculated as the product of the single incident delay impact and number of days in the cluster. The right-most column shows the percent of days in a year that are represented in each cluster for each direction of travel and directional AM or PM peak period. For the southbound morning and northbound afternoon peak direction-periods, no incidents occur about 30 percent of the time; the percentages given in this column are by direction-period. For example cluster NB PM 3 represents an occurrence of 31.4 percent for the PM peak period and in the northbound direction only.

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Table 7. Summary of all clusters for all time periods and both directions, ordered by total cluster delay impact.

Cluster by Direction and Time Period	Number of Lanes Closed	Duration (Minutes)	Precipitation (Inches)	Travel Time (Minutes)	Single Incident Delay Impact (Minutes)	Incidents Per Period	Days In Cluster	Total Cluster Delay Impact (Minutes)	Percent of Time Period
NB PM 3	1.36	22.06	0.07	28.15	6.91	2.55	33	228.03	31.4%
SB PM 1	1.32	21.01	0.05	24.24	3.00	2.57	42	126.00	28.8%
NB PM 2	1.37	23.79	0.03	27.08	5.84	2.24	21	122.64	20.0%
SB AM 2	1.21	17.71	0.03	25.16	3.92	2.63	30	117.60	32.3%
SB AM 1	1.18	22.12	0.06	26.46	5.22	2.91	22	114.84	23.7%
SB PM 4	1.77	41.08	0.01	29.12	7.88	2.92	13	102.44	–
NB PM 4	1.43	24.25	0.05	27.63	6.39	3.14	14	89.46	13.3%
SB PM 2	1.39	24.89	0.03	26.24	5.00	2.54	13	65.00	–
NB PM 1	1.25	24.25	0.04	27.44	6.20	2.60	10	62.00	9.5%
SB MID 1	1.23	20.97	0.04	22.73	1.49	2.17	35	52.15	–
NB MID 3	1.17	19.34	0.03	22.78	1.54	2.13	30	46.20	–
NB AM 3	1.23	22.47	0.07	23.31	2.07	3.00	16	33.12	11.3%
NB AM 1	1.08	14.19	0.02	23.38	2.14	2.80	15	32.10	–
NB AM 4	1.12	17.51	0.06	23.33	2.09	2.53	15	31.35	–
NB AM 5	1.00	13.73	0.01	23.32	2.08	2.33	15	31.20	–
SB MID 3	1.27	20.21	0.06	23.31	2.07	2.50	14	28.98	–
SB PM 3	1.28	19.23	0.07	23.93	2.69	1.80	10	26.90	–
NB MID 4	1.12	16.32	0.04	22.96	1.72	2.50	14	24.08	–
SB MID 2	1.39	23.48	0.04	22.70	1.46	2.88	16	23.36	–
NB PM 6	1.52	41.12	0.00	27.02	5.78	3.25	4	23.12	3.8%
NB MID 2	1.48	32.80	0.04	22.99	1.75	2.62	13	22.75	–
SB AM 5	1.16	26.19	0.32	26.61	5.37	3.25	4	21.48	4.3%
SB AM 3	1.28	50.36	0.03	24.78	3.54	2.50	6	21.24	6.5%
NB MID 1	1.00	16.14	0.03	22.66	1.42	1.70	10	14.20	–
SB MID 4	1.17	24.21	0.00	22.88	1.64	2.13	8	13.12	–
SB AM 4	1.00	39.00	0.00	34.14	12.90	1.00	1	12.90	1.1%
SB AM 6	1.20	14.60	0.00	33.52	12.28	5.00	1	12.28	1.1%
NB PM 5	1.80	132.70	0.06	26.51	5.27	3.00	2	10.54	1.9%

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Table 7. Summary of all clusters for all time periods and both directions, ordered by total cluster delay impact (continuation).

Cluster by Direction and Time Period	Number of Lanes Closed	Duration (Minutes)	Precipitation (Inches)	Travel Time (Minutes)	Single Incident Delay Impact (Minutes)	Incidents Per Period	Days In Cluster	Total Cluster Delay Impact (Minutes)	Percent of Time Period
SB MID 5	1.73	44.07	0.04	24.48	3.24	2.33	3	9.72	–
NB AM 2	1.46	57.67	0.00	23.61	2.37	2.00	4	9.48	–
NB MID 6	1.50	25.62	0.35	23.24	2.00	1.25	4	8.00	–
NB AM 6	1.36	27.89	1.04	24.91	3.67	4.50	2	7.34	–
NB MID 5	2.00	23.20	0.00	25.02	3.78	5.00	1	3.78	–
SB MID 6	1.25	42.12	0.00	22.38	1.14	3.50	2	2.28	–
SB AM 7	1.00	9.00	0.11	22.17	0.93	2.00	1	0.93	1.1%

(Source: ICM Evaluation—Dallas Cluster Analysis - Revised, Battelle, 5/19/15, p. 7, unpublished.)

Incident Matching

The initial focus for incident matching was on clusters for the two peak direction-periods (e.g., southbound-morning and northbound-afternoon). However, the U.S.-75 corridor experiences significant travel volumes during off-peak directions and off-peak periods as well and many off-peak direction-period clusters had a higher total cluster delay impact than other peak direction-period clusters. Since the delay impact was significant and Decision Support System (DSS) response plans were implemented in Dallas for nonpeak direction-periods, these nonpeak direction periods were added to the analysis.

The incident matching process followed the prioritized criteria presented in table 8 below, which shows how close the values must be to be considered a match. For the purposes of the evaluation, it was desirable that incidents from the baseline and post-deployment periods be matched that include variety, both in the cluster types shown above and type of DSS response plan that was implemented—including combinations of plans with and without Targeted Event Accelerated Response System (TEARS) traffic signal timing plan changes, as well as without dynamic message sign (DMS) messaging, with pre-ICM DMS messaging, and with a diversion message developed for ICM, e.g., "Try Greenville Avenue". As such, incident matching was sometimes performed such that an incident with a unique DSS response was matched to a cluster, while in other incidences unrepresented major clusters were matched to a post-deployment incident.

Table 8. Incident matching criteria.

Matching Element	Criteria	Priority
Number of Incidents per period	+/- 1	1
Average Peak Hourly Volume	+/- 5%	2
Average Incident Duration	+/- 20%	3
Number of Lanes Closed	+/- 1	4
Precipitation	+/- 20%	5

(Source: ICM Evaluation—Dallas Incident Matching - Revised, Battelle, 11/13/15, p. 2, unpublished.)

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The U.S.-75 DSS monitors and recommends plans (if warranted) during incidents. Figure 15 shows the incidents that were captured between December 2013 and December 2014, during post-deployment ICM. A total of 200 response plans were issued by the DSS. 35 involved implementable plans, while 165 response plans were information only. On 40 separate occasions, DSS plans were recommended but not implemented, at the discretion of the ICM Coordinator. Incidents are the most frequent causes of nonrecurrent congestion in the corridor, and their frequency of occurrence and impact was documented using ICM archived data, as summarized in table 9; based on these data, incidents were matched with representative days for each of the top cluster scenarios.
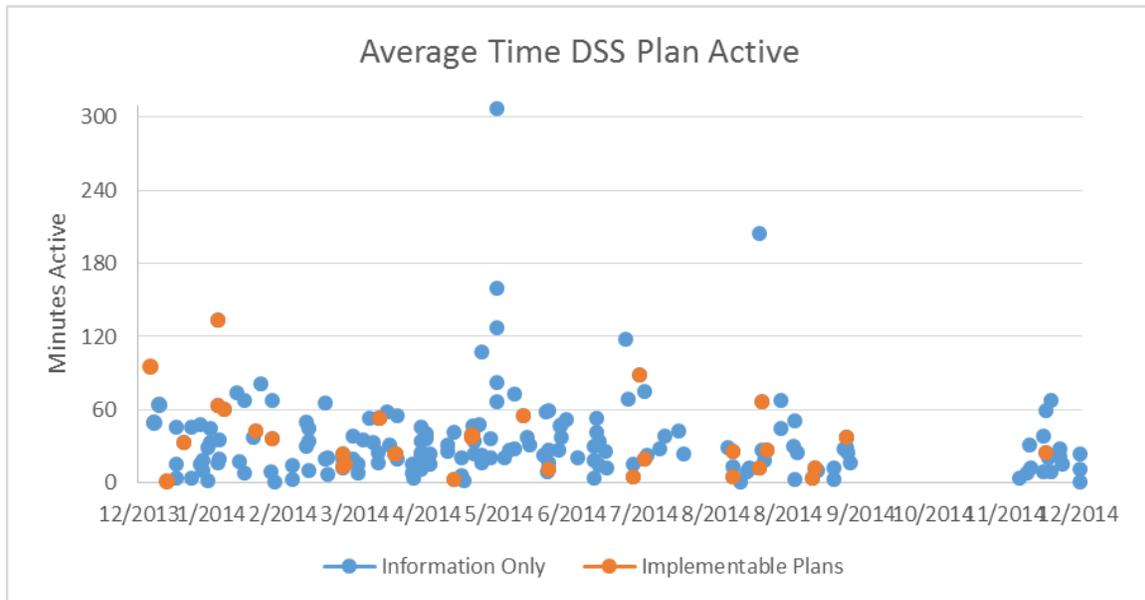
Figure 15. Chart. U.S.-75 Integrated Corridor Management system activations—December 2013 to December 2014.
(Source: Battelle.)

