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San Diego I-15 Demonstration Integrated Corridor Management System

PATH Report on Stage 3: Site Demonstration and Evaluation

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EXECUTIVE SUMMARY

This report describes activities that were performed along a section of the I-15 corridor in San Diego County for Stage 3 of Phase 3 of the federally sponsored USDOT Integrated Corridor Management (ICM) Initiative. This document reports more specifically on activities surrounding the design, building, deployment, operation, and evaluation of an innovative corridor management system aiming to improve mobility within the I-15 corridor by integrating the operations of the I-15 freeway with the surrounding arterials and transit systems.

The USDOT ICM initiative was launched in 2006 with the aim of advancing the state of practice in managing congestion in multi-modal transportation corridors. A key objective was to demonstrate how operations strategies and Intelligent Transportation Systems (ITS) technologies could be used to proactively manage the movements of people and goods in major transportation corridors through the integrated management of all transportation networks within a corridor. Other objectives were to develop a toolbox of operational policies, cross-network operational strategies, integration requirements and methods, and analysis methodologies needed to implement effective ICM systems, and to demonstrate how ITS technologies could be used to coordinate the operations among various transportation networks in a corridor to increase the effective use of the total available transportation capacity.

Following some foundational research, in the first phase of the ICM initiative, on the state of corridor management in the United States and, in the second phase, the development of a framework to model, simulate, and analyze ICM strategies, the third phase of the Initiative focused on the development and evaluation of actual ICM systems. This phase was executed in three stages. Activities within the first stage led to the development of a concept of operations for eight corridors across the country. This was followed in the second stage by simulation evaluations of three of the eight corridors. The third stage then saw the development, deployment, and evaluation of demonstration ICM systems along the US-75 corridor in Dallas, Texas, and I-15 corridor in San Diego, California.

Deployment of the I-15 ICM Demonstration System was under the leadership of the San Diego Association of Governments (SANDAG). Additional key system stakeholders included Caltrans District 11, the City of San Diego, the City of Poway, the City of Escondido, San Diego's Metropolitan Transit System (MTS), and the North County Transit District. Technical expertise for the design and development of the I-15 ICM System was further provided by Kimley-Horn and Associates, Transport Simulation System (TSS), and Delcan (now part of Parsons). In addition to the above core team of developers and operators, Cambridge Systematics provided both pre-deployment and post-deployment simulation evaluations of potential system benefits that could be expected from the proposed system concept. Staff from the U.S. Department of Transportation, Batelle Memorial Institute, and the Volpe National Transportation Systems Center were further tasked with conducting the formal evaluation of resulting system benefits and operational impacts.

In the above context, PATH was tasked with providing technical support and guidance to other project team members upon their request. PATH was not assigned either to lead any of the project tasks or to prepare any of the deliverables. Despite this limited role, PATH's guidance was sought throughout the project on various issues. In addition to commenting on the content of various plans and reports produced by the project's management and development teams, PATH's technical guidance was sought on various system design and evaluation issues. This included providing guidance on the use of simulation by the proposed decision support system to evaluate corridor operations, the development of rules to identify

and assess incidents, and the development of rules to trigger the creation of response plans addressing the congestion generated by these incidents.

Development of the I-15 Demonstration ICM System resulted in a March 2013 system launch. This was followed by a six-month shakeout period during which system parameters were gradually adjusted. Following final system acceptance tests in January and February 2014, the system was officially activated in March 2014. This was a partial activation, as not all planned features were initially activated. For instance, this initial system had very high thresholds for triggering the implementation of recommended response plans and required manual operator approval for all implementations. Automated response capabilities and lower thresholds were gradually implemented over the following month, with the final major changes occurring in November 2014. Post-deployment operational evaluations were initiated in the fall of 2014 and were expected to end in December 2015. This is 18 months later than initially projected, largely due to unexpected delays in activities related to system development and deployment.

Throughout this process, a strong emphasis was placed on the application of systems engineering principles to support the development of the demonstration ICM system. While this is a requirement for all Intelligent Transportation Systems (ITS) projects receiving federal funds, following the systems engineering process was credited by the project team with having contributed significantly to the success of the project. Many of the project deliverables were in fact imposed by the application of the systems engineering principles. This includes the development of the initial concept of operations and systems requirements documents and the development of the Project Management Plan (PMP) and Systems Engineering Management Plan (SEMP). It also includes the development of various project plans, such as plans outlining what data were to be collected and how, how specific system components were to be tested, how the overall system was to be verified and validated, how it was to be operated, and how it was to be evaluated.

While full system evaluations were not yet available when this report was written, the deployed I-15 ICM system had already demonstrated its ability to identify incidents and unusual congestion events, to develop traffic management strategies integrating freeway, arterial, and transit operational elements, and to implement recommended strategies either automatically or following approval by relevant system operators. The system has also demonstrated the feasibility of using a microscopic traffic simulation model in a real-time operational environment to forecast corridor operations under alternative scenarios. Simulation evaluations have further consistently shown operational benefits exceeding deployment costs.

1. INTRODUCTION

This report constitutes the final deliverable for Agreement 65A0377 – *San Diego Integrated Corridor Management Stage 3 Demonstration and Evaluation* – between Caltrans’ Division of Research, Innovation, and System Information (DRISI) and Partners for Advanced Transportation Technology (PATH) at the University of California, Berkeley. As part of this agreement, PATH was to provide support to a team led by the San Diego Association of Governments (SANDAG) for the development, deployment, and evaluation of a demonstration Integrated Corridor Management (ICM) system along a section of the I-15 corridor extending through the cities of San Diego, Poway, and Escondido in Southern California.

This work was executed as part of the United States Department of Transportation (USDOT) ICM initiative. This initiative was launched in 2006 with the aim of advancing the state of practice in managing congestion in multi-modal transportation corridors. A key objective was to demonstrate how operations strategies and Intelligent Transportation Systems (ITS) technologies could be used to proactively manage the movements of people and goods in major transportation corridors through the integrated management of all transportation networks within a corridor. Other objectives were to develop a toolbox of operational policies, cross-network operational strategies, integration requirements and methods, and analysis methodologies needed to implement effective ICM systems, and to demonstrate how ITS technologies could be used to coordinate the operations among various transportation networks in a corridor to increase the effective use of the total available transportation capacity.

Following some foundational research, in the first phase of the ICM initiative, on the state of corridor management in the United States and, in the second phase, the development of a framework to model, simulate, and analyze ICM strategies, the third phase of the Initiative focused on the development and evaluation of actual ICM systems. This phase was executed in three stages. Activities within the first stage led to the development of a concept of operations for eight corridors across the country. This was followed in the second stage by simulation evaluations of three of the eight corridors. The third stage then saw the development, deployment, and evaluation of demonstration ICM systems along the US-75 corridor in Dallas, Texas, and I-15 corridor in San Diego, California.

This report summarizes activities associated with the deployment of the ICM system for the I-15 corridor in San Diego. This summary is organized as follows:

- **Section 2: Background Information** – General descriptions of the ICM concept and of the systems engineering process that was followed for the design, building, and validation of the I-15 ICM system.
- **Section 3: Summary of USDOT ICM Initiative** – Summary of the various activities that were conducted across the United States as part of the USDOT ICM Initiative since its inception in 2006.
- **Section 4: Corridor Description** – Description of the key features of the section of the I-15 corridor that was selected for the deployment of the demonstration ICM system.
- **Section 5: I-15 ICM Concept** – Summary of the concept for the I-15 ICM system that was developed by SANDAG and other regional partners.
- **Section 6: Stage 3 ICM Demonstration Tasks** – Identification of the key tasks of Stage 3 of Phase 3 of the I-15 ICM Demonstration effort. This includes both a summary of the general tasks that were to be executed by the San Diego Demonstration Team and other contractors under the

USDOT ICM Initiative and a summary of PATH's contracted tasks as part of Agreement 65A0377 with Caltrans' Division of Research, Innovation, and System Information (DRISI).

- **Section 7: Summary of Stage 3 Activities** – Summary descriptions of the outcomes of Stage 3 activities. This includes descriptions of the system components that were developed or procured and, where available, descriptions of the outcomes of the various system evaluations that were conducted.
- **Section 8: Summary of PATH Activities** – Summary of activities that were executed by PATH as part of the I-15 demonstration project.
- **Section 9: Lessons Learned** – Identification of the various lessons that were learned throughout the project regarding the design, building, operation, and evaluation of the I-15 ICM system, as well as ICM systems in general.

2. BACKGROUND INFORMATION

This section provides background information on the following concepts associated with the I-15 ICM Demonstration project:

- Integrated Corridor Management
- Systems engineering process

2.1. INTEGRATED CORRIDOR MANAGEMENT CONCEPT

Integrated Corridor Management, commonly known as ICM, focuses on the coordinated management of transportation systems within a corridor. This includes freeways, arterials, transit, and parking systems. The operational goal is to manage corridors as a single system rather than as a collection of separate systems. This approach not only seeks the coordination of transportation systems covering various travel modes, but also coordination among the institutions responsible for operating these systems. An ICM system can be viewed as a “system of systems,” i.e., as an overarching system that connects individual management systems and enables joint operations according to a set of operational procedures agreed to by the owners and operators of the various systems involved.

In the context of ICM, integration is a bridging function among the various systems that make up a corridor. This involves the development of processes and activities promoting the seamless operation of the collection of systems. Depending on the situation, this integration may occur in several ways:

- **Operational integration** — Implementation of multi-agency transportation management strategies, often in real time, that promote information sharing and cross-network coordination and operations among the various transportation networks in a corridor and that facilitate management of the total capacity and travel demand of the corridor.
- **Institutional integration** — Coordination and collaboration among various agencies and jurisdictions in support of ICM, including the distribution of specific operational responsibilities and the sharing of control functions in a manner that transcends institutional boundaries.
- **Technical integration** — Provision of the means, such as communication links, system interfaces, and associated standards, by which information and system operations and control functions can be effectively shared and distributed among networks and their respective transportation management systems, and by which the impacts of operational decisions can be immediately viewed and evaluated by the affected agencies.

A key general objective behind the development of ICM systems is to improve corridor mobility and safety for travelers and goods. Depending on the corridor and management needs, objectives that are more specific may also be considered, such as increasing corridor throughput, improving travel time reliability, improving the management of incidents and special events, and facilitating intermodal travel decisions. Desired objectives are further typically achieved by considering sets of improvement strategies intended to provide better information, coordinate junctions between networks, proactively manage available transportation capacity and travel demand across networks and modes, deploy advanced technologies and systems, and/or improve institutional arrangements.

Depending on the situation, ICM initiatives may simply lead to the development of a set of coordinated operational procedures agreed to by the various network operators involved, or to the development of a physical corridor management system connecting individual transportation management systems with a centralized decision support tool.

2.2. SYSTEMS ENGINEERING PROCESS

Systems engineering is an interdisciplinary approach that was developed to enable the realization of successful systems [8]. This approach focuses on defining customer needs and required functionality early in the development cycle, documenting the requirements, and then proceeding with design synthesis and system validation while considering the complete problem. The goal is to define project requirements before technology choices are made and the system is implemented. To accomplish this, the systems engineering process attempts to integrate all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production and to operation, and which can consider both the business and the technical needs of all customers.

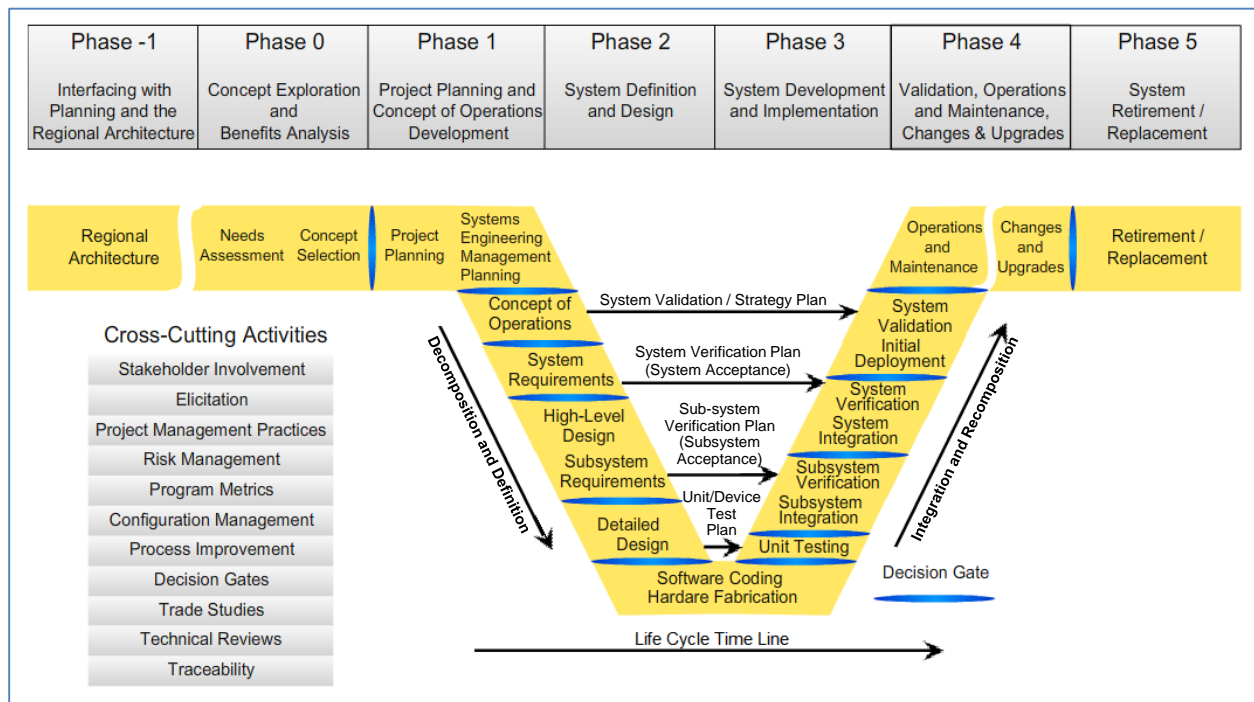


Figure 2-1 – Systems Engineering “V” Diagram Process

Figure 2-1 [9], commonly referred to as the “V Diagram,” illustrates how the systems engineering process is typically applied to ITS projects. As the figure shows, the process is usually decomposed into seven phases:

- Phase -1 – Interfacing with Planning and the Regional Architecture** – The systems engineering process generally starts with a need to interface with the regional ITS architecture and consider feasibility studies and concept exploration that may support initial identification and scoping of a project. The gap shown between this step and the next one illustrates that these considerations are not directly part of a project but of broader general discussions about regional transportation needs and separate planning processes.

- **Phase 0 – Concept Exploration and Benefits Analysis** – This phase is used to perform an initial needs assessment and feasibility analysis of a proposed project. These evaluations typically result in the development of a business case and cost/ benefit analyses for alternative concepts. Outcomes often include definitions of the problem space, key technical metrics, and refinements to the needs, goals, objectives, and vision.
- **Phase 1 – Project Planning and Concept of Operations** – This phase, which often marks the visible start of a project, seeks to plan the activities of the project and to develop a vision of how the proposed system is to operate and meet the needs and expectations of its various stakeholders.
- **Phase 2 – System Definition and Design** – Following the approval of a Concept of Operations by all corridor stakeholders, project activities focus on the definition and design of the proposed system. This process generally starts with identifying the system’s requirements, which are then used to develop detailed specifications for the system. In this process, the system is decomposed into subsystems, and the subsystems into components. As decomposition progresses, the system requirements are also decomposed into more specific requirements allocated to each system component.
- **Phase 3 – System Development and Implementation** – This phase is where the envisioned system is built. It involves hardware fabrication, software coding, database implementation, the procurement and configuration of commercial products purchased off the shelf, and the installation of field elements. Activities to verify that the developed or delivered components match their documented design are also included in this step.
- **Phase 4 – Validation, Operations and Maintenance, Changes and Upgrades** – This phase starts with an assessment of system performance to ensure that it meets the needs of the stakeholders and the system goals identified in the Concept of Operations. Following validation, the system starts to carry out the intended operations for which it was designed. Staff training is also conducted. System maintenance activities are further initiated, and repairs performed when needed. This phase is generally the longest, as it extends through the evaluation of the system and ends with its retirement or replacement.
- **Phase 5 – System Retirement/Replacement** – This phase monitors system performance against needs and technology obsolescence, and determines the need for retirement or replacement of the entire system or some of its components. Eventually, the developed system will be retired or replaced. This may occur because the system is no longer needed, cost-effective to operate, or maintainable due to obsolescence of key elements.

One of the striking things about the “V” is the symmetry between the left and right sides of the model. This symmetry reflects the relationship between the steps on each side. The system definition that is generated on the left is ultimately used to verify the system on the right. For example, the user needs and performance measures that result from the Concept of Operations form the basis for the System Validation Plan that is eventually used to validate the system at the end of project development.

The connections between the left and right are indicated by the arrows that cross the “V”, showing how plans developed on the left drive the process on the right. These connections provide continuity between the beginning and end of project development and ensure that the engineers are focused on the completion of the project from the beginning. They reflect one of the key principles of systems engineering: Start with your eye on the finish line [8].

In addition to the relations between the left and right sides of the diagram, the systems engineering process is punctuated by a series decision gates, shown in blue. Decision gates are milestones where the output of the previous step is reviewed and where the stakeholders and project team determine whether the project is ready to move to the next step. A project typically moves forward only if the criteria for the decision gate have been satisfied. Decision gates thus provide critical visibility into the project's development and allow for issue identification and course correction during development.

3. SUMMARY OF USDOT ICM INITIATIVE

The I-15 ICM Demonstration project was part of the USDOT ICM Initiative. This initiative focused on providing real-time traveler information and multi-modal operations, and using technology to reduce congestion. Recognizing that state and local transportation agencies have historically developed and operated freeways, arterials, and transit as independent systems, the goal of the ICM Initiative was to help bridge the gaps between these systems, allowing them to function as one system and better utilize existing capacity along multiple networks, especially during incidents or special events.

The initiative had the following three objectives [1]:

- Demonstrate how operations strategies and ITS technologies can efficiently, and proactively, speed the movement of people and goods in major transportation corridors through integrated management of all transportation networks in a corridor.
- Develop a toolbox of operational policies, cross-network operational strategies, integration requirements and methods, and analysis methodologies needed to implement effective ICM systems.
- Demonstrate how proven and emerging ITS technologies can coordinate operations among separate corridor networks to increase effective use of the corridor's total transportation capacity.

As illustrated in Figure 3-1, the ICM Initiative was implemented in four phases designed to promote innovation in the development of new approaches for managing existing assets efficiently within a corridor. Each phase was designed to help the USDOT and selected pioneer sites identify and advance

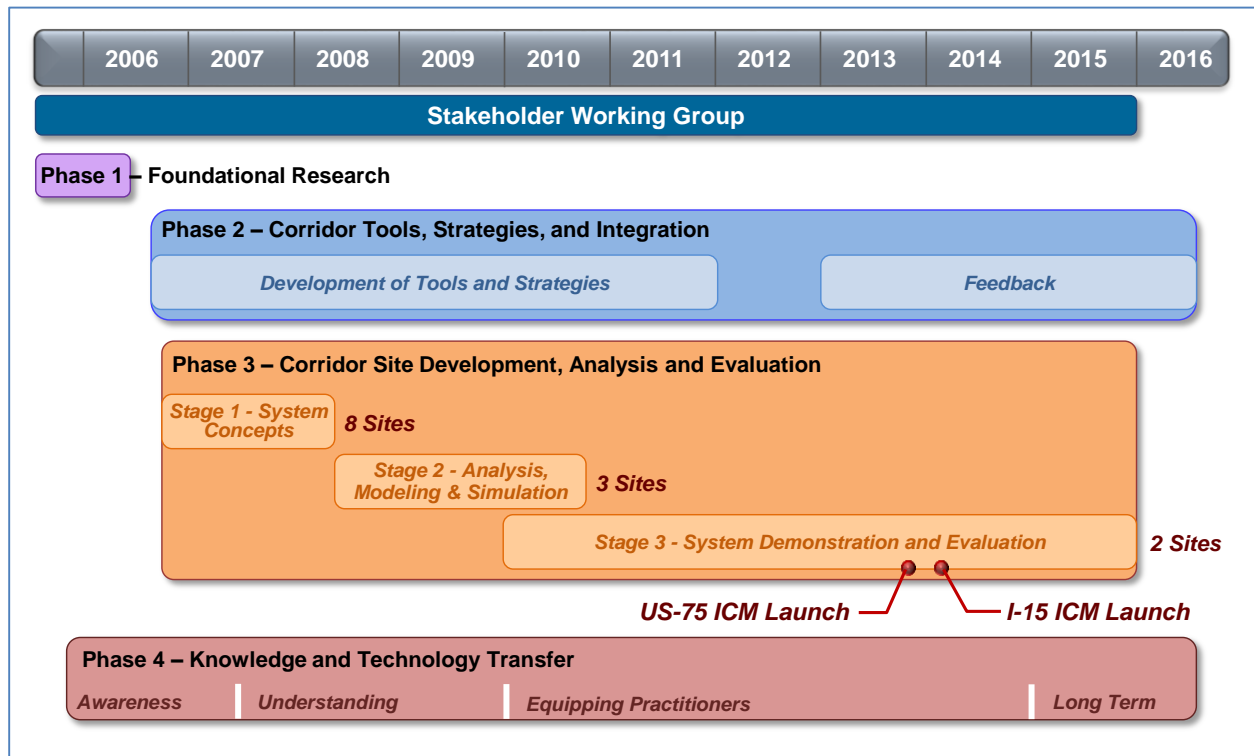


Figure 3-1 – USDOT ICM Initiative Timeline

promising ICM approaches that can serve as critical next steps in the development of tools and strategies to reduce traffic congestion across the county. The four phases of the initiative were:

- Phase 1: Foundational Research
- Phase 2: Corridor Tools, Strategies, and Integration
- Phase 3: Corridor Site Development, Analysis, and Demonstration
- Phase 4: ICM Outreach and Knowledge and Technology Transfer

Each of these phases is described in more detail below.

3.1. PHASE 1: FOUNDATIONAL RESEARCH

Phase 1 of the ICM Initiative was completed in early 2006. Its main objectives were to conduct foundational research to assess the feasibility of the integrated corridor management concept, to develop a generic concept of operations, and to develop system requirements having the support of concept stakeholders. As a part of this effort, a multi-modal working group consisting of representatives from public and private sectors was assembled by the USDOT in collaboration with ITS America. The purpose of this working group of stakeholders was to assist the ICM core team in understanding the institutional, operational, and technical integration needs and issues of integrated corridor management, and to provide input and feedback on major deliverables and various aspects of corridor management throughout the course of the initiative.

Key activities that were conducted during this phase include [2]:

- Development of alternative definitions of corridors and integrated corridor management to support the development of agreed-upon definitions
- Development of a process for delineating the boundaries of a corridor
- Identification of relationships between corridor management and regional management
- Identification and analysis of generic institutional strategies for integrated corridor management
- Identification of administrative challenges associated with planning and deployment of ICM systems
- Documentation of needs, gaps, lessons learned, and best practices from successful local integration efforts across the United States
- Characterization of various corridor types in terms of ICM needs
- Development of operational approaches and management strategies that could effectively be used for a variety of corridor types
- Feasibility analysis for the development of ICM systems

A key outcome of Phase 1 was the development of a Generic Concept of Operations for ICM [3] demonstrating how an ICM system could operate along a generic 15-mile corridor serving a central business district and consisting of freeway, arterials, bus, and rail networks. This document was developed to serve as a guidance resource for sites seeking to develop their own concepts. In addition to the Concept of Operations, a shared framework through which the ICM Initiative could identify, test, revise, and deploy appropriate technologies and techniques was developed, as well as early guidance on the steps needed to support the development, implementation, and operation of ICM systems [4].

3.2. PHASE 2: CORRIDOR TOOLS, STRATEGIES, AND INTEGRATION

Phase 2 of the ICM Initiative began in September 2006 and ran concurrently with Phases 3 and 4 described below. Its primary goal was to address the tools, strategies, and integration practices necessary to conduct effective ICM site demonstrations. Key objectives of this phase were to [2]:

- Help decision-makers identify operational gaps, evaluate ICM strategies, and identify the best combination of strategies to invest in to minimize congestion and improve safety along transportation corridors.
- Help estimate the benefit resulting from ICM across different transportation modes and traffic control systems.
- Develop and transfer knowledge about analysis methodologies, tools, and possible benefits of ICM strategies to the pioneer sites and to the entire transportation community.

Key activities conducted during Phase 2 of the initiative include:

- Refinement of the ICM strategies identified in Phase 1
- Development of a framework to analyze, model, and simulate the ICM strategies [5]
- Application of the developed analysis framework to conduct a pilot evaluation of potential ICM strategies along the I-880 corridor in Oakland, California [6]
- Development of analytical and simulation tools enabling the evaluation of proposed ICM strategies
- Development and testing of system interfaces to integrate the operation of various system components
- Development of operations management schemes to facilitate the sharing of control and responsibilities among participating corridor organizations
- Identification and selection of appropriate standards

The primary outcome of the phase was the development of validated and tested methodologies to support ICM system analyses to be conducted in Phase 3. Several of the developed tools were also subsequently used to support pre-deployment system evaluations in Stage 2 of Phase 3, and post-deployment evaluations in Stage 3 of Phase 3.

3.3. PHASE 3: CORRIDOR SITE DEVELOPMENT, ANALYSIS, AND DEMONSTRATION

Phase 3 of the ICM initiative focused on the operational evaluations of ICM concepts through modeling and simulation, and system implementation. Activities within this phase were divided into three stages, described in detail below:

- Stage 1: Concept Development
- Stage 2: Analysis, Modeling, and Simulation
- Stage 3: Demonstration and Evaluation

3.3.1. STAGE 1: CONCEPT DEVELOPMENT

Stage 1 of Phase 3 started in October 2006 with the selection of eight pioneer sites that were to be assessed for their capability to demonstrate integrated corridor management. These eight sites are mapped in Figure 3-2 and listed below:

- I-880 corridor in Oakland, California
- I-15 corridor in San Diego, California
- US-75 corridor in Dallas, Texas
- IH-10 corridor in San Antonio, Texas
- I-10 corridor in Houston, Texas
- I-394 corridor in Minneapolis, Minnesota
- I-5 corridor in Seattle, Washington
- I-270 corridor in Montgomery County, Maryland

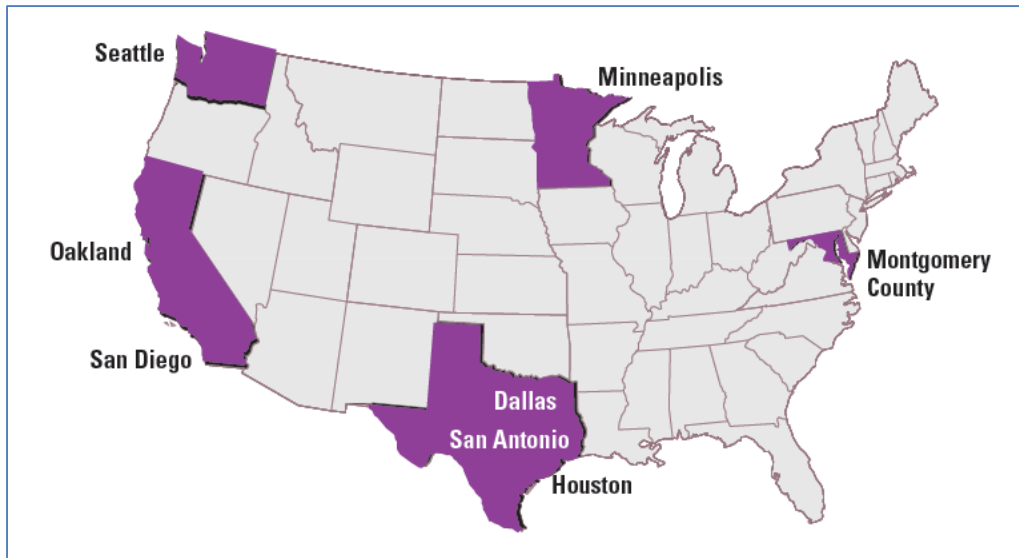


Figure 3-2 – ICM Initiative Pioneer Sites

Pioneer Site Location	Corridor Assets To Be Integrated with ICM									
	Freeway			Arterial		Bus		Rail		
	HOV	Tolling	Value Pricing	Real-time Control	Fixed Route	Express Buses	Bus Rapid Transit	Commuter Rail	Light Rail	Subway/Heavy Rail
*Dallas, Texas	◆	◆		◆	◆	◆			◆	
Houston, Texas	◆	◆	◆	◆	◆	◆	◆			
Minneapolis, Minnesota	◆	◆	◆	◆	◆	◆	◆			
Montgomery County, Maryland	◆			◆	◆	◆		◆		◆
Oakland, California	◆	◆		◆	◆	◆	◆	◆		◆
San Antonio, Texas				◆	◆	◆				
*San Diego, California	◆	◆	◆	◆	◆	◆	◆			
Seattle, Washington	◆			◆	◆	◆		◆	◆	

Bolded sites have been selected for analysis, modeling and simulation of proposed ICM systems and strategies
**Selected as ICM Demonstration site.*

Figure 3-3 – Corridor Assets Proposed to be Integrated at ICM Pioneer Sites

During this stage, stakeholders from each of the selected pioneer sites were tasked with developing a Concept of Operations and preliminary System Requirements for the ICM system they would be deploying on their respective corridors, using the Generic Concept of Operations that was developed in Phase 1 of the initiative as a guide. Sample data from each site were also provided to the USDOT to assess data availability and the suitability of each proposed ICM corridor for conducting modeling and simulation evaluations. Work on these activities ended in March 2008.

For each corridor, the resulting Concept of Operations provided an overview of the respective proposed ICM systems. Each document first inventoried existing transportation systems and described the operational performance of these systems. Each document then identified the goals and objectives of the proposed ICM system, the strategies to be pursued for improving corridor operations, the user needs and asset requirements for the proposed system, how the system was envisioned to operate under various scenarios, and the eventual responsibilities of system stakeholders. The system requirements that were subsequently developed further identified and defined the different Intelligent Transportation System (ITS) components that would need to be integrated along each corridor. For each of the sites, Figure 3-3 provides a summary of the key assets that were specifically considered for integration at this stage [7].

3.3.2. STAGE 2: ANALYSIS, MODELING, AND SIMULATION

In May 2008, the USDOT announced that the I-15 corridor in San Diego, the US-75 corridor in Dallas, and the I-395 corridor in Minneapolis were further selected as pioneer sites for Stage II of the ICM deployment initiative. Under this stage, the three corridors were first modeled according to the Analysis, Modeling, and Simulation (AMS) framework that was developed in Phase 2. For each corridor, key ICM strategies from the Concept of Operations developed in Stage I were then selected for modeling and analysis to assess the range of expected benefits associated with each proposed system. All Stage II evaluation work was completed by September 2010.

Table 3-1 lists the various management strategies that were modeled and evaluated for each corridor. Depending on the corridor, various combinations of strategies aimed at improving traveler information, traffic management, HOV/HOT operations, and transit management were considered [7].

Through comparative evaluations of simulated corridor operations with and without an ICM system, the Phase 2 evaluations suggested that the proposed ICM systems would increase travel reliability within each corridor while reducing travel time, delays, fuel consumption, and vehicle emissions, with benefit-to-cost ratios ranging from 10:1 to 20:1 over the life of each ICM system. Results further showed increasing benefits with increasing travel demand, particularly in situations in which incidents or other events result in significant capacity constraints.

Stage 2 activities further resulted in the development of new tools for the analysis of freeway ramp metering, HOT lane operations, congestion pricing systems, transit operations, and active traffic management strategies. Activities also led to improved model calibration and data analysis methods.

Table 3-1 – ICM Strategies Considered in AMS Evaluations

ICM Strategy	Minnesota	Dallas	San Diego
Traveler information			
Earlier dissemination and information sharing between agencies	•	•	
Comparative travel times (modes and routes)	•		
Parking availability at park-and-ride lots	•	•	
ABC garage display			
Freeway traveler information (pre-trip and en-route)	•	•	•
Arterial traveler information (pre-trip and en-route)	•	•	•
Transit traveler information (pre-trip and en-route)	•	•	•
Traffic management			
Reduced incident times	•		
Incident signal retiming plans for arterials/frontage roads	•	•	
Retime ramp meters for incidents or congestion			
Coordinated signal and ramp meter operation			•
System-wide coordinated ramp metering			
HOT/HOV Lanes			
HOT lane congestion pricing	•	•	•
Changes to minimum vehicle occupancy access requirements	•	•	•
Opening to single occupancy vehicles during incident		•	
Transit Management			
Dynamic rerouting	•		
Special event transit capacity expansion	•	•	
Arterial signal priority	•		•
Light-rail transit smart parking system		•	
Additional parking and valet service		•	
Physical priority to buses on arterials			•

3.3.3. STAGE 3: DEMONSTRATION AND EVALUATION

Following the completion of the Stage 2 evaluations, both the Dallas and San Diego corridors were selected in December 2009 for the final demonstration stage of the ICM Initiative. This stage, which was expected to last three to four years, consisted of the development, implementation, and operational evaluation of an actual ICM system on each corridor. A first goal was to demonstrate the application of institutional, operational, and technical integration approaches in the field. A second goal was to document the operational benefits associated with each system and the implementation issues encountered during system development and implementation to assist with future ICM system deployments along other corridors.

Specific activities associated with each deployment site included:

- Design and implementation of the system to be implemented
- Execution of pre-deployment and post-deployment simulation evaluations
- Operational evaluation of the deployed system
- Documentation of lessons learned

Following unexpected delays in system development and implementation, the US-75 ICM system was launched in the fall of 2013 and the I-15 system in March 2014. Both launches were to be followed with a six-month shakeout period and a twelve-month evaluation period, establishing a target end for Phase 3 of the ICM Initiative in mid/late 2015, pending no additional delays.

3.4. PHASE 4: ICM OUTREACH AND KNOWLEDGE AND TECHNOLOGY TRANSFER

The goal of Phase 4 of the ICM Initiative was to equip corridor managers and operators around the country with a comprehensive resource set to help them develop, implement, and evaluate prospective ICM systems. Outreach and technology transfer activities started in 2006, when the first results of the foundational research became available, and continued throughout the duration of the project. While early activities focused on promoting ICM system concepts, later activities focused in turn on disseminating developed knowledge about ICM operations and evaluation results, equipping ICM system evaluators and operators with the appropriate tools to conduct their tasks, and, finally, supporting future system deployments.

Key outreach and technology transfer activities that were conducted during this phase include:

- Development of the ICM Knowledgebase on the USDOT website, which serves as a one-stop, fully searchable repository for the knowledge developed through the ICM Initiative
- Publication of guidance documents on the development, implementation, and evaluation of ICM systems
- Development of peer-to-peer training resources, such as web-based seminars and mobile workshops
- Organization of ICM conferences
- Development of conference presentations
- Publication of fact sheets about ICM systems

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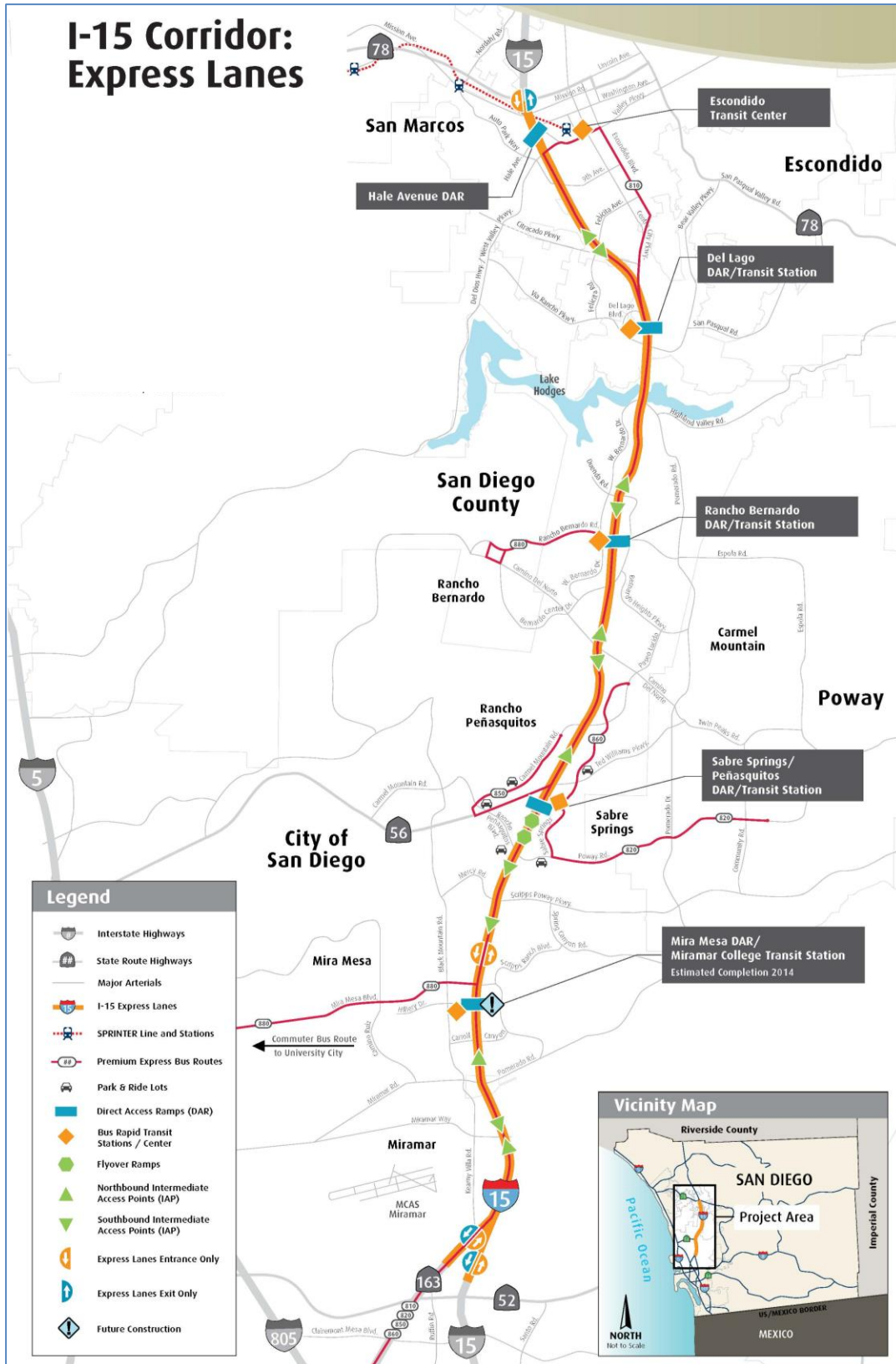


Figure 4-2 – I-15 Express Lane System



Figure 4-3 – I-15 Express Lanes at Rancho Bernardo Direct Access Ramp Overpass

Within the boundaries of the ICM demonstration section, the I-15 provides four to six general traffic lanes per direction, with additional auxiliary lanes between some interchanges. A 20-mile barrier-separated high-occupancy toll (HOT) facility with limited entry and exit points, known locally as the I-15 Express Lanes, further exists within the median of the freeway between the SR-163 and the SR-78 interchanges. A map of the facility is shown in Figure 4-2 and a picture of a typical cross-section in Figure 4-3. During normal operations, this facility can be accessed without charge by vehicles having two or more occupants or for a certain fee by single-occupancy vehicles having an electronic toll transponder onboard.

While included in the ICM Demonstration, the construction of this facility was commissioned as part of a separate project that was initiated prior to the awarding of the ICM demonstration to the team led by SANDAG. This project replaced a previous eight-mile express lane system that was opened in 1988. A first section between the SR-56 and Rancho Bernardo Road interchanges was opened in September 2008. The Express Lanes were then extended from Rancho Bernardo Road to Centre City Parkway in early 2009. The northern segment was in turn opened to traffic in November 2011, while the southern segment was opened in January 2012.

A key feature of the I-15 Express Lane facility is a movable median barrier that allows facility operators to change the number of lanes dedicated to the northbound and southbound traffic. The facility is currently set to provide two traffic lanes in each direction. To increase traffic capacity in the peak travel direction, the barrier can be positioned to provide three lanes in the southbound direction during the AM peak, and three lanes northbound during the PM peak. However, such changes have rarely been implemented to date as Caltrans is still in the process of determining when the barrier should be moved to benefit corridor operations the best considering that it can take up to 45 minutes to reconfigure the entire length of the facility.

In addition to the moving barrier, five direct-access ramps allow buses, motorcycles, carpools, vehicles with FasTrak tags, and clean-air vehicles with special decals to enter or exit the Express Lanes directly without having to cross the general-purpose freeway lanes. These direct access ramps were built to support the deployment of a new Bus Rapid Transit system along the I-15 freeway, with the specific intent to facilitate connections between the freeway and new transit stations being built along the freeway corridor. Figure 4-4 shows as an example the ramps that were built to provide direct access to the Sabre Springs/Peñasquitos Station.

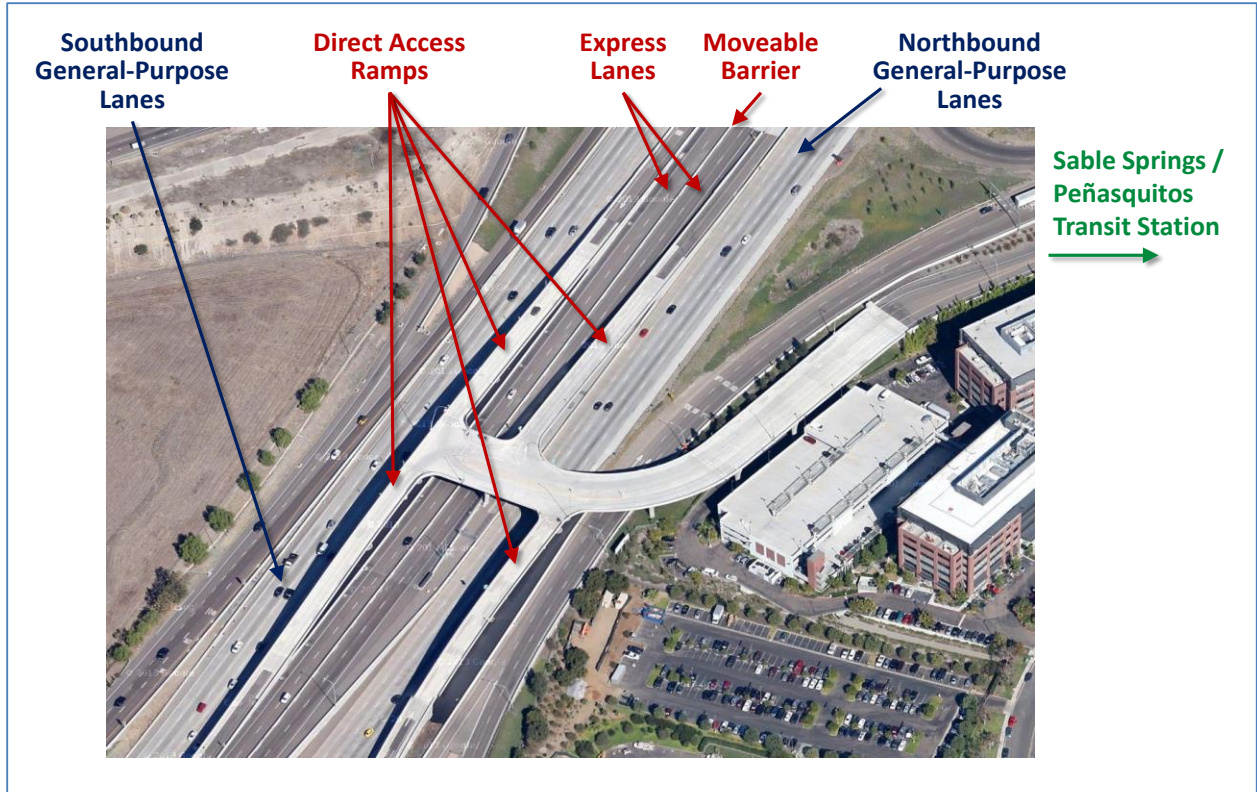


Figure 4-4 – Direct Access Ramp to the Sabre Springs/Peñasquitos Transit Station



Figure 4-5 – I-15 Express Lanes Congestion Pricing System

Congestion pricing is another key element of the I-15 Express Lane system. While carpools are provided free access to the facility, single-occupancy vehicles pay a toll that is adjusted based on the amount of congestion on the express lanes to protect them from being over congested and maintain a certain level of performance on the facility. Figure 4-5 shows as an example one of the signs used to inform travelers of the current toll rate.

During weekdays, traffic typically moves southbound during the morning peak period and northbound during the afternoon peak period. However, recent growth in manufacturing and industrial parks in the Rancho Bernardo and Carmel Mountain areas have resulted in increased peak-period travel opposite to traditional patterns. According to 2013 traffic flow data, weekday traffic volumes on the general-purpose lanes along various sections of the I-15 ranged from 194,000 to 292,000 vehicles. The total number of vehicles with FasTrak transponders traveling along the Express Lane was further estimated to top 25,900, while the number of carpools was estimated to exceed 23,500 daily.

Typical corridor bottlenecks along the I-15 include the SR-163 junction, the SR-56 interchange, the SR-78 interchange, and the Lake Hodges Bridge. These bottlenecks often cause delays averaging between 15 and 20 minutes. Prior to the opening of the Express Lanes, delays between 30 and 45 minutes were often observed. Recurrent congestion also occurs on various segments of the corridor during the weekends. Given the limited number of alternative routes, peak-period delays are further exacerbated by incidents, special events, and/or inclement weather.

4.2. SUPPORTING ARTERIALS

Figure 4-6 illustrates the arterial network that was included in the I-15 ICM corridor. This network covers all the major arterials along I-15 that can be used as potential detours. This includes arterials in the cities of San Diego, Poway, and Escondido. Within this network, the three following north-south arterials were considered backbones of the arterial network supporting the I-15 ICM operations:

- Kearny Villa Road/Black Mountain Road, west of the I-15 in the southern half of the corridor
- Pomerado Road, east of the I-15 in the southern half of the corridor
- Centre City Parkway in the northern portion of the corridor

4.3. TRANSIT SERVICES

Transit services offered within the I-15 corridor includes a Bus Rapid Transit (BRT) service into San Diego operated by San Diego's Metropolitan Transit System (MTS) using the I-15 Express Lanes. This high frequency, limited-stop transit service called *Rapid* started operating in June 2004. A map of the system is shown in Figure 4-7. At the time of its launch, this service was a first of its kind in San Diego County. It includes routes running all-day along the I-15 Express Lanes, as well as routes running only on weekdays during peak-hours. As indicated on the map, this transit service significantly benefits from the direct access ramps that have been built along I-15 to facilitate connection between the Express Lanes and the Escondido Transit Center, Del Lago Station, Rancho Bernardo Station, Sabre Springs/Peñasquitos Station, and Miramar College Station.

In addition to the MTS Rapid routes, North County Transit District (NCTD) operates several local routes in the northern section of the corridor, using the Escondido Transit Center as a local service hub. This includes operations of the Sprinter light-rail service between Escondido and Oceanside, to the west of I-15, along the SR-78 corridor.