The most impactful clusters of operational conditions were analyzed using the AMS tools, and then compared to the "do nothing" alternatives representing the transportation system without ICM turned on (but with pre-ICM corridor management practices in-place). These comparisons facilitated the evaluation of impacts of the ICM system on the U.S.-75 corridor. The identification of specific incidents representing individual clusters were closely coordinated between the AMS, Evaluation and Volpe Center survey teams so as to ensure that event start and end times, impacts (such as number of lanes closed), and other characteristics were in complete agreement between the AMS, Evaluation and Survey team efforts.

For each one of the most impactful and frequent clusters a representative day with an incident and an ICM response plan was selected for AMS as shown in table 9. Types of DSS response plans include TEARS traffic signal timing plan changes for the Frontage Road and Greenville Avenue, without DMS messaging, with pre-ICM DMS messaging, and with a diversion message developed for ICM (e.g., "Try Greenville Avenue"), as well as incidents with an information only DSS response. All incidents with a DSS response were examined.

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Table 9. Summary of representative days/incidents in the most frequent/impactful clusters during the AM and PM peak periods.

Scenario	Date of Representative Day	DSS Plan Type (TEARS, DMS Message, Intended Diversion)	DSS Plan ID	Total Cluster Day Impact (Minutes)	Percent of Total Time Period
NB PM 1	9/3/14	No TEARS, Information Only	J75N262 PM	62	9.5%
NB PM 2	8/8/14	TEARS, DMS 1, frontage	J75N260 PM	122.64	20.0%
NB PM 3[a]	4/21/14	TEARS, DMS 1, frontage	J75N260 PM	228.03	31.4%
		TEARS, DMS 2, arterial	J75N261 PM		
NB PM 4	5/14/14	No TEARS, Information Only	J75N252 PM	89.46	13.3%
SB AM 1	9/10/14	TEARS, DMS 1, frontage	J75S260 AM	114.84	23.7%
SB AM 2	7/2/14	TEARS, no DMS, frontage	J75S354 AM	117.6	32.3%
SB PM 1	5/23/14	TEARS, DMS 1, frontage	J75S254 PM	126.00	28.8%
NB AM 3	5/5/14	No TEARS, Information Only	J75N162 AM	33.12	11.3%
NB 6-8 PM Hypothetical	6/17/14	TEARS, DMS 1, frontage	J75S260 PM	–	–
Severe Transit Hypothetical[a]	5/2/14	Model: TEARS, DMS 3, transit; Actual: No TEARS, Information Only	J75S250 AM, J75S352 AM, J75S352 MD, N75S301 MD	N/A	N/A

[a] More than one DSS plans implemented for the same event.
(Source: ICM Evaluation—Dallas Incident Matching - Revised, Battelle, 11/13/15, p. 3, unpublished.)

For each one of the most impactful and frequent clusters a representative day with an incident and an ICM response plan was selected for AMS as shown in table 9. Types of DSS response plans include TEARS traffic signal timing plan changes for the Frontage Road and Greenville Avenue, without DMS messaging, with pre-ICM DMS messaging, and with a diversion message developed for ICM (e.g., "Try Greenville Avenue"), as well as incidents with an information only DSS response. All incidents with a DSS response were examined.

Incident matches with response plans issued by the DSS were identified for eight clusters with a fairly high frequency of occurrence as shown in table 9. These incident matches represent a variety of DSS response plans and clusters. The sum of all impacts across the top eight clusters shown in table 9 represents the majority of impacts associated with the implementation of ICM in the U.S.-75 corridor.

Two additional hypothetical scenarios were identified for AMS including:

1. A ninth scenario to examine the potential benefit of extending the operation of the response system up to 8 PM; right now the system operates from 6 AM to 6 PM. An incident that warrants a response was selected that occurred between 6 PM and 8 PM and its duration and number of lanes closed was similar to the average incident that warranted a response in the 6 AM to 6 PM period. In AMS, a response plan was modeled

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that is consistent with the DSS rules for response plan development for the Dallas ICM system. The outcome of the AMS for this scenario will be used by the Evaluation Team in a modified benefit-cost analysis that will examine the potential benefit resulting from extending the system operation period.

2. A tenth scenario was modeled to represent the potential for transit mode shift during a severe incident. Such an incident occurred on May 2, 2014; the incident lasted from 6:33 AM to 4:36 PM. During that time, the ICMS was not fully operational because of coding issues. This AMS scenario examined the potential for mode shift during a major incident.

Model Calibration for Days Representative of each Cluster

An iterative travel demand adjustment process was employed at the start of the analysis of each of the cluster-representative days, so that the model would reasonably represent the travel demand during each particular representative day. This process started by comparing observed versus modeled link volumes in the five links directly upstream of the primary incident during that day. Then the origin-destination (OD) table was iteratively adjusted so that the sum of the modeled volumes in these links came within 15 percent of the sum of the observed volumes in these links.

Table 10 below shows that the calibration process was able to bring the total percent error calculated for each cluster below the threshold value of 15 percent for all 45 hourly time periods, except for one instance of -17% in the NB PM 3 scenario between 3-4 PM. For the totals across all detectors in each cluster, all 10 representative days were represented in the model well within the 15 percent error margin. Therefore, the Dallas AMS team believes that the model is capable of representing the travel demand during each particular representative day. The resulting trip table was then used in modeling both the "with ICM" and "without ICM" scenarios.

Table 10. Aggregated percent error of modeled versus observed cluster volume data.

Scenario	With Incidents and with ICM					Total
NB PM 1	3-4 PM -2%	4-5 PM -12%	5-6 PM -5%	6-7 PM -4%	7-8 PM -7%	-6%
NB PM 2	3-4 PM -12%	4-5 PM 5%	5-6 PM -8%	6-7 PM 8%	7-8 PM -7%	-3%
NB PM 3	3-4 PM **-17%**	4-5 PM 2%	5-6 PM -7%	6-7 PM 11%	7-8 PM 5%	-2%
NB PM 4	3-4 PM 4%	4-5 PM -3%	5-6 PM -1%	6-7 PM -4%	7-8 PM 4%	0%
SB AM 1	6-7 AM -9%	7-8 AM -15%	8-9 AM 0%	9-10 AM -1%	–	-7%
SB AM 2	6-7 AM -5%	7-8 AM -2%	8-9 AM -8%	9-10 AM -14%	–	-6%
SB PM 1	3-4 PM -6%	4-5 PM -6%	5-6 PM 7%	6-7 PM -2%	7-8 PM -11%	-4%
NB AM 3	6-7 AM -2%	7-8 AM -13%	8-9 AM -3%	9-10 AM 9%	–	-3%
NB 6-8 PM Hypothetical	6-7 PM -12%	7-8 PM -11%	8-9 PM 7%	–	–	-6%
Severe Transit Hypothetical	1-2 PM 14%	2-3 PM 2%	3-4 PM -2%	4-5 PM 11%	5-6 PM 8%	6%

(Source: Cambridge Systematics, Inc., 2016.)

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Traveler Survey Results

The report titled *"Integrated Corridor Management Initiative: Overview of the Dallas Traveler Response Panel Survey"* presents findings from the ICM traveler behavior surveys, a set of panel surveys of U.S.-75 corridor users, conducted before and after the deployment of ICM. The purpose of the surveys was to measure the impacts of the ICM initiative on travelers' use of real-time information (pretrip and en-route), their travel behavior in the corridor, and their satisfaction with their corridor trips. In addition to surveying drivers about their general behavior in a baseline and endline survey, pulse surveys were administered immediately following incidents in the corridor to obtain a measure travelers' use of traveler information during incident conditions and its impact on their behavior. A survey of transit riders (light rail) was also conducted. Key findings, based on the US DOT report "Integrated Corridor Management Initiative: Overview of the Dallas Traveler Response Panel Survey", dated May 2016 are summarized below.

U.S.-75 Drivers

Awareness and Use of Traveler Information Sources

In both the baseline and endline surveys, respondents were asked about their awareness and use of specific information sources, including Web sites, apps, alerts, social media, and telephone numbers. For a number of the sources, there is a significant increase in awareness; however this does not translate into increased use. That is, decreases in the percentage who had "never heard of" a source were accompanied by increases in the percentage who had "heard of, but never use" the source.

In the pulse surveys, which collected data for trips in which an incident had occurred, respondents were asked about their use of information sources and devices, both pretrip and during their trip. While the general pattern of information use was similar to that found in the baseline and endline surveys, a comparison of pre and post-ICM pulse surveys did not show an overall increase in the use of apps or smartphones for acquiring real time travel information. Prior to traveling for their morning peak hour trips, pulse survey respondents consulted radio most often (24 percent), followed closely by television (20 percent, with use dropping to 1 percent in the afternoon) and apps (14 percent). Use of these sources did not change across the survey waves. During their trips, radio dominated all sources; respondents consulted this source for approximately one-third of their trips. Electronic highways signs and apps were each consulted for fewer trips (about 10 percent), and again, there are no significant changes from pre to post-ICM. Relative to their use of desktops, laptops, and tablets, however, smartphones were cited most often for acquiring information—both pretrip and during trips.

Travel Behavior in the Corridor

In the baseline and endline surveys, traveler behavior changes were captured only very generally. For a list of possible changes (e.g., minor route changes, completely change route, leave for trip earlier, leave for trip later, switch to transit, telecommute) respondents were asked whether they had made the change - as a result of learning about traffic congestion on their route—in the last month, outside of the last month or never. The question was asked separately for travel behavior changes occurring pretrip versus en-route. Overall, responses on these measures were consistent across the baseline and endline surveys. In response to learning about traffic congestion *prior to leaving for their trip*, respondents were most likely to make route changes; about one-half of respondents had done so in the last month. A relatively large share of respondents changed the timing of their trips, as nearly one

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half of respondents had left earlier for a trip in the past month and about one-third had left later. Relatively few respondents made other types of changes. In fact, in both the baseline and endline surveys, roughly three-quarters of respondents reported "never" having switched mode (e.g. taking transit or carpooling instead of driving), and two-thirds of respondents had never cancelled their trip or telecommuted instead of traveling. With respect to *en-route* changes in travel due to learning about traffic congestion, respondents were again most likely to change their route. While en-route, large majorities have never switched to transit or cancelled their trip—a finding that is consistent in both the baseline and endline surveys.

When asked about changes made in response to information at the trip level (across all pulse surveys), table 11 and figure 17 show an increase in the afternoon peak in the proportion who made a minor route change during their trip (increased from 28 percent pre-ICM to 35 percent post-ICM). Post-ICM, the percentage of travelers who changed their travel plans in response to congestion increased by 10 percent. In addition, table 11 shows that during the morning peak (across all pulse surveys), there was an increase in the proportion completely changing their route both pretrip and during trip (increased from 17 percent pre-ICM to 29 percent post-ICM); however, this change was due to two severe incidents that involved a temporary closure of U.S.-75. Figure 16 shows that when these two pulse surveys are removed from the analysis, the difference becomes negligible.

Table 11. U.S.-75 pulse survey results—changes in travel plans based on real-time information.

Travel Changes	All Pulse Surveys			Excluding Two Pulse Surveys
	AM Peak	PM Peak	Reverse Peak Trips	AM Peak
Minor route changes				
Pre-ICM	19%	28%	11%	18%
Post-ICM	26%	35%	18%	20%
Completely different route				
Pre-ICM	17%	7%	7%	3%
Post-ICM	29%	4%	9%	5%
Left earlier				
Pre-ICM	14%	5%	10%	10%
Post-ICM	11%	8%	13%	6%
Left later				
Pre-ICM	6%	1%	3%	9%
Post-ICM	7%	1%	5%	1%
Changed stops				
Pre-ICM	2%	1%	2%	*
Post-ICM	1%	*	1%	*
Used DART				
Pre-ICM	*	*	*	1%
Post-ICM	*	*	*	*

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Table 11. U.S.-75 pulse survey results—changes in travel plans based on real-time information (continuation).

Travel Changes	All Pulse Surveys			Excluding Two Pulse Surveys
	AM Peak	PM Peak	Reverse Peak Trips	AM Peak
Used other transit				
Pre-ICM	<0.5%	<0.5%	<0.5%	<0.5%
Post-ICM	<0.5%	<0.5%	<0.5%	1%
Carpooled				
Pre-ICM	1%	1%	2%	1%
Post-ICM	<0.5%	<0.5%	<0.5%	<0.5%
Other				
Pre-ICM	5%	1%	<0.5%	7%
Post-ICM	4%	1%	<0.5%	2%
No changes				
Pre-ICM	47%	61%	69%	59%
Post-ICM	30%	51%	58%	66%
Sample Size (Pre-ICM)	**660**	**249**	**187**	**479**
Sample Size (Post-ICM)	**434**	**242**	**523**	**144**

(Source: Overview of the Dallas Traveler Response Panel Survey—Draft, Volpe Center, 5/18/16, p. 93.)
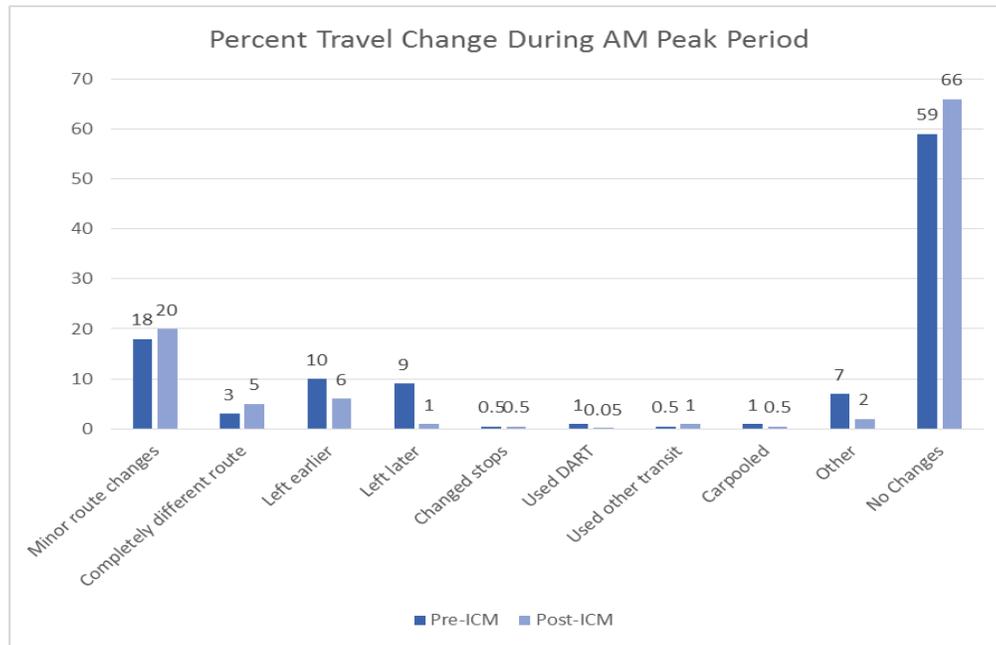
Figure 16. Chart. U.S.-75 pulse survey results—AM peak period travel plan changes (excluding pulse survey outliers).
(Source: Cambridge Systematics, Inc., 2016.)