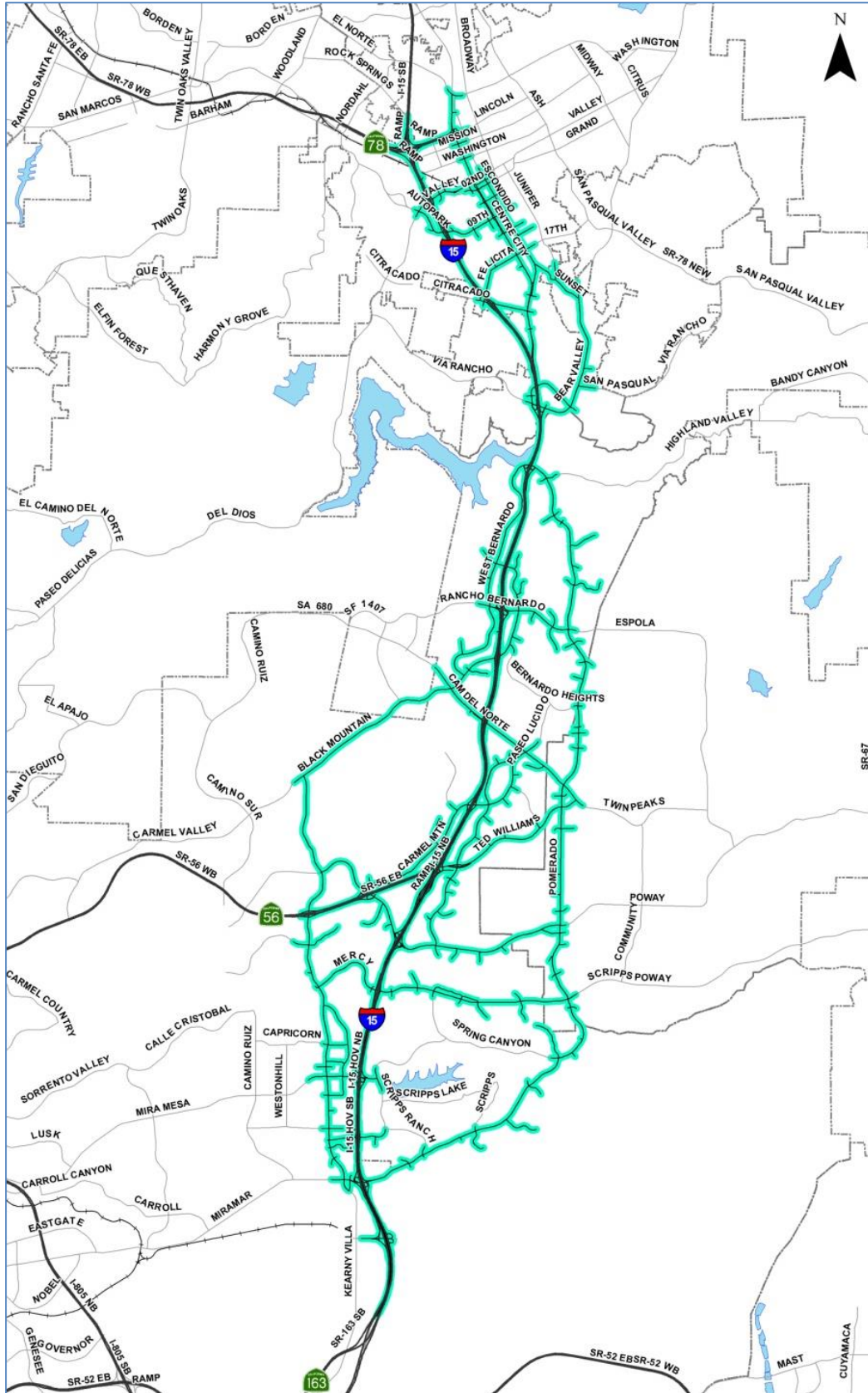


Figure 4-6 – I-15 ICM Corridor Arterial Network

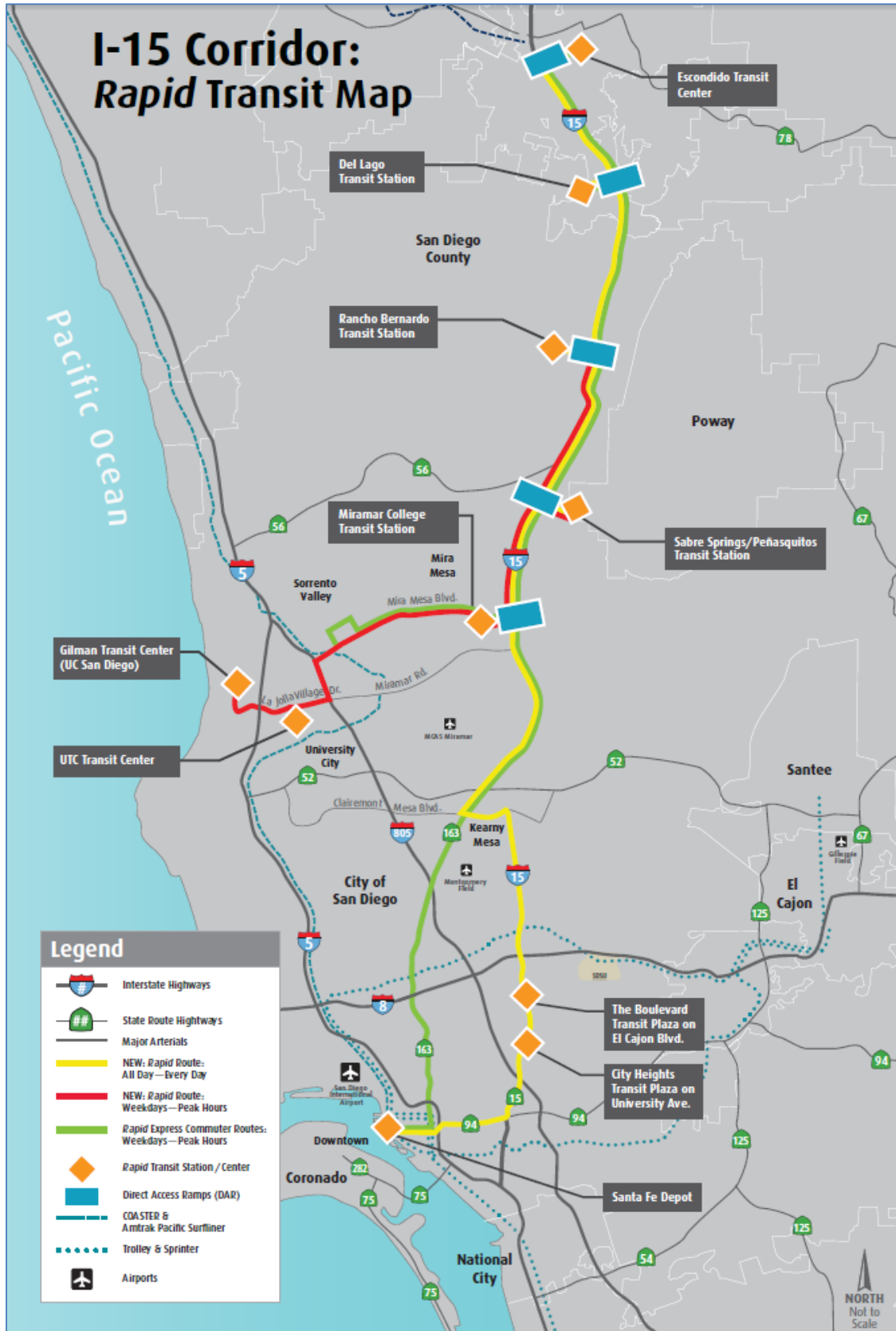


Figure 4-7 – Bus Rapid Transit Service along I-15

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5. I-15 ICM SYSTEM CONCEPT

This section presents a summary of the concept for the I-15 ICM System (ICMS) that was developed as part of Stage I and Stage II of Phase 3, and later adjusted slightly during Stage III activities. This system is commonly referred to as the ICMS. As explained in Section 3, Stage I activities focused on the development of a Concept of Operations and preliminary system requirements for the I-15 ICM Demonstration system. Stage II subsequently used analytical, modeling, and simulation techniques to produce estimates of the potential benefits that the proposed ICMS could provide. Stage III activities focused on the design and implementation of an actual system.



Figure 5-1 – Key Output Documents from Early System Development Stages

Figure 5-1 illustrates the covers of the three key documents that were produced prior to the initiation of Stage 3 and from which a majority of the information presented in this section is extracted. These include:

- **I-15 ICM Concept of Operations** document [10]
- **I-15 ICMS Requirements** document [11]
- Report on the results of the **Analysis, Modeling, and Simulation** of the I-15 corridor [12]

The development of the Concept of Operations and System Requirements followed the established systems engineering process promoted by the FHWA for the development of ITS systems. Following this process ensured that only the functionalities for which a user need exists were being developed. For the development of a Concept of Operations, a specific investigative process was established to develop in sequential order the following elements: system vision, system goals and objectives, operational concept, approaches and strategies, user needs, implementation issues, institutional framework, and operational scenarios. The subsequent development of the System Requirements further depended on the set of user needs that had been identified during the development of the Concept of Operations. Similarly, the operational evaluations that were later conducted to assess potential system benefits were largely based on the strategies and approaches identified in the Concept of Operations.

While system development generally followed the concepts outlined and considered in the above documents, some minor deviations between the information presented in this section and the information contained in the documents exist because of changes that have been made to the proposed

system during Stage 3 design and implementation activities. Some examples include the addition and removal of interfacing systems, and adjustments in how the system is envisioned to operate.

The remainder of this section presents in more detail the following elements:

- ICMS stakeholders
- Vision for the system
- System goals and objectives
- ICM strategies considered
- User needs for the ICMS
- System components
- Implementation issues
- System requirements
- Anticipated operational benefits

5.1. ICMS SYSTEM STAKEHOLDERS

The San Diego I-15 ICMS transportation corridor is to be managed collaboratively and cooperatively through ongoing partnerships among the following agencies:

- **San Diego Association of Governments (SANDAG)** – Agency responsible for transportation planning for the San Diego region and in charge of the development of the ICMS
- **California Department of Transportation (Caltrans) District 11** – Agency responsible for the operations of the I-15 freeway, including the I-15 Express Lane system. This agency is specifically responsible for the operations of ramp meters, changeable message signs (CMSs) along the freeway, and traffic signals at arterial intersections at the end of freeway on-ramps and off-ramps. The agency further operates, in partnership with the California Highway Patrol (CHP), a transportation management center in Kearny Mesa. It also operates a fiber communication system within the corridor, in addition to leasing communication lines.
- **Cities of San Diego, Poway, and Escondido** – Entities responsible, through their transportation departments, for the operations and maintenance of traffic control devices on major arterials within their jurisdiction that are part of the I-15 ICM corridor. Local police and fire departments were also expected to participate in corridor operations by reporting arterial incidents in their jurisdiction having a major impact on either local arterials or adjacent freeway operations.
- **Metropolitan Transit System (MTS)** – Operator of the San Diego metropolitan bus system, the San Diego Trolley light-rail system, the Bus Rapid Transit (BRT) system along the I-15 Express Lanes, and the regional Transit Call Center. The agency also owns and operates a fiber optic network that became part of the regional Intermodal Transportation Management System (IMTMS) communication network.
- **North County Transit District (NCTD)** – Operator of suburban transit service throughout North San Diego County, as well as the Coaster and Sprinter commuter rail services. Similar to MTS, the agency also owns and operates a fiber optic network that became part of the IMTMS.
- **California Highway Patrol (CHP)** – Agency responding to all reported incidents on freeways and state highways, as well as county roads in some areas. The CHP also operates and maintains the Freeway Service Patrol (FSP) that is provided by contracted towing companies.

In addition to the above operators, the following entities were involved in the conceptual development, design, and implementation of the I-15 ICMS:

- **Kimley-Horn and Associates** – Firm contracted to manage the development of the ICMS.
- **Delcan** (now part of **Parsons**) – Firm contracted to develop the operating software for the ICMS.
- **Transport Simulation Systems (TSS)** – Firm contracted to develop the simulation capabilities of the proposed ICMS.
- **Iteris** – Firm contracted to provide enhancements to Caltrans' Performance Measurement System (PeMS) to facilitate corridor operational analyses.

While not directly participating in system operations, the following entities also had an interest in the outcomes of the demonstration project:

- **U.S. Department of Transportation** – Agency funding the ICM Initiative and responsible for evaluating the operational benefits provided by the system.
- **Battelle Memorial Institute** – Private nonprofit applied science and technology development firm contracted by the USDOT to conduct the evaluation of the I-15 and US-75 demonstration projects. Key activities to be conducted by this entity included technical system assessments, institutional organization analyses, and corridor performance measurements.
- **Volpe National Transportation System Center** – Research center contracted by the USDOT to conduct traveler response surveys on the corridor.
- **Cambridge Systematics** – Consulting firm contracted by the USDOT to lead the analysis, modeling, and simulation (AMS) activities of the ICM initiative.

5.2. VISION FOR I-15 ICMS

One of the first elements to be developed by corridor stakeholders was a vision for the I-15 ICMS. This vision was subsequently used as a starting point for the development of goals, objectives, user needs, and operational concepts. Key ideas behind the vision were to:

- Give travelers the ability to make seamless and convenient shifts among modes and among transportation networks within the corridor to complete their trips. This included shifts between freeway, arterial, and transit networks, as well as shifts between the freeway's general-purpose lanes and the Express Lanes system.
- Achieve improved mobility for people, goods, services, and information by enhancing interoperability between field elements, as well as collaboration and cooperation among the corridor's institutional partners and their native functional environments or systems.
- Allow travelers to make informed travel choice decisions by providing them with the ability to readily access traveler information from strategically placed CMSs, as well as from the regional 511 system via telephone, Internet, or public access television focused on the I-15 market.
- Develop a corridor management system focusing on improving person and vehicle throughput, productivity, connectivity, safety, accessibility, and environmental sustainability.
- Proactively manage congestion.

5.3. SYSTEM GOALS AND OBJECTIVES

Following the definition of a vision for the proposed ICMS, corridor stakeholders developed the goals and objectives listed in Table 5-1.

Table 5-1 – Goals and Objectives of the I-15 ICMS

Goal	Objectives
The corridor’s multi-modal and smart growth approach shall improve accessibility for corridor travelers to travel options and attain an enhanced level of mobility	<ul style="list-style-type: none"> • Reduce travel time for commuters • Increase transit ridership within the corridor • Increase the use of high-occupancy vehicles for commuters • Increase person and vehicle throughput within the corridor on the general-purpose and managed freeway lanes • Increase person and vehicle throughput on arterials • Reduce delay time for corridor travel • Increase the percentage of telecommuters from the corridor’s commuter market • Increase the use of established and effective travel demand management programs • Promote development to encourage the use of transit (especially BRT)
The corridor’s safety record shall be enhanced through an integrated multi-modal approach	<ul style="list-style-type: none"> • Reduce incident rate • Reduce injury rate • Reduce fatality rate • Reduce roadway hazards
The corridor’s institutional partners shall employ an integrated approach through a corridor-wide perspective to resolve problems	<ul style="list-style-type: none"> • Improve institutional coordination among stakeholders • Strengthen existing communication linkages among all corridor institutional stakeholders and establish new communication linkages where appropriate • Enhance the regional/joint operations concept throughout the corridor • Balance the needs of through traffic and local communities by coordinating construction and overall mitigation management on I-15 and arterials
The corridor’s travelers shall have the informational tools to make smart travel choices within the corridor	<ul style="list-style-type: none"> • Improve collection and dissemination of arterial network information • Collect and process data on the operational condition/status of all transportation networks within the corridor, including: <ul style="list-style-type: none"> ○ Comparative travel times between major origins and destinations ○ Construction, detours, and other planned road work ○ Occurrence and location of incidents ○ Expected delays ○ Number of parking spaces available at Park-and-Ride lots/structures • Disseminate comprehensive, real-time, and accurate information to travelers within the corridor by means of multiple media • Make available archived historical data to travelers • Achieve a high level of 511 call volume and Web use • Achieve high overall satisfaction with 511 system
The corridor’s networks shall be managed holistically under both normal operating and incident/event conditions in a collaborative and coordinated way	<ul style="list-style-type: none"> • Establish/enhance joint agency action plans to respond to congestion, especially at I-15/arterial network interfaces and at the Lake Hodges choke point • Develop/improve methods for incident and event management • Reduce overall incident clearance time • Identify means of enhancing corridor management across all networks

As can be noted, the goals and objectives that were developed for the I-15 ICMS generally relate to a desire to improve:

- Accessibility and mobility
- Transportation safety
- Information dissemination to travelers
- Coordination among institutional partners
- Network management

From a practical perspective, these goals and objectives translated into the following institutional, operational, and technical goals:

- **Institutional goals**
 - Provide better information and coordination of multi-agency/network junctions
 - Develop an institutional platform for managing and operating multiple and individual transportation systems as a unified or integrated system across disciplines and jurisdictions
- **Operational goals**
 - Enhance mobility for people, goods, and services throughout the corridor
 - Increase ability to actively measure corridor throughput, productivity, connectivity, safety, and accessibility
 - Provide travelers with better information, allowing for seamless and convenient shifts among modes to foster better “traveler choice”
 - Provide for efficient balancing between overall corridor throughput and individual roadway operations
- **Technical goals**
 - Improve sharing/distribution of transportation data information across networks
 - Improve capability of existing systems to better manage and operate the corridor through the development of a Decision Support System
 - Utilize predictive algorithms, modeling tools, and corridor-wide visualization to support decision making and active management of the transportation system
 - Enhance current levels of existing interoperability between field elements and functional environments or systems

5.4. ICM STRATEGIES CONSIDERED

Based on the identified goals and objectives, corridor stakeholders identified the following ICM strategies that could potentially be pursued for the development of the ICMS:

- **Information sharing and distribution**
 - Establish procedures for manual information sharing among agencies
 - Establish an information exchange network between networks and agencies
 - Provide pre-trip traveler information (511 information system)
 - Provide en-route traveler information (smart signage and smart parking)
 - Enable information service providers to access corridor information
 - Provide automated, real-time information sharing capability

- Establish a common incident reporting system and asset management system
- Establish a historical data archiving system
- **Improve operational efficiency of network junctions/interfaces**
 - Provide signal pre-emption, and/or best route options, for emergency vehicles
 - Provide a multi-modal electronic payment system
 - Provide signal priority for transit vehicles
 - Coordinate the operation of freeway ramp meters and nearby traffic signals
 - Provide transit hub connection protection
 - Establish multi-agency/multi-network incident response teams
- **Accommodate/promote cross-network routes and modal shifts**
 - Modify ramp metering rates to accommodate traffic shifting from arterials
 - Modify arterial signal timing to accommodate traffic diverted from the freeway
 - Congestion pricing for managed lanes
 - Promote route shifts towards transit via en-route traveler information devices
 - Promote shifts between transit facilities via en-route traveler information devices
- **Short-term capacity/demand management**
 - Lane use control (configurable/contraflow lanes)
 - Modify HOV restrictions (minimum number of passengers, bus-only restrictions)
 - Increase roadway capacity by opening HOV/HOT lanes/shoulders
 - Scheduled closures for construction
 - Coordinate schedule maintenance and construction activities among corridor networks
 - Planned temporary addition of transit capacity
 - Modify parking fees (smart parking)
- **Long-term capacity/demand management**
 - Peak spreading
 - Ridesharing programs
 - Expand transit capacity
 - Land use around BRT stations

While most of the above strategies were considered important for the I-15 corridor, the following represents the final set of key strategies that were eventually retained for system development following an analysis of the challenges and likelihood of success associated with each of the identified strategies:

- **Information sharing and distribution**
 - Establish an information exchange network between networks and agencies
 - Provide automated, real-time information sharing capability
 - Establish a historical data archiving system
 - Provision of en-route traveler information to corridor travelers
 - Provision of pre-trip traveler information to corridor travelers
- **Improve operational efficiency of network junctions and interfaces**
 - Coordinate the operation of freeway ramp meters and nearby traffic signals

- **Accommodate/promote cross-network routes and modal shifts**
 - Modify ramp metering rates to accommodate traffic shifting from arterials
 - Modify arterial signal timing to accommodate traffic diverted from the freeway
 - Establish proactive corridor congestion management procedures for addressing both recurring congestion and incident situations
 - Bus Rapid Transit (BRT) operations
- **Short-term capacity/demand management**
 - Lane use control on I-15 Express Lanes
 - Modify HOV restrictions (minimum number of passengers, bus-only restrictions)

5.5. USER NEEDS

Table 5-2 identifies 17 user needs for the I-15 ICMS that were identified by corridor stakeholders during the development of the Concept of Operations. Key concepts associated with the identified user needs include:

- Collect and process data in real time or near real time
- Share and exchange real-time or near real-time data
- Monitor corridor travel conditions, gauge network conditions, and report on status
- Make available to the general public real-time or near real-time information on corridor travel conditions
- Manage corridor traffic flow
- Manage occurrence of events
- Coordinate the operation of corridor networks and management systems

Table 5-2 – I-15 ICMS User Needs

No.	User Need Title	Description/Rationale
1	Access/store ICMS data	Create and manage a configuration database that maintains static information on various I-15 corridor parameters.
2	Collect and process data	Collect data from a variety of existing and planned systems and subsequently invoke processing algorithms to aggregate information at a higher level.
3	Access/store ICMS historical information	Create and populate a historical database that contains real-time information on corridor performance derived from data collected.
4	Publish information to system managers	Disseminate data from all sources to agencies that manage one or more transportation modes.
5	Interactively conference with multiple agencies	Allow system managers from multiple agencies to directly collaborate in real time prior to, during, or after a major corridor event using voice, video, and data formats.
6	Display information	Display a variety of data formats that agency decision-makers can use to visualize corridor operations, make decisions, and take actions to implement the various decision components.
7	Coordinate transportation and public safety operations	Promote coordination and sharing of data between transportation and public safety communities.
8	Share control of devices	Allow agencies to remotely control selected field device functions regardless of location or agency ownership, based on interagency agreements.

Table 5-2 – I-15 ICMS User Needs (cont'd)

No.	User Need Title	Description/Rationale
9	Manage video imagery	Produce and share among system users a variety of video imagery that shows a critical view of emerging and ongoing corridor events.
10	Respond to corridor planned and unplanned events	Allow ICMS users and managers to use a decision-support tool that fuses data collected at the event site to generate a response plan, as well as to update as necessary a developed plan before transmitting its components to the affected systems.
11	Assess impact of corridor management strategies	Allow corridor managers to model various traffic and service management strategies to gauge their impact on corridor performance and return timely results to affect decision-making during a major event.
12	Publish information to system users	Provide corridor information to the regional 511 system for dissemination to various system users across a variety of media; make available a standard XML data stream and video imagery to other entities for dissemination to system users.
13	Measure corridor performance	Examine multi-modal corridor data from both short-term and long-term perspectives from both historical databases and PeMS.
14	Manage corridor demand and capacity to optimize long-term performance	Provide for corridor managers to collaboratively develop long-term corridor capacity and demand management strategies.
15	Measure system performance	Monitoring of field devices, server systems, and communications networks needed to support corridor management functions; measurement of metrics describing component operations; and storage of information in historical databases.
16	Manage ICMS system	Provide administrative functions, including data management for ICMS configuration data, user account management incorporating system-wide security functions, and IT- centric functions such as data backup and archival.
17	Document system and train system users and maintainers	Provide logistical support to the ICMS system through its full life cycle.

The identified user needs define various system elements that will need to be verified by corridor stakeholders when conducting the final system validation to ensure that the developed systems is performing all the tasks it was commissioned to do.

5.6. SYSTEM COMPONENTS

As schematically illustrated in Figure 5-2, the I-15 ICMS was envisioned as consisting of the following key components:

- **Data hub** – Collection of external systems operated by corridor stakeholder agencies providing data to the ICMS and/or receiving control requests from the system via a standardized regional communication network.
- **Decision Support System (DSS)** – Tool to help system operators identify incidents and implement response plans aimed at minimizing the impacts of identified incidents on corridor operations.
- **System services** – Services to assist with data management, system management, system maintenance, and training activities.

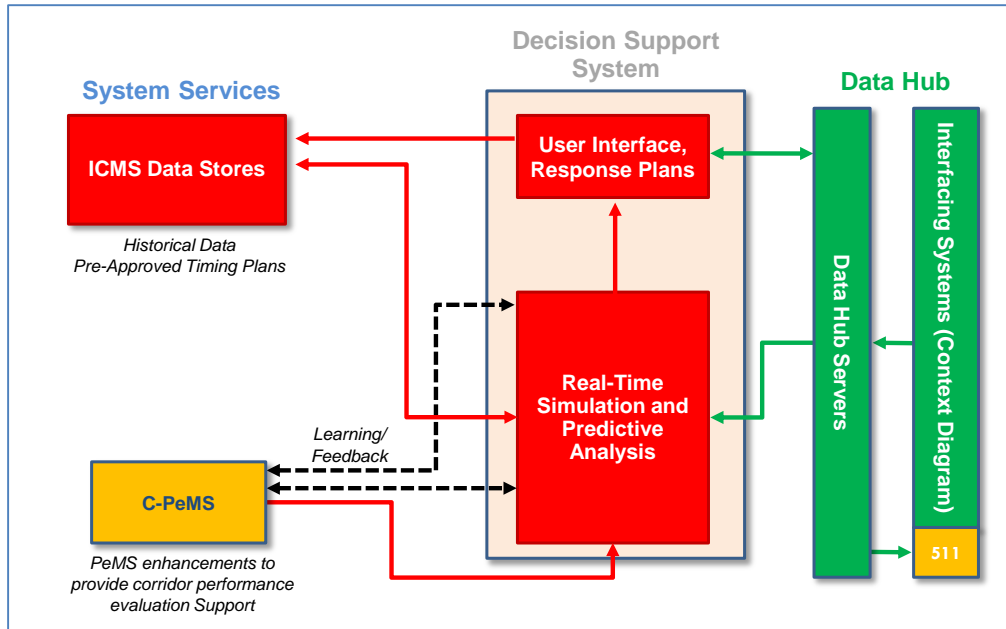


Figure 5-2 – ICMS Key Components

More information about each of the components listed above, as well as the various systems the ICMS might interface with, is provided in the subsections that follow.

5.6.1. INTERFACING SYSTEMS

Figure 5-3 shows the various existing systems that the ICMS was anticipated to interface with in its early development stages. These systems included:

- **Regional Arterial Management System (RAMS)** – System deployed by SANDAG in late 2008/early 2009 to enhance inter-jurisdictional coordination of traffic signals along major arterial corridors throughout the San Diego region. This system provides subscribing agencies the ability to view the timing plans operated by other agencies and to develop, propose, and implement timing plans spanning multiple jurisdictions. All agencies operating traffic signals within the I-15 corridor, including Caltrans, are subscribers to this system.
- **Lane Closure System (LCS)** – Caltrans system collecting and managing information related to construction projects. Information contained within this system include the time, location, and impact associated with a specific construction or maintenance project.
- **Ramp Meter Information System (RMIS)** – System used by Caltrans to manage the operations of metering signals on freeway on-ramps.
- **Advanced Traffic Management System 4.1 (ATMS 4.1)** – System used by Caltrans to manage the freeways it operates. While early project documents reference the ATMS 2005 system, this system was upgraded to ATMS 4.0, and then ATMS 4.1, in later project activities. This system provides connections to traffic detectors, CMSs, and CCTV cameras operated by the agency along I-15. In addition to collecting status data, this system also provided some data processing capabilities, an automatic incident detection logic, and some automated response plan generation capabilities through an expert system.

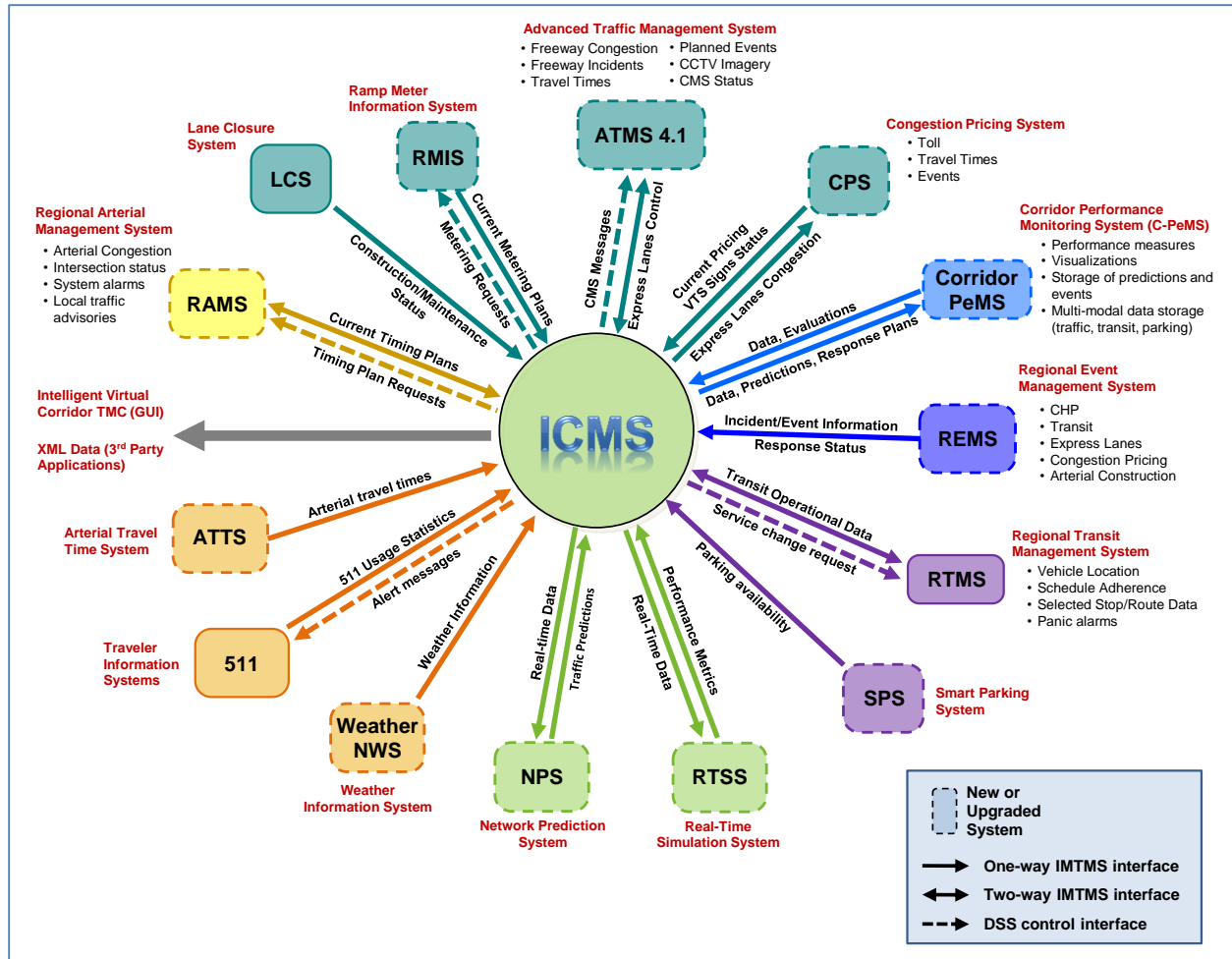


Figure 5-3 – ICMS Context Diagram

- **Congestion Pricing System (CPS)** – Caltrans system through which appropriate tolls are charged to single-occupancy vehicle users of the I-15 Express Lanes facility enrolled with FasTrak.
- **Corridor Performance Measurement System (C-PeMS)** – Web-based application designed to retrieve, process, analyze, and store data collected by traffic detectors, as well as information from Caltrans’ Lane Closure System, Caltrans-operated CMSs, incident reports logged on the CHP Computer-Aided Dispatch system, and accident records contained in the Traffic Accident Surveillance and Analysis System. C-PeMS, initially developed by Caltrans and the University of California to process freeway data, is now fully owned by Caltrans and maintained by Iteris. For the I-15 ICM Demonstration project, enhancements were made to the system to enable it to acquire and process various additional data, such as traffic signal timing data, transit data, parking data, etc.
- **Regional Event Management System (REMS)** – XML-based, Web services interface to the CHP’s CAD Media Server.
- **Regional Transit Management System (RTMS)** – System supporting all fixed-route transit operations for San Diego’s MTS and NCTD.

- **Smart Parking System (SPS)** – Future system planned by SANDAG to collect real-time parking data, set dynamic parking rates, and provide real-time parking information to travelers.
- **Real-Time Simulation System (RTSS)** – System developed as part of the ICM demonstration to support DSS operations and used to manage and execute corridor simulations.
- **Network Prediction System (NPS)** – System developed as part of the ICM demonstration to support DSS operations and used to predict origin-destination flows within the I-15 corridor.
- **Weather NWS** – Interface with weather reporting systems, such as the National Weather Service and Weatherbug.
- **Regional Traveler Information Management System (511)** – System launched by SANDAG in 2007 allowing landline and cellular callers to receive tailored travel information via the Web, phone, and public access television.
- **Arterial Travel Time System (ATTS)** – System providing arterial travel time measurements from arterial sensors. Presently, this system primarily consists of Sensys detectors installed along arterials. However, different sensing technologies may be used in future system expansions.
- **XML Data** – Data feed to third-party information service providers.
- **Integrated Virtual Corridor TMC** – System enabling corridor operators to access ICMS functionalities from the ICM servers.

The following are additional system interfaces that were mentioned in early documents that are not shown in the current version of the context diagram:

- **Managed Lane Control System (MLCS)** – Caltrans system that was under development for the management of the northbound/southbound configuration of the I-15 Express Lane system. Interfacing with this system was removed from consideration when it became obvious that the ability to track the configuration of the Express Lanes system in real time was not feasible.
- **Web Emergency Operations Center (WebEOC)** – Web-based distributed information-sharing application used by a wide variety of agencies for sharing information during major emergencies. This interface was removed from consideration due to budget constraints. However, it is still considered for potential inclusion in a future system expansion.
- **3C Communication Network** – Communication network under development, planned to provide two-way communication via video teleconferencing, publish/subscribe technology on a public safety intranet between agencies, and distribute video feeds outside the network through secure Web streaming and cable broadcasts. This interface was removed from consideration due to budget constraints. However, it is still considered for potential inclusion in a future system expansion.

5.6.2. DATA HUB

Connections between the various systems connected to the ICMS was to be established using the Intermodal Transportation Management System (IMTMS). The IMTMS is a standardized data communication network that had been developed by SANDAG as part of its Regional ITS Network Architecture and became operational in May 2007. This system can be viewed as the “glue” tying together the various systems connected to the ICMS. Operating from servers located in the Caltrans/CHP Transportation Management Center in Kearny Mesa, this communication network was implemented as a

distributed Service-Oriented Architecture using off-the-shelf Web service technologies. Using a variety of distribution servers, it is designed to take data received from participating agencies and to provide fused data to participating agencies as either Hypertext Transfer Protocol (HTTP) Web pages or XML data feeds. XML feeds are also provided to the public through the regional 511 system. Subject to regional agreements, the IMTMS also allowed the shared control of agency CCTV cameras and CMSs, in addition to providing a dynamic, Web-based Graphical User Interface (GUI) for the monitoring and control of regional field devices.

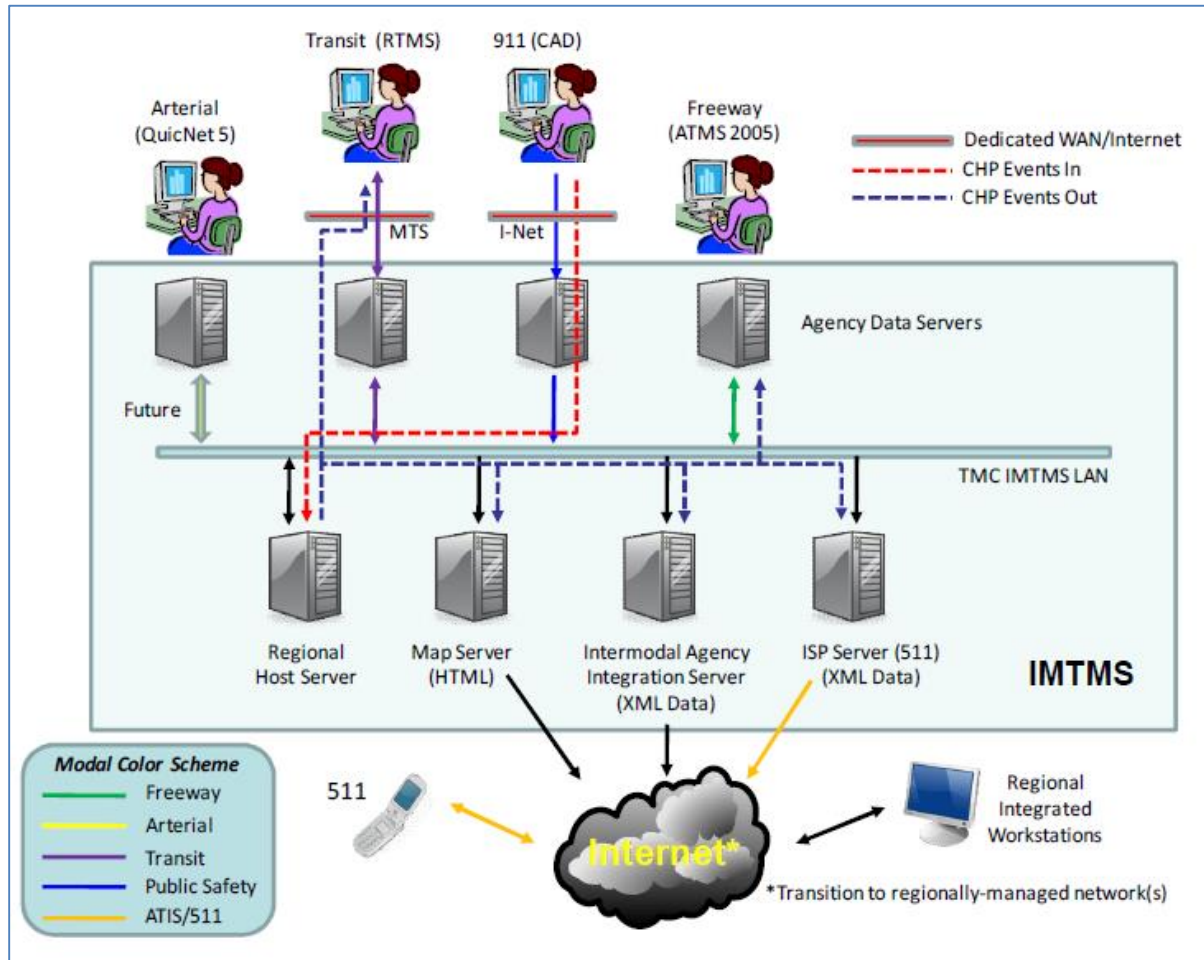


Figure 5-4 – IMTMS Architecture

Figure 5-4 illustrates the basic operating principles of the data hub, using an example often cited in early project development literature, in which:

1. A dispatcher enters information about a freeway incident into the CHP CAD system, as indicated by the dotted red line.
2. After the incident record has been created, the data is extracted by the IMTMS via the CHP Agency Data Server, converted into a XML format, and sent to the Regional Host Server.
3. As indicated by the dotted blue line, the Regional Host Server then sends the CHP incident information to the:
 - Map Server for HTML formatting and HTTP distribution,

- Intermodal Agency Integration server for XML data distribution to third-party applications, and
 - Internet Service Provider server for the regional 511 application.
4. In this scenario, the information is also sent to Caltrans' Freeway Management System and the Regional Transit Management System.
 5. Updates to the incident information follow these same steps until the need for the CHP CAD system to send updates terminates.

5.6.3. DECISION SUPPORT SYSTEM (DSS)

A central element of the ICM demonstration project was the development of a new Decision Support System (DSS), to help system operators identify situations for which response plans should be developed to limit the impacts of the developing congestion. While the existing IMTMS network already facilitated decision-making by enabling agencies to share information, it did not offer the applications needed to integrate this information into actionable control strategies. The DSS aimed to fill this gap by providing improved data fusion capabilities and a new decision-making process capable of generating, automatically or semi-automatically, multi-modal response plans to recurring, non-recurring, and planned events affecting corridor operations. The significance and importance of this new tool lay in the fact that actions to be taken were to be coordinated among corridor stakeholders and not carried out in isolation, as was usually the case.

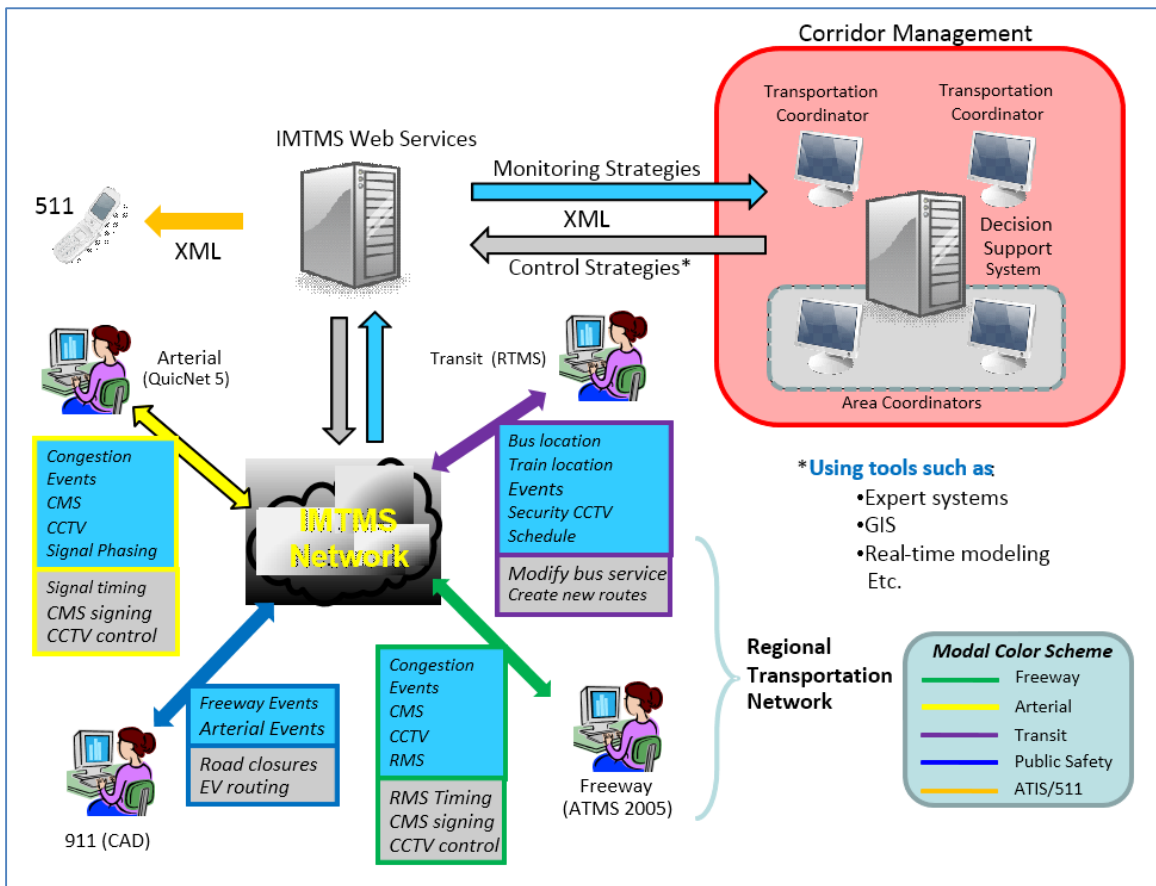


Figure 5-5 – Decision Support System Concept

Figure 5-5 provides an early conceptual view of the DSS. Core functions of the DSS are represented in the gray box shown in the upper right corner of the diagram. Based on information received from the various transportation systems via the IMTMS web services (shown in the blue boxes surrounding the IMTMS cloud), the DSS would use a rules engine to assess corridor operations and develop suitable response plans. These plans would then be converted into control actions that would be passed back to the relevant systems via the IMTMS web servers. Examples of control actions that may be received by each transportation system are shown in the grey boxes surrounding the IMTMS cloud.

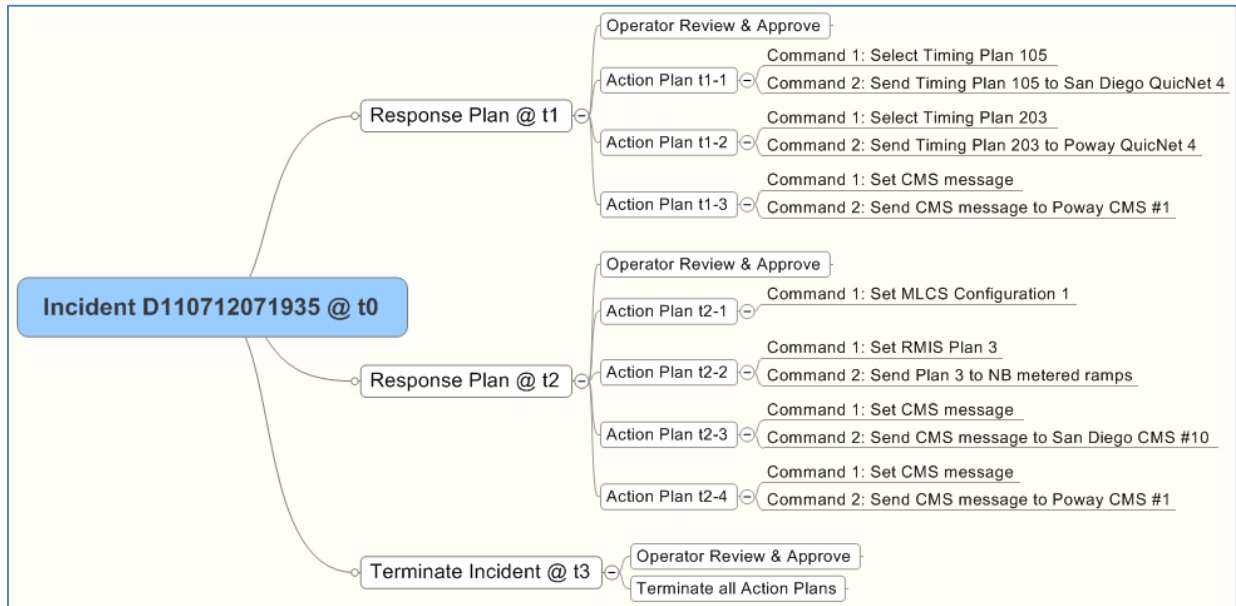


Figure 5-6 – Response Plan Concept

Figure 5-6 illustrates the conceptual process for the generation and execution of response plans. Response plans would be generated when requested for a specific incident location, type, severity, and impact, based on the time of day and other operational parameters. Each response plan would consist of one or more action plans, with each action plan consisting of one or more commands. Single commands would be recommended actions for a specific system in a specific jurisdiction. For example, the first command illustrated in Figure 5-6 would ask for the implementation of signal timing plan 105 at certain intersections. Another illustrated command would request the displaying of specific messages on freeway CMSs. This processing scheme was designed to improve accountability and auditing for actions taken in response to corridor events.

The DSS was envisioned to be an Expert System or equivalent table-driven application that would make decisions based on information available in various databases and a series of “if-then” statements describing the business rules for corridor operations under specified conditions. However, the DSS was not envisioned to be in direct control of the various devices under ICM management within the corridor. Control of these devices was intentionally left to the various management systems already in charge of this task. In this context, the primary role of the DSS was to send recommended control actions to the various management systems. Depending on the desire of individual system operators, these recommendations could be subjected to review by the operators or sent as control commands that could directly be relayed to the various device management systems for automated implementation.

When responding to an event, the DSS was to be further instructed to keep monitoring travel conditions within the corridor and issue updated recommendations when necessary. This would allow the DSS to account for unforeseen changes in travel patterns or other events affecting corridor operations in addition to the original event.

5.6.4. SYSTEM SERVICES

System services were to include various functions supporting the operation of the ICMS, such as:

- System security, backup, and archival functions
- System configuration management functions
- Historical data stores needed for ICMS functions
- Functions needed to access existing databases in connected systems, as the data contained in these systems were not to be replicated
- System maintenance functions
- Training tools

5.7. IMPLEMENTATION ISSUES

The following key implementation issues were identified during the development of the Concept of Operations:

- **Technical Issues**
 - Data archiving and accessibility for future analyses
 - Modifying/updating the San Diego Regional ITS architecture to bring it into alignment with the I-15 ICMS concept
 - Use of regional transit fare system across multiple transit service providers
 - Expansion of functionality for the 511 system
 - Ensuring quality, frequency, and accuracy of information
- **Operational Issues**
 - Enhancing transit capacity in response to accidents
 - Implementing bus signal priority for transit on arterials
 - Coordinating different operating systems across agencies to work together
 - Fully integrating commercial vehicle operations into I-15 the ICMS concept
- **Institutional Issues**
 - Establishing policies and arrangements with private entities (parking, information service providers, and major employment centers along the I-15 corridor)
 - Compatibility of responsibilities of ICMS with the conventional responsibilities of corridor stakeholders
 - Expansion of set of organizational stakeholders as part of the I-15 ICM team beyond those that are only transportation-focused
 - Enhanced level of inter-organizational coordination and integration among stakeholders

5.8. SYSTEM REQUIREMENTS

In formulating the system requirements, a key objective was to produce a top-quality system that could serve as a template for other regions interested in deploying ICM systems. To help satisfy this objective, the project team developed a set of proposed requirements based on a two-part strategy. The first part rested on the recommended guidance and practice from IEEE’s specifications documents [13], while the second part focused on the San Diego region’s vision for the ICMS.