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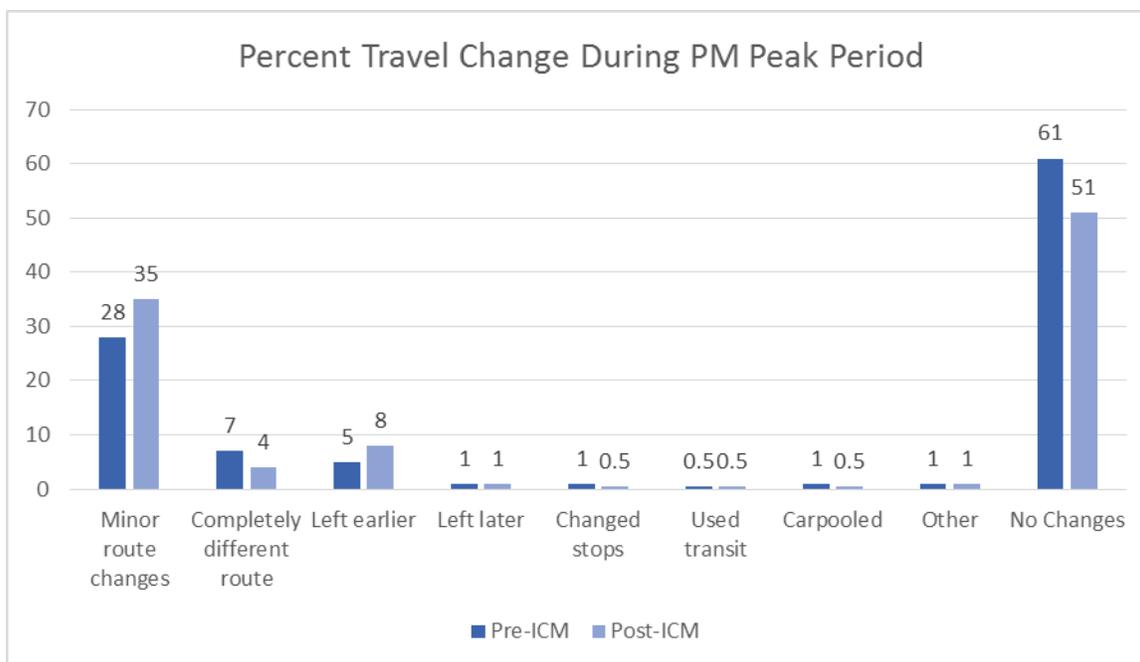
Figure 17. Chart. U.S.-75 pulse survey results—PM peak period travel plan changes.
(Source: Cambridge Systematics, Inc., 2016.)

U.S.-75 Transit Riders

Use of Communication Devices and Real-Time Traveler Information

Transit riders are most likely to use their smartphones to acquire real-time traffic or transit information, and fewer respondents cited regular use of the radio, television or highway electronic signs. Indeed, in comparison to drivers, transit riders were significantly less likely to regularly use the radio (which tends to focus on road conditions) or electronic highway signs. Like drivers, though, transit riders tended to favor Google Maps for their information, as this source dominated both Web site and app use. Other Web sites utilized by a plurality of transit riders included TV and radio station Web sites and the Dallas Area Rapid Transit (DART) Web site. At the time of the survey, the new 511 service had yet to make significant penetration. Only about one-quarter of transit riders were aware of the service and 1 percent reported using it.

Impact of Real Time Information on Travel Behavior

Similar to drivers, transit riders were asked a series of questions about the impact of real time traffic and transit information on their travel decisions, both before making a trip as well as during the trip. More specifically, transit riders were asked if they had made any of the following changes—*prior to leaving for their trip*—as a result of learning about traffic or transit problems:

- Start their trip earlier (20 percent in the last month/38 percent not in the last month/38 percent never).
- Choose a different route to get to the transit station (15 percent in the last month/26 percent not in the last month/54 percent never).

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- Start trip later (14 percent in the last month/31 percent not in the last month/52 percent never).

- Choose to drive or carpool instead of taking transit (14 percent in the last month/22 percent not in the last month/58 percent never).

- Choose a different station to get on DART (11 percent in the last month/28 percent not in the last month/57 percent never).

- Choose a different station to get off DART (10 percent in the last month/26 percent not in the last month/60 percent never).

- Decide to Telecommute (7 percent in the last month/23 percent not in the last month/63 percent never).

- Cancel Trip (6 percent in the last month/20 percent not in the last month/68 percent never).

For each change, no more than one-fifth of respondents had made the change in the last month, and a majority of transit riders had "never" made the change (with the exception of starting their trip earlier).

Similarly, respondents were asked if they had ever made any of the following changes *while en-route*, as a result of learning about traffic problems:

- Wait for a later train due to overcrowding (21 percent).

- Change route to the transit station (12 percent).

- Get off DART at a different transit station (9 percent).

- Use a different station to get on DART (6 percent).

- Turn around and return to trip start (3 percent).

While one-fifth of respondents has had to wait for a later train in the last month, relatively few respondents have made any of the other changes. Again, a majority of respondents indicates never having made each change while en-route (with the exception of waiting for a later train due to overcrowding). Based on the high level of satisfaction with their transit experience, the findings suggest that transit riders generally do not need to alter their trip behavior. In most cases, they are not facing conditions that would require some change in behavior on their part.

Analysis Results

This chapter presents the estimated mobility and reliability performance measures produced through post-deployment AMS. Daily and annual time savings from improved incident management are also presented. Potential travel time benefits for individual corridor users are converted into annual travel time savings and the "as-deployed" ICM system is stacked up against the "as-planned" ICM system.

Performance Measures

In post-deployment AMS, 10 scenarios were analyzed with- and without-ICM. Scenarios included peak and off-peak directions, off-peak periods, as well as a severe incident scenario resulting in a full highway closure. Since a deterministic mesoscopic model (Dynamic Intermodal Routing Environment for Control and Telematics or DIRECT) was used for the simulation, post-processors were used to calculate the impacts on the reliability of travel time. Mobility measures for travel time and throughput

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per scenario can be seen in tables 12 and 13. Reliability measures are presented in table 14. The positive values (bolded) represent results where the deployed ICM system had negative impacts on mobility, reliability, or variability.

Mobility

Travel Time

Table 12 shows mobility analysis results in terms of person hours traveled. The scenarios with the biggest travel time benefits are the peak directions and the ones in which a severe incident has taken place. The SB AM 1 scenario saved 262 person hours traveled in a single 4 hour window. On the other hand, the off-peak direction scenario SB PM 1 saw an increase of 1,546 person hours traveled (+1.41 percent), in the presence of the deployed ICM system.

Table 12. Mobility performance measures—daily Person Hours Traveled.

Scenario	Time Period Reported	Percent of Total Analysis Time Period	Person Hours Traveled			
			with ICM	without ICM	Difference *(With ICM— Without ICM)*	Percent Change *[(With ICM— Without ICM)/ Without ICM]*
NB PM 1	3-7 PM	9.5%	72,020	72,045	-25	-0.03%
NB PM 2	3-7 PM	20.0%	75,845	75,945	-101	-0.13%
NB PM 3	3-7 PM	31.4%	95,906	95,962	-56	-0.06%
NB PM 4	3-7 PM	13.3%	74,029	74,035	-6	-0.01%
SB AM 1	6-10 AM	23.7%	102,645	102,906	-262	-0.26%
SB AM 2	6-10 AM	32.3%	169,584	169,483	**101**	**0.06%**
SB PM 1	3-7 PM	28.8%	109,781	108,234	**1,546**	**1.41%**
NB AM 3	6-10 AM	11.3%	73,084	72,954	**130**	**0.18%**
NB 6-8 PM Hypothetical	6-8 PM	N/A	41,601	41,527	**74**	**0.18%**
Severe Transit Hypothetical (6 hrs)	6 AM-12 PM	N/A	105,881	106,054	-173	-0.16%
Severe Transit Hypothetical (13 hrs)	6 AM-7 PM	N/A	203,358	203,810	-452	-0.22%

(Source: Cambridge Systematics, Inc., 2016.)