The San Diego local area Stakeholder Working Group first provided the technical and operational foundation for the development of system requirements. The group conducted a series of workshops with both a “core” Working Group and an expanded team that included regional public safety personnel. This iterative process resulted in a set of detailed requirements reflecting the specific needs and systems of the San Diego Region. The Federal Technical Assistance Team provided further guidance during its site visits. Through this process, the project team significantly and comprehensively updated the original set of user needs to reflect the capabilities of current systems and the proposed ICMS functionalities. The resulting needs were in turn listed in an ordered way to reflect the flow of corridor activities during the life cycle of the ICMS.

In the second part of the development strategy, the project team created a high-level functional decomposition modeled on the identified user needs. This provided the benefit of maintaining a one-to-one correspondence between the requirements within each functional area and its corresponding user need(s). The team then partitioned the 17 functional areas two additional times according to the current implementation state of the ICM subsystems (operational or awaiting development and implementation) and the context of the subsystems (internal or external).

Guided by this two-part strategy, the project team followed a detailed and iterative process that resulted in an extensive set of requirements in both depth and breadth. This process consisted of:

- (1) Repeated questioning as to whether each requirement describes a capability that the I-15 ICMS must have to meet its objectives; whether it is well formed; and whether it refrains from designing the system
- (2) Revising requirements where necessary
- (3) Adding the completed requirements to the requirements list

Requirement ID	Description	User Need ID
RSDS-DF-IN-1	The DSS - Response Strategy Data Store shall collect inventory data, status data, existing business rules and workflows, and internally derived performance tiggers from the ICMS subsystems.	10
RSDS-DF-IN-1.2	The DSS - Response Strategy Data Store shall collect "business rules" and "process workflows" associated with a Response Plan from the DSS - Graphical User Interface.	10
RSDS-DF-IN-1.3	The DSS - Response Strategy Data Store shall collect the data required to configure "Response Plans" and modal "Action Plans" from the DSS - Graphical User Interface.	10
RSDS-DF-IN-1.4	The DSS - Response Strategy Data Store shall collect the DSS - Business Rules and Process Management Engine's request to retrieve the most current "Response Plan" data stored in the local archive	10

Figure 5-7 – System Requirements Example

Figure 5-7 illustrates a sample of the system requirements that were developed. Each requirement is identified by a code comprised of four elements (for example, RSDS-DF-IN-1.2). The first element assigned the subsystem to which the requirement is associated:

- Business Rules and Process Management System (BRPMS)
- Legacy Closed-Circuit Control Subsystem (CCTV)
- Data Hub (DH)
- Graphical User Interface (GUI)
- Network Prediction System (NPS)
- System Management Subsystem (SMS)
- Road Asset Configuration and Conditions Data Store (RAC)
- Response Strategy Data Store (RSDS)
- Real-Time Simulation Subsystem (RTSS)

The second element then identified the type of requirement:

- Incoming Data Flow (DF-IN)
- Outgoing Data Flow (DF-OUT)
- Functional Requirement (FR)

The remaining elements of the requirement identification code, represented by numbers, indicate parent-child relationships among the requirements.

In addition to a textual description, each requirement also listed the user need at the base of its development. This correspondence was to be used later in the systems engineering process to verify that all developed subsystems satisfy the user needs at the base of the system development.

5.9. SIMULATED ANTICIPATED BENEFITS

This section presents the high-level results of the operational evaluations of proposed ICM strategies that were conducted by Cambridge Systematics as part of the Analysis, Modeling, and Simulation (AMS) activities of the USDOT ICM Initiative. ICM strategies that were analyzed included pre-trip and en-route traveler information, mode shift to transit, freeway ramp metering, signal coordination on arterials with freeway ramp metering, physical bus priority, and congestion pricing on managed lanes.

The approach that was adopted for the AMS evaluations was based on interfacing a macroscopic travel demand model with a microscopic traffic simulation model. This integration was achieved by first extracting the study area from the regional TransCAD travel demand model used by SANDAG. The resulting network was then modeled in TransModeler traffic simulation model. Macroscopic trip table manipulations were then applied to determine the overall trip patterns within the modeled corridor, followed by a mesoscopic analysis of how drivers would select their time of departure, travel mode, and travel route in response to the ICM strategies implemented. A microscopic analysis of traffic behavior at intersections and freeway ramps was then conducted to evaluate the impacts of ICM strategies on traffic operations.

Microscopic corridor simulations were conducted using TransModeler, as this model supported the evaluation of traffic control aspects of ICM strategies, such as freeway ramp metering and arterial traffic signal coordination, as well as managed-lane operations. At any time during a simulation, this model

allowed drivers to reevaluate their route choice to account for new travel conditions. This model capability was used to evaluate how drivers having access to real-time information would respond to congestion developing from incidents. In this case, drivers having access to real-time information would use an updated trip cost table to make routing decisions. Drivers without access to such information would reconsider their paths using the same information they used to evaluate their trip before starting their journey.

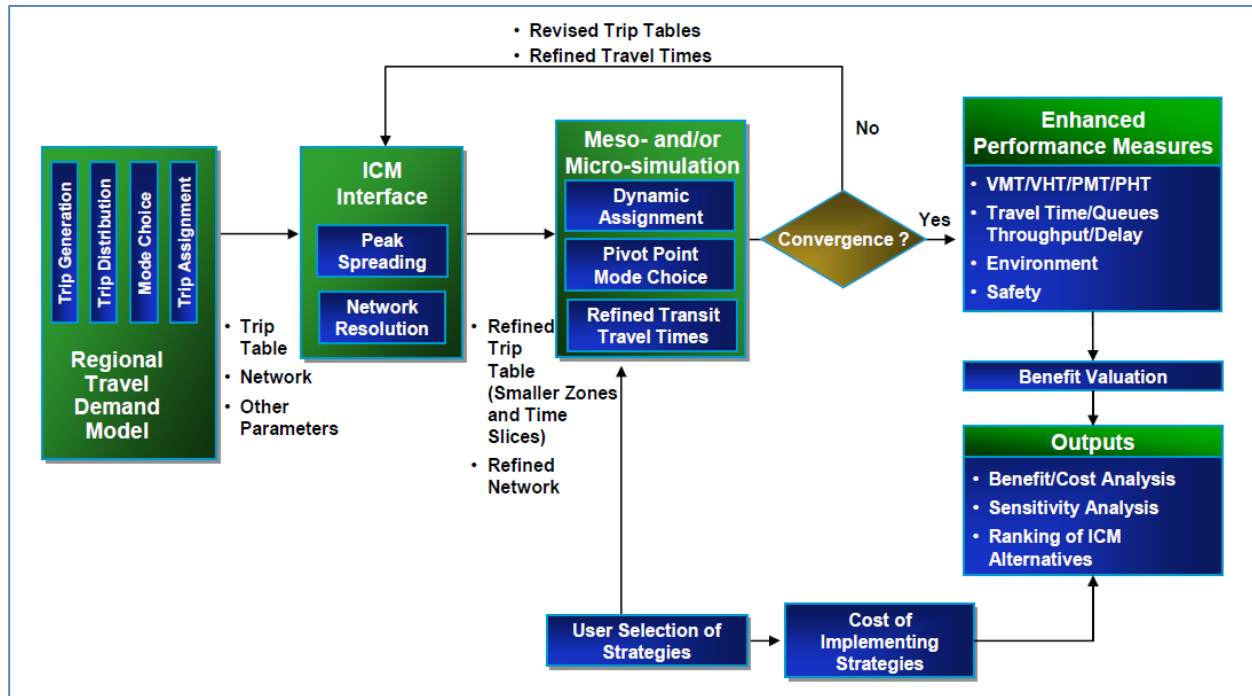


Figure 5-8 – AMS Evaluation Framework

Figure 5-8 shows an overview of the analysis process that was followed [14]. Within the analysis framework, the macroscopic, mesoscopic, and microscopic traffic analysis tools interfaced with each other, passing trip tables and travel times back and forth, looking for natural stability within the system. Absolute convergence was not guaranteed because of inherent differences at the various modeling levels. This methodology sought a natural state for practical convergence between different models, and the iterative process was terminated or truncated at a point where reasonable convergence was achieved.

Evaluations were conducted for pre-defined low, medium, and high travel demand levels. Low demand corresponded to 75% of the typical demand, while high demand corresponded to 102% of the typical demand. Table 5-3 summarizes the key characteristics of the various ICM response scenarios that were developed and applied to each travel demand level. Table 5-4 further details the characteristics of the simulation setup, particularly with respect to the modeled freeway and arterial incidents.

Major tasks associated with the AMS evaluations consisted of data collection; preparation of input files to the TransModeler simulation model such as network coding and origin-destination matrices; models validation and calibration; alternatives analysis; and performance measurement assessment. Details about these activities can be found in an experimental plan developed by Cambridge Systematics prior to initiating model development [15].

Table 5-3 – ICM Response Scenarios

Strategy	Baseline operations	Daily ICM operations	Freeway incident	Arterial incident	Disaster response
Pre-trip and en-route traveler information		•	•	•	•
Provision of transit signal priority		•	•	•	•
Ramp meters/traffic signal coordination		•	•	•	•
Bus Rapid Transit system		•	•		•
Congestion pricing for I-15 Express Lanes		•	•		•

Table 5-4 – Modeling of Incidents

Parameter	Value	Comment
Base year	2003	Base analysis year based on the available validated model year in the regional travel demand model, and in the absence of major construction activity within the corridor.
Analysis year	2012	Analysis year derived from the anticipated completion of construction of the I-15 ICMS, and the implementation of ICM strategies.
Analysis time period	AM	Analysis of the AM peak period provided the most benefits in terms of proposed ICM strategies.
Simulation period	3-5 hours	6 AM – 9 AM was the primary analysis period. Future baseline scenarios ran from 6 AM to 11 AM to calculate performance metrics.
Freeway incident location	South of Ted Williams Parkway (SR_56)	This location was found to experience a high number of incidents, offered the potential for route divers, and had a high impact on corridor travel.
Freeway incident duration	45 min	This duration was chosen to represent a major blockage in the peak period. The incident was modeled to occur at 7 AM and to be cleared by 7:45 AM.
Freeway incident severity	Lane closures	3 lanes closed, with reduced speed on lanes 4 and 5, from 7 AM to 7:30 AM. Only 2 lanes closed, and reduced speeds on lanes 3, 4 and 5, for the remaining duration of the incident.
Arterial incident location	On Carmel Mountain Road, east of I-15	Based on 2012 demand projects for different arterials under study.
Arterial incident duration	40 min	This duration was chosen to represent a major blockage in the peak period. The incident was modeled to occur at 7:30 AM and to be cleared by 8:10 AM.
Arterial incident severity	Lane closures	Variable lane closures and speed reductions.

Figure 5-9 shows the total estimated benefits that were assessed from the AMS work for specific corridor elements [12]. The analysis results showed that significant benefits could be obtained from the ICM strategies that were considered for the proposed I-15 ICMS. The following is a summary of the key estimated benefits identified in the AMS Report:

- Overall, deployment of ICMS on the I-15 corridor would produce \$13.7 million in user benefits per year. Over a 10-year life cycle, the total benefits would amount to **\$115.9 million**.
- The overall costs to deploy the system, annualized over a 10-year period, were estimated to be \$1.42 million. The total life cycle costs to deploy and operate over this period were further estimated at **\$12.0 million**.

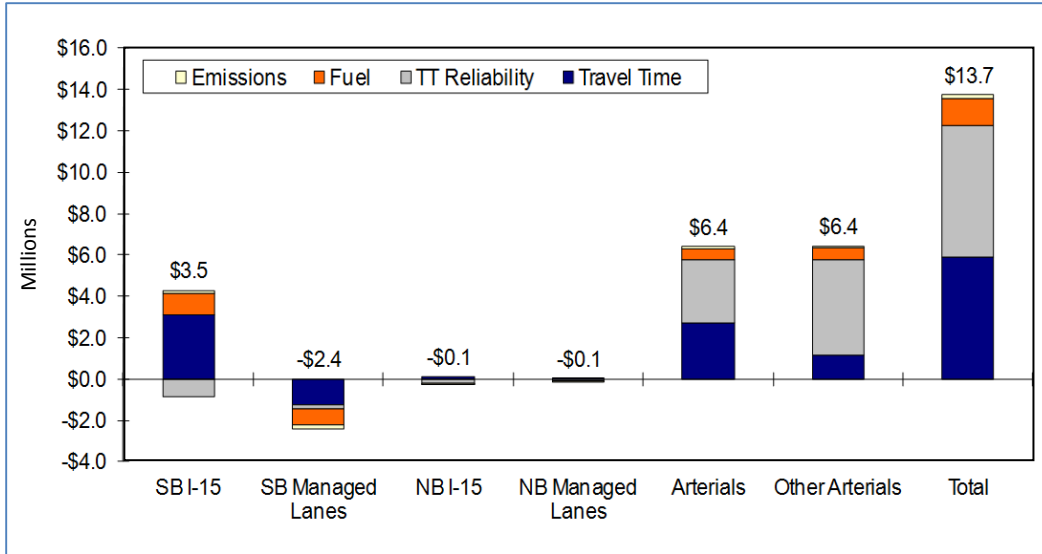


Figure 5-9 – Overall Estimated ICM Benefits, by Corridor Element [12]

- The estimated benefit/cost ratio for the deployment of the ICMS, when considering 10-year life cycle costs, was approximated at **9.7:1**.
- Benefits from the ICMS were attributable to reduced travel times, improved travel time reliability, reduced fuel consumption, and reduced mobile emissions, particularly for traffic in the southbound direction. Expected annual savings included 245,594 hours of vehicle-hours of travel, a 10.6% reduction in travel time variability, a reduction of fuel consumption by 322,767 gallons, and an annual reduction of 3,057 tons of vehicular emissions.
- With the provision of improved traveler information, it was anticipated that more arterial travelers would be attracted to the freeway. This shift in traffic would then improve arterial performance and overall system performance.
- The I-15 Express Lanes show some operational disbenefits due to their opening to all traffic during major freeway incidents. However, since the additional vehicles using the Express Lanes would be removed from the adjacent general-purpose lanes and arterials, overall corridor improvement results would still be obtained from opening the Express Lanes to the general traffic during incidents.
- Along the arterials, most of the improvements in travel time and travel time reliability are owed to changes in arterial signal optimization.
- The proposed ICM strategies would produce more benefits at higher levels of travel demand, and during non-recurrent congestion. Approximately 93% of the total ICM benefits resulted from the high- and medium-demand scenarios, which represented 69% of all commute days. In addition, two-thirds of the total benefit were attributed to high- and medium-demand scenarios with an incident. For individual travelers who primarily rely on the I-15 southbound facility, the majority of benefits were accrued under operational conditions associated with high travel demand and incidents. This finding validated the hypothesis that ICM would be most effective under the worst operational conditions.
- Other corridor-wide travelers saw smoothed benefit over most travel days as the system reacted more intelligently and more rapidly to variations in congestion conditions. These travelers

experienced small benefits accrued over many days rather than on particular days. Benefits from ICM were related to a ripple effect from better addressing the impacts of major disruptions. Benefits that accrued from multiple, distant ripples were smoothed over travel time, reliability, and fuel consumption. As a result, travelers close to the source of disruption would experience more reliability benefits.

- Transit excess capacity was found to be better utilized overall, particularly under incident conditions, drawing additional travelers to the BRT facility without overwhelming the BRT.
- The AMS evaluations validated the assumption that dynamically applying ICM strategies in combination across a corridor would reduce congestion and improve the overall productivity of the transportation system as a whole.

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6. STAGE 3 ICM DEMONSTRATION TASKS

This section provides a summary of the key tasks executed by SANDAG's I-15 ICM Demonstration project team as part of Stage 3 of Phase 3 of the USDOT ICM Initiative. Two specific descriptions are presented:

- General project tasks to be executed by the project team
- Description of the specific activities that defined PATH's involvement on the project

6.1. GENERAL PROJECT TASKS

The following eight tasks were defined for Stage 3 of the I-15 ICM Demonstration project:

1. Project management
2. Refinement of system requirements
3. System design and system build
4. System testing
5. Training
6. System operations and maintenance
7. Participation in the Analysis, modeling, and simulation of the system
8. Participation in system evaluation
9. Participation in outreach activities

Each of the above tasks are described in detail in the subsections that follow.

6.1.1. TASK 1 – PROJECT MANAGEMENT

The objective of this task was to provide overall project management. In addition to general project management activities, a key focus was to develop a Project Management Plan (PMP) detailing:

- The steps to be taken and procedures to be put in place at the start of the project
- Identification of the project's schedule, activities, budget, milestones, and deliverables
- Arrangements for managing the implementation of major project elements
- Arrangements for monitoring and control, including progress reporting
- Arrangements for closing each stage of the project, including the planning, design, implementation, and operations phases of the ICMS

A Systems Engineering Management Plan (SEMP) detailing how the systems engineering process will be applied to project activities was also to be produced by the project team.

The following documents were the key anticipated deliverables for this task:

- Project management plan (PMP)
- Systems engineering management plan (SEMP)
- Risk registry
- Quarterly reports to be submitted to the USDOT

6.1.2. TASK 2 – REFINEMENT OF SYSTEM REQUIREMENTS

The objective of this task was to refine and revise, as necessary, the Concept of Operations and System Requirements documents that were initially developed during Stage 1 and updated during Stage 2 of demonstration project.

The following documents were the key anticipated deliverables for this task:

- Revised Concept of Operations for I-15 ICM
- Revised Systems Requirements Specification for I-15 ICM

6.1.3. TASK 3 – SYSTEM DESIGN/BUILD

The objective of this task was to design and build, and then integrate, each of the subsystems required for the I-15 ICMS based on the developed Concept of Operations and System Requirements. Among the key subsystems that were to be developed in this task were the Decision Support System (DSS), the Network Prediction System (NPS), and the Real-Time Simulation System (RTSS).

Throughout the design/build process, the project team was to employ the IBM “Rational Unified Process” (RUP) to achieve consistent results across the multiple vendor development teams that were expected to work on this software-intensive project. This approach is an iterative development process that can be tailored to the specific needs of each project. This process typically involves the four following phases within each iteration:

- Inception of components to be developed: business case development, use case modeling, project planning, initial risk assessment, and project description.
- Elaboration of system architecture, software architecture, executable architecture, risk expansion and control, and prototypes to be developed.
- Construction of software components and other features of the system.
- Transitioning the system from development to production. This includes training of both users and maintainers, and testing of the system to validate it against the end user’s expectations.

The main tasks that the project team were to address during design activities were:

- **Business Use Case Modeling** - Capturing the business logic in a structured approach to the system description.
- **Software Architecture Definition** – Development of a high-level architecture for the system and more detailed architectural definitions for each of the design iterations.
- **Software Development Process Planning** – Planning of phases and iterations for the software development process.
- **Execution Architecture Definition** – Identification of business use cases that were architecturally significant, and phasing of these cases to ensure they correctly support future developments.
- **Business Case Risk Listing** – Capturing and addressing of risks highlighted within the Project Management Plan.
- **Prototyping for Risk Mitigation** – Preparation of non-functional prototypes for stakeholder input to help address business use cases carrying significant risks.

During the build phases, software development activities were to be tracked for completion against milestones before proceeding to the next stage. At each iteration, this development was to be guided by the previously agreed-to Phase Plan and Iteration Plan in effect at that point.

The Phase Plan was to include the following elements:

- **Measurement Plan** – Document defining the measurement goals, the associated metrics, and the primitive metrics to be collected to monitor the project’s progress
- **Risk Management Plan** – Document detailing how to manage the project risks
- **Risk Registry** – List of known and open risks to the project, sorted in decreasing order of importance and associated with specific mitigation or contingency actions
- **Problem Resolution Plan** – Document describing the process used to report, analyze, and resolve problems that occur during the project
- **Product Acceptance Plan** – Document describing how the ICM stakeholders will evaluate the deliverables from the project to determine if they meet a predefined set of acceptance criteria

Iteration Plans were to track progress and to capture the following elements:

- The project plan definition
- The status of the project (on track, late, etc.)
- The list of scenarios or use cases that were to be completed at the end of the iteration
- The list of risks that must be addressed by the end of the iteration
- The list of changes that must be incorporated in the product (bug fixes, change requirements)
- A list of the major program components that must be completely implemented in the iteration

The following documents were the key anticipated deliverables associated with design activities:

- Preliminary Design Review (40% Design) documents
- Critical Design Review (90% Design) documents
- Final System Design documents

The following documents were the key anticipated deliverables associated with build activities:

- Software development plan
- As-built diagrams
- Operations manuals

6.1.4. TASK 4 – SYSTEM TESTING

The objective of this task was to prepare for and perform various system tests to ensure that the developed ICM functions properly and as expected. Planned tests included:

- **Unit Test** – Testing of individual software modules
- **Integration Test** – Testing of groups of modules
- **System Test** - Testing conducted of complete, integrated system
- **Acceptance Test** – Testing to determine if the requirements of a specification or contract are met

Test elements to be documented during this task included:

- **Test plan** – Overall planning document, outlining test procedures, equipment being tested, support requirements, personnel requirements, procedures needed to ensure that the operational environment is not unduly impacted
- **Test cases** – Scenarios identifying major system functions to be tested and leading, in turn, to test procedures
- **Test procedures** – Individual procedures to be followed, listing the expected and observed result

Before a phase or final acceptance test occurred, the project team was to schedule a Test Readiness Review. The purpose of this activity was to review the test plan, specific test requirements for equipment availability, the need for field observers, how the test will be conducted, how defects would be recorded, the defect clearance procedures to be followed, and other topics that were needed to ensure that all participants knew their responsibilities during the test event. Particular care was also to be used during the acceptance tests to account for operational systems, particularly for the potential for adverse impacts on these systems during the tests.

The following documents were the key anticipated deliverables for this task:

- System Test Plan
- System Test Report

6.1.5. TASK 5 – TRAINING

The objective of this task was to design and implement a training program to document system operations and delivery of knowledge to system users. The overall goal of the training program was to initiate a common, coordinated, and unified platform for operating and managing the I-15 ICMS. A specific goal of the training activities was to establish a high degree of interagency, multi-disciplinary understanding and confidence among the system stakeholders to ensure the actual use of the developed ICMS for managing congestion along the I-15 corridor. Details of the training program were to be identified in a Training Plan to be developed by the project team. Specific training activities were envisioned to include possibly any combination of remote/centralized transportation management exercises, tabletop exercises, and classroom lectures and discussion based on specific ICM training needs.

This task was to include the following key activities:

- **Analysis of the ICMS**
 - Relate ICMS objectives to training objectives
 - Analysis of ICMS from a training perspective
 - Compilation of a task list for ICMS operation, management, and usage, drawing on the ICMS Operations and Management Plan
 - Identification of ICMS tasks requiring training
 - Identification of performance measures to be learned, and synchronization of these measures with ICMS objectives
 - Selection of instructional methods and settings for the training

- **Design of the ICMS Training Program**
 - Development of objectives for the training
 - Identification of the training steps required to perform each task
 - Development of performance tests to confirm mastery of the tasks
 - Identification of the behaviors and characteristics that agency staff is expected to possess or exhibit prior to entering the training program
 - Sequencing and structuring of the training objectives
- **Development of ICMS training materials**
 - Listing of activities that would help the project staff learn the required tasks
 - Selection of the delivery methods
 - Review of existing materials that had been developed by local agencies or the USDOT
 - Development of the training materials
 - Packaging of the training materials into a coherent and practical training program tailored to the needs of the agency staff and the ICMS
 - Validation of the training materials to ensure that all goals and objectives are addressed
- **Implementation of ICMS training program**
 - Creation of a training plan to guide the delivery of the training program
 - Execution of the training program

The following documents were the key anticipated deliverables for this task:

- I-15 ICMS Training Plan
- I-15 ICMS Training Manuals

6.1.6. TASK 6 – OPERATIONS AND MAINTENANCE

This task focused on what happens after the system has been launched. Its objective was to conduct training program evaluation, assess operations and maintenance needs for the I-15 ICMS, develop an operations and maintenance plan, and develop operations and maintenance reports.

A key objective of this task was to ensure that decision makers, system managers, and system operators receive targeted understanding and training in joint mode corridor operations and how collaborative operations would change operating procedures and philosophies. Proposed operational and management plans were seeking to reflect the following key principles:

- Identify and come to consensus on the selected ICMS operational needs and scenarios to be operated and maintained over the planned 18-month operations and maintenance period.
- Achieve institutional commitment on protocols for operating the ICMS.
- Achieve institutional commitment on protocols for managing the ICMS.
- Identify and articulate long-term institutional and technical needs and resources for the ICMS.

Thorough discussion on scheduling, work force, materials, and equipment were to allow all ICM partners to estimate and attain an understanding of the short- and long-term operational and maintenance resource and funding requirements. To achieve this, an Operational and Maintenance Plan was to be organized and developed to reach different levels of detail, from high-level summary overviews, to detailed systematic operational sequences, to more detailed specifications. The development of this plan was to be completed through an iterative process consisting of ongoing coordination and communications

to achieve appropriate levels of consensus, commitments, and direction for establishing formal operational and management level agreements for long-term system operations.

The following documents were the key anticipated deliverables for this task:

- I-15 ICMS Operations and Maintenance Plan
- I-15 ICMS Operations and Maintenance Reports

6.1.7. TASK 7 – PARTICIPATION IN THE ANALYSIS, MODELING, AND SIMULATION OF SYSTEM

The objective of this task was for the project team to provide support to the National Evaluation Contractor (Battelle Memorial Institute) and AMS Contractor (Cambridge Systematics) for the following activities:

- **Comparison of observed operational results against predicted impacts** – A series of pre-deployment analyses were to be conducted by the AMS Contractor using simulation software to define the anticipated impacts of the proposed I-15 ICMS on the freeway, arterial, managed lanes, and transit elements on travel times, travel time reliability, and other performance measures.
- **Evaluation of the demonstration project** – The project team was to work in close coordination with the National Evaluation Contractor and the AMS Contractor to help assess the effects and impacts of the I-15 ICMS project over an 18-month operational period.
- **Development of Pre-Deployment AMS Plan and Post-Deployment AMS Plans** – The plans were to identify, define, and describe the tools and data to be used, as well as activities to be followed, for executing the pre-deployment and post-deployment ICMS analyses.
- **Development of AMS Data Collection Plan and related data collection** – Development and execution of a plan to collect, assemble, prepare, and supply to the USDOT evaluation team and AMS Contractor the data needed to support the conduct of their ICM evaluation activities.

The following documents were the key anticipated deliverables for this task:

- Pre-Deployment AMS Plan
- Pre-Deployment Data Collection Plan and “Before” Data
- Post-Deployment AMS Plan
- Post-Deployment Data Collection Plan and “After” Data
- Post-Deployment AMS Transition Plan

6.1.8. TASK 8 – PARTICIPATION IN THE SYSTEM EVALUATION

The objective of this task was to support the National Evaluation Contractor selected by the USDOT (Battelle Memorial Institute) in its evaluation of the ICM demonstration project. As part of this effort, the project team was to develop a Demonstration Project Evaluation Plan specifying the data to be collected and provided to the National Evaluation Contractor to support the evaluation of the following metrics

- Improve situational awareness
- Enhance response and control
- Better inform travelers
- Improve corridor performance

The Evaluation Plan would also specify and lay out anticipated support for conducting data collection efforts through surveys or other means, including motorist-specific questionnaires. The establishment of baseline pre-implementation efforts, and support for undertaking post-implementation data collection efforts, were also to be addressed.

Throughout this process, the team was to request input and guidance from the USDOT and the National Evaluation Contractor to assure consistency and verification of the anticipated data collection needs, tools, and gathering and reporting of existing and readily available survey information that were to be provided to the evaluation contractor.

The following document was the only key anticipated deliverable for this task:

- I-15 ICM Demonstration Project Evaluation Plan

6.1.9. TASK 9 – PARTICIPATING IN OUTREACH PROGRAMS

The objective of this task was to develop and conduct an Outreach Program at both the national and local levels for the I-15 ICMS. To perform this task, a National Outreach Participation Plan was to be created to define target events, describe the primary messages to be conveyed, provide detailed outlines for presentation materials, and define any agendas required for workshops.

Specific activities that the plan had to address included:

- At the national level, commitment by the project team to participate in two pioneer site workshops per year during the duration of the demonstration project. In support of these activities, ICMS partners were to prepare and assemble suitable materials to communicate key aspects of the demonstration project, practical lessons learned, issues identified, and challenges addressed and overcome.
- Participate in at least two conferences per year to supply information and experience to a wider audience of practitioners and potential ICM adopters.
- Develop result-focused material to support effective technology transfer to other future ICM adopters.
- At the local level, development of outreach activities with the guidance of SANDAG's and Caltrans' Public Information Team to effectively deliver and convey ICM benefits to system users/travelers and decision makers.

Both the national and local outreach activities were to be coordinated to ensure consistency in message definition and delivery.

The following document was the only key anticipated deliverable for this task:

- I-15 ICM Demonstration Project National Outreach Plan

6.2. PATH CONTRACTED TASKS

This section provides a summary of the activities that were specifically contracted to PATH as part of Stage 3 of the I-15 demonstration project. PATH's involvement was essentially to provide technical support and guidance to other project team members upon their request. PATH was not assigned the lead of any of the project tasks, nor the preparation of any of the deliverables listed in Section 6.1.

Below is a summary of PATH's contracted tasks:

- **Task 1- Project Management**
 - Provide support for the development of the Project Management Plan (PMP) and Systems Engineering Management Plan (SEMP)
 - Provide support for the production of quarterly and annual progress reports to be submitted to the USDOT
 - Produce support for the development of the final and draft versions of the Project Report to be submitted to the USDOT

- **Task 2 – Refinement of System Requirements**
 - Participate in System Requirements Walkthrough meeting
 - Participate in the review of the System Requirements Specification document
 - Participate in the review of the Concept of Operations document

- **Task 3 – System Design/Build**
 - Contribute to the design of the Decision Support System (DSS) and Traffic Prediction Tool (now called the Real-Time Simulation System and Network Prediction System)
 - Provide assistance with the development of system design documents

- **Task 4 – System Testing**
 - Provide assistance in the execution of test readiness reviews and the production of test reports

- **Task 5 – Training**
 - Provide assistance in the execution of ICMS training needs analysis, design of the training program, development of training material, and implementation of training program

- **Task 6 – Operations and Maintenance**
 - Provide assistance in the evaluation of ICMS training program
 - Help team members analyze ICMS operations and maintenance needs
 - Help develop the Operations and Maintenance Plan
 - Help develop the Operations and Maintenance Report

- **Task 7 – Participation in the Analysis, Modeling, and Simulation of the ICMS**
 - Help develop the pre-deployment and post-deployment plans
 - Help develop the pre-deployment and post-deployment plans site data collection plans
 - Help collect the “before launch” and “after launch” data

- Help develop the post-deployment AMS Transition Plan
- **Task 8 – Participation in the System Evaluation**
 - Help the project team coordinate its activities with those of the National Evaluation Contractor (Battelle Memorial Institute)
 - Participate in the development of the evaluation plan for the I-15 Demonstration Project
 - Assist team members in providing performance measure data
 - Help with the provision of required tools for conducting performance measurements
 - Assist team members coordinating the collection of existing survey data
- **Task 9 – Participation in Outreach Programs**
 - Provide assistance with the development of a National Outreach Participation Plan
 - Help the project team conduct outreach activities defined in the National Outreach Participation Plan

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7. SUMMARY OF PHASE 3, STAGE 3 ACTIVITIES

This section presents a summary of the activities that have been conducted as part of Phase 3, Stage 3 of the USDOT ICM Initiative. This includes a description of the activities that have been conducted by SANDAG's development team and a description of the outcomes of these activities. The summary of activities is structured around the key project tasks described in Section 6 and includes the following topics:

- Project timeline
- Task 1 – Project management
- Task 2 – Refinement of system requirements
- Task 3 – System design
- Task 4 – System testing
- Task 5 – Training
- Task 6 – System operations and maintenance
- Task 7 – Analysis, modeling, and simulation of the ICMS
- Task 8 – System evaluation
- Task 9 – Outreach activities

7.1. PROJECT TIMELINE

Figure 7-1 presents a timeline of project activities associated with Stage 3 of Phase 3 of the USDOT ICM Demonstration project. Project activities technically started in May 2009 with the submission by SANDAG to the USDOT of a proposal to participate in Stage 3 of the ICM Demonstration project. Following a positive response to the proposal, Stage 3 project activities formally started in January 2010. While the project was initially expected to end by July 2014, various contractual and technical issues forced the project team to extend the project over time. This is not surprising given the innovative nature of the development work that was to be executed and the need for the project team to address various unexpected design issues. While the ICMS launch was initially planned for March 2013, it actually occurred in March 2014 due to the need for the project team to resolve various technical issues with the proposed system design. In March 2014, completion of project evaluation activities was further expected by June 2015. However, the need to resolve various unexpected system operational issues again gradually pushed the anticipated end of the project to December 2015.

PATH's involvement in Stage 3 of the demonstration project officially started in June 2010. While this involvement was initially expected to end by April 2013, changes in the anticipated end date of project activities led Caltrans to award PATH in November 2012 a first contract extension to October 2014, and in March 2014 a second extension to June 2015. At the time of the second extension, system evaluation activities were expected to end by March 2015. However, the forecasted end of evaluation activities has slipped since then to December 2015, past PATH's contractual end date of June 2015. While a third extension was considered, it was determined that project activities had sufficiently started to draw down to allow PATH's involvement to end in June 2015. By March 2015, very few system tweaks were being performed, and system evaluations were well underway. All that was left to do was to wait for the delivery of the system evaluation reports to be produced by the USDOT evaluation team, the post-launch simulation evaluation report to be produced by Cambridge Systematics, and some reports to be produced or finalized by the SANDAG development team.

7.2. TASK 1 – PROJECT MANAGEMENT

Figure 7-2 shows the cover pages of the two primary documents developed by the project team to support project management activities:

- Project Management Plan (PMP)** – Document detailing how the project team intends to management the project. Elements defined in the document include a general project management approach, how requested changes to the project will be tracked and reviewed, how communication between team members is to be managed, how project costs will be measured and managed, how services and products supporting the project will be acquired, how the project scope and schedule will be monitored and managed, how the project team will ensure that quality products are developed, how staff resources will be managed, and how project risks will be identified, documented, and managed.
- Systems Engineering Management Plan (SEMP)** – Document detailing how the project team intends to use systems engineering principles to guide technical project activities. This document defines the scope of the project; the technical plans that will be developed throughout the project; the control gates that will be used to determine when specific tasks or activity sets have been completed; the iterative process that will be used to design, build, and implement the proposed ICM system; how technologies critical to the project will be identified, evaluated, and implemented; and how system integration with existing systems will occur.



Figure 7-2 – Project Management Plan and Systems Engineering Management Plan

Development of the Project Management Plan and Systems Engineering Management Plan occurred in the fall of 2010 and spring of 2011. Development of these two documents is a requirement of the systems engineering management approach that the USDOT requested the project team follow. Since 2001, the FHWA has required that all Intelligent Transportation Systems projects moving into a design stage follow a systems engineering approach that is commensurate with the project scope. These requirements are detailed in FHWA Rule 940, which provides policies and procedures for implementing section 5206(e) of the Transportation Equity Act for the 21st Century (TEA-21), Public Law 105-178, 112 Stat. 457, pertaining to conformance with the National Intelligent Transportation Systems Architecture and Standards.

In addition to the above two documents, the project team developed an Excel document detailing the potential risks to the project. A screenshot of the resulting Risk Registry is shown in Figure 7-3. From an initial set of three risks raised in January 2010, the registry grew to include 73 risks by August 2012. For each risk, the registry provides a brief description of the associated issue, a score reflecting the risk's probability of occurrence and its potential impact on project activities, factors used to assess whether the risk has been triggered, and the response strategy to address the risk. Information about whether a risk has been triggered, and its resolution status, is also provided.

As of June 2015, 16 of the identified risks have been triggered at one point or another during the project. Examples of risks that have been triggered include:

- **System design/build**
 - Project delay due to longer than anticipated time to sign contract with selected system designer
 - Project delay due to longer than anticipated time needed to review and edit systems requirements
 - Additional efforts requirement to correlate activities defined in the systems engineering V diagram with the Rational Unified Process
- **Communication between project partners**
 - Inconsistent messaging to project partners, decisions makers, and public could undermine how each agency perceives project success
- **Project partnership**
 - Impact on scheduled activities of departure of key personnel from partner agencies
- **Project funding**
 - Delay to the initiation of the project due to the inability of the USDOT to provide the required funding
 - Inadequate data collection effort assumptions due to a lack of information regarding the detailed scope of work assigned to the Federal Evaluation Contractor
- **Project scheduling**
 - Impact of competing schedules on project activities
 - Impact of complex system design elements on budget and/or schedule

I-15 ICM Demonstration: Stage 3 PATH Report

Last Reviewed	Issue ID	ID No.	Description	RISK IDENTIFICATION AND ANALYSIS								RESPONSE PLANNING			RISK MONITORING			
				Risk Categories	Probability	Impact	Score	Trigger	Potential Outcome	Raised By	Date Raised	Source	Response Strategy	Response Plan Notes	Risk Owner	Risk Status	Trigger Date	Notes
6/27/2011	1	1-1	Procurement of development/integrator services is not achieved in a timely manner.	1 - Initiation	high	very high	0.56	Variance in anticipated time of completion by > 20%	Delay to Project Schedule	PMT	4/8/2010	Risk ID Process	Mitigate	Use On-call process to simplify procurement of services - Rebaselined schedule due to risk being triggered; new trigger date for Design Team task order is November 1, 2010 - Anticipated mid February 2011	Peter Thompson	Retired	6/1/2010	Procurement method to obtain system designer has taken longer than anticipated - Task Orders to System Design Team complete 6/16/2011
8/25/2010	2	1-2	USDOT is unable to or is delayed in providing funding because the demonstration project has not been included in the TIP.	1 - Initiation	very low	high	0.04	Delay in project funding by > 20%	Delay to Project Schedule	PMT	4/8/2010	Risk ID Process	Avoid	Project has already been included in the TIP	USDOT	Retired		
8/17/2012	3	2-1	Managing complexity of the project causes risk to the schedule, budget or operational performance of the ICMS.	2 - Project Management	low	very high	0.24	Variance in project management effort by > 20%	Cost/Schedule over runs and sub-optimal system performance	PMT	4/8/2010	Risk ID Process	Mitigate	Have put together strong project management team to address all components of the project including coordination, communication, technical and design	Alex Estrella Peter Thompson	Identified		
8/17/2012	4	2-2	Development team is too remote for effective coordination and facilitation	2 - Project Management	low	high	0.12	Variance in design task time by > 40%	Cost/Schedule over runs	PMT	4/8/2010	Risk ID Process	Mitigate	Have established weekly coordination meetings (Design Working Group) including system design leads to promote consistent coordination	Peter Thompson Richard Chylinski Matthew Jukes	Identified		
8/17/2012	5	2-3	Delay in an activity on the critical path has consequential delays to the whole project	2 - Project Management	low	very high	0.24	Variance in milestone completion by > 20%	Delay to Project Schedule	PMT	4/8/2010	Risk ID Process	Accept	Monthly review of project schedule to try and identify and resolve activity delays prior to consequential project delays	Alex Estrella Mike Washkowiak	Identified	6/1/2010	Project has been delayed because system designer contracting has taken longer than anticipated; risk mitigation is compression of schedule. Revised Baseline schedule has been adopted - continue tracking project for adherence to baseline schedule
8/17/2012	6	2-4	There are insufficient resources to complete the project successfully	2 - Project Management	low	moderate	0.06	Variance in build task time by > 40%	Sub optimal system performance	PMT	4/8/2010	Risk ID Process	Mitigate	Have scaled project components consistent with the project funding that has been procured	Alex Estrella	Identified		
8/17/2012	7	2-5	Cost and time estimates for project planning and management are not accurate enough	2 - Project Management	low	moderate	0.06	Variance in project management effort by > 40%	Cost/Schedule over runs	PMT	4/8/2010	Risk ID Process	Accept		Alex Estrella	Identified		
8/17/2012	8	3-1	The scope of the project is not clearly defined and ambiguities lead to cost and time over runs	3 - Requirements	probable	high	0.20	Repeated scope change requests that Change Control Board identifies	Cost/Schedule over runs	PMT	4/8/2010	Risk ID Process	Mitigate	The System Requirements have undergone rigorous review and editing to further clarify the	Peter Thompson	Planning Complete		

Figure 7-3 – Project Risk Registry

7.3. TASK 2 – REFINEMENT OF SYSTEM REQUIREMENTS

The focus of Task 2 was to refine and revise, if necessary, the Concept of Operations and System Requirements for the I-15 ICMS that had been developed in 2008 during Stage 1 of Phase 3 of the ICM Demonstration effort (see Figure 7-4). The purpose of these revisions was to adjust the proposed operational concept and requirements based on additional information that may have been collected or incremental concept development that may have occurred since these two elements had been developed.



Figure 7-4 – Concept of Operations and System Requirements Documents

Review of the existing Concept of Operations and Systems Requirements occurred in the spring and summer of 2010. No change was made to the Concept of Operations document. Following a requirements walkthrough workshop in March 2010 and subsequent reviews of requirements by the system stakeholders, the updated System Requirements were formally accepted by the project participants in August 2010.

7.4. TASK 3 – SYSTEM DESIGN

This section presents a summary of the design activities for the I-15 ICMS. This includes both a summary of the design process that was followed and brief descriptions of the resulting system components that were developed. Specific elements presented in this section include:

1. Adopted iterative design process
2. General system architecture
3. Delcan's iNET system platform
4. Interfacing systems
5. Key input data
6. Arterial detection improvements
7. Modified ALINEA ramp metering algorithm

8. Event characterization
9. Response plan elements
10. Basic control loop
11. Asset availability criteria
12. Action-triggering parameters
13. Incident response posture
14. Evaluation of response plans
15. Real-time simulation system
16. Network prediction systems
17. Implementation of response plans
18. Dissemination of routing information
19. Corridor-PeMS application

7.4.1. ITERATIVE DESIGN PROCESS

Development of the I-15 ICMS generally followed the systems engineering process described in Section 2.2 and illustrated in Figure 2-1. While project activities sought compliance with the standard systems engineering methodology, which seeks to sequentially identify system requirements, design the system, build system components, and integrate these components into a coherent system, the development methodology used within the project was modified to allow multiple software iterations during the lifecycle of the project, as schematically illustrated Figure 7-5. This type of modification is permitted by the systems engineering framework if it allows the implementation of a more suitable development process without sacrificing the underlying systems engineering principles. In this case, the adoption of an iterative design process was greatly influenced by the complexity of the system, which made difficult and costly the prospect of resolving problems that may be uncovered late in the development process.

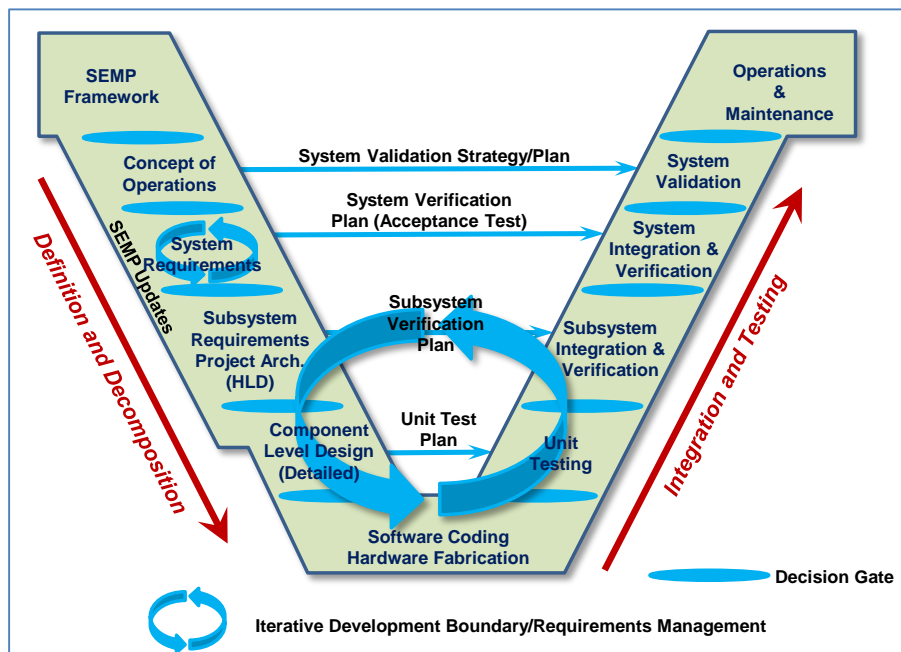


Figure 7-5 – Iterative Development Process within Systems Engineering Framework

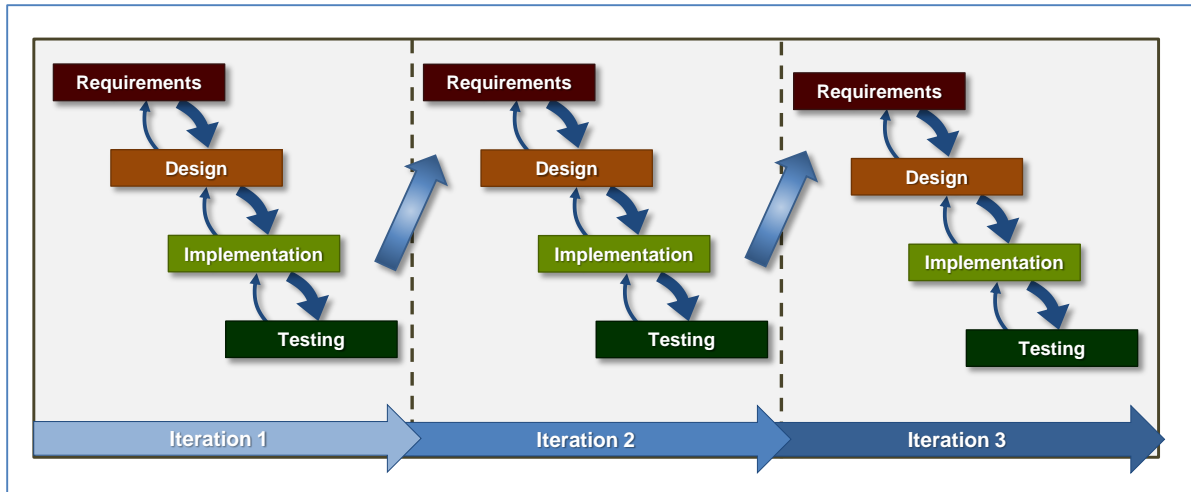


Figure 7-6 – Iterative Development Model

Implementation of the iterative development process followed the Rational Unified Process (RUP) framework. As illustrated in Figure 7-6, the central element of this framework is the adoption of an iterative development process allowing system features to be built and tested incrementally. This approach reduces the risk of uncovering problems late the development cycle by focusing on creating a working software early and then incrementally adding and testing new functionalities. This allows the project team to confront and mitigate high-risk items first and facilitates accommodating changes in requirements and/or strategies that may occur later in the project. The process further promotes constant collaboration among team members, which tends to increase productivity.

As suggested in Figure 7-6 and detailed in Figure 7-7, three main iterations were defined to carry the design of the proposed ICMS from start to finish. The specific development goals that were associated with each of these iterations were as follows:

- **Iteration 1 (July 2011 – Feb 2012): Design of graphical user interface and development of interfaces to existing systems**
 - Develop new IMTMS interfaces
 - Configure Delcan’s iNet application that will be used to host the ICMS
 - Develop response strategies and incident catalog
 - Develop measures of effectiveness
 - Preliminary development of off-line traffic simulation model
 - Develop Limited Functionality Prototypes
- **Iteration 2 (Mar 2012 – Nov 2012): Design of real-time corridor evaluation and decision-making tools**
 - Calibrate the off-line traffic simulation model
 - Develop the real-time simulation model
 - Integrate the real-time simulation model with the iNet Graphical User Interface
 - Develop the business rules and processes managing the development of response plans
 - Configure and update road assets
 - Incident and response plan testing within the simulation environment
 - Update the developed Limited Functionality Prototypes

- **Iteration 3 (Sep 2012 – Feb 2013): Design of a fully operational ICM system**
 - Tie together real-time modeling, predictive analysis, intermodal response plans, and operator corridor management

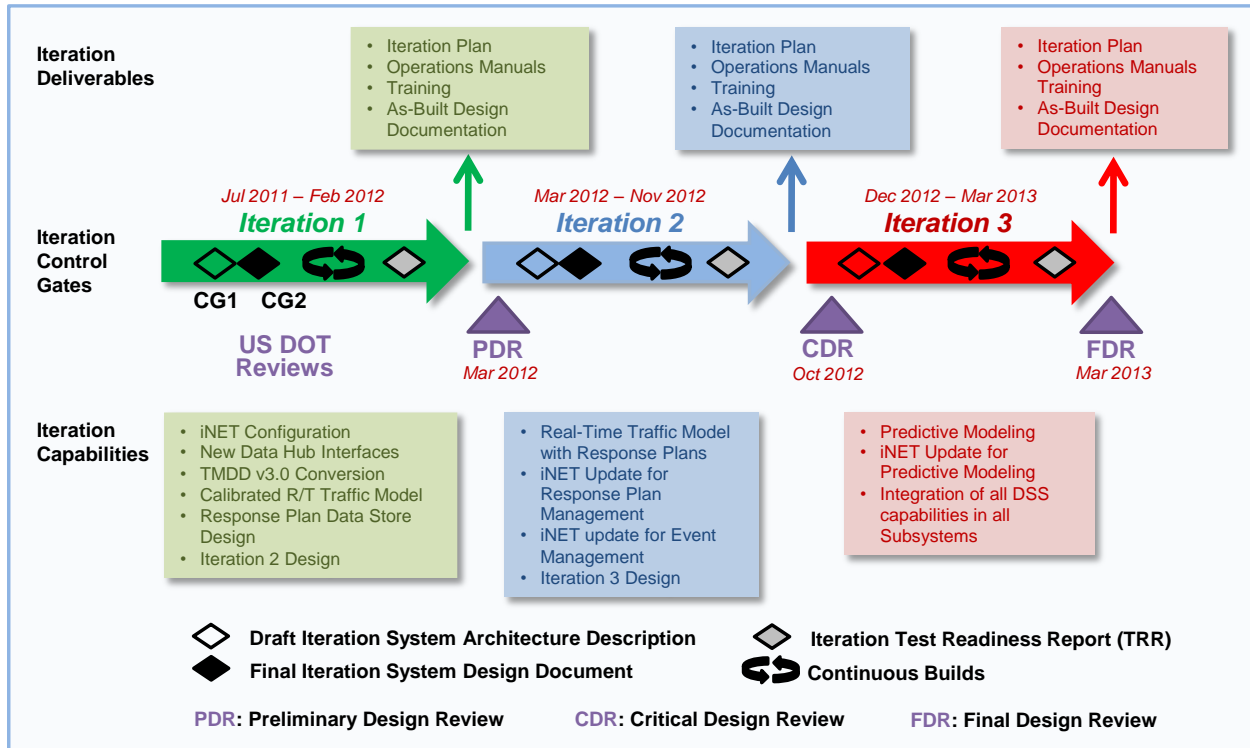


Figure 7-7 – Outcome of Design Iterations

As conceptualized in in Figure 7-6, each iteration first sought to refine, if needed, the existing system design and component requirements. This work was then followed by a series of micro-iteration build efforts aiming to provide incremental demonstrable additions to the developed system components. These micro-iterations varied in length from a few days to a few weeks, with most lasting between one and two weeks. Nine micro-iterations were conducted for the first design iteration, 21 for the second iteration, and two for the third and final iteration. At the end of each iteration, various tests were conducted to assess the readiness of the developed system components and determine whether the design could proceed to the next iteration. Each iteration also involved some training.

Figure 7-7 identifies the key deliverable and new system capabilities that were sought for each design iteration. The figure also identifies the various control gates that were used to determine whether project design could move from one iteration to the end:

- End of iteration 1 (March 2012): **Preliminary Design (40% Design) Review**
- End of iteration 2 (October 2012): **Critical Design (90% Design) Review**
- End of iteration 3 (March 2013): **Final Design (100% Design) Review**

Table 7-1 provides a summary of the key documents that were submitted to the USDOT as part of each of the three design reviews identified above.

Table 7-1 – Design Documents Submitted to USDOT

Preliminary Design Review (PDR)	Critical Design Review (CDR)	Final Design Review (FDR)
Development Plans		
<ul style="list-style-type: none"> • Communication Plan • Configuration Acceptance Plan • Product Acceptance Plan • Software Development Plan 	<ul style="list-style-type: none"> • Communication Plan • Configuration Acceptance Plan • Data Collection Plan • Product Acceptance Plan • Software Development Plan • Air Quality Test Plan 	<ul style="list-style-type: none"> • Product Acceptance Plan • Test Scripts
Iteration Plans		
<ul style="list-style-type: none"> • Iteration 1 Test Procedures • Micro-iteration Plans (1 to 9) 	<ul style="list-style-type: none"> • Iteration 2 Test Procedures • Micro-iteration Plans (1 to 21) 	<ul style="list-style-type: none"> • Iteration 3 Test Procedures • Micro-iteration Plans (1 and 2)
Design Documents		
<ul style="list-style-type: none"> • Architecture Alternative Analysis • Center-to-Center Interface Control • Database Dictionary • Interface Control Document • Software Architecture • Description of Limited Functionality Prototypes 	<ul style="list-style-type: none"> • Architecture Alternative Analysis • Database Dictionary • Interface Control • Software Architecture • System Requirements • Description of Limited Functionality Prototypes 	<ul style="list-style-type: none"> • Center-to-Center Interface Control • Interface Control • Software Architecture
Simulation Modeling		
<ul style="list-style-type: none"> • Data Collection Plan • Calibration Performance Plan • Error Checking Plan 	<ul style="list-style-type: none"> • Calibration and Performance Plan • Calibration Performance Report • Refined Calibration Guidelines • Error Checking Plan • Error Checking Report 	
Operations Manuals		
<ul style="list-style-type: none"> • External Operator • System Operator • System Administrator • System Maintenance 	<ul style="list-style-type: none"> • Barracuda VPN Client Procedures • External Operators • System Operators • System Administrators • System Maintenance 	<ul style="list-style-type: none"> • System Operators • System Administrators
Training Manuals		
<ul style="list-style-type: none"> • Administrators • System Operators 	<ul style="list-style-type: none"> • Administrators • System Operators 	<ul style="list-style-type: none"> • Administrators • System Operators

7.4.2. GENERAL SYSTEM ARCHITECTURE

Figure 7-8 illustrates the general architecture of the ICMS that was deployed along the I-15 corridor. This architecture defines the three following groups of components:

- **Data hub** – Collection of external systems operated by corridor stakeholder agencies providing data to the ICMS and/or receiving control requests from the system via a standardized regional communication network
- **Decision Support System (DSS)** – Tool to help system operators identify incidents and implement response plans aimed at minimizing the impacts of identified incidents on corridor operations
- **System services** – Services to assist with data management, system management, system maintenance, and training activities

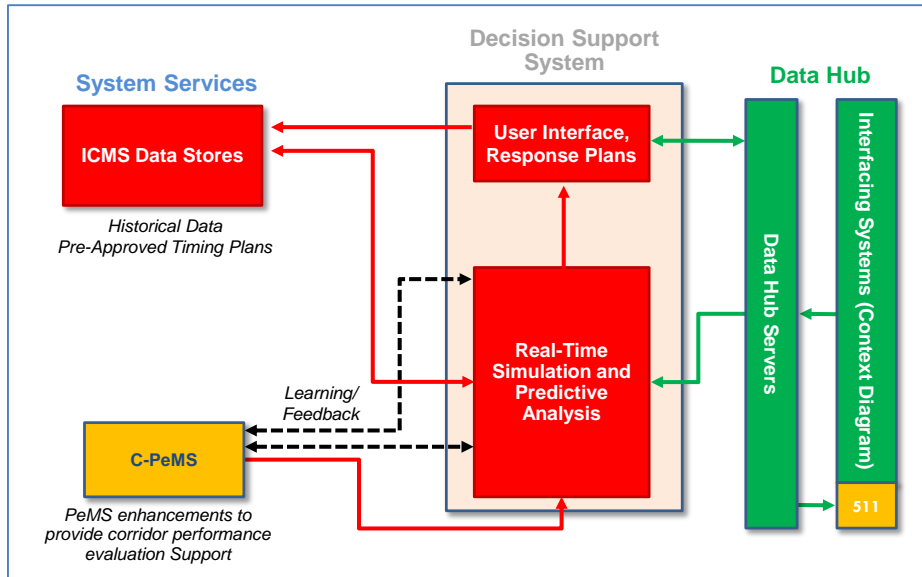


Figure 7-8 – ICMS Key Components

7.4.3. DELCAN’S INET SYSTEM PLATFORM

Delcan’s Intelligent NETWORKS (iNET) application was selected by SANDAG to serve as the operating platform of the I-15 ICMS. iNET is a commercial, web-based, off-the-shelf Advanced Transportation Management software package that can be configured and customized to meet the specific management needs of an agency. Figure 7-9 illustrates the various functionalities offered by the software. These functionalities cover various freeway, arterial, transit, and emergency operation needs. Available functionalities within a specific system depend on the specific modules purchased by the agency acquiring the system.

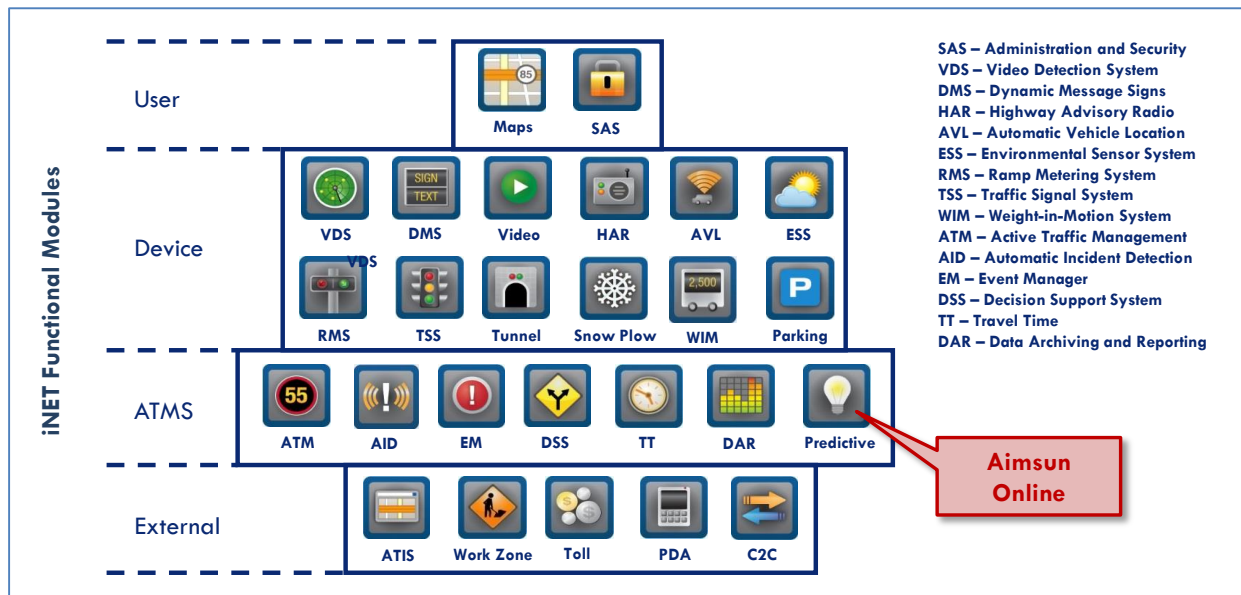


Figure 7-9 – Delcan’s iNET Software Functionalities

For the I-15 ICMS, iNET can be viewed as the operating system within which all the desired functionalities were implemented. The software was used to implement all the required ICM management functions, including system access control, ICM parameter configuration, data visualization, response plan development processes, and response plan implementation processes. Figure 7-10 provides an example of the operating environment that was developed using iNET.

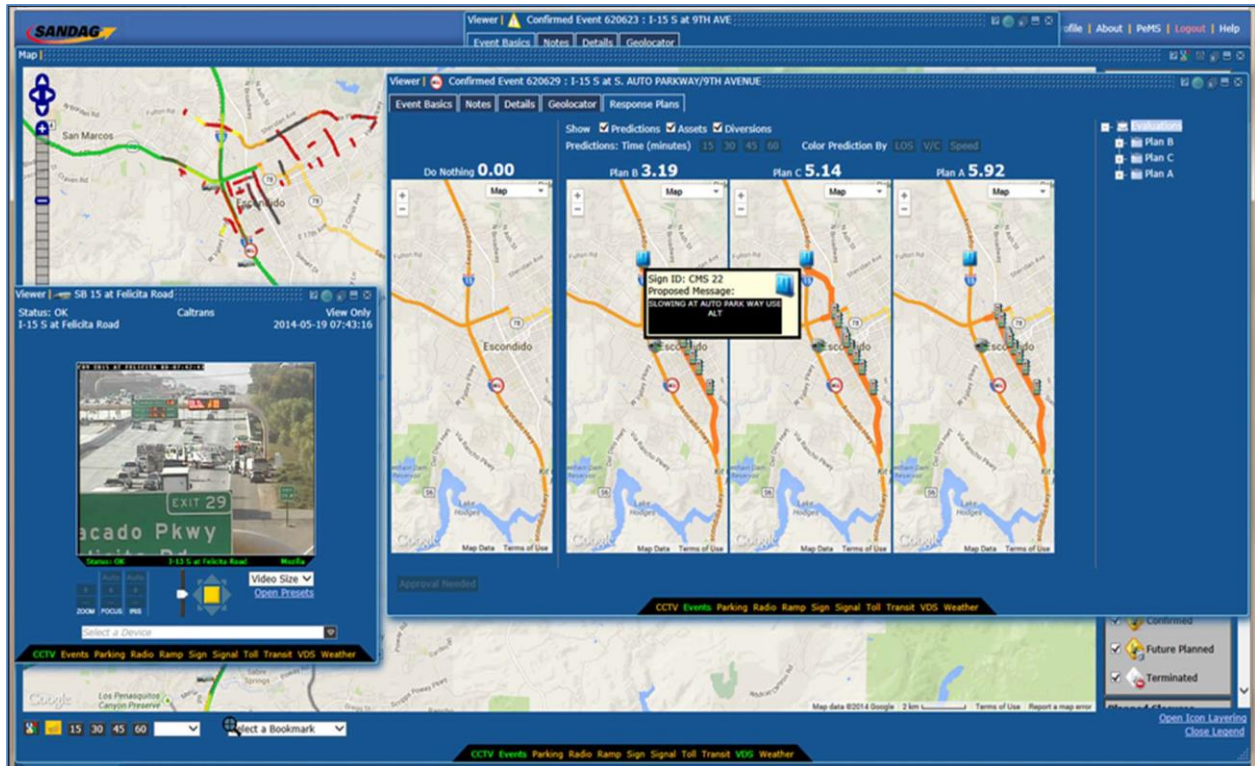


Figure 7-10 – iNET Environment for the I-15 ICMS

7.4.4. INTERFACING SYSTEMS

Figure 7-11 maps the various external systems that were interfaced with the ICMS and the type of information exchanged with these external systems. Key interfacing systems are as follows:

- **Regional Arterial Management System (RAMS)** – Regional traffic signal management software enabling the implementation of cross-jurisdictional signal timing plans. All agencies operating traffic signals within the I-15 corridor, including Caltrans, use this system to control their signals.
- **Lane Closure System (LCS)** – System used by Caltrans to collect and manage information regarding planned construction and maintenance projects.
- **Ramp Meter Information System (RMIS)** – System used by Caltrans to manage the operations of metering signals on freeway on-ramps.
- **Advanced Traffic Management System 4.1 (ATMS 4.1)** – System used by Caltrans to manage the traffic detectors, CMSs, and CCTV cameras operated along I-15.
- **Congestion Pricing System (CPS)** – System used by Caltrans to determine and collect appropriate tolls from single-occupancy vehicles using the I-15 Express Lanes facility.

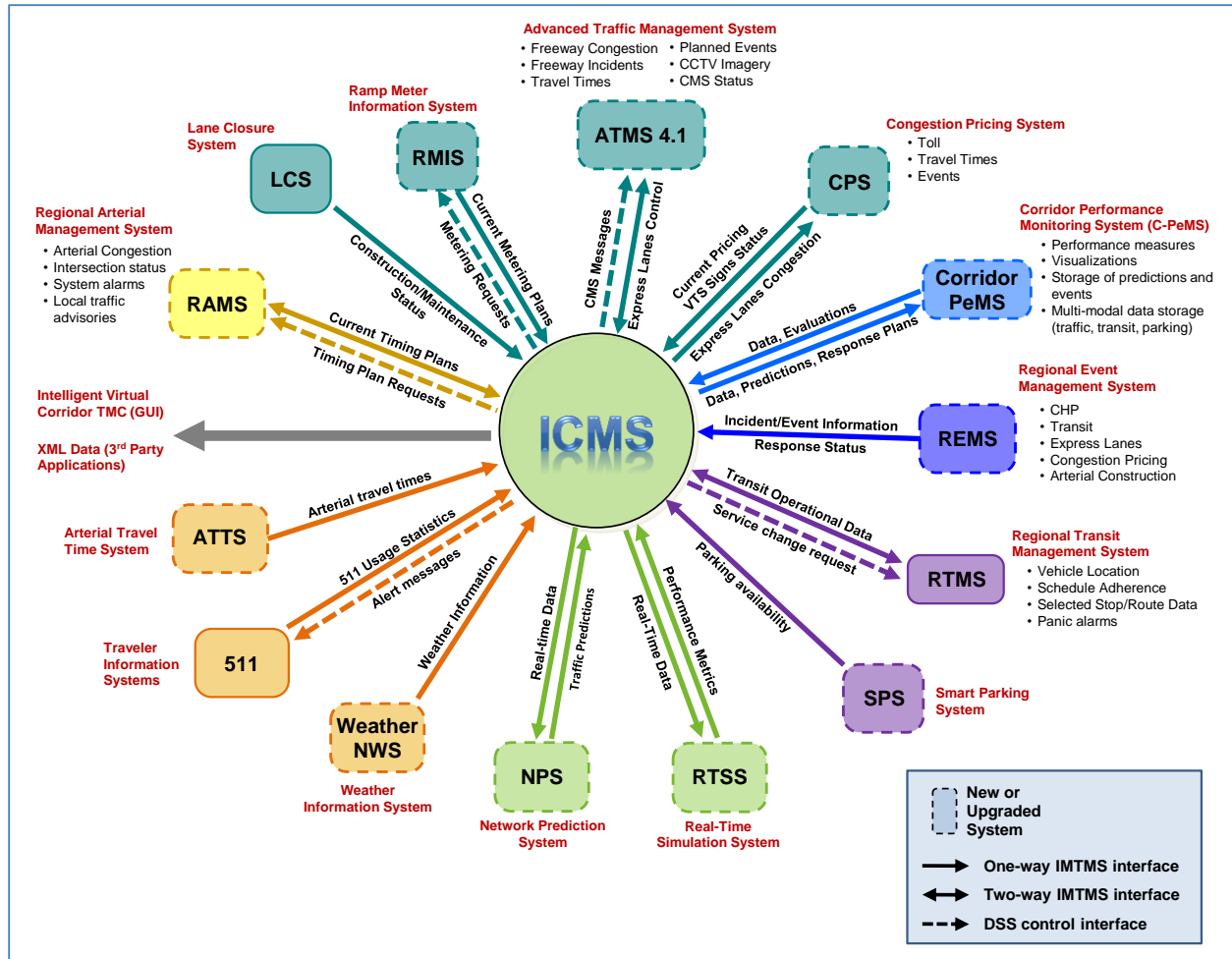


Figure 7-11 – ICMS Context Diagram

- **Corridor Performance Measurement System (C-PeMS)** – Caltrans’ web-based application providing various data visualization and analysis tools.
- **Regional Event Management System (REMS)** – XML-based web interface to the CHP’s Computer-Aided Dispatch Media Server.
- **Regional Transit Management System (RTMS)** – System used by MTS and NCTD to manage their fixed-route transit operations.
- **Smart Parking System (SPS)** – Future system planned by SANDAG to collect real-time parking data, set dynamic parking rates, and provide real-time parking information to travelers.
- **Real-Time Simulation System (RTSS)** – System developed as part of the ICM demonstration to support DSS operations and used to manage and execute corridor simulations.
- **Network Prediction System (NPS)** – System developed as part of the ICM demonstration to support DSS operations and used to predict origin-destination flows within the I-15 corridor.
- **Weather NWS** – Interface with weather reporting systems.

- **Regional Traveler Information Management System (511)** – System launched by SANDAG in 2007 allowing landline and cellular callers to receive tailored travel information via the Web, phone, and public access television.
- **Arterial Travel Time System (ATTS)** – System providing arterial travel time measurements from arterial sensors, primarily Sensys detectors installed along key arterials.
- **XML Data** – Data feed to third-party information service providers.
- **Integrated Virtual Corridor TMC** – System enabling corridor operators to access ICMS functionalities from the ICM servers.

7.4.5. KEY INPUT DATA

The list below identifies the frequency at which key input data is provided to the I-15 ICMS from the various interfacing systems identified in Section 7.4.4.

- **Roadway operations**
 - Traffic detection data from roadway sensors: every 1 minute
 - Estimated travel times along roadway segments from the Sensys sensors connected to the Arterial Travel Time System: every 1 minute
 - Lane configuration on the I-15 Express Lanes: every 2 minutes
 - Traffic signal operation data from all participating agencies: every 1 minute
 - Data from Caltrans Ramp Meter Information System: every 1 minute
 - Messages posted on CMSs along the I-15 mainline and Express Lanes: every 1 minute
 - Incident reports from the CHP, Caltrans, and MTS: every 1 minute
- **Parking operations**
 - Parking facility occupancy data from ParkingCarma: every 2 minutes
- **Transit operations**
 - Bus location from MTTs and NCTD Automated Vehicle Location systems: every 2 minutes
 - Bus occupancy data from Automated Passenger Counters onboard MTS and NCTD buses: every hour
- **Weather data**
 - Weather data from WeatherBug stations (every 5 minutes)

7.4.6. ARTERIAL TRAFFIC DETECTION IMPROVEMENTS

The ICMS has been designed to use the following information to assess corridor operations and to support online traffic simulations:

- **Traffic volumes**, for understanding traffic demand and travel patterns
- **Traffic detector occupancy**, for understanding congestion levels
- **Travel times**, for understanding corridor performance

While it was quickly assessed that traffic detection was adequate along the I-15 mainline and Express Lanes, existing detection along the corridor arterials was deemed inadequate to support system operations and in need of significant upgrade.

Figure 7-12 maps the traffic detection stations in operation along the corridor arterials in early 2012. This includes an identification of the stations used by the Arterial Travel Time System to estimate travel times. The shaded areas further indicate the eastbound and westbound arterials of particular interest to the ICMS. An initial analysis of existing detection capabilities first led the project team to identify 14 intersections where traffic detection improvements would be needed to improve traffic monitoring along the east-west arterials. Adequate detection was thought to exist along the north-south arterials.

However, when reviewing detection needs for the simulation modeled, it was later determined that the recommended improvements would be insufficient to support the simulation modeling needs. Based on the assumption that travel times could be obtained from the simulation model, the project team identified the 49 intersections mapped in the left diagram of Figure 7-13 as key intersections for which traffic detection improvements would be needed. This set was estimated to allow capturing flow data from 80% to 85% of all trips estimated to occur within the corridor. However, to reduce deployment costs, this set was later reduced to the 39 intersections identified by a yellow square in the right diagram of Figure 7-13. This included 19 intersections in San Diego, 18 intersections in Escondido, and 2 intersections in Poway. Simulation analyses indicated that this set of improvements would retain the capture of 73% of all trips estimated to occur within the corridor while reducing deployment costs by 30%.

To achieve the desired detection coverage, the following actions were taken:

- Configure, where possible, existing advance detectors on intersection approaches as system detectors to capture volume and occupancy information
- Deploy additional detection devices to capture travel time and to fill volume/occupancy gaps that can't be accomplished through utilization of existing infrastructure
- Upgrade the signal controller firmware to McCain's Program 233 (this was required for all locations in San Diego and Escondido)
- Loop and cabling improvements

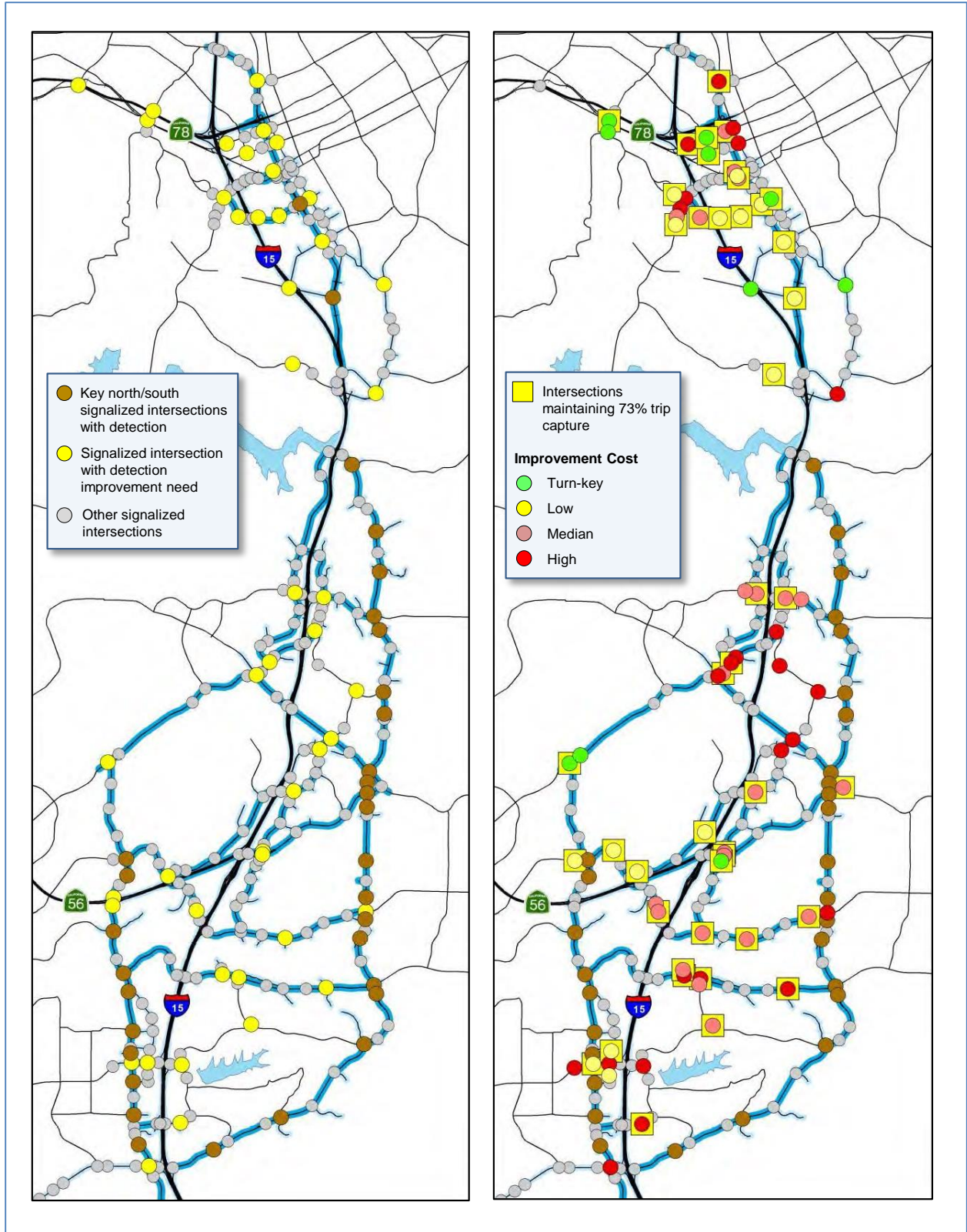


Figure 7-13 – Initial Arterial Detection Improvement Plan

Table 7-2 – Detection Improvement Needs for Caltrans Intersections

INT ID#	North/South	East/West	Northbound (Off-Ramp)	Southbound (Off-Ramp)	Eastbound (Crossroad)	Westbound (Crossroad)
100	Kearny Villa	Mission Ave, Freeway Direction - NB			X	
102	I-15, Freeway Direction – NB	Miramar/Pomerado	X			X
105	I-15, Freeway Direction – SB	Carrol Canyon		X	X	
106	I-15, Freeway Direction – NB	Mira Mesa			X	
107	I-15, Freeway Direction – SB	Mira Mesa				X
108	I-15, Freeway Direction – NB	Mercy/Scripps Poway	X			X
109	I-15, Freeway Direction – SB	Mercy/Scripps Poway		X	X	
110	I-15, Freeway Direction – NB	Rancho Penasquitos/Poway				X
111	I-15, Freeway Direction – SB	Rancho Penasquitos/Poway			X	X
112	Carmel Mountain/Rancho Penasquitos	SR-56, Freeway Direction - WB		X	X	
113	Rancho Penasquitos	SR-56, Freeway Direction - EB	X		X	X
114	I-15, Freeway Direction – NB	Carmel Mountain	X		X	
115	I-15, Freeway Direction – SB	Carmel Mountain		X	X	
116	I-15, Freeway Direction – NB	Ted Williams	X			X
117	I-15, Freeway Direction – SB	Ted Williams		X	X	
118	I-15, Freeway Direction – NB	Camino Del Norte	X			X
119	I-15, Freeway Direction – SB	Camino Del Norte		X	X	
120	I-15, Freeway Direction – NB	Bernardo Center	X		X	X
121	I-15, Freeway Direction – SB	Bernardo Center			X	X
122	I-15, Freeway Direction – NB	Rancho Bernardo	X			X
123	I-15, Freeway Direction – SB	Rancho Bernardo		X	X	
124	I-15, Freeway Direction – NB	Pomerado	X			
125	I-15, Freeway Direction – SB	West Bernardo/Pomerado	X			
126	I-15, Freeway Direction – NB	Via Rancho	X		X	
127	I-15, Freeway Direction – SB	Via Rancho	X		X	X
128	I-15 Managed Lanes, Freeway Direction - NB/SB	Del Lago/Beethoven	X	X	X	X
130	I-15, Freeway Direction – NB	Ninth	X	X	X	X
131	I-15, Freeway Direction – SB	Ninth		X	X	X
132	I-15, Freeway Direction – NB	Valley	X			
133	I-15, Freeway Direction – SB	Valley		X	X	
134	I-15 Managed Lanes, Freeway Direction - NB/SB	Hale	X		X	X
136	I-15, Freeway Direction - NB	El Norte	X		X	
137	I-15, Freeway Direction - SB	El Norte		X		

In addition to the intersections shown in Figure 7-13, it was later determined that detection improvements were also needed at the Caltrans-operated intersections at the end of freeway on-ramps or off-ramps. This led to the identification of the 33 intersections listed in Table 7-2 needing detection improvement. However, implementation of all of the identified detection improvement did not occur until late 2014/early 2015, as the required activities were impacted by competition for resources within Caltrans.

7.4.7. MODIFIED ALINEA RAMP METERING ALGORITHM

After testing several potential ramp-metering algorithms, Caltrans and the University of California, San Diego proposed to implement along the I-15 ICM corridor a modified version of the original ALINEA closed loop feedback control logic proposed by Papageorgiou *et al.* [16] [17]. As illustrated in Figure 7-14, this modified algorithm features a feed-backward occupancy-based controller over any two consecutive ramps. In this system, the occupancy measured at the downstream ramp is used to calculate the allowable on-ramp rate for the upstream detector.

As of June 2015, implementation of this algorithm had not yet occurred. Information obtained from SANDAG indicated that deployment of this algorithm would occur in December 2015.

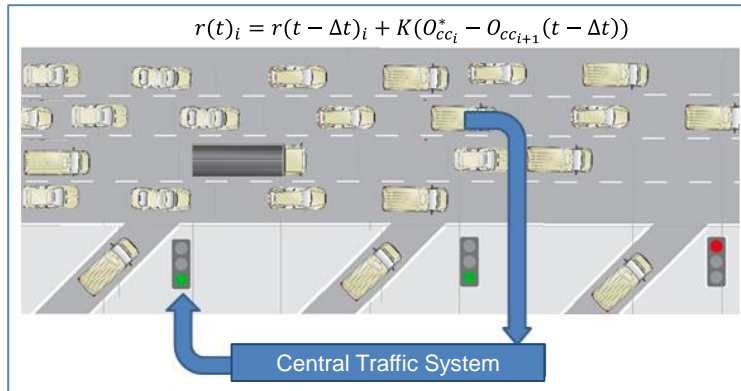


Figure 7-14 – Proposed Modified ALINEA Ramp Metering Control Concept

7.4.8. EVENT CHARACTERIZATION

All events captured by the system are characterized by the following elements:

- Event source: ICMS, Caltrans ATMS, CHP CAP, operator-detected, etc.
- Event type: Congestion event, non-congestion event
- Project impact on operations: Minor, medium, or major
- Location of incident: Route name, direction, road type, cross street, mile marker
- Lanes blocked
- Start time
- Expected duration and end time

Figure 7-15 provides a screenshot of the windows used by system operators to view and edit event information.

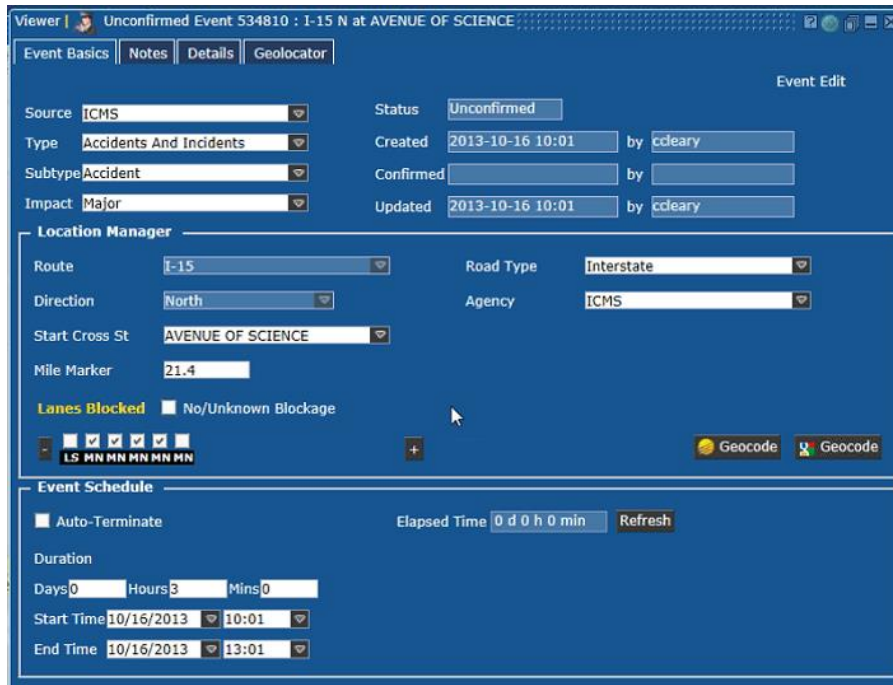


Figure 7-15 – Event Viewer

	Freeway Congestion Events	Arterial Congestion Events
Congested		
	Speed	Speed
Minimum Speed Differential vs Free Flow	10.0 mph	10.0 mph
Minimum % Speed Change vs Free Flow	0.2 %	0.2 %
Minimum Delay Differential vs Free Flow	120.0 scc/veh	120.0 scc/veh
Minimum Delay Differential vs Free Flow	10.0	10.0
Over Congested		
	Speed	Speed
Minimum % Change in Speed vs Historical	0.1 %	0.1 %
Minimum Speed Differential vs Historical (-)	24.1	11.3
Minimum % Change in Delay vs Historical	0.1 %	0.1 %
Minimum Delay Differential vs Historical (-)	300.0	300.0

Figure 7-16 – Congestion Event Thresholds

Events for which response planning is considered can be automatically generated by the ICMS based on external sources, such as the CHP CAD, automatically generated by the ICMS itself based on congestion analysis, or manually entered by system operators.

Congestion events created by the ICMS are identified by comparing current and projected corridor operations against normal operations. Figure 7-16 illustrates the window used by system operators to define the thresholds to use for identifying congestion events on the freeway and arterials. The following are the key parameters used to determine whether observed congestion on a roadway segment should result in the creation of a congestion event:

- **Situations in which demand does not exceed capacity**
 - Minimum speed differential from speed limit
 - Minimum percent speed differential from speed limit
 - Minimum increase in delay from free-flow situation
 - Minimum v/c ratio differential from free-flow situation
- **Situations in which demand exceeds capacity (oversaturation)**
 - Minimum speed differential from historical data
 - Minimum percent speed differential from historical data
 - Minimum increase in delay from historical data
 - Minimum percent delay increase from historical data

Figure 7-17 illustrates an additional set of parameters used for identifying events:

- **Bridging parameters** – Distance thresholds used to determine whether two separate hotspots can be considered as being part of the same event

- **Upstream distance** – Upstream distance from an incident location within which the queue resulting from an incident should remain to categorize the incident as having a low, medium, or high impact on freeway or arterial operations
- **Transition time** – Number of minutes that should elapse following the upgrade or downgrade of the impact level of an incident by incident managers for this level to be also changed in the ICMS

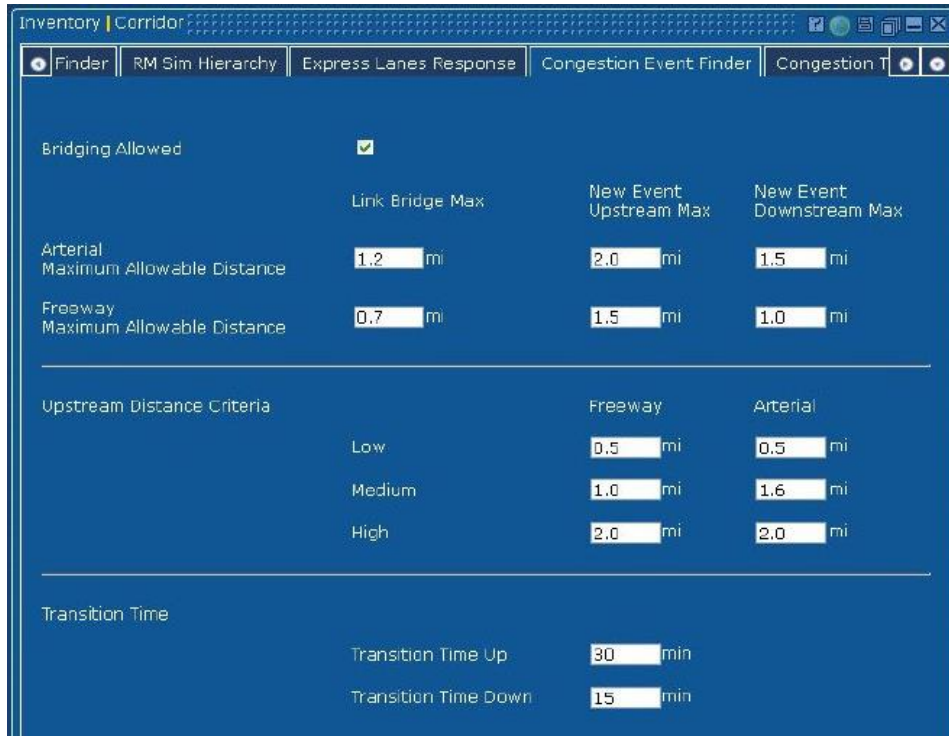


Figure 7-17 – Congestion Event Bridging Parameters

7.4.9. RESPONSE PLAN ELEMENTS

Figure 7-18 illustrates the various control actions that may be considered by the ICMS when developing a response plan. These potential actions can be categorized as followed:

- Change of signal timing plan in use at a specific intersection
- Change in the traffic metering rate in use at specific freeway on-ramps
- Change in the number of northbound and southbound lanes on the I-15 Express Lanes
- Dissemination of traveler information on freeway CMSs and traveler information systems
- Change in transit operations, such as recommendation for a bus to follow an alternate route

Figure 7-19 further illustrates the basic concept behind the development of a response plan. A particular response plan is put together by grouping actions targeting specific intersections, freeway ramps, the I-15 Express Lanes, information devices, and transit services.

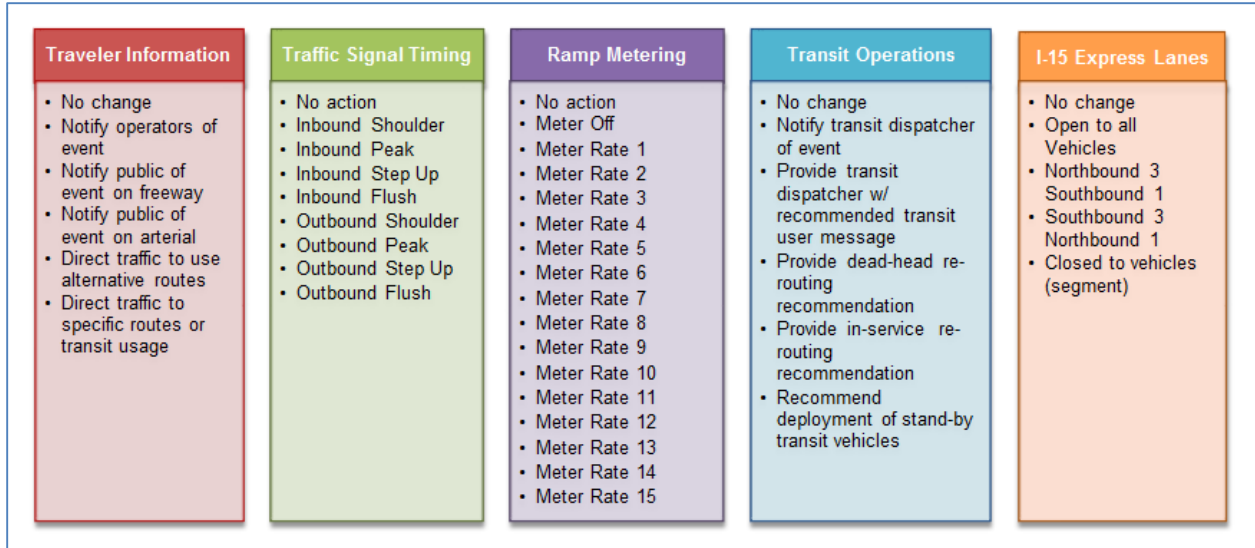


Figure 7-18 – Potential Control Actions

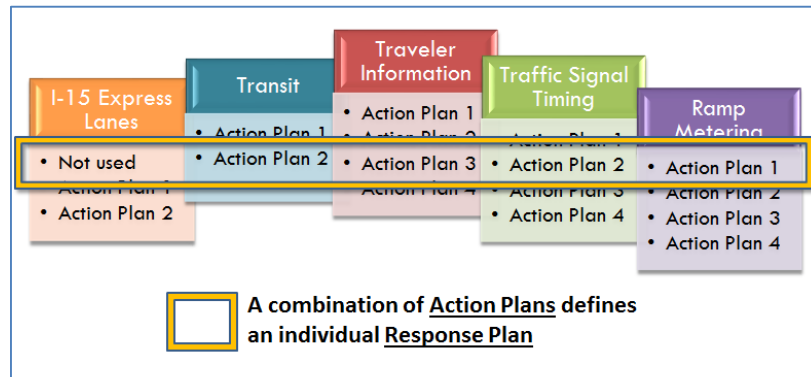


Figure 7-19 – Definition of Response Plan

Not all of the elements illustrated in Figure 7-18 are necessarily considered in the preparation of response plans. Which element is included depends on control preferences specified by system operators. These preferences are set up in a Strategy Matrix indicating which type of assets can be considered for specific types of events. Figure 7-20 provides an illustration of a portion of the screen used to define these preferences. As can be noted, operators are able to specify asset preferences for various combinations of the following elements:

- **Event type:** congestion event or any time of event
- **Event location:** mainline freeway, Express Lanes, or arterial
- **Forecasted impact:** low, medium, or high
- **Diversion type:** diversion or no diversion

Event Type	Route Type	Forecasted Impact	Diversion	511	DMS	Arterial Timing	Ramp Metering	Transit	Managed Lanes
Any	Arterial	Low	No	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Arterial	Low	Yes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Arterial	Medium	No	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Arterial	Medium	Yes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Arterial	High	No	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Any	Arterial	High	Yes	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Any	Freeway	Low	No	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Freeway	Low	Yes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Freeway	Medium	No	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Freeway	Medium	Yes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Freeway	High	No	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Freeway	High	Yes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Managed Lanes	Low	No	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Managed Lanes	Low	Yes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Managed Lanes	Medium	No	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Managed Lanes	Medium	Yes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Managed Lanes	High	No	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Any	Managed Lanes	High	Yes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 7-20 – Asset Availability Matrix

In addition to the asset availability matrix, various additional rules are used to determine whether specific assets should be included in a response plan and how these assets should be modified to address a particular situation. A summary of these rules is provided below:

- **Route identification**
 - Alternate routes candidates are found by laterally searching out from an event location. Once a set of routes is found, it is then narrowed and ranked by checking congestion levels, asset availability, the associated travel distance, and location relative to the traffic queue. In support of this search, the user is provided with the ability to specify the maximum percentage of congested links and unavailable signals along a route for the route to be deemed acceptable as a detour under conservative, moderate, and aggressive response postures. These parameters can be specified globally and for specific routes. An example is shown in Figure 7-21.

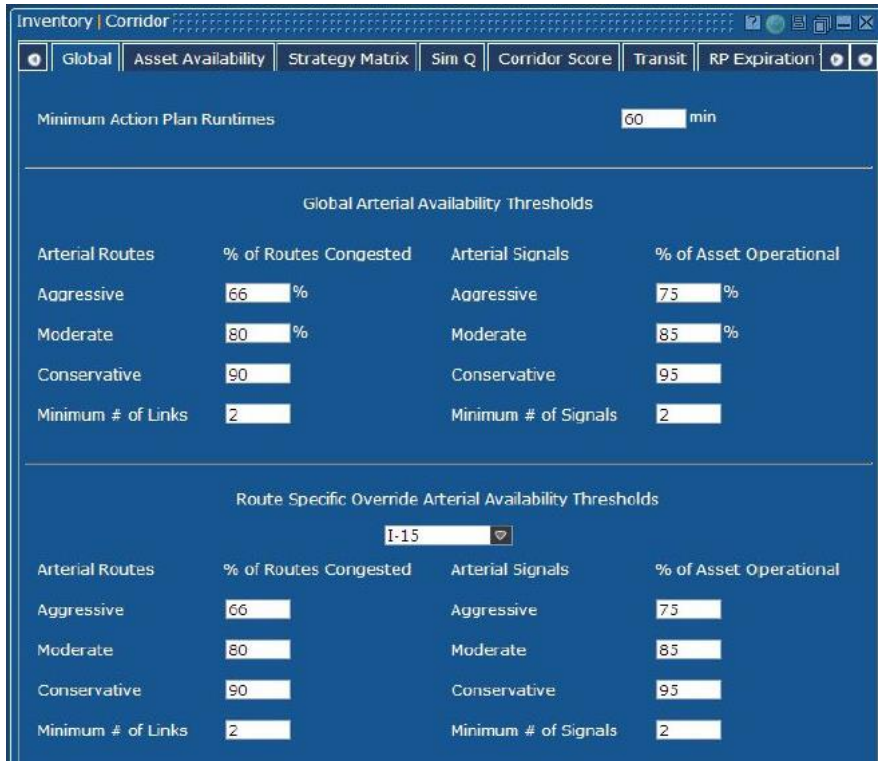


Figure 7-21 – Route Availability Options

- **Traffic signal response**
 - In this case, configuration parameters allow the users to determine which route(s) and timing plans should be considered in the response planning. An example is shown in Figure 7-22. This example indicates that no specific detour or timing plan is considered for a conservative response. For a moderate response, both the highest and second ranked detours are to be considered with a peak timing plan. For an aggressive response, the highest ranked detour with a step-up plan is to be considered, as well as a scenario including both the highest and second ranked detours.