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Delay

Delay results, normally represented by person-hours of delay, are reflected in the travel time results shown in table 12.

Throughput

Table 13 shows mobility results in terms of throughput, using PMT as a macroscopic measure of the general throughput in the corridor. The scenarios with the biggest PMT reduction are the southbound AM peak direction and the off-peak directions (SB PM 1 and NB AM 3). The SB AM 2 scenario saved 6,180 person miles traveled in a single 4 hour window. The off-peak direction scenario NB AM 3 also saw a significant reduction of 1,541 in the presence of the deployed ICM system.

None of the mobility performance measures indicated a benefit for extending the operation of the ICM DSS system for an additional two hours until 8 pm. However, the AMS results *do* indicate that ICM would be beneficial to the traveling public during a severe incident. The AMS also forecasted a 5.5-percent increase in transit ridership as a result of providing improved transit information during the severe incident.

Table 13. Mobility performance measures—daily Person Miles Traveled.

Scenario	Time Period Reported	Percent of Total Analysis Time Period	Person Miles Traveled			
			with ICM	without ICM	Difference *(with ICM— without ICM)*	Percent Change *[(with ICM - without ICM) / without ICM]*
NB PM 1	3-7 PM	9.5%	2,354,009	2,354,100	-92	0.00%
NB PM 2	3-7 PM	20.0%	2,381,400	2,381,260	**139**	**0.01%**
NB PM 3	3-7 PM	31.4%	2,237,106	2,237,484	-378	-0.02%
NB PM 4	3-7 PM	13.3%	2,354,520	2,354,394	**127**	**0.01%**
SB AM 1	6-10 AM	23.7%	2,801,627	2,802,871	-1,245	-0.04%
SB AM 2	6-10 AM	32.3%	3,688,483	3,694,663	-6,180	-0.17%
SB PM 1	3-7 PM	28.8%	2,860,504	2,861,408	-904	-0.03%
NB AM 3	6-10 AM	11.3%	2,292,494	2,294,035	-1,541	-0.07%
NB 6-8 PM Hypothetical	6-8 PM	N/A	1,492,763	1,492,746	**18**	0.00%
Severe Transit Hypothetical (6 hrs)	6 AM-12 PM	N/A	3,077,547	3,078,088	-541	-0.02%
Severe Transit Hypothetical (13 hrs)	6 AM-7 PM	N/A	6,272,036	6,272,127	-92	0.00%

(Source: Cambridge Systematics, Inc., 2016.)

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Reliability and Variability

The scenarios were aggregated into four categories based on direction and time period to show the trends in mobility and reliability performance measures, as seen in table 14 below. Travel time reliability is reported in terms of the Planning Time Index, a ratio of the 95th percent peak period travel time to the free flow travel time. Travel time variability is linked to travel time reliability, but is instead reported in terms of the standard deviation of average travel time. The Planning Time Index values increased for all aggregated scenarios. The average travel time standard deviation also increased for all aggregated scenarios, except for the northbound afternoon scenario, which included half of the incident-based scenarios (NB PM 1, NB PM 2, NB PM 3, and NB PM 4).

Table 14. Aggregated mobility, reliability, and variability performance results by direction and time period.

Aggregated Scenario	Time Period Reported	Percent of Total Analysis Time Period	Difference (with ICM—without ICM)				
			Average Travel Time (Second)	Planning Time Index (Percent)	Average Travel Time Standard Deviation (Second)	Person Miles Traveled	Person Hours Traveled
NB AM	6-10 AM	11.3%	**1.26**	**0.0045**	6.5	-1,541.0	**129.6**
NB PM	3-7 PM	74.2%	-0.44	**0.0646**	-1.1	-175.1	-43.9
SB AM	6-10 AM	56.0%	-0.67	**0.0004**	8.0	-3,672.1	-99.0
SB PM	3-7 PM	28.8%	**12.65**	**0.0202**	19.8	-903.8	**1,546.3**

(Source: Cambridge Systematics, Inc., 2016.)

Figure 18 shows the impact the Dallas ICM strategies have on travel time reliability, in terms of changes to the Planning Time Index. For all aggregated scenarios, the Planning Time Index either stays the same, or increases. This means that the deployment of the ICMS causes travelers to need to budget the same amount, if not more time to ensure on-time arrival 95 percent of the time. It is possible that the changes in travel behavior (e.g., minor or completely different route changes, left earlier or later, etc.) due to the availability of actionable traveler information caused an influx in the travel demand on diversion routes, which negatively impacted the travel time reliability for travelers.

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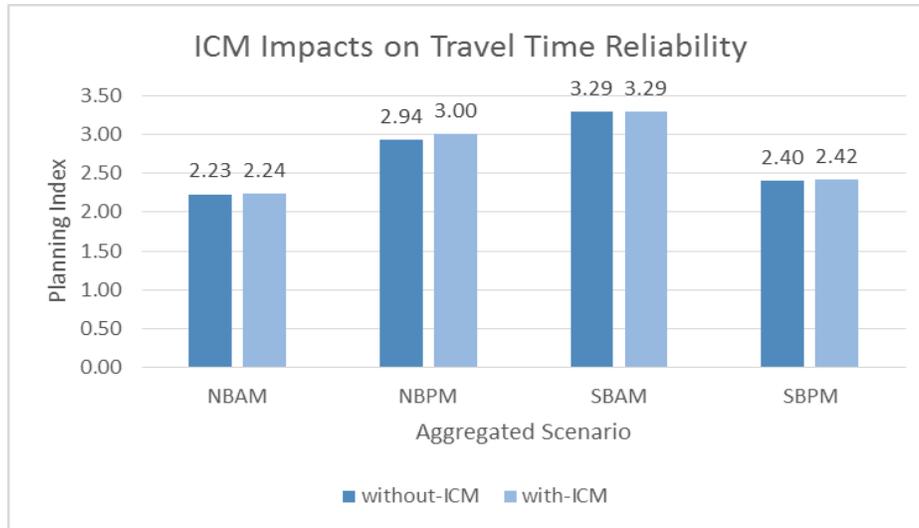
**Figure 18. Chart. Integrated Corridor Management impacts
on travel time reliability—Planning Time Index.**
(Source: Cambridge Systematics, Inc., 2016.)

Response Plan Details for NB PM 2

This section presents the AMS results for one of the representative days (in this case for the NB PM 2 cluster) as an example representing the AMS work that was done for all ten clusters. NB PM 2 represents a minor collision during the PM peak period on U.S.-75 at Galatyn Parkway, as indicated by the pink segment in figure 19. The incident matched to this scenario triggered an implementable response plan which intended to divert traffic to the Frontage Road. To aid in this diversion, a DMS message indicating "US75 North at Campbell Road. Right Lane Closed" was displayed south of the incident at Midpark Road. The TEARS response plan required the City of Richardson and the City of Plano to activate the incident signal timing plan which adjusted the timing of five signals (indicated by the green circles in figure 19) to accommodate the increased demand of traffic along the Frontage Road. After the incident signal timing plan was activated, the agencies monitored traffic every 15 minutes to ensure that the incident management strategy was operating smoothly. As a result, 101 person hours of travel were saved, compared to a similar incident without an operating ICMS. 28.94 percent of travelers along the corridor experienced a decrease in travel time, including an individual experiencing up to an 11 minute travel time reduction.