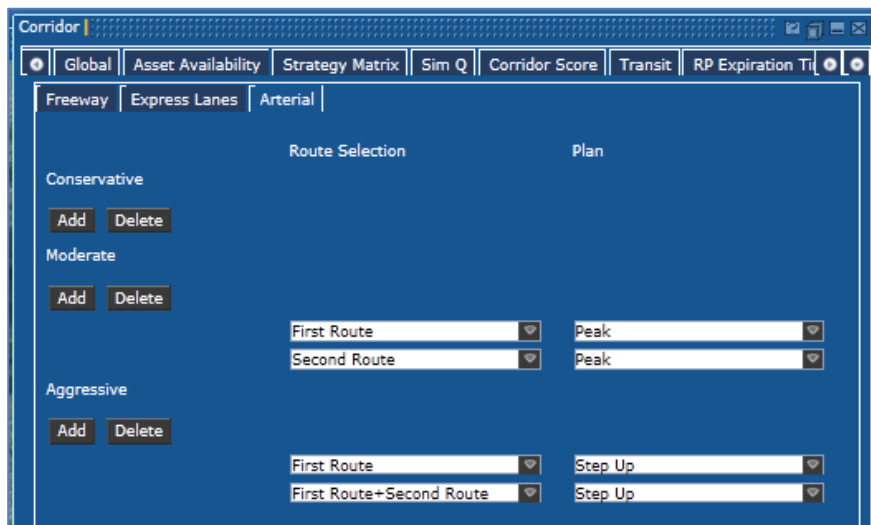


Figure 7-22 – Traffic Signal Response Options

- **Ramp metering response**

- Users can determine whether the ramp meters should be left operating as is, turned off, or transitioned to a minimum or maximum rate when developing a response to an upstream or downstream incident under a conservative, moderate, or aggressive posture. An example is shown in Figure 7-23.

Freeway		If On		If Off	
Upstream	Override Traffic Responsive Strategy	Option 1	Option 2	Option 1	Option 2
Conservative	<input checked="" type="checkbox"/>	Off	Off	Off	Off
Moderate	<input checked="" type="checkbox"/>	Min Rate	Do Nothing	Min Rate	Do Nothing
Aggressive	<input checked="" type="checkbox"/>	Min Rate	Do Nothing	Min Rate	Do Nothing
Downstream		Option 1	Option 2	Option 1	Option 2
Conservative	<input checked="" type="checkbox"/>	Off	Off	Off	Off
Moderate	<input checked="" type="checkbox"/>	Do Nothing	Max Rate	Do Nothing	Max Rate
Aggressive	<input checked="" type="checkbox"/>	Do Nothing	Max Rate	Do Nothing	Max Rate

Figure 7-23 – Ramp Metering Response Options

- **Transit availability**

- Transit options may only be triggered if there is at least X percent overall ridership capacity available on BRT buses, if there is at least X percent parking availability at monitored BRT stations, if current bus travel times do not exceed Z percent of their historical average, and if the event is within Q miles of the event.

- **Expiration timers**

- Reuse timers - Timers defining the intervals that must elapse before an asset can be included in another response plan after it has been included in a plan.
- Auto-approval timers - Interval after which an asset can be automatically considered as available if no input is obtained from its operator.
- No reply timers - Interval after which an asset should be considered unavailable if no approval has been obtained from its operator.

7.4.10. BASIC CONTROL LOOP

Figure 7-24 illustrates the basic control loop implemented by the ICMS. This control loop involves the following steps:

1. The control loop starts with the continuous monitoring of traffic conditions within the I-15 corridor.
2. Every 15 minutes, checks are made to assess whether the observed traffic conditions within the corridor significantly deviate from normal operations associated with the specific day and time-of-day period.

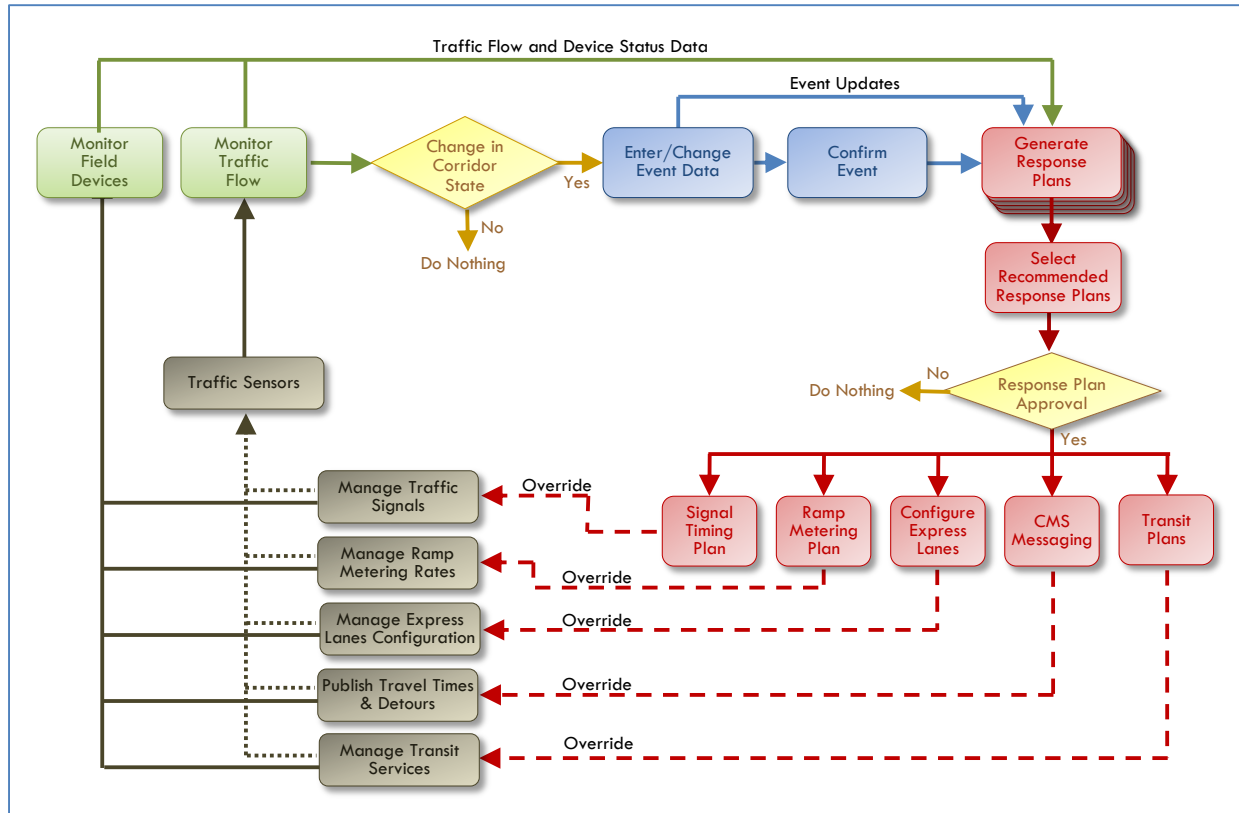


Figure 7-24 – Basic Control Loop

1. If a significant deviation from normality is detected, a corridor event is created and submitted for confirmation by system operators. If the situation is the result of an event that has already been identified and confirmed, updates may then simply be made to the characterization of the event.
2. Following the confirmation of an event, the ICMS initiates the development of response plans to address the situation created by the incident. This process starts with a verification of assets that are available for control. Once the asset determination is completed, a number of response plans that can be implemented based on the available assets are developed by the ICMS. If no asset is found available, no response plan is developed and the process is terminated.
3. The various response plans developed in Step 4 are submitted for operational evaluation. This evaluation uses simulation to predict corridor operations over the next 60 minutes under each developed plan. At the end of the evaluation, the plan yielding the best corridor performance based on the selected corridor metric is recommended for implementation by the ICMS.
4. The recommended response plan identified in Step 5 is submitted for review and confirmation by system operators. The plan is submitted for approval to each of the agencies that would have control devices affected by the response plan. Depending on administrative setup, the recommended plan may either be automatically approved or require a system operator to manually enter approval into the system.
5. Following approval of the recommended plan, control actions are then sent to various control devices for which the response plan requires an operational change.
6. Implemented control actions result in changes in travel behavior that are captured by the various traffic sensors in operation within the corridor.

- At the next corridor evaluation interval, the control loop restarts. Depending on needs, the existing response plan may be maintained or a new plan developed. Response actions are triggered as long as travel conditions within the corridor warrant it.

7.4.11. ASSET AVAILABILITY CRITERIA

Not all control assets are necessarily available for use in the development of response plans. For instance, some assets may become unavailable because of other prior or more important commitments. Examples of assets that may be unavailable include:

- CMSs displaying Amber Alerts
- Traffic signals down for maintenance
- Traffic signals that have been intentionally removed from consideration by local operators

Various rules have been imbedded into the ICMS to determine asset availability when response planning is initiated. In addition, system operators can set up the default availability of each type of asset as follows:

- Unavailable** – The asset is unable to be used for a response plan at any time
- Auto approve** – The asset can be used in a response plan without approval being granted by system operators
- Deny on timeout** – After a timeout period, the asset cannot be used in a response plan if approval for its use has not been granted by system operators
- Approve on timeout** – After the timeout period, the asset is able to be used even if no approval has been received



Figure 7-25 – Asset Finding Parameters

In addition to the above considerations, a distance criterion is used to identify which assets within a specific category may be considered for use. For instance, the development of a response plan could be restricted to considering only upstream ramp meters within 5 miles of the incident or traffic signals within 2 miles. Figure 7-25 presents a screenshot of the screen used by operators to define how far from an incident the system will search for assets along the mainline freeway, Express Lanes, and arterials when developing conservative, moderate, or aggressive responses to incidents.

7.4.12. ACTION TRIGGERING PARAMETERS

Table 7-3 identifies the key parameters used to determine whether a response action may be warranted from the various control assets connected to the ICMS. Several of these parameters are linked to operational assessments produced by the simulation model associated with the Decision Support System

Table 7-3 – Action Triggering Parameters

Action Item	Primary Parameter(s)	Other Parameters Considered
Traffic signal coordination	<ul style="list-style-type: none"> Projected volume-to-capacity (v/c) ratio on arterial segments based on simulation results 	<ul style="list-style-type: none"> Arterial speed Arterial travel time Maximum acceptance volume Level of service (based on arterial speed)
Change in ramp metering rate	<ul style="list-style-type: none"> Change in freeway speed downstream of ramp Implementation of arterial diversion route involving the ramp 	<ul style="list-style-type: none"> Ramp queue spillover Freeway volume Diversion plan in effect
Change in I-15 Express Lanes configuration	<ul style="list-style-type: none"> Freeway capacity loss as a result of the incident or event Change in freeway travel time 	<ul style="list-style-type: none"> Managed lane volume Managed lane speed
Change in transit service	<ul style="list-style-type: none"> Predicted route travel time above normal by a certain percentage 	<ul style="list-style-type: none"> Route availability/closures Dead-head return route travel time comparisons Ridership
Posting of message on CMSs	<ul style="list-style-type: none"> Response plan in effect 	<ul style="list-style-type: none"> Travel time comparisons Incident location/description Wayfinding information
Dissemination of traveler information on 511 system	<ul style="list-style-type: none"> Response plan in effect 	
Dissemination of parking information	<ul style="list-style-type: none"> Parking occupancy 	

7.4.13. INCIDENT RESPONSE POSTURE

Figure 7-26 illustrates the characterization that was adopted to determine how the ICMS should respond to identified incidents and events. This characterization is based on the three following factors:

- **Impact of event** – Degree to which an event is projected to impact corridor operations
- **Demand level** – Magnitude of traffic on the corridor roadways
- **Response posture** – Degree to which changes should be made to control elements to maintain corridor mobility

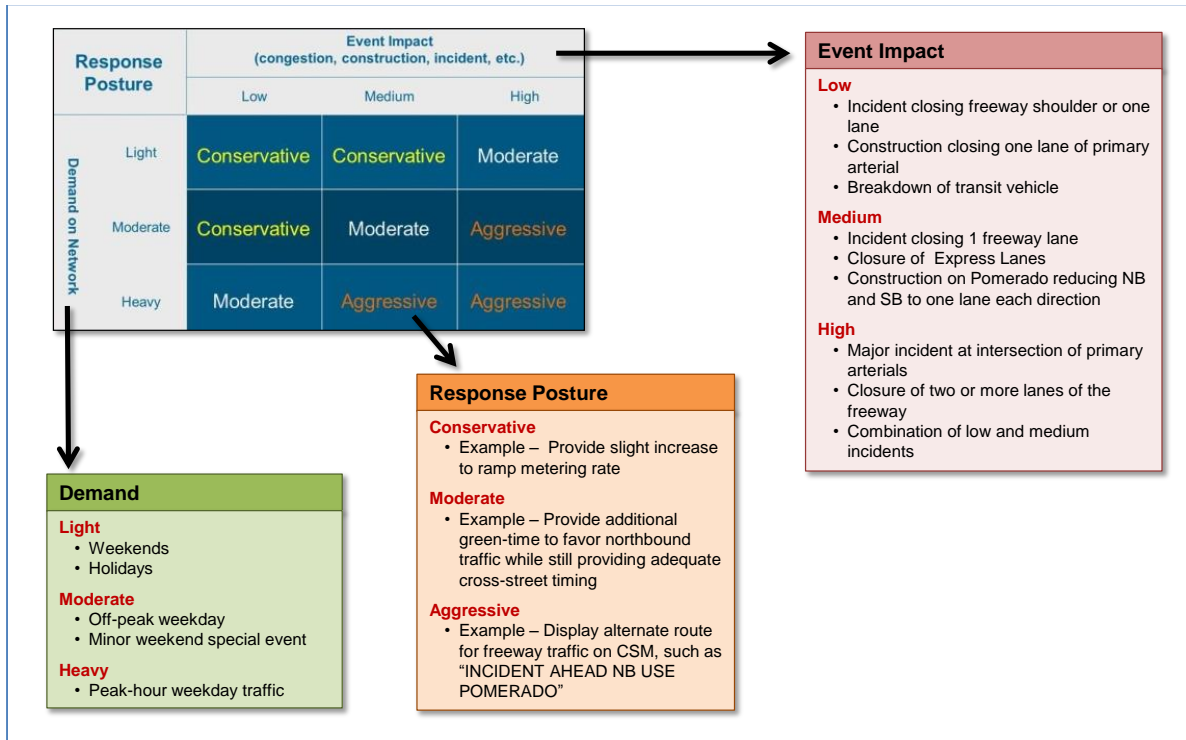


Figure 7-26 – Incident Response Posture

As an example, a low-impact incident occurring during a period of low demand would result in a conservative response posture, i.e., relatively small changes made to control elements within the corridor. However, a high-impact incident occurring within the same period would trigger a moderate response. Aggressive responses significantly altering control operations are only considered for high-impact incidents occurring in moderate- and high-demand situations, such as during peak hours, or for incidents with medium impact occurring in high-demand situations, such as incidents occurring in the peak travel direction during the peak hour.

7.4.14. EVALUATION OF RESPONSE PLANS

Each response plan developed by the ICMS is assigned an evaluation score that expresses its ability to improve corridor operations. Each score represents the ability of the proposed response plan to reduce the person-hours of delays incurred by travelers within the I-15 corridor over the next 60 minutes of operations. As an example, Figure 7-27 illustrates the results of the evaluation that were conducted by the ICMS in response to an incident on the northbound lanes of I-15 near Westview Parkway anticipated to block 4 lanes for 3 hours. For this incident, five plans were generated and evaluated, in addition to the “do-nothing” scenario. Plan D is the recommended plan with a score of 0.29. This means that implementation of this plan should reduce total person-delay within the corridor by 0.29% when compared to the “do-nothing” scenario. Since it is used as a reference, the “do-nothing” scenario is always assigned a score of 0.00. Plan B and Plan E then both have negative scores, indicating these plans would increase delay within the corridor by 5.20% and 3.87% respectively.

The format of the corridor score went through several modifications throughout the course of the project. Scores initially represented the total change in person-hours of delay associated with each plan. In an

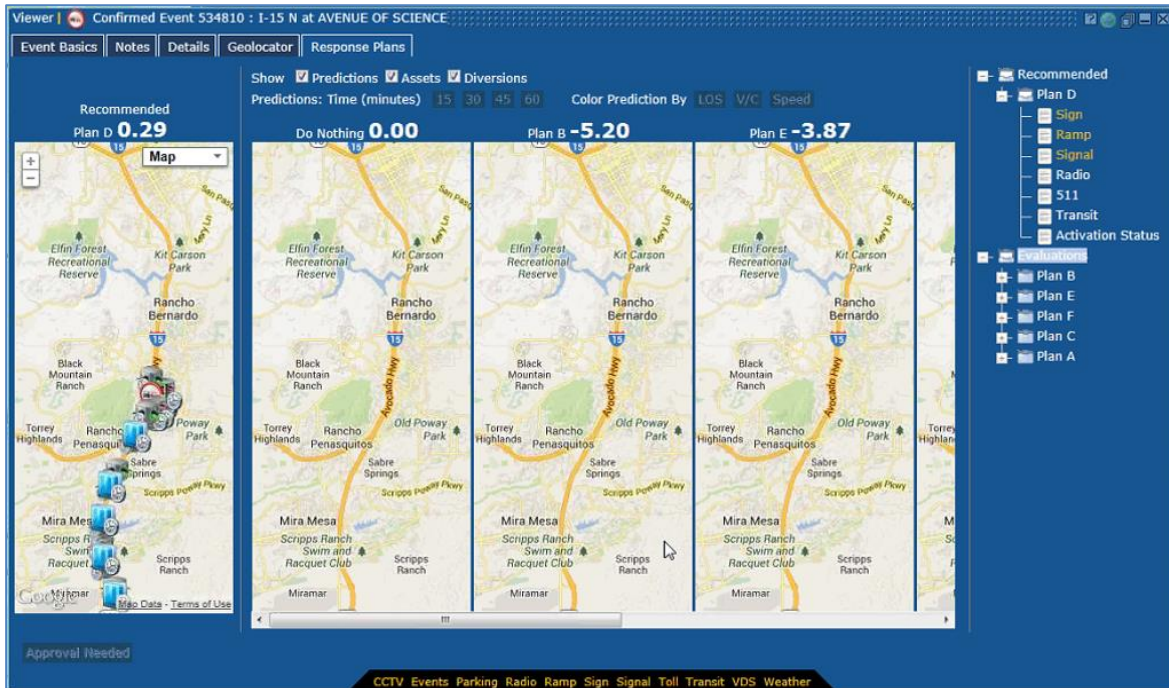


Figure 7-27 – Response Plan Evaluation Example

attempt to facilitate comparisons of response plans, the score was later changed to represent, on a scale of 0 to 100, the ability of a particular plan to reduce delays. Since system users had difficulty relating the produced scores to the magnitude of potential operational improvements, the project team eventually adopted the current format in which each score simply expresses a percentage change in person-delay.

The use of person-delay instead of vehicle-delay to produce evaluation scores was retained to reflect the fact that transit vehicles and high-occupancy vehicles carry more passengers than private vehicles and should consequently have a higher weight in corridor evaluations. As indicated by the equation below, the delay calculations performed for each roadway segment specifically distinguish four types of vehicles: single-occupancy passenger cars, high-occupancy passenger cars, trucks, and buses.

$$D_{Link\ Per} = (O_{SOV} V_{SOV} + O_{HOV} V_{HOV} + O_{Truck} TV_{Truck} + O_{Bus} V_{Bus}) * D_{Link\ Veh}$$

- where:
- $D_{Link\ Per}$ = Average person delay on roadway segment
 - $D_{Link\ Veh}$ = Average vehicular delay on roadway segment
 - $V_{SOV}, V_{Hov}, V_{Truck}, V_{Bus}$ = Volume of single-occupancy vehicles (SOV), high-occupancy vehicles (HOV), trucks, and buses on roadway segment
 - $O_{SOV}, O_{Hov}, O_{Truck}, O_{Bus}$ = Average occupancy of single-occupancy vehicles (SOV), high-occupancy vehicles (HOV), trucks, and buses

Despite the decision to use person-hours of delay as the primary comparison metric, the option to use vehicle-hours of delay in the evaluation remains possible if so desired. To assess corridor scores on a vehicle-delay basis, system operators would simply need to assign an equal occupancy factor to all types of vehicles being simulated in the model used to conduct the evaluations.

For each proposed response plan, the corridor score is not developed by summing the delays that would be incurred on each link of the corridor. While this approach was adopted at first, it often produced very small scores for response plans that would only affect a portion of the corridor, making it difficult to

compare various response plans. Because of the resulting small scores, system operators would also often perceive the recommended plan as having only a marginal impact potential and would therefore often elect to disregard them. To address this problem, the following rules were established to select the roadway segments to consider in a score evaluation:

- All links within a bounding box surrounding the location of the incident are automatically included in a corridor score evaluation. As illustrated in Figure 7-28, the size of this bounding box is set to extend Y miles on the east and west side of the incident, X miles downstream of the incident, and X miles upstream of the incident, with the parameters Y and X user-definable based on the type of response posture. Default values for these parameters are shown in Table 7-4. The bounding box is intentionally made longer upstream of the incident to create a focus on the congestion generated by the incident upstream of its location.

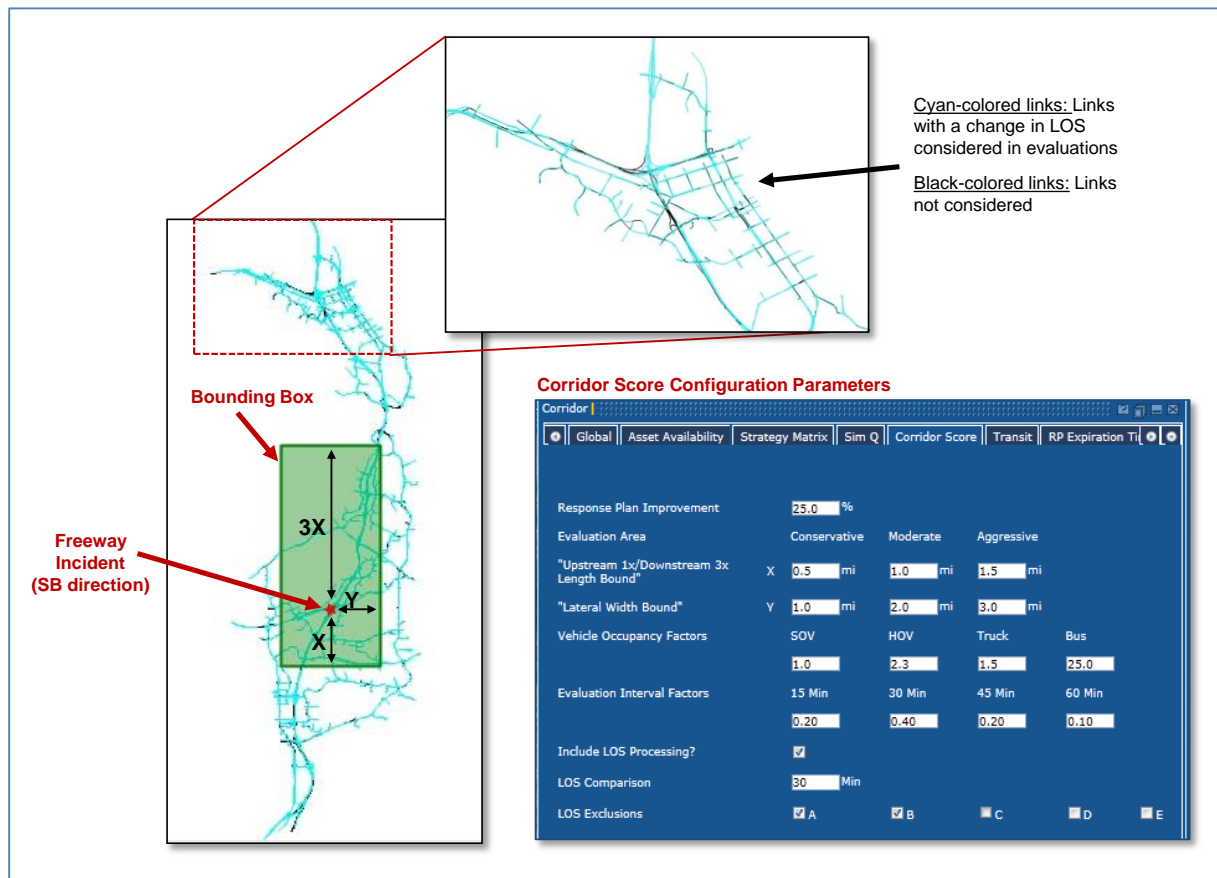


Figure 7-28 – Determination of Corridor Score

Table 7-4 – Evaluation Score Bounding Box Default Dimensions

Response Posture	X	Y
Conservative	1.0 mile	1.0 mile
Moderate	1.5 miles	2.0 miles
Aggressive	2.0 miles	3.0 miles

- Outside the bounding box, the evaluation focuses on the identification of roadway segments where the potential impacts on delay (either positive or negative) are significant enough to be noticeable to the users of the network. This is accomplished by comparing level-of-service (LOS) between the proposed response plan and the “do-nothing” scenario for each link outside the bounding box. Any segment exhibiting a difference in LOS in any of the 15-minute evaluation periods considered during the evaluation is, in this case, identified for inclusion in the corridor metric calculation.
- To avoid including isolated segments in the evaluations, downstream segments providing a continuous route to the bounding box are also included in the analysis, whether or not there is a change of LOS on them.
- To ensure that all plans developed during a given response planning are evaluated on the same basis, the inclusion of a particular link in the evaluation of one scenario automatically results in the same link being included in the evaluation of the other scenarios, whether there is a change of LOS in that particular scenario or not.
- To remove from consideration links with changes in level of service that may be considered without interest by roadway operators, such as a change from LOS A to LOS B, operators are provided with the option to exclude from consideration any link with a particular LOS.

Finally, to reflect that predictions tend to have a reduced accuracy the further they are in time from the present, the option is provided to weight the delay estimates obtained for each 15-minute interval within the 60-minute evaluation period according to the following formula:

$$D_y = (W_{15} D_{15}) + (W_{30} D_{30}) + (W_{45} D_{45}) + (W_{60} D_{60})$$

With: $W_{15} + W_{30} + W_{45} + W_{60} = 1$

Where: D_y = Time-weighted link delay

$D_{15}, D_{30}, D_{45}, D_{60}$ = Delay estimated for the 0-15, 15-30, 30-45 and 45-60 minute interval respectively

$W_{15}, W_{30}, W_{45}, W_{60}$ = Weighting factor for the 0-15, 15-30, 30-45 and 45-60 minute interval respectively

In the example of Figure 7-28, the delays obtained for the first 15-minute interval accounts for 20% of the total score, while the delays obtained for the remaining three intervals respectively account for 40%, 20%, and 10% of the total score. A lower weight is assigned to the first interval to account for the time needed to implement a response plan, which causes the second interval to be the first full interval during which recommended control actions could be implemented.

7.4.15. REAL-TIME SIMULATION SYSTEM

The Real-Time Simulation System (RTSS) is the module responsible for conducting corridor evaluations using the Aimsun Online application that has been developed by Transport Simulation Systems. This tool has been previously deployed in Madrid, Spain, to help manage the M30 bypass urban freeway. For the I-15 ICM Demonstration Project, Aimsun Online was integrated into the Decision Support System to use live data feeds and microscopic traffic simulations to forecast traffic conditions dynamically within the corridor based on the current state of the roadway network.

Figure 7-29 illustrates the Aimsun Online operational framework. Key input data are shown in the top left corner of the diagram. These include information, shown in the dark blue boxes, about historical origin-destination flow patterns and historical link traffic volumes. Another important data input is real-time traffic flow data from roadway sensors, shown in the green box at the center top. Both the historical and real-time data are used by the application to identify, from a library of origin-destination flow patterns representing typical days, which origin-destination flow pattern the traffic observed through the real-time data belongs to. Once a flow pattern has been matched, the corresponding origin-destination flow matrix is fed into a model of the corridor, together with information detailing the traffic signal control plans in effect, known events, and specific traffic management strategies that may have been enacted to address the known events or other situations. The resulting simulation model is then used to forecast corridor operations over the next 60 minutes, in 15-minute increments, under alternative response plans, with the simulation results subsequently used to identify a best scenario. Simulation results are also later compared against real-time data to perform quality checks and ensure that the forecasts were within reasonable range of reality.

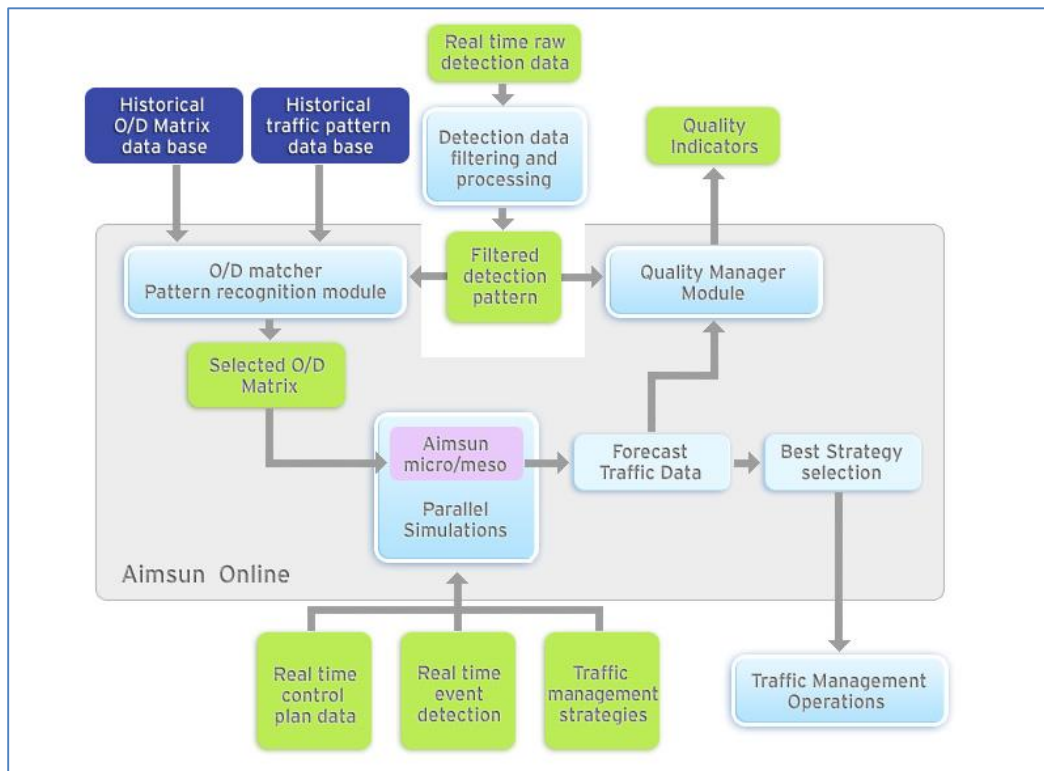


Figure 7-29 – Aimsun Online Operational Framework

Figure 7-30 further provides screenshots of the developed Aimsun simulation model. The area that was modeled is shown at the center of the diagram on the left. While Aimsun is a hybrid model platform allowing users to code different links using a microscopic, mesoscopic, or macroscopic modeling approach, the entire I-15 corridor model was developed microscopically. This has allowed retaining the highest level of details when simulating traffic behavior.

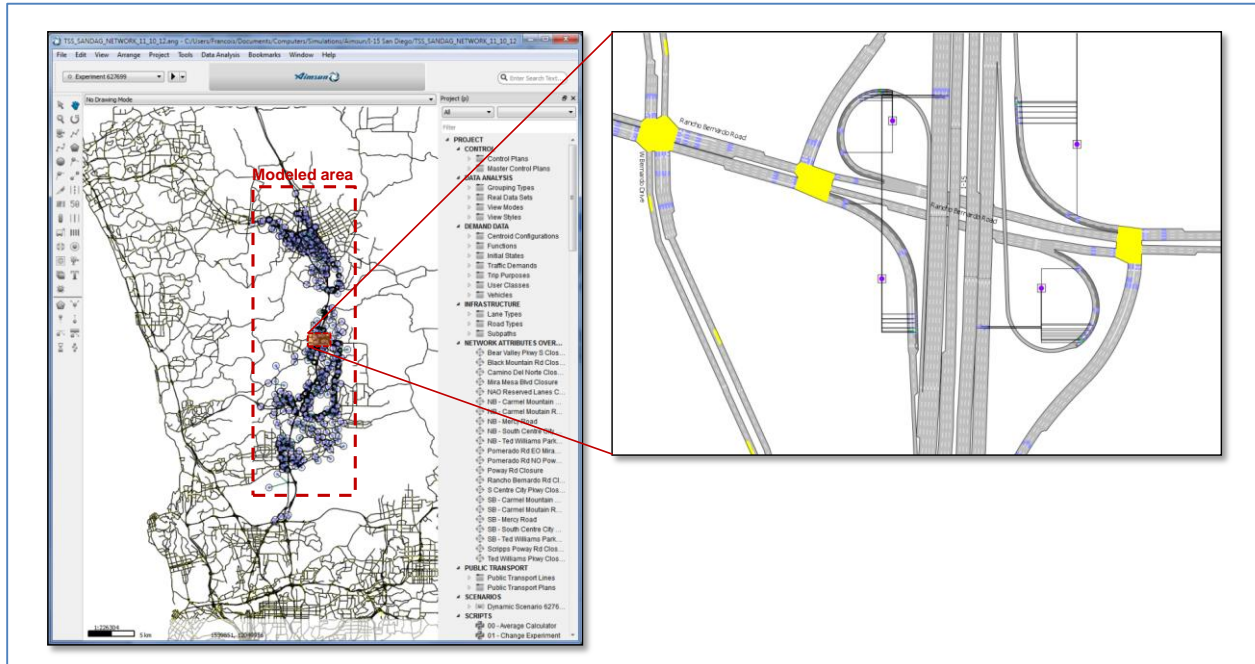


Figure 7-30 – Aimsun Microscopic Simulation Model of the Corridor

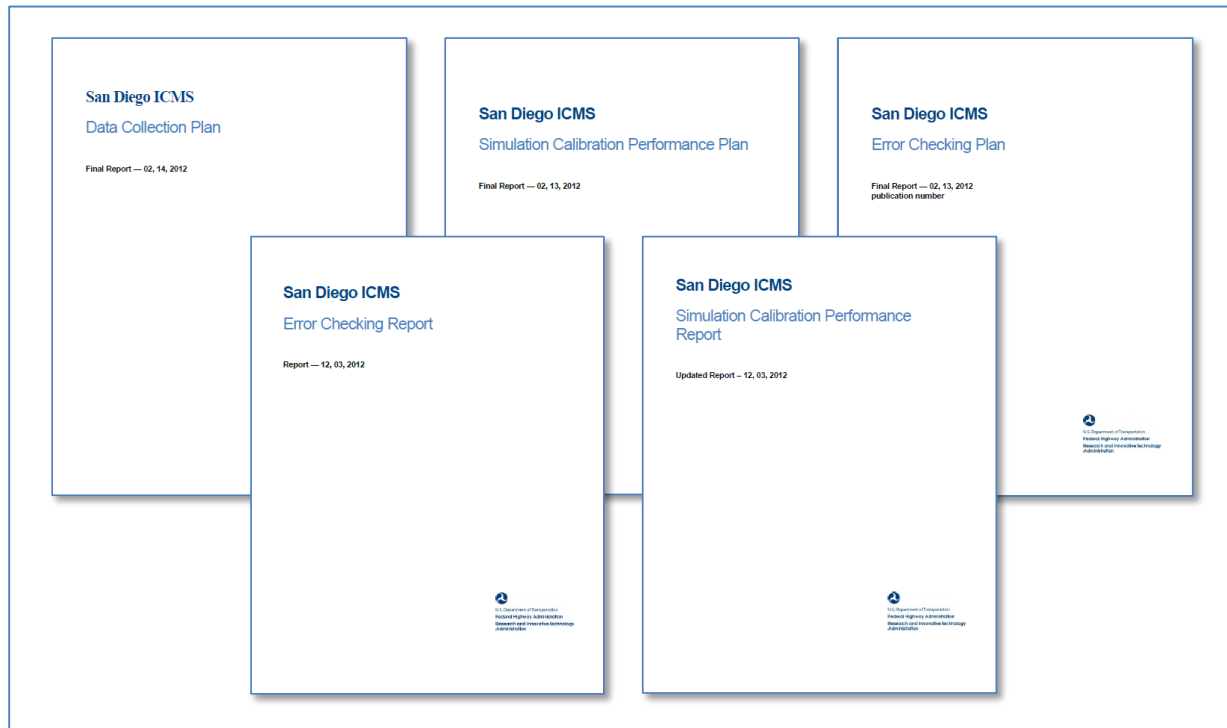


Figure 7-31 – Documents Detailing Simulation Model Development and Calibration

Figure 7-31 illustrates the various technical documents that were produced regarding the development and calibration of the Aimsun microscopic simulation model of the I-15 corridor. These documents include:

- **Data Collection Plan** (February 2012), indicating how the data that will be used to develop and calibrate the model will be collected.
- **Simulation Error Checking Plan** (February 2012), indicating how the project team will check the developed model for potential coding errors.
- **Simulation Calibration Performance Plan** (February 2012), indicating how the project team intends to calibrate the developed simulation model so that it accurately represents traffic behavior within the corridor.
- **Error Checking Report** (December 2012), presenting the result of the visual audit of the model that was conducted in April 2012 and the subsequent changes that were made to the model to address the various coding problems that were uncovered.
- **Simulation Calibration Performance Report** (December 2012), detailing the results of the model calibration.

7.4.16. NETWORK PREDICTION SYSTEM

The Network Prediction System is the module responsible for determining the travel demand to be placed on the I-15 corridor to reasonably forecast traffic conditions over the next 60 minutes.

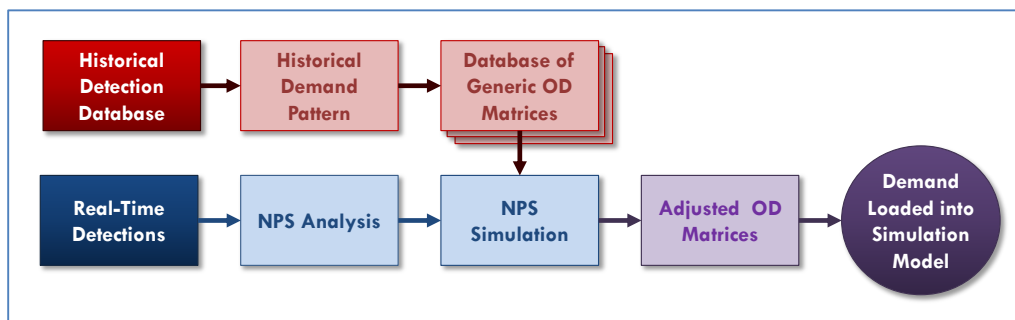


Figure 7-32 – Simulation Demand Estimation Framework

Figure 7-32 illustrates the basic process used to determine the demand to be fed to the simulation model in the Real-Time Simulation System. The process determines the probable traffic demand to be observed on the corridor by comparing real-time flow data against historical data. Based on historical detection data covering at least one year, typical origin-destination flow patterns were developed for each 15-minute interval for each of the following 11 types of operational days:

- Regular days
 - Monday
 - Tuesday/Thursday
 - Wednesday
 - Friday
 - Saturday
 - Sunday

- Exception days
 - Rainy weekday
 - Rainy weekend day
 - Soft holiday
 - Hard holiday
 - Christmas/Thanksgiving

During a particular corridor evaluation, real-time data collected from road sensors is used to compile flow, speed, and occupancy data over the various traffic detectors and develop origin-destination flow patterns reflecting observed traffic. The resulting flow pattern is then used to assess whether the observed traffic generally matches the historical pattern for the corresponding day. If it does, the historical demand is fed to the simulation model and used for the evaluation of corridor operations. If the live data does not match the historical pattern for the day, the live data is then used to model the travel demand for the first 15-minute interval of the 60-minute evaluation period, and adjusted historical data are used to model the demand for the remaining 45 minutes, as illustrated in Figure 7-33. In the latter case, adjustments to the historical data are performed by determining a global flow adjustment factor based on a comparative analysis of the live and historical data. Figure 7-34 illustrates how the application of this adjustment factor may modify historical demand data to produce an estimate of the future demand to be placed on the network in the next 15 to 60 minutes based on currently observed traffic patterns.

Figure 7-35 further details the sequence of activities associated with the prediction process. Three basic steps are involved:

- **Step 1:** Projection of flow, occupancy, and speed data over traffic detectors based on live traffic data. This process typically takes 2 minutes or less.
- **Step 2:** Determination of the origin-destination flow patterns to use over each 15-minute interval based on a comparison of the projected live traffic data with historical data for the same type of day. Due to the complexity of the estimation process, this step can take up to 10 minutes.
- **Step 3:** Simulation of corridor operations over the next 60 minutes under alternative traffic management strategies using the demand determined in Step 2 to assess various performance metrics. This process typically takes less than 3 minutes.

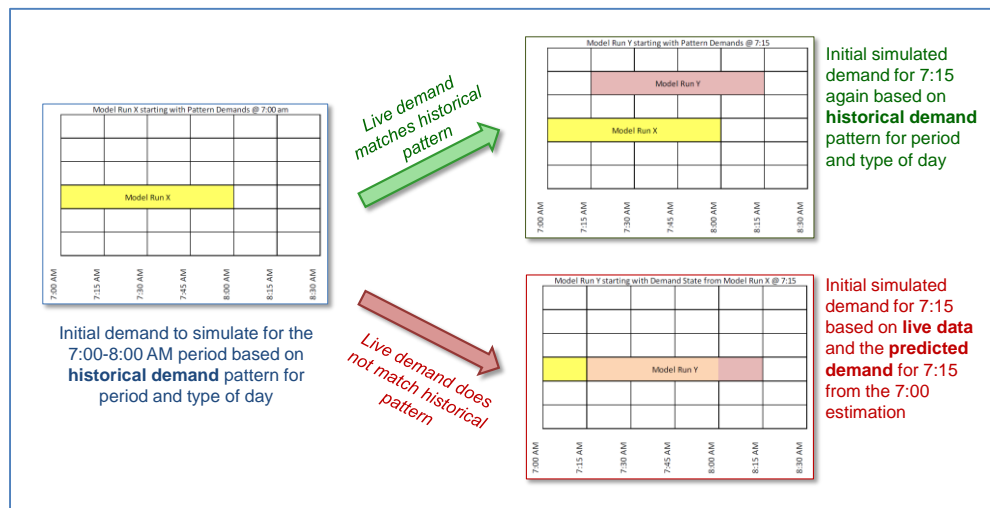


Figure 7-33 – Section Between Historical and Current Demand Patterns

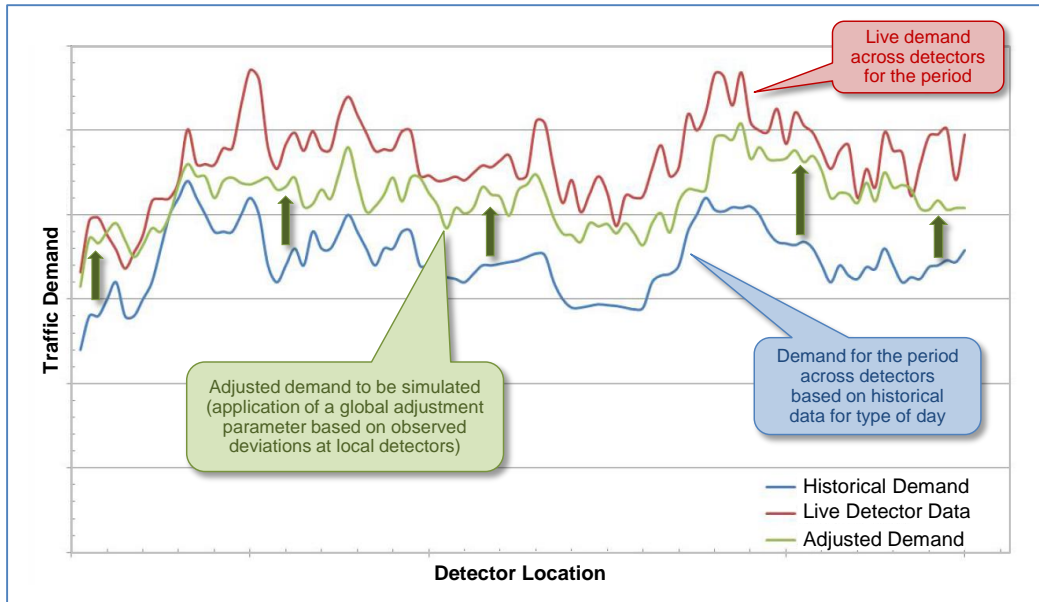


Figure 7-34 – Demand Adjustment Process Example

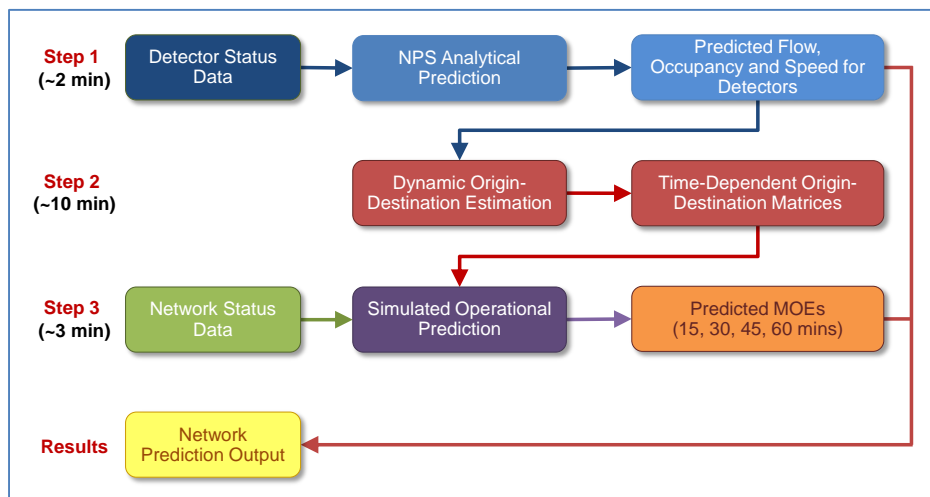


Figure 7-35 – Demand Estimation Process

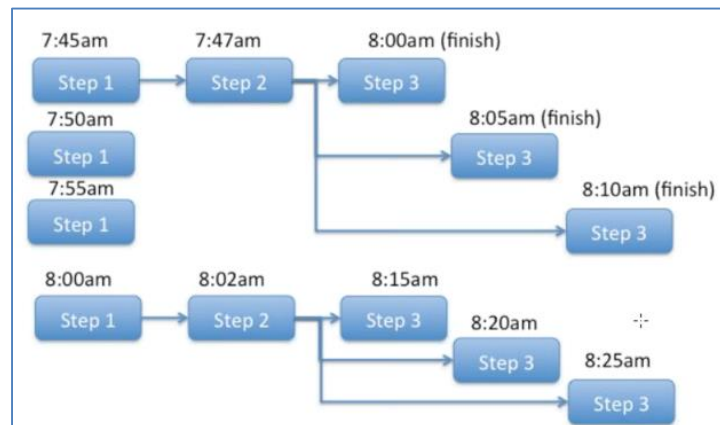


Figure 7-36 – Corridor Evaluation Steps

As can be noted, execution of the second step could take significant time. Since it is required that corridor evaluations be conducted every 5 minutes, the process illustrated in Figure 7-36 was adopted to satisfy this requirement while providing periodic updates to the simulated travel demand pattern. Assuming a first corridor evaluation starting at 7:45, all three prediction steps detailed above would be executed during this first step. This process would result in an updated demand pattern to be ready by 8:00. At 7:50, a new corridor evaluation would be initiated. However, since the development of an updated travel demand pattern would not be ready, the demand pattern that was in effect at 7:45 would again be used to forecast traffic conditions within the corridor. The same situation would repeat for the 7:55 evaluation. At the 8:00 evaluation, the newly estimated demand pattern would be made available for simulation, while work would be initiated on the development of an updated pattern for the 8:15 evaluation.

7.4.17. IMPLEMENTATION OF RESPONSE PLANS

As indicated in Section 7.4.10, the implementation of response plans is subject to approval by the operators of the various systems affected by the plan. Depending on administrative setup, the adoption of a recommended response plan could be automatically denied if an approval is not manually provided by a certain interval (for instance, 5 minutes), automatically approved after a review period has elapsed if no rejection has been received, or approved automatically without review.

A key element of the approval process is that all elements of a response plan must be approved for the plan to be implemented. Following the identification of a recommended plan, operators of the various assets involved in the plan are informed of the recommended control actions affecting their assets. Each of these operators must provide a positive response for the recommended plan to be implemented. If one operator declines approval, the recommended plan is then rejected or put on hold.

7.4.18. DISSEMINATION OF ROUTING INFORMATION

An important element of the management of the I-15 corridor is the dissemination of routing information to motorists. This dissemination occurs in the three following ways:

- Posting of messages on freeway CMSs
- Deployment of arterial wayfinding signs
- Mobile 511 application

7.4.18.1. *Routing Information Dissemination on Freeway*

The I-15 corridor has the distinction of having CMSs roughly every 2 miles. This is a much higher density than is normally found on other freeways in California or elsewhere in the country. While there is a high density of signs, a desire was expressed to reduce the number of signs that would be required to disseminate routing information to motorists so that the remaining signs could be used for other purposes. This led the project team to consider two-phase messaging on freeway signs, i.e., messages that would require two screens to be displayed fully.

A concern in using two-phase messaging was that motorists would require a certain amount of time to read the full message. This could entice some motorists to slow down, which could create a safety hazard in addition to potentially reducing freeway performance. After carefully considering the various options, the following guidelines were adopted by Caltrans District 11 for the posting of two-phase messages on freeways:

- Two-phase messaging is only allowed for messages related to incidents blocking two or more traffic lanes.
- Two-phase messages can only be posted on freeway signs where the speed of the approaching traffic is below 35 mph. This speed was judged sufficiently low to provide enough time for motorists to read the two panels of the posted message.

The panels shown on the left side of Figure 7-37 illustrate the basic template that was adopted for posting detour messages on freeway CMSs in a situation in which dynamic wayfinding signs would be used on arterials. Table 7-5 further indicates the values assigned to the various parameters within the message, based on the specific location of an incident. As an example, an incident occurring on I-15 northbound at Mira Mesa Boulevard would result in the message shown in the panels on the right in Figure 7-37. Following the decision to abandon the deployment of dynamic wayfinding signs on arterials in late 2014 and instead using static signs showing lettered routes (see next section), it is expected that the template of Figure 7-37 will be modified slightly to show the letter associated with the recommended route.



Figure 7-37 – Initial Template for Routing Information on Freeway CMSs

Table 7-5 – Content on Routing Messages Posted on I-15 based on Incident Location

Northbound			Pomero	Black Mtn	Centre City	Scripps-Poway	Camino del Norte	Rancho Bernardo	I-15 (Pomero)	Mira Mesa	SR 56	Valley	SR 78	NB1	NB2	NB3	NB4	NB5		
Roadname	Exit #	Direction	Backbone			Reentry										CMS ID				
Pomero	14	East	X			X	X	X	X					X						
Miramar	14	West		X						X				X						
Mira Mesa	16	West		X							X			X						
Scripps-Poway	17	East	X				X	X	X					X						
Ted Williams	19	East	X				X	X	X					X	X					
Rancho Bernardo	24	East	X						X					X	X	X	X	X		
Centre City	34	--			X							X	X	X	X	X	X	X		

Southbound			Pomero	Black Mtn	Centre City	Valley	I-15 (Centre City)	Rancho Bernardo	Ted Williams	Scripps-Poway	I-15 (Pomero)	Mira Mesa	Miramar	SB1	SB2	SB3	SB4	SB5		
Roadname	Exit #	Direction	Backbone			Reentry										CMS ID				
SR 78	SR 78	--			X	X	X							X						
Valley	31	East			X		X							X						
Pomero	26	East	X					X	X	X	X			X	X					
Rancho Bernardo	24	East	X						X	X	X			X	X	X				
Camino del Norte	22	East	X						X	X	X			X	X	X				
SR 56	SR 56	West		X								X	X	X	X	X	X	X		
Scripps-Poway	17	East	X								X			X	X	X	X	X		
Mira Mesa	16	West		X								X	X	X	X	X	X	X		

7.4.18.2. Arterial Wayfinding

The initial concept for arterial wayfinding relied on the use of dynamic signs to inform motorists of the route to follow to get back to the I-15. While the use of electronic signs was initially considered, a decision was eventually made to deploy mechanical rotary drum signs at the six locations shown in Figure 7-38. Figure 7-39 illustrates the initial concept for providing information using these signs. The use of drum signs allowed using three panels to display information to motorists. One panel was to be used to direct traffic in one direction, another panel to direct traffic in the other direction, and a third panel would should a blank face when no active routing is in effect.

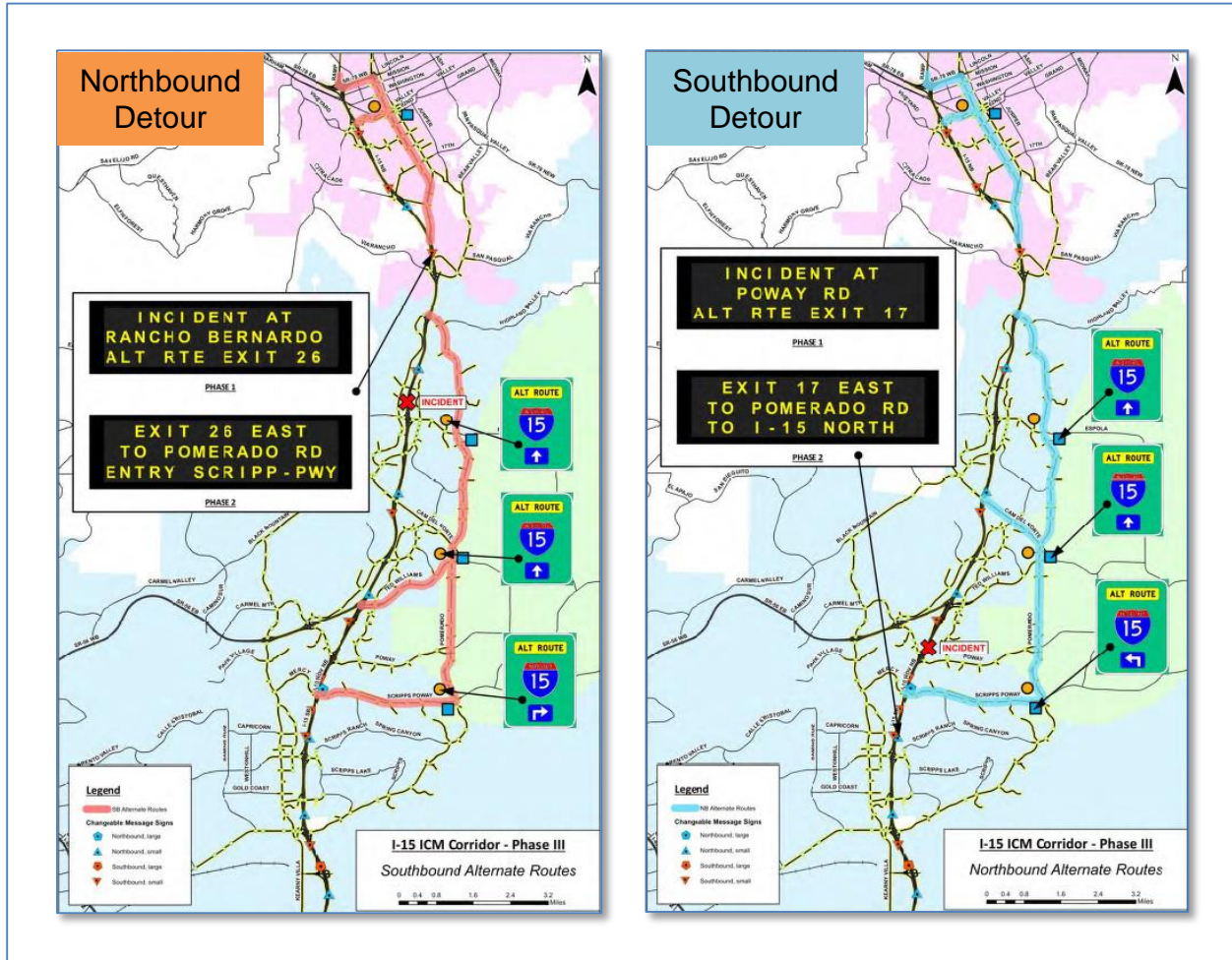


Figure 7-38 – Proposed Arterial Drum Sign Locations

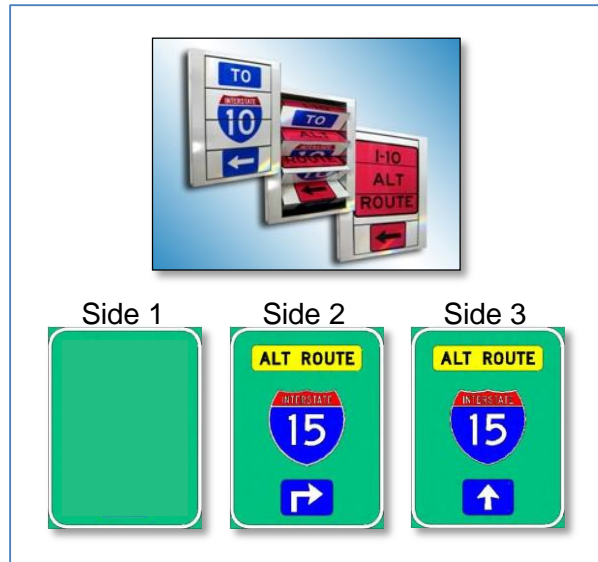


Figure 7-39 – Arterial Wayfinding Drum Sign Concept

Due to difficulties in securing a contract order to implement the rotary drum signs, a decision was made in late 2014 to install instead static signs showing lettered routes to follow, as illustrated in Figure 7-40. These new signs were to be delivered by June 2015 and installed by August 2015. While this decision removed the dynamic signing aspect, it still allowed for changing the recommended detour routes by using the lettered route to follow on the posted CMS messages. Instead of being told to follow a detour using Pomerado Road or other arterials, freeway motorists are instructed to follow Route A, Route B, or other pre-defined route.

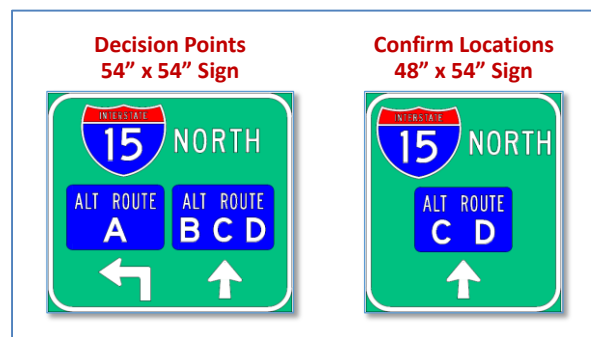


Figure 7-40 – Static Arterial Wayfinding Signs

After evaluating various placement options, a decision was made to deploy 28 signs to provide guidance on northbound routes and 17 signs to provide guidance on southbound routes. Figure 7-41 maps the selected locations for the signs. An unexpected benefit of replacing the drum signs with static signs has been to increase the number of routes that could dynamically be signed from the freeway. This increase in alternate routes can be observed by comparing the highlighted arterial segments shown on the maps of Figure 7-38 and Figure 7-41.

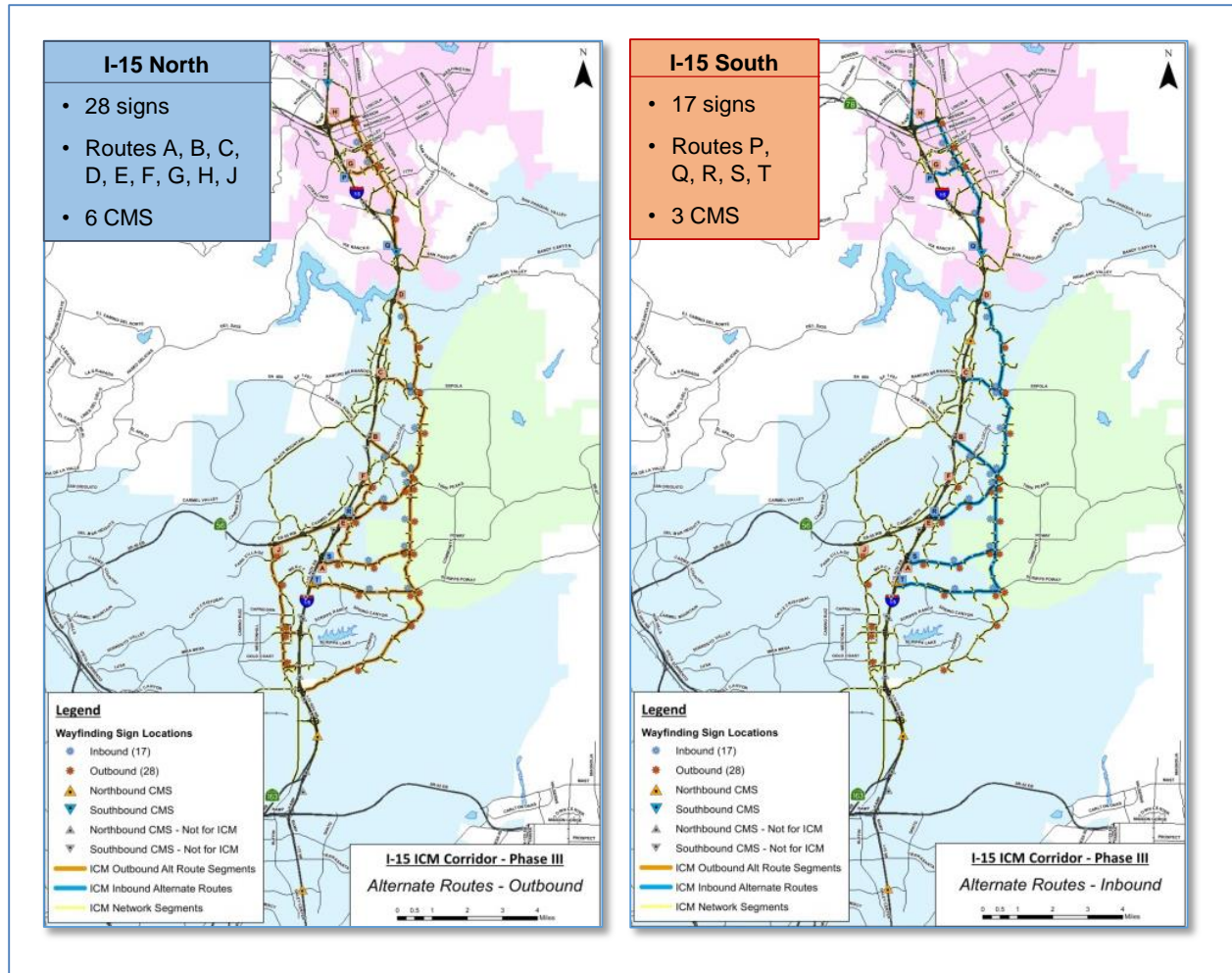


Figure 7-41 – Location of Static Arterial Wayfinding Signs

7.4.18.3. 511 Mobile Application

The final component of the information dissemination strategy has been the release of a free 511 mobile application that corridor travelers could use to get information about incidents and recommended detours. This application was developed by Iteris, and a first version was released in May 2014. Various screenshots of the application are shown in Figure 7-42. This version provided real-time predictions from Aimsun Online and system-based advisories. It also let users view predictive travel times on I-15; current CMS traffic conditions within the corridor; MTS bus routes, fares, and arrival times; and real-time dynamic toll rates for the I-15 Express Lanes. It also used text-to-speech to give users alerts for the latest incident and construction information in the region. The release of an updated version in June 2015 further added real-time delay for MTS bus arrivals and the ability for users of the application to set up customized push notifications.

Since its launch in May 2014, this application has had over 27,000 downloads. SANDAG’s initial goal was to reach a customer base of at least 5,000 travelers. This goal was not only driven by a desire to justify the development work for the application, but also by the fact that the application was to be used to collect trip information from travelers that could help monitor travel patterns.

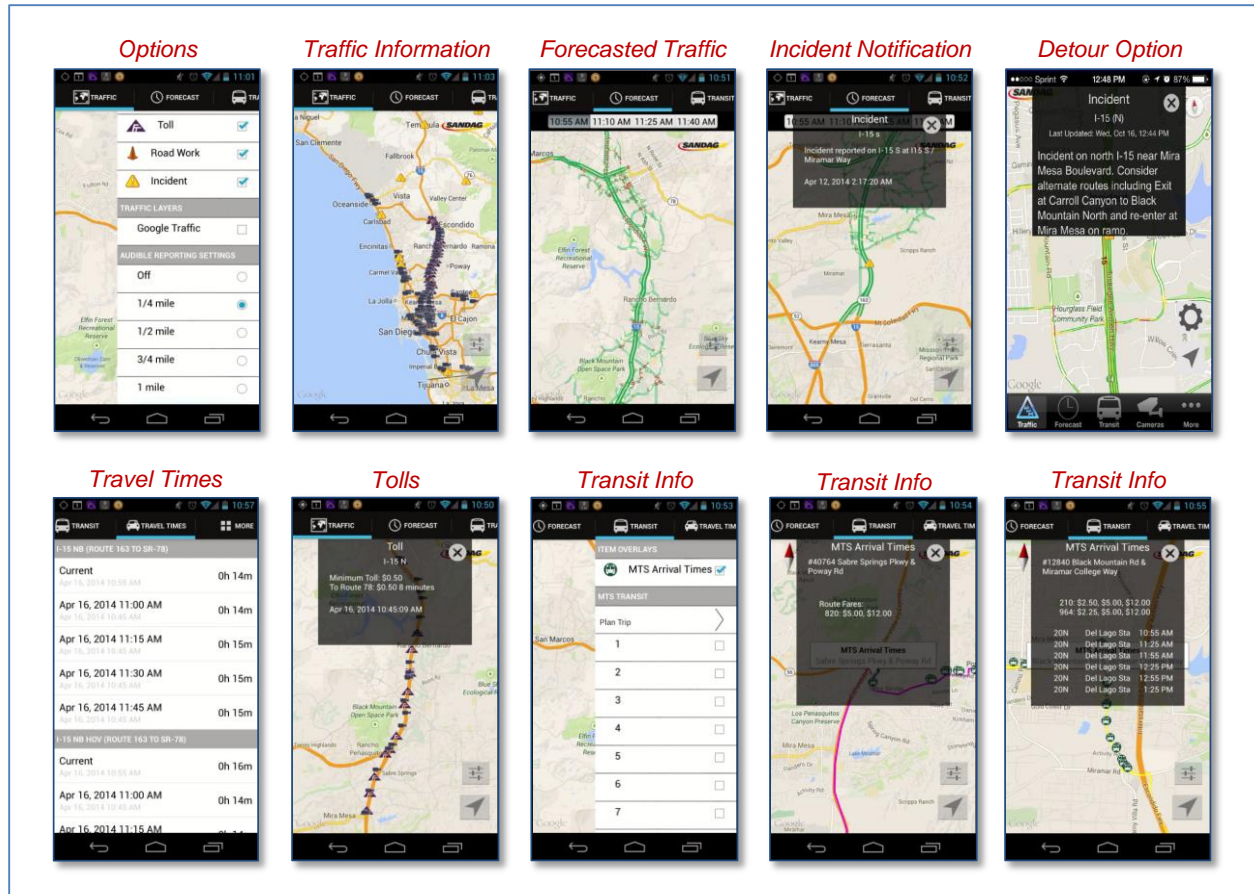


Figure 7-42 – 511 San Diego Mobile Application

7.4.19. CORRIDOR-PEMS (C-PEMS) APPLICATION

A final design element was the development of an application to facilitate the visualization and analysis of data collected and generated by the ICMS. To accomplish this, Iteris was contracted to expand the functionalities normally found within the Performance Measurement System (PeMS) to enable the:

- Visualization of response plans
- Calculation of corridor-wide performance measures
- Comparison of simulation predictions to real data
- Calculation of simulation quality performance measures

At the time this report was written, the Beta version of the Corridor-PeMS (C-PeMS) application could be accessed at the following address:

<http://pems.dot.ca.gov:3502/>

Once within the site, the I-15 pages could be accessed by going to the “Facility & Devices” tab and selecting the “Multimodal Corridors” option in the dropdown menu. Information about events could then be accessed by going to the “Event” tab. Information about which response plan has been implemented could further be accessed by clicking the “DSS Visualization” option under the “Overview” tab.

Several screenshots of the application are presented below:

- Figure 7-43** – Response plan visualization tool. The example shows the response plan that was recommended at 8:38 AM for an incident that had occurred on March 25, 2015 a few minutes earlier on I-15 in Escondido. The figure illustrates the recommended detour around the incident and the affected signals and ramp meter. Information on the right side of the figure further indicates that response plans for this incident were produced at 8:34, 8:38, 8:56, 9:00, and 9:23 (additional plans for this event were also produced at 9:42, 9:46, 10:09, 10:28, and 10:32), and that the 8:38 plan had an evaluation score of 3.9. The other response that was scored is the 9:00 plan, with a score of 1.4. Since these scores were below the 7% improvement threshold in effect at the time, none of the developed plans was implemented.
- Figure 7-44** – General dashboard comparing simulated and observed travel time along the I-15 freeway, I-15 Express Lanes, and arterials.
- Figure 7-45** – Page summarizing the person-hours of delay that were measured along the corridor between March 11 and March 25, 2011 when using 90% of the free flow speed as a reference.

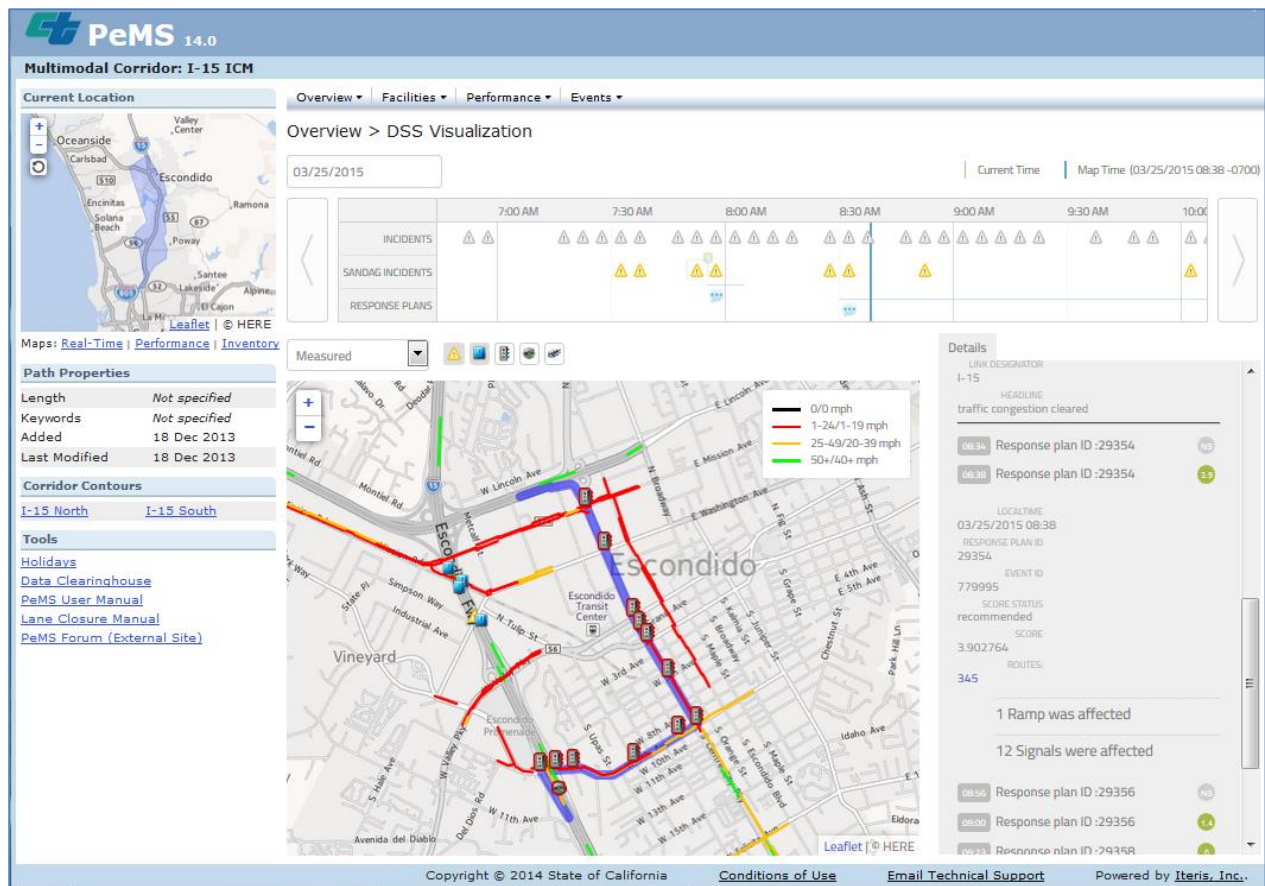


Figure 7-43 – C-PeMS Response Plan Visualization Tool



Figure 7-44 – C-PeMS Dashboard

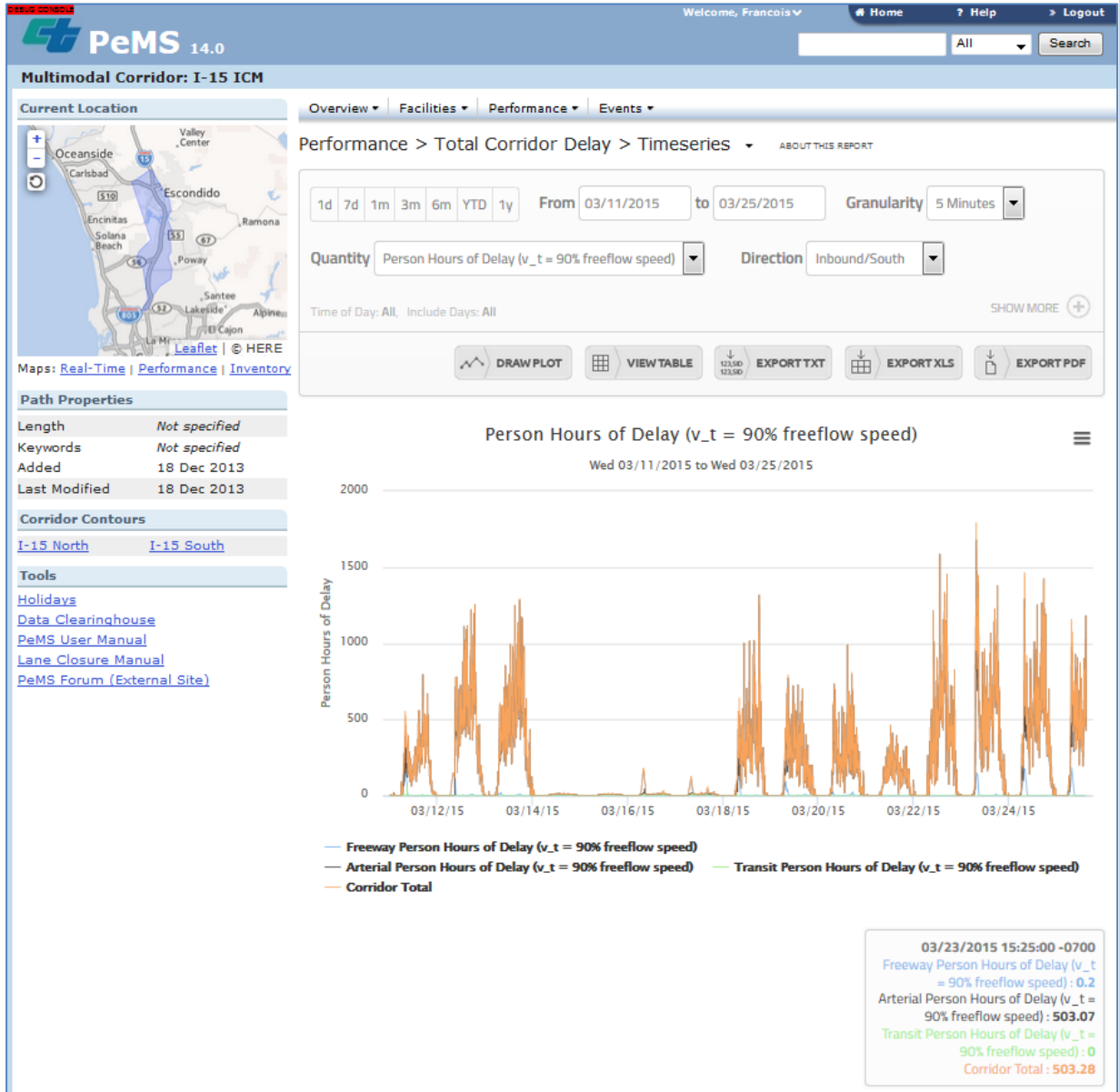


Figure 7-45 – C-PeMS Performance Analysis

7.5. TASK 4 – SYSTEM TESTING

Three specific test phases were executed during the project:

- Testing during system design
- Final system tests before launch
- Operator testing during shakeout period after system launch

7.5.1. TESTING DURING SYSTEM DESIGN

System testing started during the design process. At this stage, tests were conducted on new system elements as they became available. As illustrated in Figure 7-46, the following test plans and procedures were developed for each of the three main design iterations:

- **Product Acceptance Plan** (Initial version January 2012, final update June 2013) – Document detailing the general strategy for testing and verifying that the ICMS delivered at the end of each iteration meets its stated requirements.
- **Iteration 1 Test Procedures** (January 2012) – Document detailing the test procedures to be used during the first design iteration.
- **Iteration 2 Test Procedures** (November 2012) – Document detailing the test procedures to be used during the second design iteration.
- **Iteration 3 Test Procedures** (January 2013) – Document detailing the test procedures to be used during the third design iteration.
- **Test Procedures - Final** (September 2013) – Document detailing the various test procedures that were executed during the three design iterations.

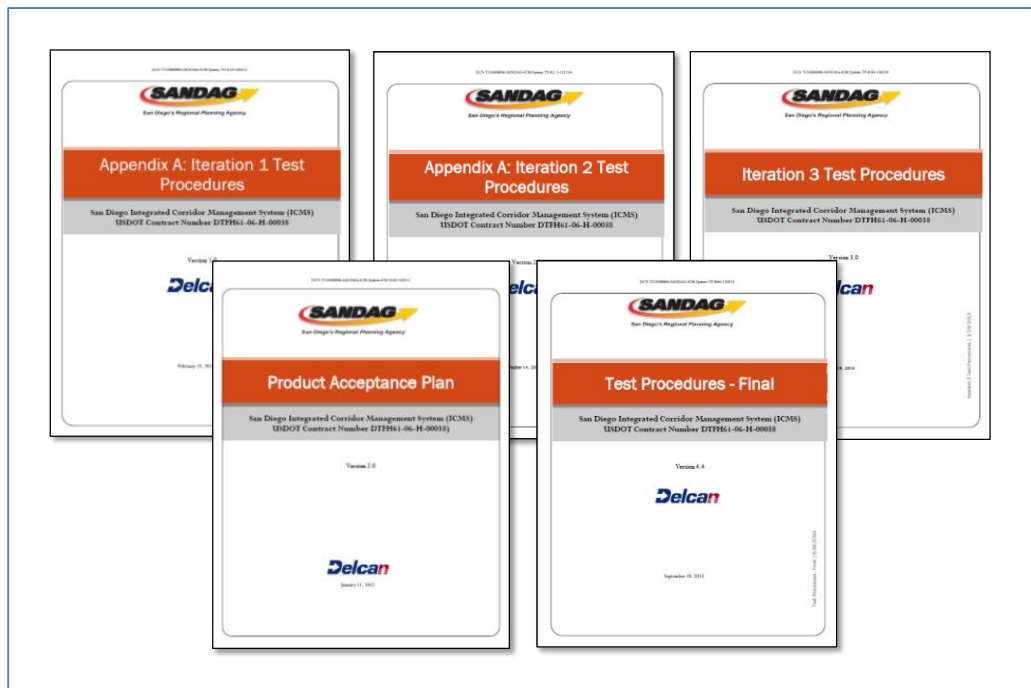


Figure 7-46 – Design Iteration Test Documents

Table 7-6 lists the various elements that were tested at the end of each iteration. While some elements were tested at the end of multiple iterations, later tests were often conducted to assess new functionalities added during the iteration. All tests were conducted to demonstrate that the various system components satisfy the system requirements that were to be addressed in the iteration. Where applicable, some of the test procedures were also used to verify data boundary conditions.

Table 7-6 – System Components Tested at Each Iteration

Test Element	Iteration 1	Iteration 2	Iteration 3
Road asset configuration and condition data store	•	•	•
Data collection, processing, and dissemination	•	•	•
System access control	•	•	•
Graphical User Interface (GUI) data flows		•	•
Data display and map manipulation	•	•	•
Data configuration		•	•
User profile / preferences	•	•	•
Business Rules and Process Management Subsystem (BRPMS)		•	•
Response Strategy Data Store Subsystem (RSDS)		•	•
Real-time Simulation Subsystem (RTSS)		•	•
System time source	•	•	•
System monitoring	•	•	•
System backup	•	•	•

7.5.2. FINAL SYSTEM TESTS

The final system tests started in October 2013. While the tests were initially planned for completion in the same month, various technical issues pushed the last tests to February 2014. This final testing sequence occurred in three stages:

- **Stage 1 – Interface Test:** Separate verification of each control interface with each stakeholder/vendor. Most of these tests occurred in October and November 2013.
- **Stage 2 – Coordinated Test:** Verification of all interfaces with all stakeholders/vendors to ensure that all assets in the corridor can be controlled by the ICMS. Coordinated tests occurred between October 2013 and January 2014.
- **Stage 3 – Acceptance Test:** Operations of the system for over a period of 30 days in January 2014 to see if everything is operating as intended.

The objective of the testing was to verify the ability to control in coordination the various devices operated the by corridor stakeholders using their own systems. This included verifying that a ramp metering plan, signal timing plan, and message to post on CMSs could be selected and implemented. To verify these features, scenarios were developed to test the following activities:

- **Event creation:** Verification that ICMS controls are received at stakeholder systems and that field assets are controlled
- **Event update:** Verification that ICMS control updates are received at the stakeholder systems and that field assets are controlled; verification that asset status changes are displayed correctly
- **Event termination:** Verification that ICMS control are removed from stakeholder systems and that field assets are reverted back to normal operation; verification that asset status changes are displayed correctly

All system servers and network elements were also tested at this stage to ensure that they have been configured correctly with respect to the minimum standards for security defined by SANDAG.

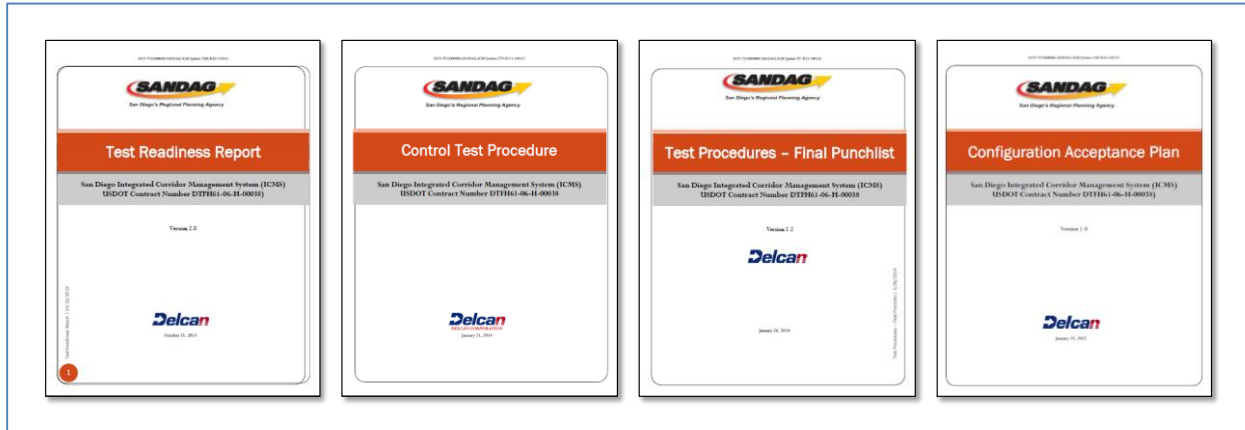


Figure 7-47 – Final System Test Documents

Documents detailing the tests that were conducted at this stage are shown in Figure 7-47. These include:

- **Test Readiness Report** (October 2013) – Document detailing the results of the various test procedures that were executed by Delcan and TSS in October 2013 at the end of the third design iteration.
- **Control Test Procedure** (January 2014) – Document detailing the tests that were conducted during the coordinated testing.
- **Test Procedures – Final Punchlist** (January 2014) – Document detailing the final set of tests that were conducted on the system.
- **Configuration Acceptance Plan** (February 2014) - Document describing the approach that was used for the system servers and network elements.

7.5.3. OPERATOR TESTING DURING SHAKEOUT PERIOD

Launch of the ICMS occurred in March 2013. Following this launch, system features were gradually brought online over a six-month shakeout period to allow operators to become familiar with the system and enable them to note any problems with the system operations. During this period, system functionalities were gradually rolled out according to the following schedule:

- **Months 1-2 (March-April 2013):** Operators started receiving event notifications and were able to log into the ICMS, view the operations of the assets, and review identified elements. Operators were not asked to respond to events, and no commands were issued to the field.
- **Months 3-4 (May-June 2013):** Operators were now asked to authorize the commands contained in the notifications they receive, prior to allowing the system to issue field commands. However, since the focus was on getting operators familiar with what is expected from them, field commands were still not sent to the field.
- **Month 5-6 (July-August 2013):** Full operation of the ICMS. While operators continued to review and approve command notifications, the system was allowed to send commands to the field to change the affected devices.

7.6. TASK 5 – TRAINING

Training of system users occurred between February and June 2013, during the ICMS shakeout period. Kimley-Horn was responsible for the delivery of the training, while Delcan was responsible for the development of the training material. For most users, training involved participation in two separate sessions: an initial 2-hour training for all system users in March 2013 and a subsequent 2-hour in-depth training session in late May or early June 2013. Specific in-depth sessions were organized for system managers, ICM event operators, MTS operators, and Caltrans operators. The specific topics that were covered during the training sessions include:

- Overview of ICMS
- How the ICMS works
- System administration
- User interfaces
- ICM response plans (exercises, events)
- CMSs, ramp meters, transit operations, and traveler information systems
- Management of traffic along signalized arterials

The basic idea behind the two-phase training approach was to allow users to become comfortable with the ICMS environment before tackling the more in-depth modules. This approach also allowed an opportunity to gather meaningful feedback from the users during the in-depth modules.



Figure 7-48 – Training Material

In support of the training sessions, training material was developed by Delcan for the two following types of system users (see Figure 7-48):

- **System administrators** – This material was developed for system administrators and managers working in a Traffic Management Center or Transit Operation Center. The focus of this material is on demonstrating how to create and modify user accounts, set permissions for users, and manage corridor operational settings.
- **System operators** – This material was developed for individuals conducting the operation of the various transportation systems within the I-15 corridor. The goal of the training material is to aid operators in navigating Delcan’s iNET interfaces; get them familiar with the system’s mapping functionalities; demonstrate viewer windows for CMSs, traffic detectors, ramp meters, traffic

signals, transit services, parking facilities, and traffic events; demonstrate the window used to view response plans; and identify parameters used for response plan management.

7.7. TASK 6 – SYSTEM OPERATIONS AND MAINTENANCE

System operations officially started in March 2014, following the successful conclusion of the 30-day Acceptance Test. This section presents a summary of the following topics related to system operations and maintenance:

- Operations and maintenance documents produced
- Operations review process
- Summary of operational adjustments
- Special low-impact event assessment

7.7.1. OPERATIONS AND MAINTENANCE DOCUMENTS

Figure 7-49 illustrates the key documents that were developed to support system operations and maintenance. These documents include:

- **Operations and Maintenance Plan** (January 2011) – Early project document establishing how each of the partner agencies will conduct business in an efficient manner while complying with the cooperative agreements governing the ICMS operations and maintenance goals.
- **Barracuda VPN Procedure** (July 2012) – Document guiding system users through the installation of the VPN client used to gain access into the San Diego ICMS environment.
- **Aimsun Online Administrator Manual** (October 2013) – Document covering all aspects related to the operation and administration of the Network Prediction System (NPS) and Real-Time Simulation System (RTSS), generically referred to as Aimsun Online.

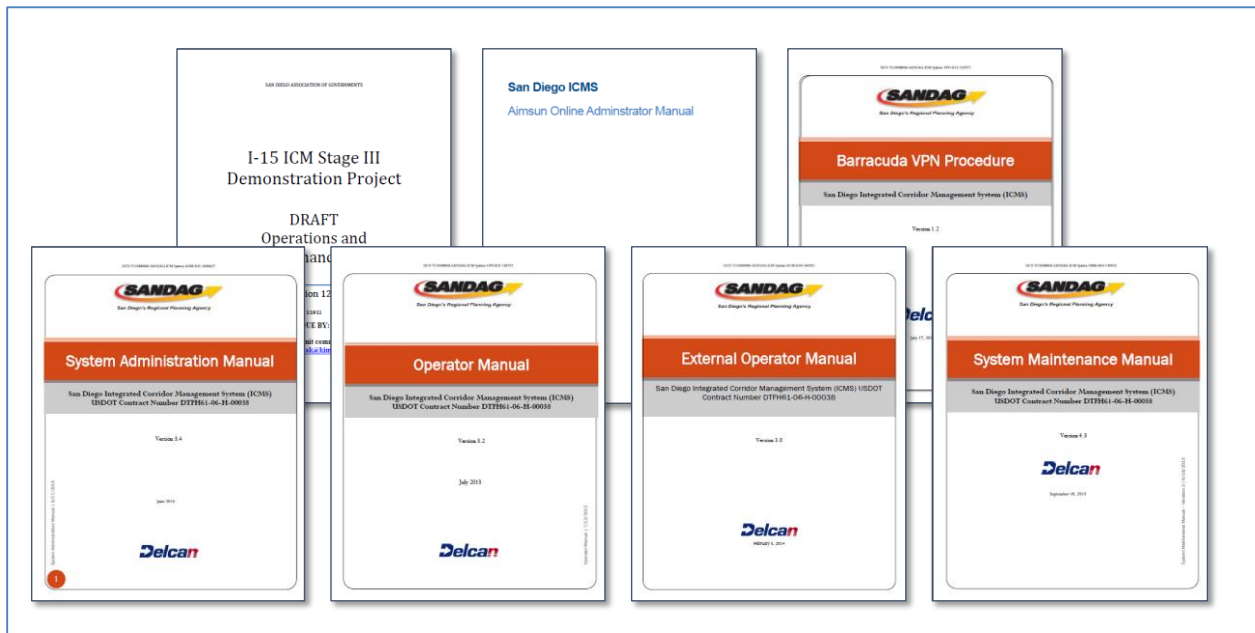


Figure 7-49 – Operations and Maintenance Documents

- **Operator Manual** (July 2013) – Document providing information to system operators on how to navigate the user interface, access equipment and other data, use the viewer window for specific equipment, use the system to manage day-to-day operations, and generate reports to show device status and activity.
- **System Administration Manual** (June 2014) – Document providing information to system administrators on how to create and modify operator accounts and groups, set permission for groups, create a priority list for groups, manage equipment and other data, manage system parameters, and manage center-to-center access.
- **System Maintenance Manual** (September 2013) – Document providing information to system administrators and managers on how to start up and shut down the ICM application, troubleshoot the system, maintain databases, and document the system architecture and server configuration for the Linux and Windows platforms.
- **External Operator Manual** (February 2014) – Document describing how to use the Center-to-Center Interface to retrieve information from the Data Hub component of the ICMS. This document provides information concerning available data types, data sources, and options for acquiring the data. It is intended as a guide that external agencies and users may use to develop clients that consume the data provided by ICMS.

7.7.2. OPERATIONS REVIEW PROCESS

Following the official launch of the system, a meeting schedule was organized to allow corridor stakeholders to review system operations and discuss any issues that may have been encountered. Specific topics that were discussed during these meetings include:

- Events and response planning activities that have occurred since the last meeting
- Performance statistics associated with the events
- Expectations regarding event identification and appropriate responses
- Corridor configuration parameters, particularly congestion score, congestion event finder, congestion thresholds

The aim of these meetings was to foster an ongoing process for discussing, reviewing, assessing, and ultimately modifying ICMS settings and response plans. Between February 2014 and October 2014, corridor operational review meetings typically occurred every week. Due to the reduction in discussion topics, the stakeholders moved to bi-weekly meetings in November 2014, and monthly meetings in December 2014.

7.7.3. SUMMARY OF OPERATIONAL ADJUSTMENTS

The proposed activation schedule for the ICMS called for a phased implementation of all system functionalities according to the following 4-month plan:

- **Initial deployment**
 - Implementation of response plans if delay reduction achieves 25% or more
 - Deny recommended actions on time out, to ensure that all system operators review and assess the recommendations

- **Phase 1 activation**
 - Reduce the delay threshold needed to trigger the implementation of a response plan
 - Approve recommended actions on time out
 - Traffic signals independently controlled from one jurisdiction to the next
 - Ramp metering control during peak period only
 - Consider existing message library for posting messages on CMS
- **Phase 2 activation**
 - Reduce the delay threshold needed to trigger the implementation of a response plan
 - Approve recommended actions on time out
 - Traffic signal coordination across agencies
 - Ramp metering control during peak period only
 - Consider existing message library for posting messages on CMS
- **Phase 3 activation**
 - Maintain the delay threshold needed to trigger the implementation of a response plan
 - Automated approval of recommended actions
 - Traffic signal coordination across agencies
 - Ramp metering control during peak period only
 - Consider existing message library for posting messages on CMS, with review requirement by Caltrans operators
- **Phase 4 activation**
 - Similar to Phase 3, but some adjustments to the delay threshold needed to trigger the implementation of a response plan
- **Phase 5 activation**
 - Maintain as is the delay threshold to trigger the implementation of a response plan
 - Automated approval of recommended actions
 - Traffic signal coordination across agencies
 - Peak and off-peak ramp metering control, depending on public/media awareness
 - Implementation of two-phase CMS messaging on freeway

The following is a summary of the various specific adjustments that were made to the operating parameters and rules of the ICMS since the formal beginning of its operation in March 2014:

- **Identification of congestion events**
 - May 2014 – Reduction in the speed differential required to trigger an over-congested event from 25% to 20%; change in the minimum speed difference to trigger a congestion even when comparing to historical data from 15 to 10 mph.
 - October 2014 – The end time of congestion events was increased from 2 hours to 24 hours to enable the ICMS to track more events to their proper termination.
 - November 2014 – Change in how the system handles low-volume data supplied by PeMS to avoid discarding the information as faulty data (as reported by PeMS).