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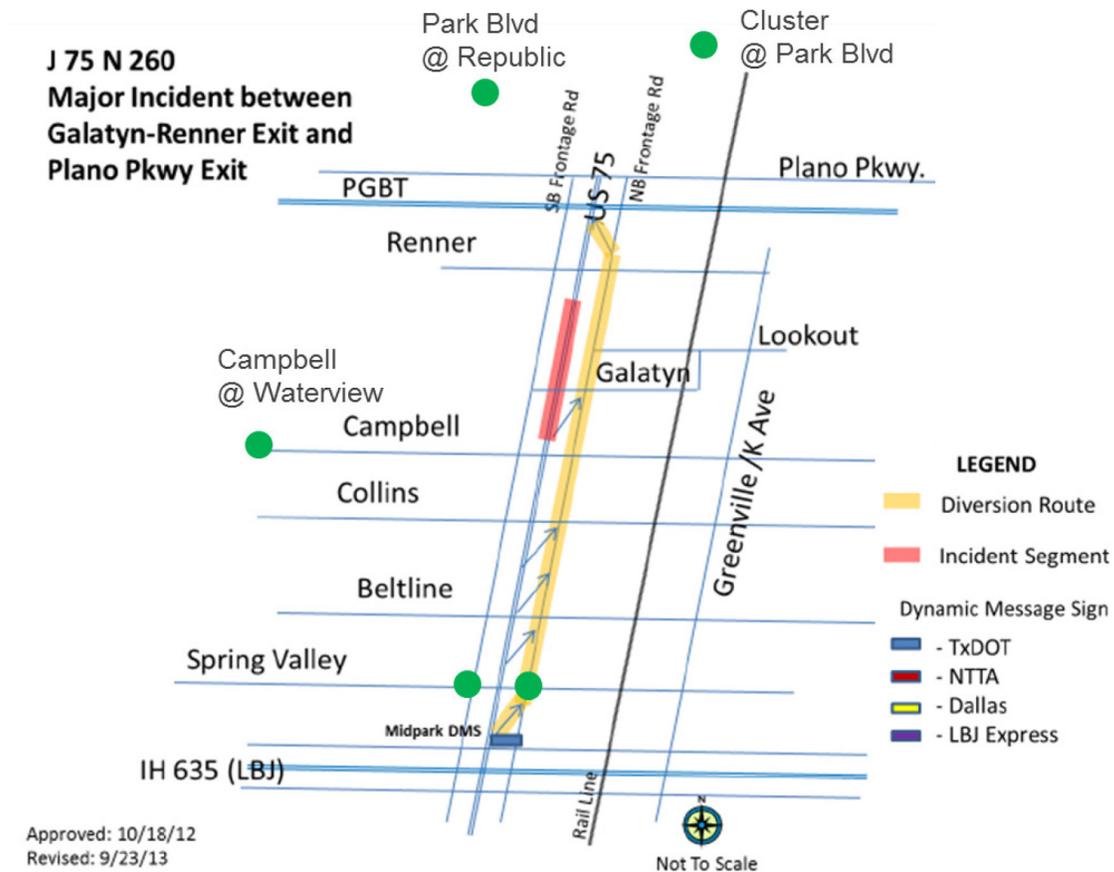
**Figure 19. Diagram. Implementable response plan
for peak direction scenario northbound PM 2.**
(Source: Implementable Response Plans for Stage 3,
Texas A&M Transportation Institute, 11/18/13, p. 86, unpublished.)

Summary

By multiplying the difference in PHT in table 12 by each real scenario's percentage of total analysis time period and assuming 250 workdays in a year, the implementation of ICM is expected to produce savings of 22,004 annual person hours of travel.

Travel time variability improves only in the northbound afternoon aggregated scenario. The scenarios in the northbound peak direction (NB PM 1, NB PM 2, NB PM 3, and NB PM 4) represent 74.2 percent of the total time period. This equates to a cumulative annual variability improvement of 20,145 hours for the northbound afternoon aggregated scenario.

Emissions, Fuel Consumption, and Cost Estimation

The U.S.-75 Corridor AMS also produced model outputs for use by the Evaluation Contractor to estimate emissions and fuel consumption, associated with the deployment of ICM strategies. The data provided to the Evaluation Contractor include: 1) link lengths, link characterization (freeway, major arterial, frontage road, minor arterial) and average grade for all network links; and 2) average hourly

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directional link volumes and speeds for the U.S.-75 freeway, the frontage roads, Greenville Avenue and other strategic and relevant north-south arterials, and arterial links connecting the U.S.-75 freeway to potential diversion routes. The emissions analysis methodology will incorporate reference values to identify the emissions and fuel consumption rates based on variables, such as facility type, vehicle mix, and travel speed. The emissions and fuel consumption rates will be based on available sources. Emissions will be computed by pollutant, mode, and facility type. Fuel consumption will be computed by fuel type, mode, and facility type.

For the identified ICM strategies and based on input by the Evaluation Contractor, planning-level cost estimates will be prepared for life-cycle costs (capital, operating, and maintenance costs). Within each of the capital, operations and maintenance, and annualized cost estimates, the costs are further disaggregated to show the infrastructure and incremental costs. The costs will be estimated for each scenario and a benefit/cost ratio will be assigned to all the individual performance measures. The annualized benefits for each of the measures mentioned above will be calculated using cluster frequencies of occurrence as presented in table 9.

Travel Time Beneficiaries

Table 15 shows the percentage of travelers along the corridor who experienced improved, worsened or unchanged travel times, as a result of the implemented incident response plan. For example, in the SB AM 1 scenario, a TEARS traffic signal timing plan and a DMS message with intended diversion to the frontage road was implemented. As a result, 39.34 percent of travelers experienced a shorter travel time than usual, 36.26 percent of travelers' travel time increased, and 24.4 percent of travelers saw no change in their travel time. Overall, 3.08 percent of travelers in the SB AM 1 scenario experienced a travel time net gain (overall travel time *reduction*). In general, benefits are concentrated in the vicinity of the incidents disrupting flow in the peak direction. Travelers directly affected by the incident would experience the greatest benefits. Travel time benefits were up to 85 minutes for an individual traveler (in the severe incident scenario). The most significant travel time disbenefits occurred during the southbound PM off-peak direction (SB PM 1). Overall, both peak directions (NB PM and SB AM) experience significant travel time benefits.

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Table 15. Travel time-based analysis results.

Scenario	Time Period Reported	Weighted Percent of Total Analysis Time Period	Improved Travel Time	Worsened Travel Time	Unchanged Travel Time	Improved Percent— Worsened Percent	Maximum Travel Time Disbenefit (Minute)	Maximum Travel Time Benefit (Minute)
NB PM 1	3-7 PM	12.8%	14.75%	13.53%	71.71%	1.22%	27.3	20.7
NB PM 2	3-7 PM	27.0%	28.94%	27.64%	43.42%	1.30%	15.8	11
NB PM 3	3-7 PM	42.3%	19.67%	18.17%	62.16%	1.50%	23.7	29.1
NB PM 4	3-7 PM	17.9%	27.42%	26.24%	46.34%	1.18%	22.5	31.7
NB PM (Weighted Avg)	3-7 PM	100%	22.93%	21.58%	55.50%	1.35%	21.8	23.6
SB AM 1	6-10 AM	42.3%	39.34%	36.26%	24.40%	3.08%	62.3	66.7
SB AM 2	6-10 AM	57.7%	34.50%	35.07%	30.44%	**-0.57%**	57.7	42.1
SB AM (Weighted Avg)	6-10 AM	100%	36.55%	35.57%	27.88%	0.98%	59.7	52.5
SB PM 1	3-7 PM	100%	45.28%	52.86%	1.86%	**-7.58%**	88	66.3
NB AM 3	6-10 AM	100%	31.50%	30.83%	37.67%	0.67%	42.4	19.9
NB 6-8 PM Hypothetical	6-8 PM	N/A	35.82%	33.53%	30.64%	2.29%	23.5	19.4
Severe Transit Hypothetical (6 hrs)	6 AM-12 PM	N/A	46.73%	43.73%	9.53%	3.00%	189.6	84.9
Severe Transit Hypothetical (13 hrs)	6 AM-7 PM	N/A	43.81%	41.20%	14.98%	2.61%	189.6	84.9

(Source: Cambridge Systematics, Inc., 2016.)