- **Location of incidents**
 - November 2014 – Additional logic was added to the system core to integrate additional data sources and improve the location of incidents along roadways.
- **Corridor score calculation**
 - April 2014 – Slight adjustment to the calculation methodology and correction of an undetected bug in the score calculation methodology.
 - May 2014 – Reduction in how far laterally the bounding box extends (parameter Y in Figure 7-28) from 0.9 to 0.7 mile for low-demand events, 1.2 to 1.0 mile for medium-demand events, and 1.5 to 1.2 mile for high-demand events.
 - June 2014 – Expanded the length of the bounding box to 5 miles downstream and 15 miles upstream (X = 5 miles) under an Aggressive Posture to better capture queues generated by an event.
 - November 2014 – A change was made in how the ICMS assesses faulty data. It was uncovered that PeMS often assesses as faulty low-volume data from traffic detection stations downstream of an incident while the low volume is actually caused by the incident. This led the ICM system to rely on historical data to compensate for the “faulty” data, causing large sudden swings in evaluation scores.
- **Response planning process**
 - June 2014 – Change in the re-evaluation interval from 20 min to 15 min.
 - June 2014 – Provision of two additional signal timing route/plan options for aggressive system responses (Third Route, and First/Third Routes Combinations).
 - July 2014 – Enabled routes passing near schools to be used as detours during summer school vacation.
 - September 2014 – Review of signal availability and cataloging for conformance.
- **Response plan approval**
 - March 2014 – Deny on time out replaced by approve on time out.
- **Minimum corridor score needed to implement a response plan**
 - May 2014 – Reduction from 25% to 18% on May 7, and from 18% to 8% on May 21.
 - March 2015 – Reduction from 8% to 7%.
 - May 2015 – Reduction from 7% to 6%.
- **Response plan run time**
 - October 2014 – The minimum runtime of a response plan corresponds to the time needed to conduct an evaluation, submit a plan change request, and receive a confirmation. This runtime was changed from 15 to 22 minutes to better address situations in which additional events occur during the runtime (the previous setting sometimes resulted in the newer event being solely considered in replacement of the first event).

- **System hardware**

- October 2014 – The RAM on two of the iNET servers was upgraded from 24GB to 32 GB. The RAM on the SANDAG server was also upgraded from 32GB to 128GB, which required the installation of a new operating system.

7.7.4. OPERATIONAL PERFORMANCE SUMMARY

Table 7-7 compares events identified by the Caltrans ATMS against the events that were identified by the ICMS during various one-week evaluation periods between April 2014 and March 2015. For the ICMS events, the table also indicates how many events triggered the development of response plans (but not necessarily the implementation of these plans), and how many response plan evaluations were conducted by the system for those events.

Table 7-7 – Summary of Event Responses

	Period	Caltrans ATMS Events	ICMS Events	ICMS Congestion Events	Events Triggering Response Planning	Response Plans & Do Nothing Evaluations	Notes
2014	April 3-9	46	35		0		25% Response threshold
	May 8-20	95	78		60		18% Response Threshold
	June 6-17	100	45	30	30		8% Response Threshold
	July 4-11	75	55	20	15		Planning interval reduced to 15 minutes; increased bounding box for aggressive posture
	Aug 9-15	45		33	26	311	
	Sep. 6-12	61		16	12	104	
	Nov. 8-14	55		39	19	138	Minimum plan runtime changed from 15 to 22 minutes
	Dec. 6-12				18	173	
2015	Jan 10-Jan18			84	30	250	
	Jan 31-Feb 13	123		169	63	311	
	Feb 28-Mar 13	131		194	61	315	7% Response Threshold
	Mar 28-Apr 10	144		171	27	144	
	May 2-May 15	144		166	39	209	6% Response Threshold
	May 30-Jun 12	41		164	40	160	

Figure 7-50 and Figure 7-51 further illustrate the scores that were produced by the system between April 2014 and March 2015. As can be observed, the majority of the response plans produced have scores ranging between -5 and +5. Only a few plans had a score exceeding the implementation threshold represented by the dotted line. This has resulted in very few response plans being actually implemented. This low response rate explains the several revisions that were made to the implementation threshold that eventually brought it down to 6%. While further reducing the threshold below 6% would certainly increase the number of implemented response plans, some team members have expressed strong hesitation to do so, concerned that triggering responses too often could disrupt intended corridor operations.

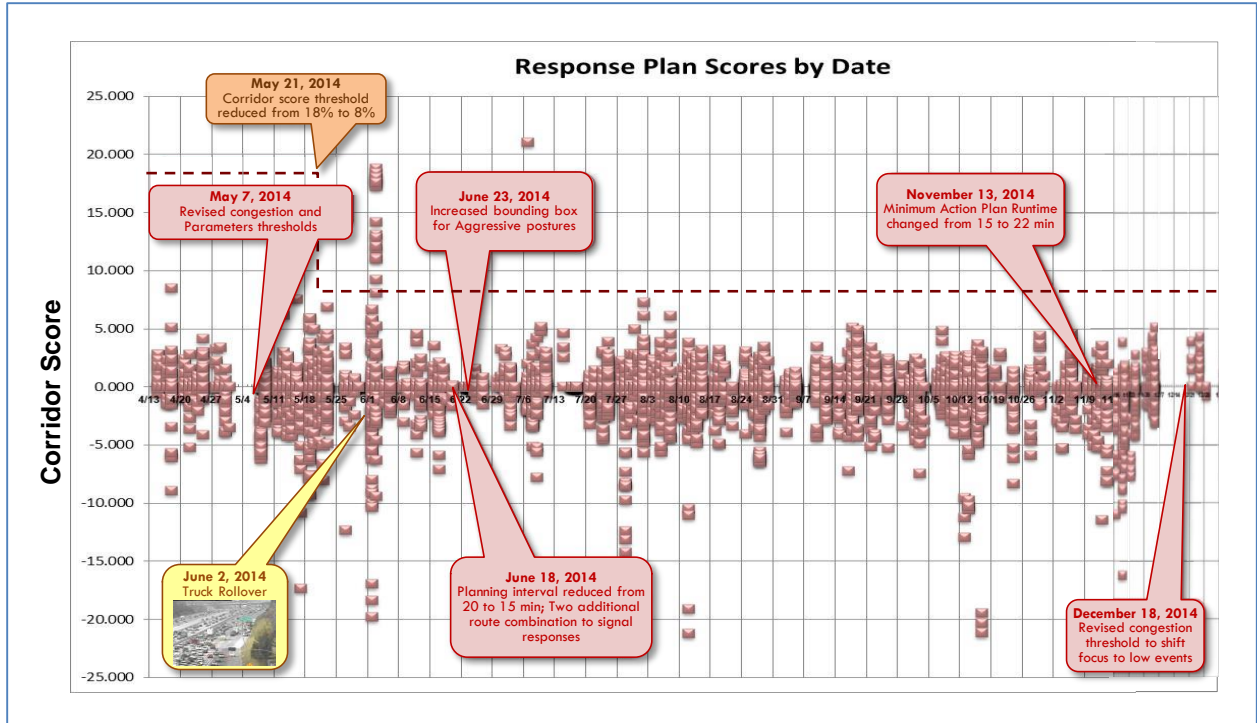


Figure 7-50 – Response Scores by Date (April – December, 2014)

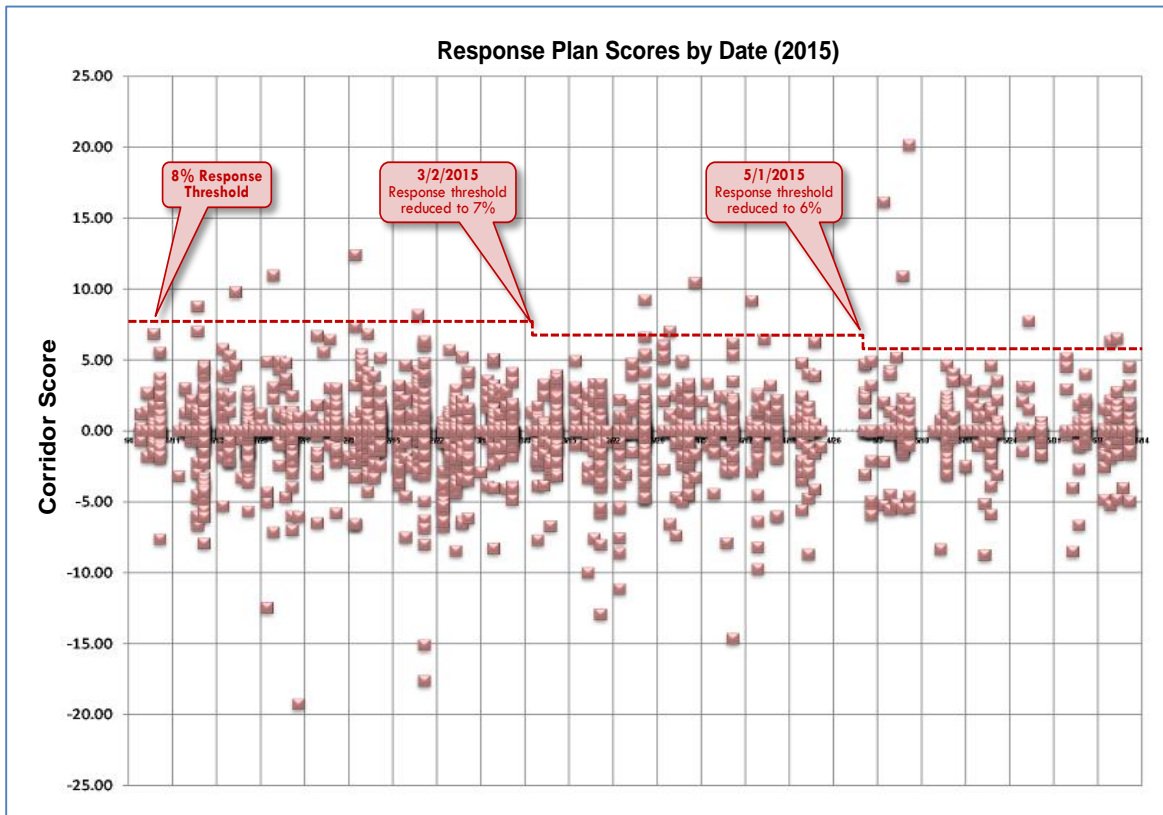


Figure 7-51 – Response Scores by Date (January – June, 2015)

7.7.5. SPECIAL LOW-IMPACT EVENT ASSESSMENT

In December 2014, after assessing that very few low-impact events were being responded to by the ICMS, temporary changes to the system configuration parameters were adopted to force the system to respond more frequently to low-impact events over a period of a few months. This operational change was achieved by modifying as follows the queue length thresholds used to categorize congestion events as being low-, medium-, or high-impact events:

- **Low impact queue threshold:** 0.5 mile instead of 0.9 mile
- **Medium impact queue threshold:** 1.5 mile instead of 1.0 mile
- **High-impact queue threshold:** 2.5 miles instead of 1.2 mile

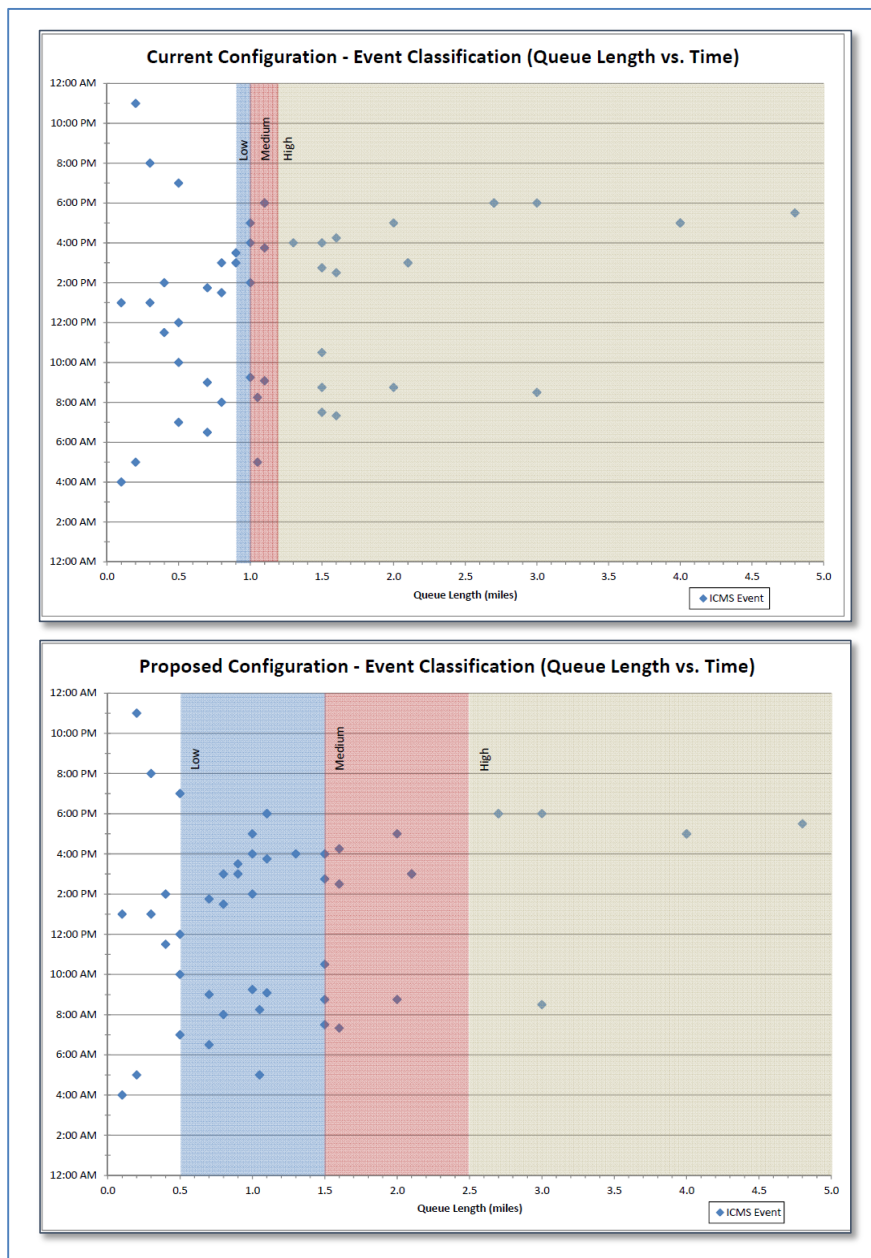


Figure 7-52 – Effect of Queue Threshold Change on Low-, Medium-, or High-Impact Event Classification

Figure 7-52 illustrates how the changes affected the classification of congestion events. Both diagrams shown in the figure illustrate the same set of incidents. As can be observed, the redefined queue length thresholds significantly increased the width of the low and medium impact regions, thus artificially causing significantly more events to be classified as low-impact events than the normal queue threshold values.

Based on the proposed change in queue threshold parameters, the following four-phased plan was then developed to assess how the ICMS would respond to low- and medium-impact incidents that would occur within the I-15 corridor between December 19, 2014 and March 18, 2015:

- **Phase 1** – Assessment of responses considering 511 messaging only
- **Phase 2** – Assessment of responses considering 511 messaging and traffic signal control changes
- **Phase 3** – Assessment of responses considering 511 messaging, traffic signal control changes, and ramp metering changes
- **Phase 4** - Assessment of responses considering 511 messaging, traffic signal control changes, ramp metering changes, and use of freeway CMS

7.8. TASK 7 – ANALYSIS, MODELING, AND SIMULATION

Analysis, modeling, and simulation (AMS) activities were managed by Cambridge Systematics, the USDOT AMS Contractor. AMS activities included under Stage 3 of the USDOT ICM Initiative were performed in two sub-stages:

- Stage 3A – Enhancement of Stage 2 evaluation tools/pre-deployment evaluations
- Stage 3B – Post-deployment evaluations

The objective of the Stage 3A efforts were to ensure that the models and methodologies developed during Stage 2 could sufficiently replicate and evaluate corridor conditions, as well as the proposed ICM strategies, prior to the deployment of the ICMS. This involved confirming, refining, and validating the parameters/assumptions that served as the basis for the control strategies defined in the Stage 2 models. Stage 3B was to conduct evaluations focusing on corridor operations after the launch of the ICMS. In addition to estimating the impacts of ICM operations on corridor performance post-launch, this included updating the evaluation models used to reflect the “as built” ICM system and strategies and updating model parameters based on observed data.

Figure 7-53 identifies the key AMS documents that have been produced by Cambridge Systematics as of June 2015. These include:

- **Pre-Deployment Analysis Plan** (December 2011) – Document outlining the various tasks that Cambridge Systematics planned to execute to assess the validity of the available Stage 2 evaluation tools and to support the pre-deployment analysis of the proposed ICMS.
- **Pre-Deployment AMS Assessment** (August 2012) – Document detailing the results of the pre-deployment AMS evaluations.
- **Post-Deployment Analysis Plan** (January 2015 draft) – Document outlining the tasks that were planned to be executed to conduct the formal post-deployment evaluation of the ICMS.

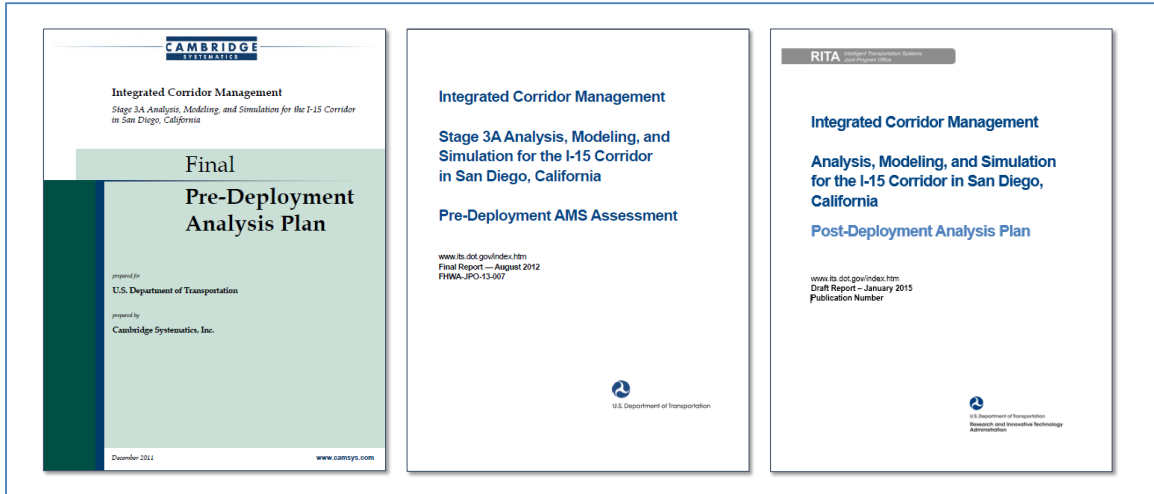


Figure 7-53 – Pre- and Post-Deployment AMS Analysis Documents

Discussions presented in the remainder of this section focus on the following topics:

- Summary description of the Stage 2 evaluation tools
- Activities conducted to enhance the Stage 2 evaluation tools
- Results of pre-deployment analyses
- Results of post-deployment analyses

7.8.1. STAGE 2 EVALUATION TOOLS

As part of Stage 2 of the USDOT ICM Initiative, Cambridge Systematics developed a TransModeler microscopic simulation model reflecting the corridor geometry and travel demand that were expected to exist within the I-15 corridor in 2012 at the projected launch date of the ICMS. This model was developed in 2008 based on 2003 data reflecting conditions that existed along the I-15 corridor prior to the start of construction of the expanded Express Lanes facility.

Table 7-8 summarizes the evaluation scenarios that were developed for the Stage 2 evaluations, while Table 7-9 summarizes the various assumptions that were made regarding corridor operations before and after the launch of the ICM system.

Table 7-8 – AMS Stage 2 Evaluation Scenarios

ICM Strategy	Daily Operations (ICM A)	Freeway Incident (ICM B)
Traveler information		
Pre-trip and en-route information	•	•
Transit operations		
Bus Rapid Transit Capacity	•	•
Traffic management		
Ramp metering	•	•
Arterial/ramp coordination	•	•
Incident traffic signal response plan		•
Incident management		
Improve incident response times		•
Express Lanes open to all		•
Route choice		
Congestion pricing on Express Lanes	•	•

Table 7-9 – Model Assumptions for Stage 2 Evaluations

Outcome of strategy	Without ICM	With ICM
Dissemination of Pre-trip and En-route Traveler Information		
Earlier dissemination of en-route incident and travel time information	<ul style="list-style-type: none"> • 10 minutes to dissemination (5 minutes for agency notification and 5 minutes for dissemination) • 5% of travelers with information 	<ul style="list-style-type: none"> • 5 minutes to dissemination • 30% of travelers with traveler information (via smart phones, 511, radio)
Comparative travel times (mode and route)	<ul style="list-style-type: none"> • Travel time only available for travel on general purpose freeway lanes 	<ul style="list-style-type: none"> • Travelers make diversion choices at equal intervals (for the next interval) • Decision choices based on a generalized cost that feeds into a decision model • As travel conditions worsen, more travelers consider taking alternative travel options, including transit
Improved Traffic Management		
Coordination of ramp meters and traffic signals	<ul style="list-style-type: none"> • No coordination 	<ul style="list-style-type: none"> • Ramp metering and traffic signal operations coordinated under RAMS framework
Express Lanes	<ul style="list-style-type: none"> • HOT-lane access maintained during incidents 	<ul style="list-style-type: none"> • HOT lanes opened to all traffic during major incidents to maximize throughput
Improved Incident Management		
Reduced time for detecting, notifying, and verifying incidents	<ul style="list-style-type: none"> • All agencies notified within 30-60 minutes • Incident clearance in less than 90 minutes 	<ul style="list-style-type: none"> • All agencies notified within 5 minutes

7.8.2. ENHANCEMENT OF STAGE 2 EVALUATION TOOLS

Since this model had been the subject of a full calibration effort, it was not anticipated that another full model calibration effort would take place during Stage 3 of the initiative due to resource constraints. Work expected to be conducted included model reviews, an assessment of the need to recalibrate the model, modifications to model inputs, a limited number of model runs to produce calibration statistics, and the production of a model calibration report.

To assess whether the 2012 Future TransModeler simulation model could be used for Stage 3 AMS evaluations, a reasonableness assessment of the model was conducted by Cambridge Systematics to assess the need to recalibrate the model and modify its inputs to ensure that it sufficiently replicates and simulates travel conditions currently observed in the field. This assessment was conducted using volume, travel speed, and bottleneck location data capturing typical weekday operations between 5:00 AM and 11:00 AM for September and October 2010 and 2011.

Results of the reasonableness assessment indicated that the 2012 Future TransModeler model that was developed in 2008 underestimated travel demand within the corridor by 20%. Adjustments were thus made to adjust this situation. Small discrepancies between the projected and actual corridor geometry were also noted and adjusted. Once these changes were made, it was determined that the 2012 Future TransModeler model accurately portrayed the location of bottlenecks that were observed in the corridor in 2010-2011. While some differences between the field and simulation data were found in the temporal and spatial extent of the bottlenecks, these differences were attributed to differences between the 2012 network geometry and the geometry that existed in 2010 and 2011. Since it was assumed to be counterproductive to develop an interim 2011 simulation model that would only be used once, it was therefore determined that the observed deviations were sufficiently explained to assume that the updated 2012 Future TransModeler model adequately represented travel conditions within the I-15 corridor for the intended purpose of the Stage 3 AMS analyses.

Specific enhancements that were made to the evaluation tools in the pre-deployment work include:

- **Modeling of traveler information**
 - Travel information is disseminated with a 5-minute latency, for both notifications issued by agencies and disseminations to traveler information services.
- **Modeling of traffic signal control responses**
 - A sensitivity analysis was conducted to determine reasonable times for the activation of traffic signal flush plans (i.e., plans providing maximum capacity in a given direction). This analysis was conducted to address uncertainties associated with current corridor operations where the time to initialize a timing plan could vary between 5 and 15 minutes.
- **Modeling of ramp metering**
 - A TransModeler plug-in module was developed to enable the simulation of a modified ALINEA ramp-metering algorithm that SANDAG and Caltrans plan to use on the I-15 corridor. This algorithm, which was developed and tested by Caltrans and the University of California at San Diego, uses occupancy measured at a downstream ramp to calculate the allowable metering rate for the upstream ramp.
- **Road network**
 - Inclusion of an additional parallel route option along Kearny Villa Road, which required an extension of the south portion of the network to SR-163.

Table 7-10 – Simulation Model Assumptions for Stage 3 Pre-Deployment Evaluations

Outcome of strategy	Without ICM	With ICM
Dissemination of Pre-trip and En-route Traveler Information		
Earlier dissemination of en-route incident and travel time information	<ul style="list-style-type: none"> • 10 minutes to dissemination (5 minutes for agency notification and 5 minutes for dissemination) • 5% of travelers with traveler information 	<ul style="list-style-type: none"> • <i>2 minutes to dissemination</i> • <i>3% of travelers will defer the trip to later or cancel</i> • 30% of travelers with near-perfect traveler information (via smart phones, 511, radio) • Based on the information received, traffic will spread to other routes and modes
Comparative travel times (mode and route)	<ul style="list-style-type: none"> • Travel time only available for travel on general purpose freeway lanes 	<ul style="list-style-type: none"> • Travelers make diversion choices at equal intervals • Decision choices based on feeding a generalized cost into a decision model, resulting in more travelers considering alternative travel options, including transit, as travel conditions worsen
Improved Traffic Management		
<i>Signal retiming following an incident</i>	<ul style="list-style-type: none"> • <i>30-60 minutes to implement</i> 	<ul style="list-style-type: none"> • <i>10 minutes to implement (variable based on severity)</i> • <i>Signal timing changes result in higher throughput</i> • <i>Off-ramp and diversion planning</i>
<i>Freeway ramp metering plans</i>	<ul style="list-style-type: none"> • <i>30 minutes to deploy closures</i> 	<ul style="list-style-type: none"> • <i>Less than 10 minutes to deploy planned closure points</i> • <i>Drivers aware of the closure disseminated to other ramps</i>
Coordination of ramp meters and traffic signals	<ul style="list-style-type: none"> • No coordination 	<ul style="list-style-type: none"> • Ramp metering and traffic signal operations coordinated under RAMS framework
Express Lanes	<ul style="list-style-type: none"> • HOT-lane access maintained during incidents 	<ul style="list-style-type: none"> • HOT lanes opened to all traffic during major incidents to maximize throughput
Improved Incident Management		
Reduced time for detecting, notifying, and verifying incidents	<ul style="list-style-type: none"> • All agencies notified within 30-60 minutes • Incident clearance in less than 90 minutes 	<ul style="list-style-type: none"> • All agencies notified within 5 minutes
Improved Transit Management		
<i>Transit signal priority along arterials</i>	<ul style="list-style-type: none"> • <i>No priority</i> 	<ul style="list-style-type: none"> • <i>Near real-time signal priority for transit</i> • <i>Physical bus priority</i>

Table 7-10 summarizes the various assumptions that were retained for the Stage 3 evaluation tools. Many of these assumptions were carried over from the Stage 2 models, while others were modified or added. Changes that were made to the assumptions since the Stage 2 evaluations are shown in italics.

7.8.3. PRE-DEPLOYMENT AMS ANALYSIS RESULTS

Table 7-11 summarizes the scenarios that were evaluated during the Stage 3 pre-deployment AMS analysis. As indicated, three scenarios had already been evaluated during Stage 2. These were the scenarios considering normal daily operations and the impacts of freeway and arterial incidents with ICM control. The following three scenarios were added for the Stage 3 pre-deployment analysis:

- **Scenario D: Daily operations with new corridor ramp metering algorithm** – Comparative performance assessment of the proposed modified ALINEA corridor ramp metering system against the current San Diego Ramp Metering System (SDRMS) algorithms.
- **Scenario E: Freeway incident under refined responsive traffic signal operations** – Evaluation of corridor operations with responsive traffic signal operation. Since responsive signal operations were still under design at the time of the study, the scenario implemented volume thresholds for the two primary north/south arterials (Pomerado Road and Black Mountain Road) that were developed by the AMS team based on a Synchro analysis of corridor operations.
- **Scenario F: Freeway incident under suboptimal ICM performance** – Evaluation of corridor operations when one of the ICM strategies fails to be initiated during an incident. The only failure that was considered for the scenario is a 30-minute delay in the implementation of a required flush traffic signal control plan, from a normal implementation 15 minutes after an incident occurrence to an implementation 45 minutes after the incident occurrence.

Table 7-11 – AMS Stage 3 Evaluation Scenarios

ICM Strategy	Stage 3 Scenarios		
	ICM D ALINEA Ramp Metering	ICM E Responsive Traffic Signal Control	ICM F Sub-Optimal Response
Traveler information			
Pre-trip and en-route information	•	•	•
Transit operations			
Bus Rapid Transit Capacity	•	•	•
Traffic management			
Ramp metering	•	•	•
Arterial/ramp coordination	•	•	•
Incident traffic signal response plan		•	•
Incident management			
Improve incident response times		•	•
Express Lanes open to all		•	
Route choice			
Congestion pricing on Express Lanes	•	•	•

Table 7-12 presents the evaluation results of the proposed implementation of a new ramp metering control algorithm. The simulation results indicated that the implementation of the proposed modified ALINEA ramp metering control algorithms would reduce total vehicle-hours and person-hours of travel by 5% over the AM peak period. These reductions would translate into a 7% reduction in delay.

Table 7-12 – AMS Pre-Deployment Assessment Results: Ramp Metering Control

Road Type	ALINEA	SDRMS	Difference	Percentage of Difference
VMT (Vehicle-Miles)				
SB 1-15	675,232	680,012	-4,780	-1%
SB Managed Lanes	176,311	176,131	180	0%
NB 1-15	429,756	432,600	-2,843	-1%
NB Managed Lanes	152,592	152,225	367	0%
Arterials	176,696	180,716	-4,020	-2%
Total	2,008,536	2,022,423	-13,887	-1%
VHT (Vehicle-Hours)				
SB 1-15	16,845	20,524	-3,680	-18%
SB Managed Lanes	2,825	2,912	-87	-3%
NB 1-15	7,062	7,136	-74	-1%
NB Managed Lanes	2,404	2,397	7	0%
Arterials	14,575	15,043	-468	-3%
Total	64,256	67,400	-3,144	-5%
Delay (Hours)				
SB 1-15	3,717	6,594	-2,877	-44%
SB Managed Lanes	29	103	-74	-72%
NB 1-15	91	109	-17	-16%
NB Managed Lanes	0	0	0	0%
Arterials	11,095	11,487	-393	-3%
Total	28,206	30,361	-2,155	-7%

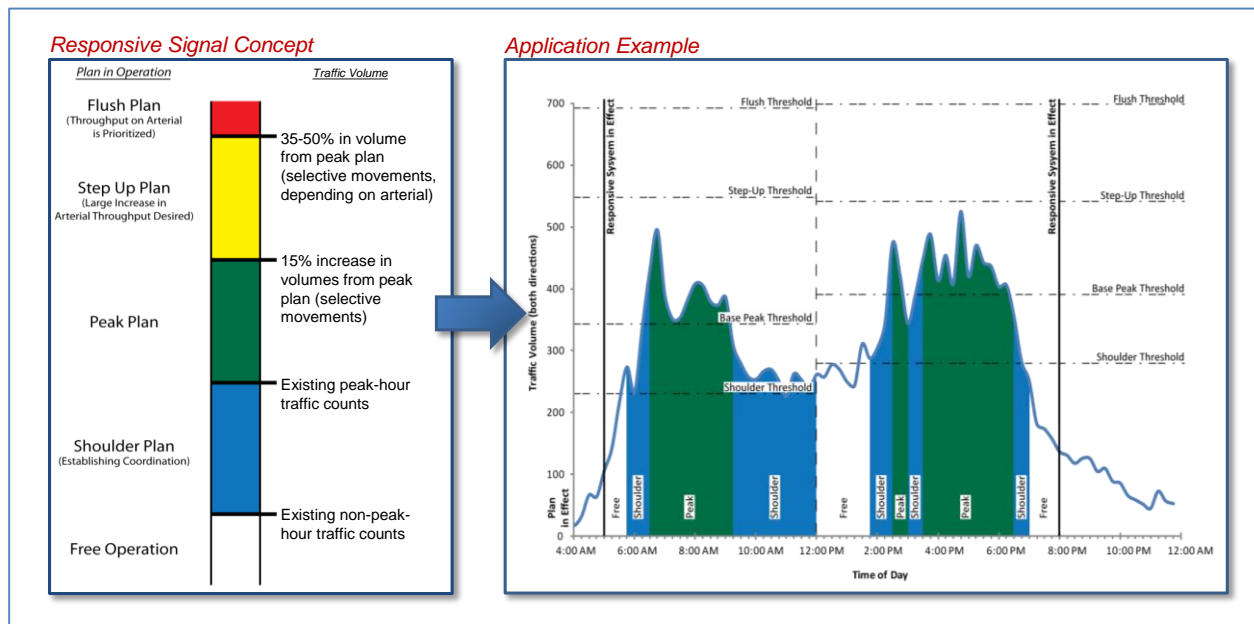


Figure 7-54 – Responsive Traffic Signal Control AMS Evaluation Concept

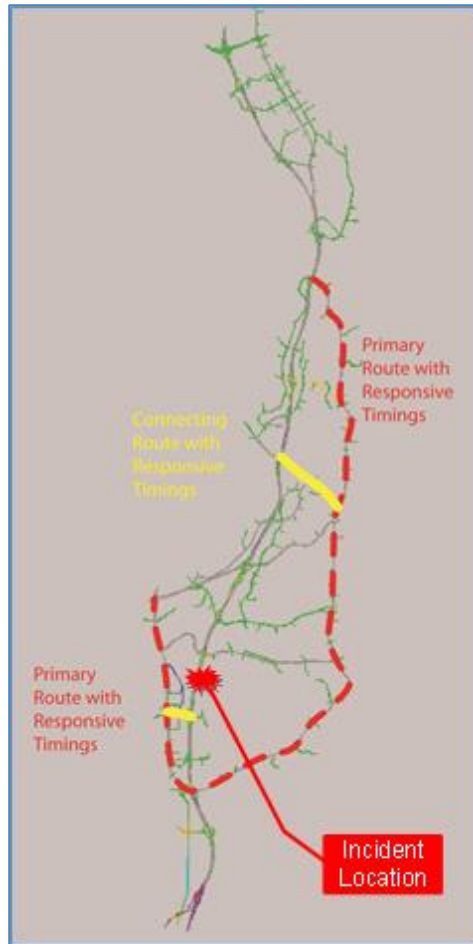


Figure 7-55 – Responsive Traffic Signal Control Scenario

Figure 7-54 illustrates the responsive traffic signal control framework that was simulated for the evaluation of the remaining two scenarios. This framework called for the automated implementation of shoulder, peak, step-up, and flush traffic timing plans when specific volume thresholds are crossed. In this setup, a shoulder plan is used to establish coordination among traffic signals, a step-up plan to provide some increase in traffic throughput, and a flush plan to maximize available capacity on the arterial. As illustrated in Figure 7-55, the anticipated benefits provided by the responsive traffic signal control capability were evaluated by assuming that an incident on I-15 blocked four of the six available northbound traffic lanes between 7:00 AM and 7:30 AM, and subsequently three lanes between 7:30 AM and 8:00 AM. Three response options were then compared:

- Existing signal timing operations
- Responsive signal timing with incident response 15 minutes after the start of the incident (Scenario E)
- Responsive signal timing with incident response 45 minutes after the start of the incident (Scenario F)

To support the evaluations of the responsive traffic signal control scenarios, the AMS team used the Synchro traffic signal optimization software to develop refined flush and step-up plans for the arterials, updated signal coordination groups and cycle lengths, and volume thresholds to trigger the implementation of a specific plan.

Table 7-13 provides a summary of the evaluation results. It was estimated that the ability to provide responsive traffic signal control within 15 minutes of an event occurrence would reduce total vehicle-hours and person-hours of travel within the corridor by 3%, translating into a 5% delay reduction. Responding within 45 minutes would reduce the anticipated benefits by half.

Table 7-13 – AMS Pre-Deployment Assessment Results: Responsive Traffic Signal Control

Road Type	Responsive (15 Minutes)	Responsive (45 Minutes)	Existing (Non Responsive)	Difference Responsive (15 Minutes) vs. Existing	Percent Difference Responsive (15 Minutes) vs. Existing
VMT (Vehicle-Miles)					
SB 1-15	385,845	382,000	375,713	10,132	3%
SB Managed Lanes	135,997	141,850	138,113	-2,115	-2%
NB 1-15	288,178	288,235	291,252	-3,074	-1%
NB Managed Lanes	109,954	109,956	112,576	-2,622	-2%
Selected Arterials	135,334	137,230	135,264	70	0%
Entire Network	1,313,810	1,317,771	1,311,903	1,907	0%
VHT (Vehicle-Hours)					
SB 1-15	15,085	14,906	16,632	-1,547	-9%
SB Managed Lanes	4,206	4,238	4,212	-6	0%
NB 1-15	4,916	4,794	4,860	56	1%
NB Managed Lanes	1,862	1,859	1,891	-29	-2%
Selected Arterials	7,656	8,574	7,285	372	5%
Total	46,839	47,466	48,134	-1,295	-3%
Delay (Hours)					
SB 1-15	7,000	6,999	8,569	-1,568	-18%
SB Managed Lanes	1,490	1,412	1,422	68	5%
NB 1-15	150	38	57	93	163%
NB Managed Lanes	88	77	71	18	25%
Selected Arterials	4,923	5,802	4,581	342	7%
Total	21,935	22,614	23,128	-1,193	-5%

7.8.4. POST-DEPLOYMENT AMS ANALYSIS

Pre-deployment AMS activities focused on the expected impacts and benefits associated with the ICM strategies that were planned for deployment. These activities were intended to refine and prepare the AMS capabilities to represent the “as-planned” ICM strategies, and to inform an ICM evaluation regarding the type, location, and magnitude of potential benefits. Post-deployment AMS activities focused on identifying the impacts and benefits of the “as-deployed” ICM system. The distinction between “as-planned” and “as-deployed” is important, as the deployed ICM strategies may differ from the planned strategies. Some differences may exist due to strategies that may not have been deployed successfully, strategies that have been deployed differently because of technical issues, or strategies that have been deployed differently to take advantage of enhancements or impacts that were not anticipated in the pre-deployment considerations.

In the above context, key objectives of post-deployment AMS activities were to:

- Identify and facilitate further enhancements to tools, data, and methods developed from previous AMS activities.
- Conduct modeling analysis to assess the impacts of the ICM strategies deployed in the corridor.

- Provide guidance for the integration of the developed AMS tools and methods with ongoing corridor management practices.
- Support site-specific ICM Demonstration evaluation efforts.
- Manage the successful transition of modeling leadership responsibilities from the AMS contractor to the San Diego ICM 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.

An important decision that was made regarding the post-deployment evaluations was to use the AIMSUN traffic simulation model that had been developed for the ICMS to conduct the evaluations instead of the TransModeler platform that was used for the pre-deployment evaluations. While using the existing TransModeler model would have ensured consistency with previous evaluations, use of this model for the post-deployment evaluations would have required modifications to allow it to represent post-deployment corridor ICM operations correctly and to enable it to simulate traffic during the afternoon peak period. In addition, the corridor's AIMSUN model already included all deployed ICM strategies and covered both the AM and PM period. However, modifications were still required to allow certain validation benchmarks to be made, simulate full peak periods rather than single hours, conduct real-time mode-shift analyses, conduct real-time analyses of parking demand and capacity, enable it to assess travel time reliability, and enable it to calculate vehicle emissions based on California standards.

Following the execution of a reasonableness analysis, various modifications to be made to the existing ICMS AIMSUN model were identified and implemented in the model. This included incorporating data from travel surveys conducted by the Volpe National Transportation Systems Center characterizing the proportions of travelers using pre-trip information, changing their trip plan based on pre-trip information, consulting travel information during a trip, and altering their route based on en-route information received. While some calibration efforts followed, this did not include a full recalibration of the model. Calibration was conducted only to the extent needed to allow the model to match post-deployment field conditions reasonably, particularly with respect to the location, extent, and severity of congestion bottlenecks.

To characterize representative corridor operations, the USDOT Evaluation Team was tasked to conduct a cluster analysis to characterize different operational conditions in the I-15 corridor and how frequently these conditions occurred. This included a characterization of events triggering an ICM response, such as major freeway incidents, minor freeway incidents, or high travel demand events, as well as a characterization of other conditions that did not trigger an ICM response. The goal was to use the available AMS tools to analyze the most impactful clusters of operational conditions and compare them to “do-nothing” alternatives representing the transportation system without ICM turned on (but with pre-ICM corridor management practices in place).

Based on discussions among the corridor stakeholders, the USDOT Evaluation Team, and the Volpe National Transportation Systems Center, the following evaluation scenarios were identified for analysis:

- **Major Freeway Incident with ICM** – Corridor operations in the presence of a major freeway incident and with all ICM strategies and response plans in place.
- **Major Freeway Incident without ICM** – Corridor operations in the presence of the same major freeway incident as the previous scenario but without any of the ICM system responses. This means evaluating corridor operations with the existing locally adaptive ramp-metering algorithm

instead of the proposed adaptive ramp metering, and using fixed-time arterial traffic signal control instead of responsive signal operations.

- **Minor Freeway Incident with ICM** – Corridor operations in the presence of a minor freeway incident and with all ICM strategies and response plans in place.
- **Minor Freeway Incident without ICM** – Corridor operations in the presence of the same minor freeway incident as in the previous is scenario but without any of the ICM system responses.
- **High-Demand Event with ICM** – Corridor operations in the presence of a high-demand event and with all ICM strategies and response plans activated.
- **High-Demand Event without ICM** – Corridor operations in the presence of the same high demand event as in the previous scenario but without any of the ICM system responses.

Evaluations were to be conducted for both the AM and PM peak periods using a simulation model representing fall 2014 traffic conditions. For each scenario, the specific location, duration, and impact of the incidents being evaluated will be based on the results of the cluster analysis. The various assumptions listed in Table 7-14 were also be considered. Most of these assumptions were made to correspond to the assumptions that had been adopted for the pre-deployment evaluations based upon findings from surveys conducted by the evaluation team and the Volpe Center, local and regional agency feedbacks, transportation conditions, and expected traveler behavior (see Table 7-10).

Table 7-14 – Simulation Model Assumptions for Stage 3 Post-Deployment Evaluations

Outcome of strategy	Without ICM	With ICM
Dissemination of Pre-trip and En-route Traveler Information		
Earlier dissemination of en-route incident and travel time information	<ul style="list-style-type: none"> • 10 minutes to dissemination 	<ul style="list-style-type: none"> • X% minutes to dissemination (based on findings from the USDOT Evaluation Team) • Y% of travelers with traveler information and willing to change their travel plan (based on finding from the Volpe National Transportation Systems Center Travel Surveys)
Comparative travel times (mode and route)	<ul style="list-style-type: none"> • Travel time only available for travel on general purpose freeway lanes 	<ul style="list-style-type: none"> • Decision choices based on feeding a generalized cost into a decision model, resulting in more travelers considering taking alternative travel options, including transit, as travel conditions worsen
Improved Traffic Management		
Coordination of ramp meters and traffic signals	<ul style="list-style-type: none"> • No coordination 	<ul style="list-style-type: none"> • Ramp meters and traffic signal operations coordinated under the corridor’s coordinated ramp metering framework
Ramp metering	<ul style="list-style-type: none"> • Use of existing local occupancy-based algorithms (San Diego Ramp Metering System) 	<ul style="list-style-type: none"> • Alternate ramp metering algorithms and new signal timing plans will be created and customized to fit a particular incident scenario
Improved Incident Management		
Reduced time for detecting, notifying, and verifying incidents	<ul style="list-style-type: none"> • All agencies notified within 30-60 minutes • Incident clearance in less than 90 minutes 	<ul style="list-style-type: none"> • All agencies notified within 5 minutes

As of June 2015, the analysis of the various scenarios identified above had not yet started. Cambridge Systematics was still waiting to receive approval from the USDOT to use the developed AIMSUN model. The firm was also waiting on the USDOT Evaluation Team to provide the clusters of representative operation conditions that were to form the basis of the analysis activities. It was anticipated that the analysis would be complete by September 2015, and that all reporting activities would subsequently be done by December 2015.

7.9. TASK 8 – SYSTEM EVALUATION

Evaluation of the deployed ICM system was the only task not directly under the responsibility of the San Diego deployment team led by SANDAG. The USDOT ICM Management Team was responsible for directing the evaluation of the San Diego ICM system, with support from the following entities:

- **Battelle Memorial Institute** – Institute officially leading the evaluation of the I-15 and US-75 ICM systems. As part of its leadership role, Battelle was tasked with organizing and conducting workshops and interviews, analyzing collected data, preparing reports and presentations documenting the evaluation results, and archiving evaluation data and analysis tools in a repository that was to be available to other researchers.
- **Volpe National Transportation Systems Center** – Entity responsible for providing technical input to the evaluation and for carrying out traveler surveys.
- **Cambridge Systematics** – As the AMS Contractor, Cambridge Systematics was to provide key AMS modeling results to the evaluation that could not be collected in the field and was to utilize certain evaluation outputs, such as those related to traveler response, to calibrate the AMS tools post-ICM deployment.
- **Noblis** – Entity providing program support to the USDOT on the ICM Initiative. This included coordination of activities between the various parties involved in the ICM Initiative, and review and comment on the AMS and evaluation materials produced.
- **SAIC** – Firm responsible for knowledge and technology transfer activities under the USDOT ICM Initiative.

In the above context, the San Diego deployment team was primarily responsible for providing input to the evaluation planning activities and for collecting and transmitting to the Battelle team most of the evaluation data not collected directly by the Battelle team.

The remainder of this section summarizes the various evaluation activities that were conducted by the various entities listed above. Specific elements that are detailed in the subsections that follow include:

- USDOT preliminary hypotheses regarding the benefits of ICM systems
- San Diego ICMS evaluation plan
- Summary of findings of traveler surveys
- Summary of findings of system user interviews and surveys

7.9.1. USDOT ICM BENEFITS PRELIMINARY HYPOTHESES

The U.S. DOT has established the testing of the following eight hypotheses as the primary objective and analytical thrust of the evaluation phase of the ICM demonstration project:

1. **Improve situational awareness** – Operators will realize a more comprehensive and accurate understanding of underlying operational conditions considering all networks in the corridor.
2. **Enhance response and control** – Operating agencies within the corridor will improve management practices and coordinate decision-making, resulting in enhanced response and control.

3. **Better-informed travelers** – Travelers will have actionable multi-modal information resulting in more personally efficient mode, time of trip start, and route decisions.
4. **Improve corridor performance** – Optimizing networks at the corridor level will result in an improvement to multi-modal corridor performance, particularly in high travel demand and/or reduced capacity periods.
5. **Positive or no impacts on air quality** – ICM will affect air quality through changes in Vehicle Miles Traveled (VMT), person throughput, and speed of traffic, resulting in a small positive or no change in air quality measures relative to improved mobility.
6. **Positive or no impacts on safety** – The implementation of ICM systems will not adversely affect overall safety outcomes, and better incident management may reduce the occurrence of secondary crashes.
7. **Greater benefits than costs** – Because ICM systems must compete with other potential transportation projects for scarce resources they should deliver benefits that exceed the costs of implementation and operation.
8. **Usefulness and effectiveness of decision support system** – Decision support systems provide a useful and effective tool for ICM project managers through the ability to improve situational awareness, enhance response and control mechanisms, and provide better information to travelers, resulting in at least part of the overall improvement in corridor performance.