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"As-Planned" versus "As-Deployed" Analysis, Modeling, and Simulation Results

There were several significant differences between the scope of the pre- and post-deployment analyses. Post-deployment AMS scenarios used a smaller analysis study area from the online model because reducing the AMS area boundaries helped achieve improved computational efficiency in the Decision Support System model. The time period of analysis was also extended for post-deployment analysis. Instead of focusing only on the AM peak period (6-9 AM), both AM (6-10 AM) and PM (3-7 PM) peak periods, as well as PM off-peak periods (6-8 PM) were simulated.

The "as-planned" ICM system included a shuttle service to light rail transit (LRT) private overflow parking, secured via public-private partnerships, and a valet service at the park-and-ride parking expansion lot. However, DART recently expanded the Parker Road and the President George Bush Turnpike (PGBT) Stations, which will provide needed capacity for future ICM strategies, so the "as-deployed" ICM system did not implement the private parking or valet parking strategies. In addition, incident signal retiming plans for arterials and frontage roads were developed in a targeted way to address specific incidents in the "as-planned" ICM system. Post-deployment AMS analysis was reliant on incident signal retiming plans that were developed before ICM deployment. And of these response plans, only a small subset were fully implemented for several reasons including not being able to do full traffic signal retiming analysis and a lack of field controller capability.

Overall Analysis Findings

Overall, the U.S.-75 corridor post-deployment AMS results show consistent travel time improvements in the two peak directions as a result of ICM implementation, and travel time increases in the off-peak directions. It is possible that the limitations in the AMS tools used contributed to some of the counterintuitive results produced by the analysis. Despite the enhancements made to the DIRECT model to better represent signal timings and phasings, the analysis tool still engages a fairly simplistic modeling of traffic signals, using two-phase instead of multi-phase signals. It may also be the case that the ICM system was designed specifically to accommodate route diversion in the peak directions, resulting in a solution which does not produce travel time savings for travelers in the off-peak directions.

Summary of post-deployment AMS key findings:

- For the two peak directions, the expected daily travel time savings are 143 person hours of travel; expected annual savings are 22,004 person hours of travel.
- Travel time does not improve during the off-peak directions.

- Travel time reliability does not improve during peak or off-peak directions.
- Travel time variability improves during the NB PM peak direction; expected cumulative annual variablity improvements is 20,145 hours.
- Travel time benefits were concentrated in the vicinity of the incidents disrupting flow in the peak direction. Travelers directly affected by the incident would experience the greatest benefits, up to 84.9 minutes expected to be saved for an individual traveler (severe incident scenario).

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- A hypothetical AMS exercise examined the potential benefit from extending the operation of the ICM DSS system for two additional hours until 8 PM. No benefits were found in the AMS resulting from this potential action for the scenario analyzed.

- Another hypothetical AMS exercise looked into the potential benefit from engaging the ICM system during a severe incident on U.S.-75 (including diversion to frontage roads, Greenville Ave and transit). Such an incident did occur on May 2, 2014, but the ICM system was not operational during that day. The AMS results indicate that ICM would be beneficial to the traveling public during a severe incident. The AMS also indicates that transit ridership would slightly increase as a result of providing improved transit information during the severe incident—transit ridership increases of up to +5.5% were forecast by the AMS during a severe incident.

- Overall, in 8 out of the 10 scenarios more travelers benefited from ICM, compared to the ones who did not.

Observations

While the Dallas project partners and stakeholders used a systems engineering approach to define the needs for their corridor and the needs and requirements for a system to support ICM as recommended by US DOT (reference figure 1 or ''Integrated Corridor Management: Implementation Guide and Lessons Learned'' for further details), two areas of the U.S.-75 ICMS were observed in the AMS as having the potential to be improved upon to yield even larger mobility and reliability benefits.

Observation #1—Update Response Plans Frequently

It is possible that potential benefits of ICM along U.S.-75 did not achieve optimal levels because the TEARS response plans were generated under different conditions compared to the cluster representative days used to generate the scenarios for alternatives analysis. All response plans were developed in 2011-2012 during pre-deployment AMS and were not updated to accommodate the continued growth along the study area. So in the analysis of off-peak directions these response plans that were developed 18 months prior of the ICM implementation were not found to be necessarily capable of addressing the congestion conditions that were prevalent 18 months later. Response plans are most effective if they match the operational conditions of the incident or event one-to-one. This observation indicates a likely benefit to ICM if the U.S.-75 ICM site creates response plans that are more closely related to the condition they are expected to address and updates them on a regular basis.

Observation #2—Real-time Adaptive Response Plans

It is also possible that the U.S.-75 ICM does not produce significant benefits because of the system's limitation due to its predefined expert rules-based response plans, as opposed to a more adaptive response. The U.S.-75 ICM system was designed around a filtering approach to select from a finite set of predetermined response plans whenever an incident or event occurs. This observation suggests that stakeholders should explore the potential benefits of adopting a more real-time adaptive implementation of ICM.

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Benefits of Analysis, Modeling, and Simulation

The ICM methodology encourages transportation professionals to manage the transportation corridor as a multimodal system, as opposed to managing individual assets, as is traditionally done. The Dallas ICM demonstration involved the coordination of operations along the U.S.-75 corridor, including increased communication and coordination among partner agencies, facilitated by the deployment of an interagency-dependent DSS. AMS aids in the broader goals of ICM Evaluation by providing a framework that can be used to quantify potential and actual benefits of localized ICM strategies. Unlike traditional corridor studies, which often focus on a specific element of a corridor, ICM AMS is a comprehensive approach that analyzes different operational conditions across time and modes and across a large enough geographic area to absorb all impacts.

The AMS methodology and results included in this report demonstrate the feasibility of reducing congestion using ICM. The observations and benefits of AMS listed below highlight the lessons learned through this initiative.

The AMS process provides an invaluable framework for conducting assessments of the potential impacts and benefits of ICM strategies. The analytical complexity involved in these types of assessment goes far beyond what is typically required for more traditional types of transportation investments. The inclusion of multiple facility types (freeway and arterial) and multiple modes complicates the analysis. The focus of the ICM strategies on nontypical operations scenarios (e.g., high demand, incidents, and inclement weather) adds further complexity to the assessment. The AMS procedures provide a pragmatic roadmap to guide practitioners through this complexity while not being too rigid to allow for flexibility in addressing project contingencies.

One major benefit of the ICM AMS methodology for Dallas was that it instigated the use of performance measures to inform and refine the response plans. This allowed AMS to provide insights through measurable results, enabling stakeholders to determine how well the ICM system is working and whether it is accomplishing its goals. This is a major factor that can help agencies determine which transportation investments are worthwhile.

The ICM AMS methodology also builds in continuous improvement through the availability of new data sources. AMS allows agencies to "see around the corner", producing simulations of possible future conditions, allowing agencies to react proactively. AMS offers the flexibility of trying different combinations of traffic mitigation strategies, opening up an envelope of potential benefits, and can also provide more insight to realizing benefits. While models may take effort to set up initially, these models are not only used once. Managers can integrate the methodology with ICM decision support systems to facilitate predictive, real-time, and scenario-based operational decisionmaking. Overall, this helps agencies create better, more informed products and services.

For the ICM Demonstration Sites (Dallas and San Diego), the costs of developing and conducting AMS accounted for approximately five percent of the overall deployment budget. If the analysis was successful in better structuring the deployment to increase the efficiency of the ICM by a minimum of five percent, or reduced the risk of a deployment cost overrun of five percent or more, the investment in AMS paid for itself. The partners at the Demonstration Sites felt there was significant value in AMS which greatly outweighed the analysis costs. The AMS costs for the Demonstration Sites were likely proportionately higher than they would be in future analysis, due to the need to develop and refine new analysis methods and procedures. Hopefully, the best practices from this development

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procedure, highlighted in the Traffic Analysis Toolbox Volume XIII "Integrated Corridor Management Analysis, Modeling, and Simulation Guide", can be leveraged by subsequent practitioners to reduce the costs of conducting these activities.

The Demonstration Sites reported that using AMS not only improved their analysis capabilities for the ICM evaluation, but also served to enhance many existing tools and capabilities that can be applied to analysis of other investments. This analytical capital will enhance future analysis and increase confidence in the models. Some of the improvements reported by the Demonstration Sites included new software modules for analysis of multimodal assignment (transit), congestion pricing, high-occupancy toll (HOT) lanes, ramp metering, and real-time decision support systems. The Demonstration Sites also cited improved data quality control methods and enhanced model calibration procedures as examples of the continuous improvement benefits of the AMS process.

The ICM AMS approach is neither inexpensive, nor easy to accomplish. However, the value gained outweighs the expense and pays dividends throughout an ICM initiative. The lessons learned during this ICM initiative can be applied to other initiatives as well (e.g., Connected Vehicle Pilot Deployment Program). These closing thoughts highlight the benefits of successful ICM AMS planning and implementation:

- **Invest in the right strategies.** The methodology offers corridor managers a predictive forecasting capability 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 optimal 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.

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Appendix A. List of Acronyms

AMS	Analysis, Modeling, and Simulation
AVL	Automatic Vehicle Locator
BRT	Bus Rapid Transit
CO	Carbon Monoxide
CO$_2$	Carbon Dioxide
DART	Dallas Area Rapid Transit
DIRECT	Dynamic Intermodal Routing Environment for Control and Telematics
DMS	Dynamic Message Sign
DOT	Department of Transportation
DSS	Decision Support System
FHWA	Federal Highway Administration
GPS	Global Positioning System
GUI	Graphical User Interface
HC	Hydrocarbon
HOV	High-Occupancy Vehicle
HOT	High-Occupancy Toll
ICM	Integrated Corridor Management
ICMS	Integrated Corridor Management System
ITS	Intelligent Transportation Systems
LBJ	Lyndon B Johnson
LRT	Light Rail Transit
MOP	Measure of Performance
NCTCOG	North Central Texas Council of Governments
NOAA	National Weather Service
NO$_x$	Nitrogen Oxides
NTTA	North Texas Tollway Authority
OD	Origin-Destination
ODME	Origin-Destination Matrix Estimation
PGBT	President George Bush Turnpike
PHT	Person Hours Traveled
PM	Particulate Matter
PMT	Person Miles Traveled
RITIS	Regional Integrated Transportation Information System
SH	State Highway
SMU	Southern Methodist University
SO$_2$	Sulfur Dioxide
SOV	Single-Occupant Vehicle
TEARS	Targeted Event Accelerated Response System
TMC	Traffic Management Center
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation

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V/C	Volume/Capacity
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound

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Appendix B. Performance Measure Calculation Using Simulation

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

Calculation Procedures for Key Integrated Corridor Performance Measures from Simulation Outputs

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

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

Travel Time

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

We record travel time from a single run of the simulation under operational conditions k for this unit of observation as $t_i^k = t_{o,d,\tau',m}^k$. In the case where multiple random seeds are varied, but the operational conditions are identical, this travel time represents an average for a single trip across the multiple runs. Also, note that this discussion of measures assumes that we are calculating measures for a single case (e.g., pre-ICM); later we will address comparisons between cases.

Operational conditions here refer to a specific set of simulation settings reflecting a specific travel demand pattern and collection of incidents derived from a cluster analysis of observed traffic count data and incident data. An example of an operational condition would be an AM peak analysis with 5 percent higher than normal demand and a major arterial incident. Let k be a specific operational condition and the set of all conditions K.

Note that each condition has a probability of occurrence p_k and $\sum_k p_k = 1$.

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

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

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

$$T^k_{o,d,\tau,m} = \frac{\sum_{i \in \mathbf{I}^k_{o,d,\tau}} t^k_i}{n^k_{o,d,\tau,m}} \tag{1}$$

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

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

Next, we calculate the average travel time for this same set of trips across all operational conditions, that is, $\forall k \in K$. Note that it is possible that we may have trips for some o, d, τ, m under some conditions and no trips for the same o, d, τ, m under other conditions. Let $K'_{o,d,\tau,m}$, $K'_{o,d,\tau,m} \subseteq K$ be the subset of conditions where $n^k_{o,d,\tau,m} > 0$.

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

$$T_{o,d,\tau,m} = \frac{\sum\limits_{k \in K'_{o,d,\tau,m}} T_{o,d,\tau,m}^k p_k}{\sum\limits_{k \in K'_{o,d,\tau,m}} p_k} \tag{2}$$

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

$$n_{o,d,\tau,m} = \sum\limits_{k \in K} n_{o,d,\tau,m}^k p_k \tag{2a}$$

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

$$T_{o,d,\tau}^k = \frac{\sum\limits_{m} T_{o,d,\tau,m}^k n_{o,d,\tau,m}^k}{n_{o,d,\tau}^k} \tag{3}$$

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

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

$$T_{o,d,\tau} = \frac{\sum\limits_{k \in K'_{o,d,\tau}} T_{o,d,\tau}^k p_k}{\sum\limits_{k \in K'_{o,d,\tau}} p_k} \tag{4}$$

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

$$n_{o,d,\tau} = \sum\limits_{k \in K} n_{o,d,\tau}^k p_k \tag{4a}$$

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

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

Delay

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

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

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

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

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

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

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

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

$$D_{o,d,\tau,m}^{k} = max\left[T_{o,d,\tau,m}^{k} - T_{o,d,\tau,m}^{0}, 0\right] \tag{7}$$

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

$$D_{o,d,\tau,m} = \frac{\sum_{k \in K_{o,d,\tau,m}'} D_{o,d,\tau,m}^{k} p_{k}}{\sum_{k \in K_{o,d,\tau,m}'} p_{k}} \tag{7a}$$

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

$$D_{o,d,\tau} = \frac{\sum_{m} D_{o,d,\tau,m} n_{o,d,\tau,m}}{n_{o,d,\tau}} \tag{8}$$

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

Systemwide average trip delay (Equation 9):

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

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

$$\widehat{D} = \sum_{\forall o,d,\tau} D_{o,d,\tau} n_{o,d,\tau} \tag{10}$$

Travel Time Reliability

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

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

$$\mathrm{T}_{o,d,\tau,m} = \left[T_{o,d,\tau,m}^1, T_{o,d,\tau,m}^2, \cdots, T_{o,d,\tau,m}^J \right] \text{ where } T_{o,d,\tau,m}^j \le T_{o,d,\tau,m}^{j+1} \text{ for all } j = 1 \cdots J. \tag{11}$$

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

$$T_{o,d,\tau,m}^{[95]} = T_{o,d,\tau,m}^j \text{ where } \sum_{k=1}^{j} p_k = 0.95 \tag{11a}$$

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

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

$$\rho_{o,d,\tau,m} = \frac{T_{o,d,\tau,m}^{[95]}}{T_{o,d,\tau,m}^0} \tag{12}$$

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

$$\rho_{o,d,\tau} = \frac{\sum_m \rho_{o,d,\tau,m} \, n_{o,d,\tau,m}}{n_{o,d,\tau}} \tag{12a}$$

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

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

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

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

Variance in Travel Time

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

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

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

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

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

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

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

Throughput

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

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

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

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

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

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

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

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

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

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

Estimation of Travel Times and Travel Distance for Incomplete Trips

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

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

The average distance traveled over these trips is:

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

Note: If $\ddot{n}^0_{o,d,\tau} = 0$ then $\ddot{X}^0_{o,d,\tau}$ is indeterminate. In this case, find τ', the closest time interval such that

$\underset{\tau'}{\arg\min} |\tau' - \tau|$ where $n^0_{o,d,\tau'} > 0$. Approximate $\ddot{X}^0_{o,d,\tau}$ using $\ddot{X}^0_{o,d,\tau'}$.

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

$$\bar{v}^k_i = \frac{\bar{x}^k_i}{\bar{t}^k_i} \tag{25}$$

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

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

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

Comparing Pre-ICM and Post-ICM Cases

All of the travel time and throughput measure calculation procedures defined above are conducted under a single set of simulation settings reflecting a specific set of corridor management policies, technologies and strategies (here referred to as a *case*, but often called an *alternative*). The complete suite of delay, travel time

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reliability and throughput measures are calculated independently for each case (e.g., Pre-ICM or Post-ICM). Comparisons of the resulting measures are then made to characterize corridor performance under each case.

Comparing Observed and Simulated Performance Measures

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

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