7.9.2. EVALUATION PLAN

Figure 7-56 illustrates the various plans that were produced to define the activities for evaluating the San Diego I-15 ICMS:

- **National Evaluation Framework** (May 2011) – Document detailing the general approach that the USDOT Evaluation Team intended to use to evaluate the ICM deployments in San Diego and Dallas.

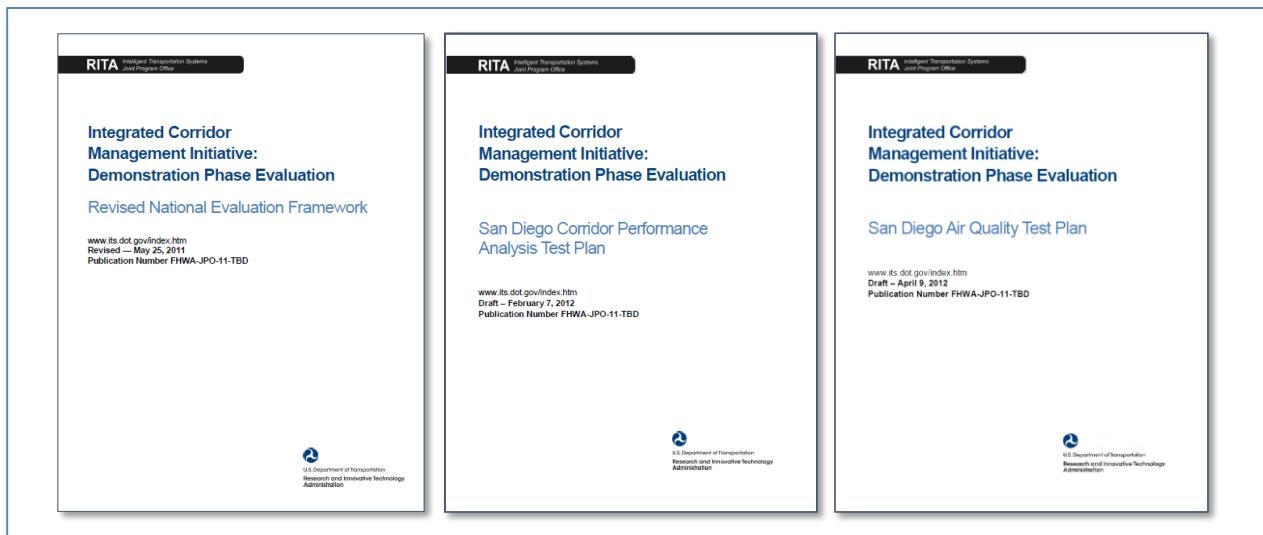


Figure 7-56 – Evaluation Plan Documents

- **San Diego Corridor Performance Analysis Test Plan** (February 2012) – Document providing a high-level overview of the specific approaches that were to be followed for conducting the mobility and safety analyses of the San Diego ICM system.
- **San Diego Corridor Air Quality Test Plan** (April 2012) – Document providing a high-level overview of the specific approaches that were to be followed for conducting the air quality analysis of the San Diego ICM system.

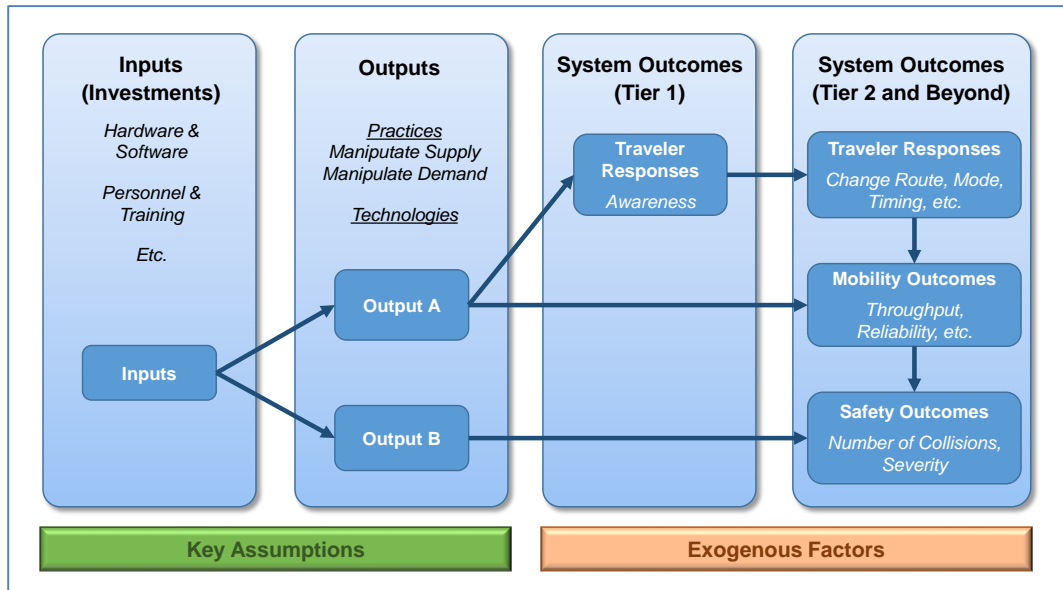


Figure 7-57 – Evaluation Logic Model

Figure 7-57 illustrates the evaluation logic model that was followed to identify the various tests to be conducted to verify each of the eight hypotheses listed in Section 7.9.1. This model was commonly used by the USDOT to evaluate technological deployments at the time the evaluation plans were being developed. This model explicitly recognizes that the ultimate successes or shortcomings of a technology deployment are the results of a long series of interdependent events and conditions. This leads to the determination that successes and shortcomings are best evaluated using a stepwise approach that specifically investigates each link in the cause-effect chain. In this case, this means investigating the following dimensions:

- **System inputs** – Investments made by the agencies deploying the system, including hardware, software, infrastructure, staff hiring, training, changes in policies and procedures, etc.
- **System outputs** – Measures describing how the investments are utilized, the capabilities provided, and how these capabilities are exercised.
- **System outcomes** – Impacts of the investment on the performance of the transportation system, such as traveler responses and changes in traffic congestion and safety.

Figure 7-58 identifies the various evaluation areas that were identified by the USDOT Evaluation Team from the application of the logic model of Figure 7-57 to investigate the eight hypotheses listed in Section 7.9.1. These evaluation areas include:

- Capability to monitor, control, and report on the status of the corridor
- Traveler response to disseminated information

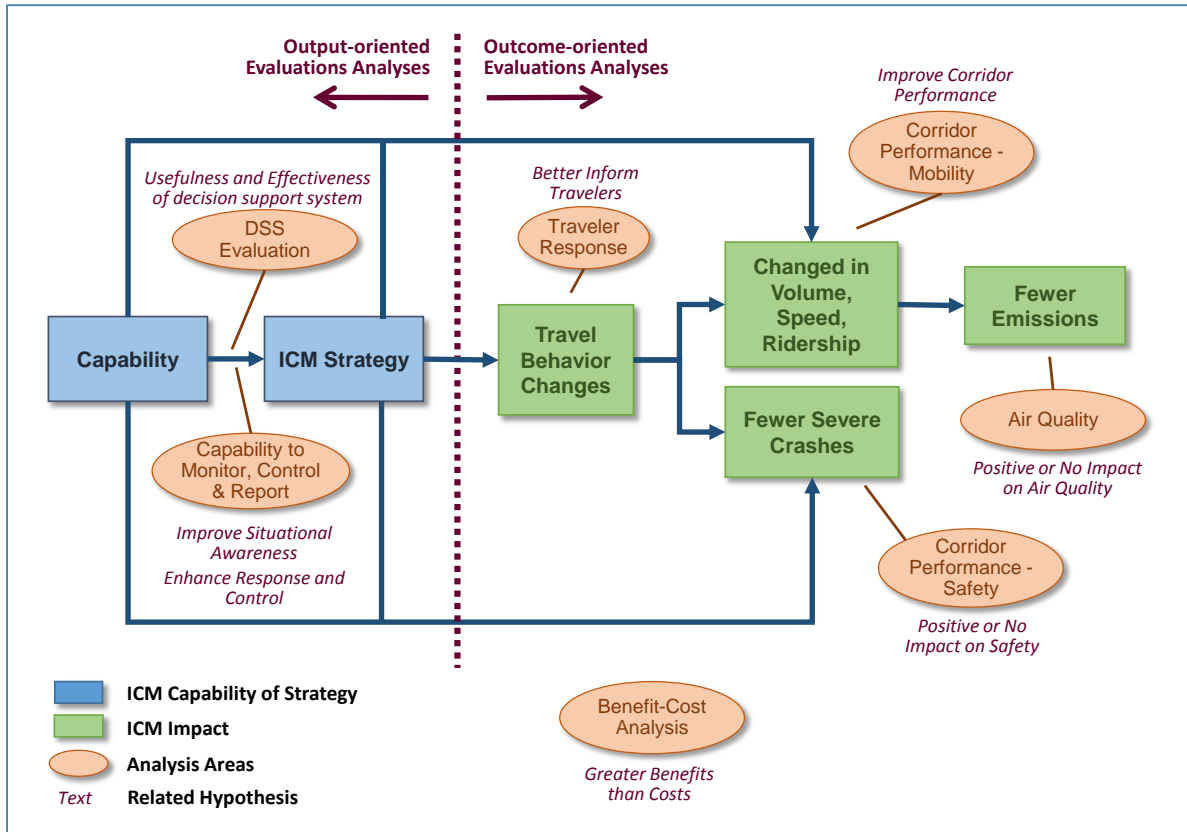


Figure 7-58 – Evaluation Areas

- Impacts on corridor mobility
- Impacts on corridor safety
- Impacts on air quality
- Benefit-cost of the deployed system
- Effectiveness and efficiency of the developed decision support system

Collectively, the results of these various analyses were to provide a comprehensive understanding of the ICM demonstration phase experience. This included providing answers to the following general questions:

- What was invested?
- What capabilities were realized through those investments? How were they exercised and to what extent did they enhance previous capabilities?
- What were the impacts of the ICM deployments on travelers, transportation system performance, safety, and air quality?
- What institutional and organizational factors explain the successes and shortcomings associated with the implementation, operation, and effectiveness of ICM, and what are the implications for U.S. DOT policy and programs and for transportation agencies around the country?
- How well did the DSS perform?
- What is the overall value of the ICM deployments in terms of benefits versus costs?

Figure 7-59 presents a timeline of key evaluation activities pertaining to the I-15 ICMS. These activities can be divided into the following stages:

- **Development of the National Evaluation Framework** – Development of a generic evaluation framework that could be applied to both the San Diego and Dallas ICM evaluation sites. This stage included a January 2011 workshop organized by Battelle aimed at familiarizing the San Diego deployment team with elements of the National Evaluation Framework and gaining feedback on these elements.
- **Development of site-specific test plans** – Development of site-specific test plans supplementing the general test plans defined in the National Evaluation Framework. This stage include one site visit by the USDOT Evaluation Team in September 2011.
- **Baseline data collection** – Collection of data describing corridor operations prior to the launch of the ICMS. This data collection period extended over 12 months. This included the execution by the Volpe National Transportation System Center of a pre-deployment traveler survey.
- **Post-launch shakedown period** – Period following the launch of the system during which operational parameters were adjusted and no data were collected. While this period was initially expected to last six months, the need to address various unexpected operational issues with the deployed ICM system has resulted in a much longer shakeout period. This stage has included the execution of a post-deployment travel survey by the Volpe National Transportation Systems Center in the spring of 2014, the execution of post-deployment interviews with system operators and administrators in the fall of 2014, and a site visit by the USDOT Evaluation Team in February 2015.

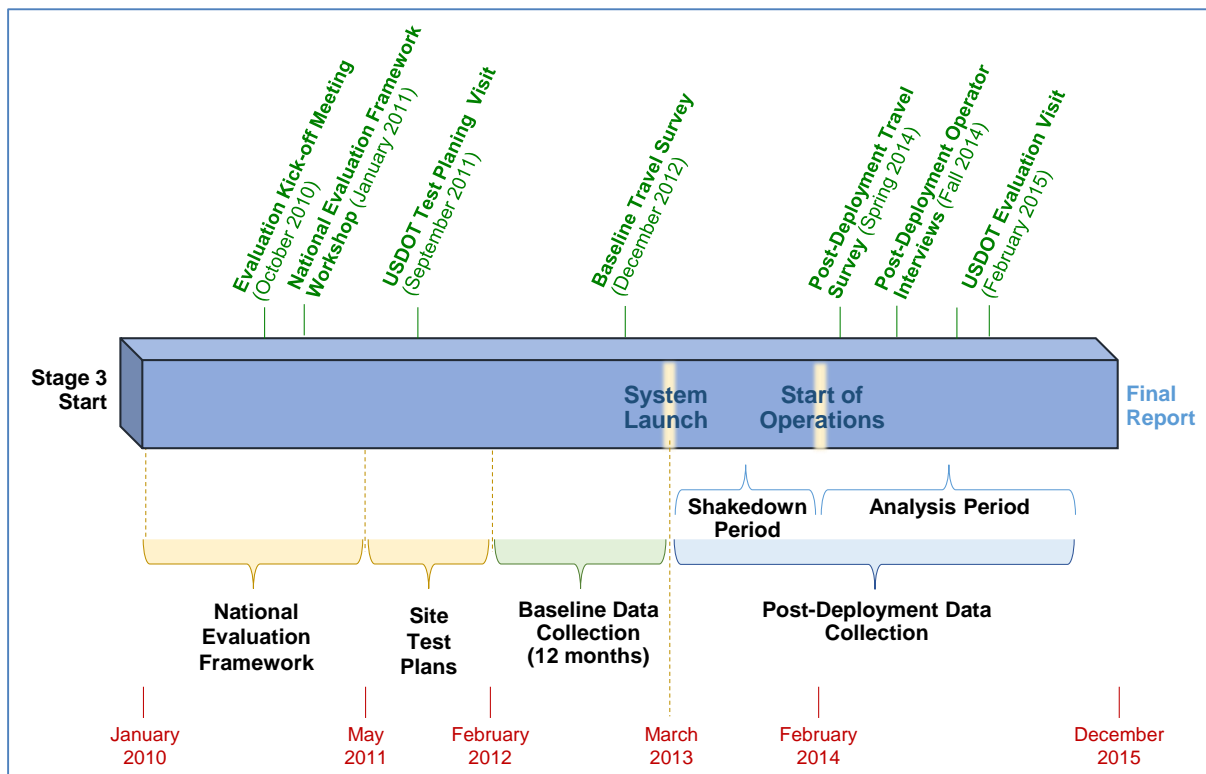


Figure 7-59 – Timeline of Evaluation Activities

- Post-deployment data collection** – Collection of data describing corridor operations following the deployment of the ICMS. Similar to the pre-deployment data collection, this period was initially expected to last 12 months. However, the need to address various issues with system operations has significantly extended this period.

7.9.3. CAPABILITY TO MONITOR, CONTROL, AND REPORT

Figure 7-60 illustrates the approach that was adopted for assessing the technical capabilities provided by the deployed ICM system. The focus of this analysis was to process various information characterizing system coverage and various statistics characterizing how the deployed ICM system enables system operators to take appropriate actions. The latter were to be obtained by both compiling operational statistics, such as the number of times that response plans are being generated and number of times that recommended response plans are implemented, and gathering information detailing how system operators perceive the utility of the ICM system.

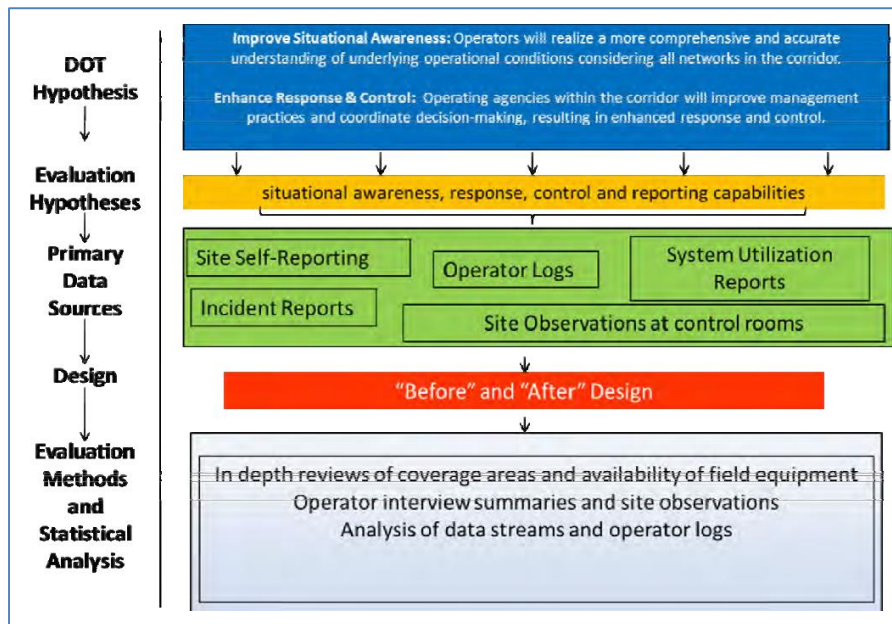


Figure 7-60 – Technical Capability Evaluation Approach

Post-deployment surveys were sent to system operators late spring/early summer 2014 using Survey Monkey. Post deployment interviews were further initiated in September 2014. However, results of these surveys and interviews had not yet been made available by June 2015.

7.9.4. EFFECTIVENESS AND EFFICIENCY OF DECISION SUPPORT SYSTEM

Evaluation of the effectiveness and efficiency of the developed decision support system focuses on assessing the ability of the system to fuse data, provide reliable predictions of corridor operations, and generate response plans within a reasonable period. This evaluation also aimed to look at how varying conditions and data loads impact system performance. These assessments were to be conducted through on-site observations, interviews and surveys with system operators, and laboratory tests.

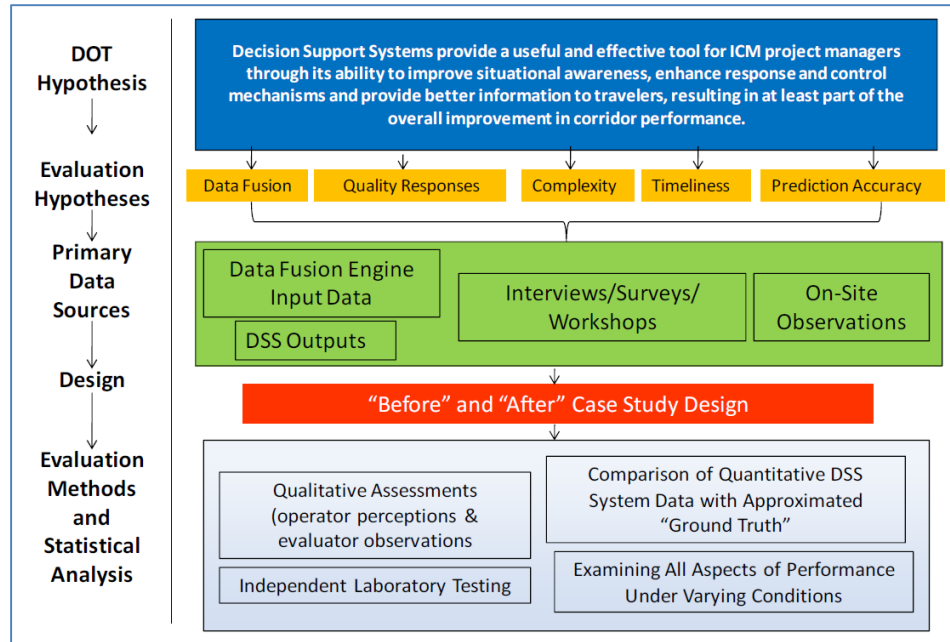


Figure 7-61 – Decision Support Effectiveness Evaluation Approach

As indicated in Section 7.9.3, post-deployment surveys were sent to system operators late spring/early summer 2014 using Survey Monkey, and post deployment interviews were initiated in September 2014. However, results of these surveys and interviews had not yet been made available by June 2015. No other information regarding the assessment of system performance have also been made public.

7.9.5. TRAVELER SURVEY FINDINGS

As part of the national evaluation of the ICM Initiative, the Volpe National Transportation Systems Center conducted traveler behavior surveys at both San Diego and Dallas ICM demonstration sites. The purpose of these surveys was to measure the impacts of ICM strategies on traveler behavior. More specifically, the surveys sought to determine:

- 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

To measure the above changes, a panel survey approach was selected whereby the same individuals were surveyed both before and after the deployment of the ICM system. For the San Diego site, the study population included only regular users of the I-15 freeway. Respondents were recruited by capturing the license plates of vehicles traveling the corridor during the AM and PM peak periods and subsequently attempting to contact the owner of each vehicle. To qualify for the survey, contacted individuals had to travel on the I-15 facility two or three weekdays per week, either during the AM or PM peak period. This constraint was imposed based on the assumption that regular commuters would be more sensitive to changes in corridor performance than occasional users. It was also imposed to maximize the possibility

of including in the sample travelers who would be more likely to be available to participate in pulse surveys planned to be administered immediately following an incident.

Table 7-15 summarizes the various activities that were conducted or planned to assess traveler behavior within the I-15 corridor. A pilot study was first conducted in August and September of 2012 to test and refine the proposed survey methodology. A baseline survey capturing traveler behavior prior to the deployment of the ICMS was then formally conducted in December 2012, followed by 28 pulse surveys between January and March 2013 to capture traveler behavior during notable incidents. Official launch of the system occurs in March 2013. Following a 6-month shakedown period during which system operations were to be refined, additional pulse surveys were to be administered between October 2013 and February 2014 to capture traveler behavior during incidents with the ICMS active. A formal post-deployment evaluation survey was then to be conducted in March and April of 2014, followed by a survey of transit riders later in the spring of 2014. However, the formal start of system operations did not occur until February 2014, as more time than anticipated had been required to fix various operational issues with the ICMS. As a result, all post-launch surveys were delayed in time. As of June 2015, no information had been received from the USDOT evaluation team indicating when the various post-launch surveys had been executed or were planned to be conducted.

Table 7-15 – Traveler Survey Activities

Period	Interval	Activity	Purpose
Pre-ICM	08/2012 – 09/2012	Pilot Study	<ul style="list-style-type: none"> Testing and refinement of survey methodology, administration process, and survey instrument
	12/2012	Baseline Survey	<ul style="list-style-type: none"> Characterize typical travel behavior, awareness and use of traveler information, trip satisfaction, satisfaction with available traveler information Use data to target pulse survey invitations
	12/2012 – 03/2013	Pulse Surveys	<ul style="list-style-type: none"> Survey respondents on incident days to measure use of traveler information, satisfaction with information, and how the information impacts the trips being made
Shakedown	03/2013 – 02/2014	Panel Maintenance	<ul style="list-style-type: none"> Maintain contact with respondents to keep them engaged
Post-ICM	<i>Initially planned for 10/2013 – 02/2014</i>	Pulse Surveys	<ul style="list-style-type: none"> Survey respondents on incident days to measure use of traveler information, satisfaction with information, and its impact on their trip
	<i>Initially planned for 03/2014 – 04/2014</i>	Final Survey	<ul style="list-style-type: none"> Repeat baseline measures to capture changes in travel in the corridor, awareness and use of traveler information sources, trip satisfaction, and satisfaction with traveler information
	<i>Initially planned for Spring 2014</i>	Transit Survey	<ul style="list-style-type: none"> Assess impacts of ICM on transit users

From 48,740 invitations, 4,480 individuals completed the pre-deployment baseline survey while 2,884 also completed one or more of the pre-deployment pulse surveys. Key findings from the responses provided were as follows:

- A majority of travelers generally prefer to stay on the freeway during incidents: 56% of AM peak travelers and 53% of PM peak travelers indicated that they would not use an alternate route if the freeway became heavily congested due to an incident or construction.
- Use of parallel routes within the corridor was not particularly high. Only 20% of travelers used Pomerado Road, 17% Black Mountain Road, and 15% Centre City Parkway.

- A notable proportion of travelers had significant flexibility to alter their travel plans: 34% of respondents indicated having the ability to vary their trip time by 30 minutes or more in the morning, while 59% reported having the same ability for the afternoon peak period. 25% of respondents further indicated using flextime or following a compressed work schedule, with an additional 17% reporting that they normally telecommute.
- The potential market for transit shifts appeared relatively small. Only 14% of respondents had ever elected to switch to using transit before starting a trip after learning about congestion along their intended route, and only 4% have ever switched to transit while en-route. 98% of all drivers further indicated that they never used the MTS Premium express bus service for their peak-hour trips, with only 10% indicating that they had ever used the service.
- Travelers were more likely to change their route or the timing of a particular trip than to make other changes, such as switching modes, cancelling a trip, or changing the number or order of interim stops. More than 75% of respondents reported having ever made a route change or a timing change to their trip (pre-trip or en-route) after learning about traffic congestion on their route, with 27% to 41% reporting having made such changes in the last month.
- Respondents were most likely to rely on traditional sources, such as radio and traffic signs, for obtaining real-time traffic information. Beyond these sources, the use of real-time traffic information was not very high. The top mentioned sources included the Google Maps mobile application (21%), Google Maps website (16%), and TV/radio station websites (14%).
- While 73% of respondents had access to real-time traveler information via their smartphone, the use of these devices had room for growth, as only 38% used them a few times per week for acquiring real-time information.
- While 68% of respondents also regularly used laptops and 74% desktop computers, only 20% used these devices regularly to acquire real-time traffic information.
- Respondents were generally more satisfied with the reliability of their AM peak commute trip than their afternoon peak trip.
- Overall, respondents were satisfied or very satisfied with the traveler information they used for their peak hour trips.

Post-deployment surveys were conducted late spring/early summer of 2014. As of June 2015, findings from these activities had not yet been released and could therefore not be included in this report.

7.9.6. IMPACTS ON CORRIDOR MOBILITY

Figure 7-62 illustrates the approach that was adopted for evaluating the mobility impacts of the deployed ICM system. The key metrics for this analysis were changes in travel time, travel time reliability, delay, and throughput, evaluated both on a person and vehicle basis. Since it was expected that the benefits of the ICM system would be mostly realized during high-demand conditions and major capacity-reduction events, the evaluations were to pay special attention to analyzing performance under those circumstances. Data needed for the evaluations were to be collected from the various monitoring systems in operation within the corridor, both before and after implementation of the ICM system. Plans were also made to obtain critical data that could not be collected from existing monitoring systems from the results of the AMS evaluations. System impacts were then to be obtained by analysis before and after operations for a variety of scenarios.

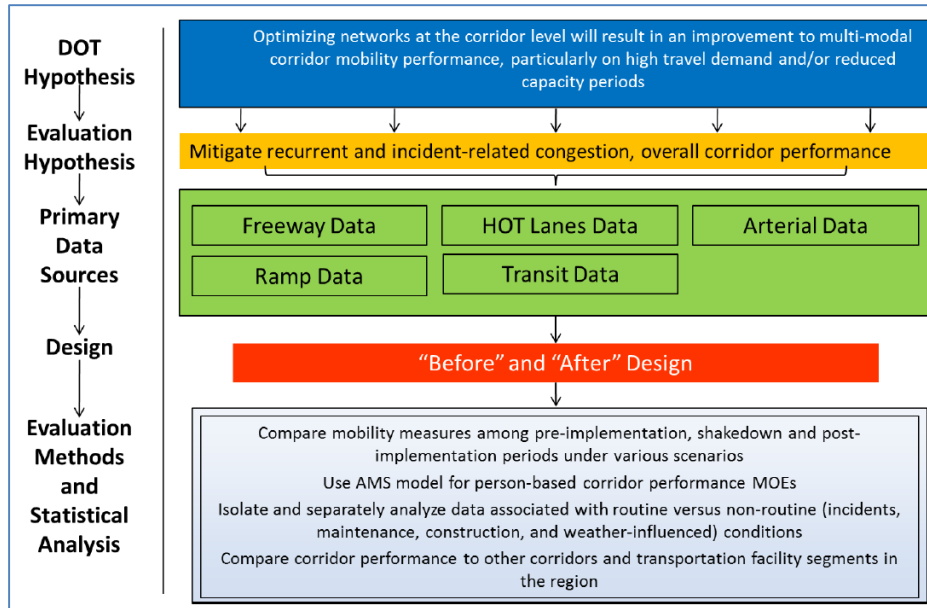


Figure 7-62 – Corridor Mobility Performance Evaluation Approach

As of June 2015, the corridor mobility analysis had not yet been completed. Results from this analysis could therefore not be included in this report.

7.9.7. IMPACTS OF CORRIDOR SAFETY

Figure 7-63 illustrates the approach that was adopted for evaluating the safety impacts of the deployed ICM system. This analysis focused on comparing the accident rate per million vehicle miles traveled within the corridor before and after deployment of the ICM system, with the primary intent of demonstrating that the ICM system had not degraded safety along the corridor. A full safety analysis attempting to demonstrate exactly how the ICM system may have improved safety, such as through a reduction of secondary crashes, was not to be conducted due to the absence of appropriate data to do so.

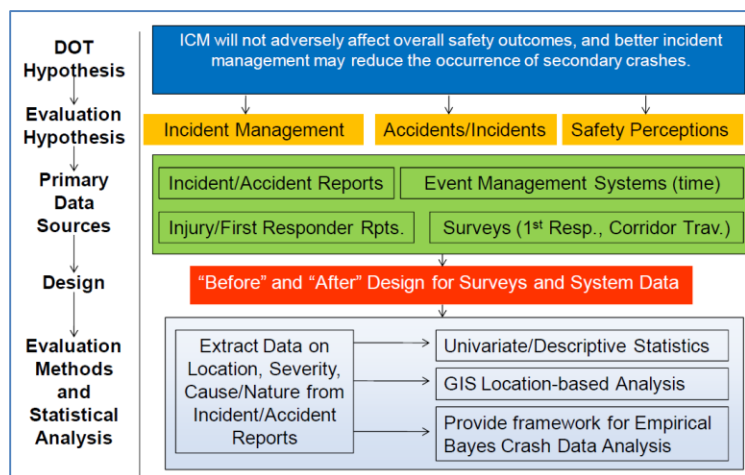


Figure 7-63 – Corridor Safety Performance Evaluation Approach

As of June 2015, the corridor safety analysis had not yet been completed. Results from this analysis could therefore not be included in this report.

7.9.8. AIR QUALITY EVALUATION

Figure 7-64 illustrates the basic approach that was adopted for the evaluation of the impacts of the ICM system on air quality. These impacts were to be evaluated using the Motor Vehicle Emissions Simulator (MOVES) model that had been developed by the U.S. Environmental Protection Agency to estimate the level of vehicle emissions associated with corridor operations. Various data from the AMS evaluations, such as data characterizing vehicle throughput and representative speeds on all relevant links within the corridor, were to be used as input to the MOVES model. Other model inputs, such as data characterizing the fleet of vehicles traveling along the I-15 corridor, were to be derived from regional data provided by SANDAG and/or the California Air Resource Board (CARB). Emission impacts were to be assessed by considering three pre-deployment and three post-deployment scenarios.

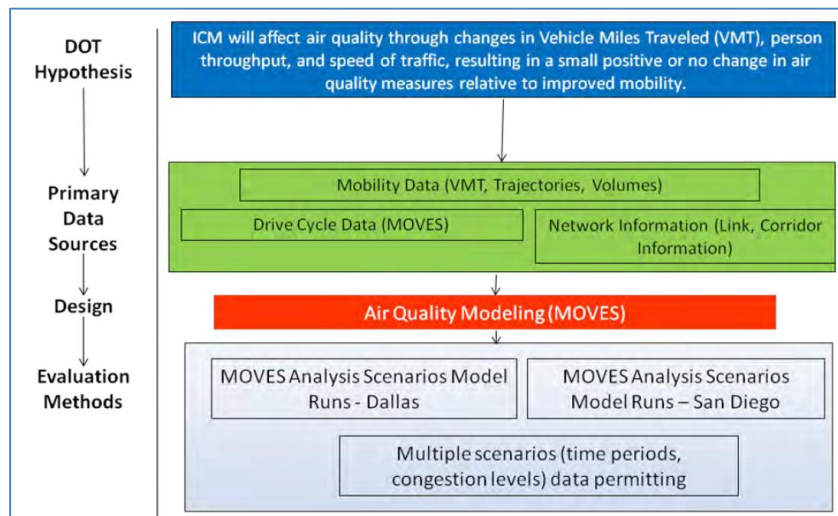


Figure 7-64 – Air Quality Impact Evaluation Approach

Due to delays in the execution of the post-deployment AMS evaluations, the air quality evaluations had not yet been completed by June 2015. Consequently, results of the planned air quality evaluations could not be included in this report. It was anticipated that these results would become available in mid-late fall 2015.

7.9.9. BENEFIT/COST OF THE DEPLOYED SYSTEM

Figure 7-65 illustrates the basic approach that was adopted for assessing the benefit/cost ratio of the deployed ICM system. To estimate system benefits, it was proposed to monetize the changes in travel time, travel time reliability, delay, number and severity of crashes, vehicle emission levels, and transit ridership. System costs would then be estimated by including capital costs and annual expenditures that can be attributed directly to the ICM system. Based on these results, an overall benefit/cost ratio would in turn be produced by compiling benefits and costs over a 10-year horizon using an economic model to be developed by Battelle.

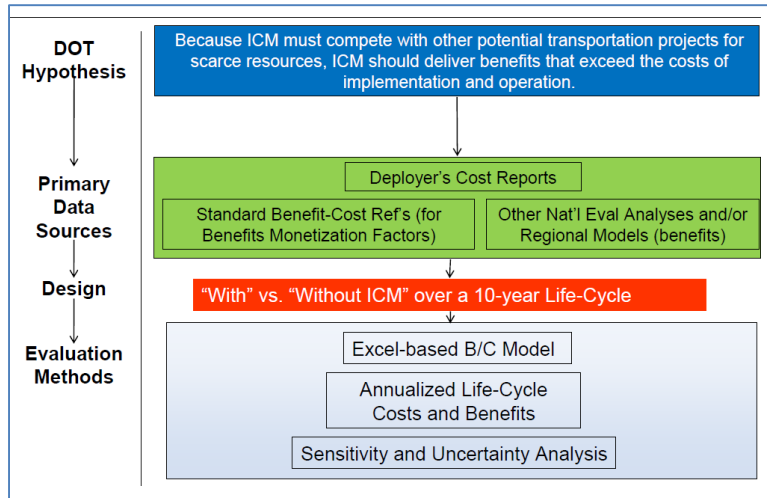


Figure 7-65 – Benefit/Cost Evaluation Approach

As of June 2015, the cost/benefit analysis had not yet been completed. This was again because other evaluations scheduled to feed information into the cost/benefit analysis had not been completed.

7.10. TASK 9 – OUTREACH ACTIVITIES

The objective of this task was to develop and conduct an outreach program at both the national and local levels to promote awareness of the I-15 ICM Demonstration project, disseminate key findings from the project, and develop various resources to help transportation practitioners implement ICM systems within other corridor. While the development of a National Outreach Participation Plan was mentioned in an early project plan, it appears that this plan was never formally written. Most of the outreach activities that were conducted as part of the project were identified based on need as the project progressed.

The audience for the various outreach efforts primarily consisted of the following groups:

- Traveling public
- ICM system operators
- Council members
- Decision makers
- USDOT staff

The following is a summary of key outreach efforts that were conducted over the course of the project:

- **Engagement of local agencies**
 - *June 2009*: Project charter signed by SANDAG, Caltrans District 11, and the cities of San Diego, Poway, and Escondido.
 - *April 2011*: Preparation of memoranda for the cities of Escondido, Poway, and San Diego detailing plans for active rerouting of freeway traffic on local arterials.
 - *April 2011*: Preparation of a memorandum for Caltrans describing operations of ramp metering under a 24-hour ICM control environment.

- *June 2012*: Development of a Memorandum of Understanding (MOU) with the cities of Poway, Escondido, and San Diego; development of an Operations Understanding with MTS for support of transit messaging when implementing ICM response plans.
- *August 2012*: Informational packets about the I-15 demonstration project sent to local agencies, to help attain concurrence on arterial routing strategies and to serve as reference information for staff reports to city management.
- *December 2012/January 2013*: In-person meetings with city mayors/councilmen.
- **Public awareness campaigns**
 - *January 2013*: Information campaign to the public and local agencies by SANDAG about the ICM project.
 - *December 2013/January 2014*: Mailing of flyers to corridor travelers and NBC newscast in support of the pre-deployment traveler survey conducted by the Volpe National Transportation Systems Center.
 - *Spring 2014*: Marketing campaign in support of the upcoming release of the mobile 511 application.
 - *Spring/Summer 2015*: Information campaign in support of the rolling out of arterial routing signs. This included a coordination of efforts with SANDAG's Travel Demand Management employer outreach team and ongoing outreach activities for the I-15 Express Lane system. Information about the rollout was also included in newsletters, social media, and other distribution channels managed by partner agencies.
- **Participation in workshops and technical scans**
 - *2010-2015*: Preparation of various presentations about the I-15 ICM system at various workshops organized by the USDOT.
 - *October 2013*: Presentation describing the I-15 ICM concept at the ITE/WTS Joint Workshop.
 - *June 2014*: Participation of team members on a discussion panel at the Integrated Transportation Management Workshop organized by the Transportation Research Board in Irvine, California.
 - *July 2014*: Participation of agencies involved in the operation of the I-15 ICMS in the ICM Scanning Tour organized by the National Cooperative Highway Research Program (NCHRP).
 - *August 2014*: Participation of team members in a two-day workshop on decision support systems that was organized by ITS America.
- **Participation at technical conferences**
 - *March 2013*: Presentations at the Institution of Transportation Engineers (ITE) Technical Conference held in San Diego. This included an official announcement about the upcoming system launch, presentation of information about the going live process, and technical tours of the I-15 corridor.

- *April 2013*: Participation at the ITS America Annual Meeting in Nashville, Tennessee. This included SANDAG's participation in an information session on the USDOT ICM Initiative and in a FHWA ICM training session, as well as live demonstration of the I-15 ICMS. A Best New Innovative Practice Award was also presented to the project partners during the meeting.
- *September 2013*: Organization of technical tours of the I-15 ICMS for the ITS California Annual Meeting in San Diego.
- *September 2014*: Participation of SANDAG at the ITS World Congress held in Detroit, Michigan.
- *October 2014*: Presentation on I-15 corridor management by SANDAG in the session on connected corridors at the ITS California Annual Meeting in Santa Clara, California.

- **Development of fact sheets**
 - Provision of material to the USDOT for the preparation of fact sheets about the ICM Initiative and the I-15 ICM Demonstration Project.

- **Production of promotional videos**
 - *August 2012*: Production of a video showing Aimsun animations.
 - *April 2013*: Release of a promotional video to inform the public about the I-15 ICM project ahead of the official launch of the system (available through the following link <http://www.youtube.com/watch?v=c9nqWXL5avo> in June 2015).

- **Journal papers**
 - *January 2012*: Publication by TSS of a paper explaining the role of the real-time simulation in the I-15 ICMS in *Thinking Highways*.
 - *March 2013*: Publication of a short paper outlining the I-15 ICM project in *Traffic Technology International*.
 - *May 2014*: Publication of a paper by TSS on the benefits of real-time simulation forecasts in issue 11 of *Data & Modeling*.

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8. SUMMARY OF PATH ACTIVITIES

The following is a summary of activities that were conducted by the PATH team to support the I-15 ICM Demonstration project on behalf of Caltrans, first by Mark Miller (January 2010 – July 2011), and then by Dr. Francois Dion (July 2011 – June 2015):

- **Task 1 – Project Management**
 - Reviewed various versions of the *Project Management Plan (PMP)* that were developed by SANDAG and Kimley-Horn between December 2010 and June 2011.
 - Reviewed various versions of the *Systems Engineering Management Plan (SEMP)* that was developed by SANDAG and Kimley-Horn between December 2010 and September 2011.
 - Track updates made to the *Risk Registry* throughout the project. This included reviewing the details and rationale of all new risks submitted by project partners; tracking changes in the status of specific risks; and tracking efforts by members of the development team to resolve risks that had been triggered.
 - Attended, either by phone or in person, the weekly Project Management Team meetings with the core development team and the monthly Project Development Team meetings with all corridor stakeholders that were held throughout the project to discuss project status and various issues affecting project activities.

- **Task 2 – Refinement of Systems Requirements**
 - Reviewed the initial *Concept of Operations* document that was developed by SANDAG and other corridor partners in 2008 as part of Stage 1 of Phase 3 of the USDOT ICM Initiative.
 - Reviewed various versions of the *Requirements Specifications* that were developed by SANDAG and Kimley-Horn during the project. This included reviewing the initial requirements document that had been produced in 2008 as part of Stage 1 of Phase 3 of the USDOT ICM Initiative and various updated requirements that were developed in the first half of 2011 as part of Stage 3.

- **Task 3 – System Design**
 - Participated in the Operations Workshop that was held in April 2011 to help clarify assumptions used for AMS evaluations, identify appropriate corridor variables, and review the proposed user interface concept.
 - At SANDAG's request, conducted a literature review on the potential effectiveness of using freeway CMSs to entice motorists to select alternate routes around an incident.
 - Attended in March 2012 the presentation of the limited functionality prototypes that had been developed by Delcan.
 - Attended in May 2012 the training on how to use the Aimsun traffic simulation model that was provided by TSS to staff from participating agencies.

- Reviewed various versions of the I-15 corridor microscopic simulation model that had been developed by TSS to enable the ICMS to evaluate corridor operations under alternative response plans. This included visual reviews of road geometry elements coded within the model, visual assessments of vehicle behavior during simulation runs, and analyses of simulation results. Issues with the modeling of simulation runs were discussed with Matthew Jukes, from TSS.
- Conducted detailed reviews of various draft versions of the *Data Collection Plan*, *Error Checking Plan*, and *Simulation Calibration Performance Plan* documents that were developed by TSS in late 2011 and early 2012 in support of the simulation modeling effort of the I-15 corridor. For each document, detailed review comments were provided to TSS.
- Reviewed various draft versions of the *Error Checking Report* and *Simulation Calibration Performance Report* that were prepared by TSS in mid-late 2012. For each document, detailed review comments were provided to TSS.
- Collected the various documents that were submitted to the USDOT for the Preliminary Design Review (PDR) in February 2012, Critical Design Review (CDR) in October 2012, and Final Design Review (FDR) in March 2013.
- Actively discussed various design elements with the project development team during the weekly Project Management Team meetings and monthly Project Development Team meetings, as well as through email and phone exchanges with specific individuals. Key topics for which PATH provided input include:
 - Simulation modeling of corridor
 - Methodology for scoring corridor operations
 - Criteria for triggering the development of response plans
 - Rules for developing suitable response plans
 - Provision of arterial routing information to motorists
 - Impacts of data quality on system operations
- **Task 4 – System Testing**
 - Tracked the testing activities being conducted by the project development team through information presented at the weekly Project Management Team and monthly Project Development Team meetings. Also periodically contacted Alex Estrella and Peter Thompson, from SANDAG, and Mike Washkowiak, from Kimley-Horn, to inquire about specific testing activities.
 - Collected the various test plans and documents detailing the test procedures to be executed that were developed by the project team.
- **Task 5 – Training**
 - Tracked training activities through information presented at the weekly Project Management Team and monthly Project Development Team meetings; also periodically contacted Alex Estrella, from SANDAG, and Mike Washkowiak, from Kimley-Horn, to inquire about specific training activities.
 - Collected and reviewed the various training materials that were prepared by Delcan for the training of system administrators and system operators.

- **Task 6 – System Operations and Maintenance**
 - Collected and reviewed the various operations manuals developed by the project team in support of system operations.
- **Task 7 – Analysis, Modeling, and Simulation of the ICM System**
 - Periodically contacted Vassili Alexiadis, of Cambridge Systematics, to discuss the progress of the pre-deployment and post-deployment simulation evaluations.
- **Task 8 – System Evaluation**
 - Reviewed the draft *Revised National Evaluation Framework* that was prepared by Battelle in collaboration with URS Corporation, the University of Maryland, and Eastern Research Group; provided review comments back to the USDOT Evaluation Team.
 - Reviewed the draft *San Diego Air Quality Test Plan* that was prepared by Eastern Research Group for Battelle and provided detailed review comments to the USDOT Evaluation Team.
 - Reviewed the *San Diego Corridor Performance Analysis Test Plan* that was jointly prepared by URS Corporation and Battelle and provided detailed review comments to the USDOT Evaluation Team.
 - Tracked the activities conducted by the Volpe National Transportation Systems Center for the execution of pre-deployment and post-deployment traveler surveys.
 - Tracked activities conducted by Battelle, Noblis, and other members of the National ICM Evaluation Team to assess the benefits and operational impacts associated with the deployed ICM system along the I-15 corridor.
 - Compiled lessons learned from discussions held with various members of the San Diego Deployment Team.
- **Task 9 – Outreach Activities**
 - Reviewed and commented on the answers that were provided by SANDAG and Kimley-Horn to the questions that were submitted by the firm tasked with conducting the NCHRP ICM Scanning Tour in the summer of 2014.
 - Participation in the two-day workshop on decision support systems that was organized by ITS America in San Diego in August 2014.

Additional activities that were conducted by PATH to keep Caltrans Division of Research, Innovation, and System Information (DRISI) abreast of project activities include:

- Development and quarterly updates of a PowerPoint presentation summarizing project activities.
- Quarterly presentations of a summary of project activities at Caltrans Headquarters in Sacramento. Several elements of this presentation have been used by SANDAG in the preparation of other project material.

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9. LESSONS LEARNED

The following are various lessons that were learned throughout the I-15 Demonstration Project:

- **Project management**
 - A dual project management mechanism works exceptionally well, as it may be difficult to find all the attributes required in one person – transportation policy, planning, local context, information technology, systems engineering, telecommunications, people, and meeting dynamics.
- **Selection of corridor to implement ICM system**
 - The selected corridor may not have been the best to test new ICM concepts. The section of I-15 that was retained for the ICM demonstration was selected in part to leverage the recent completion of the I-15 Express Lanes. While the presence of this facility within the ICM test section offers some additional traffic management opportunities, the fact that Caltrans and SANDAG were still learning how to best use its capabilities to improve corridor operations introduced complexities in the evaluation of proposed ICM concepts. Providing single-occupancy vehicles with the ability to use the Express Lanes at no charge during major freeway incidents further likely reduced the number of situations where it would be beneficial to implement detours around freeway incidents along nearby arterials. A better test environment might thus have been created by first implementing the ICM system on a well-established freeway corridor where no new major ITS system had been recently introduced and along which traffic operations are fully understood.
- **Stakeholder engagement**
 - When initiating discussions about the potential deployment of an ICM system, look to include all potential stakeholders early in the process. While some agencies and organizations may choose not to participate, all should at least be invited to the early discussions.
 - Stakeholders should be given the ability to decide what their involvement would be. Even if some agencies or organizations choose not to participate at the start, they should be kept informed about the decisions being made, as initially reluctant agencies can prove to be strong participants later on.
 - The support of executive leaders is essential in the success of the project, and particularly valuable if one or more of those executive leaders becomes a champion for the project.
 - Transportation planners and modelers, along with operations personnel, should be involved early in the discussions, as they can provide valuable input into the selection of relevant performance measures and can help understand how to best track system performance against established goals.
 - Maintaining regular communication with partner agencies throughout a project is critical, as continuous information exchange fosters understanding and perspective.

- Legal agreements, such as Memoranda of Understanding, generally need to be established between agencies to enable them to support each other.
- **Systems engineering process**
 - Following the systems engineering process can be challenging at first, but provides an essential technical platform for building a robust design.
 - Developing a clear Concept of Operations early in the project lifecycle allows stakeholders to develop a clear view of why an ICM system is needed, what the proposed system intends to do, and how they may be involved in the system's operations.
- **System design and development**
 - While major building blocks may already be in place within a corridor, there may still be significant fragmentation across systems and operations to be addressed during the design of an ICM system.
 - Collecting and processing the necessary data can be one of the most time-intensive aspects of planning and designing an ICM system. Figuring out how to use that data post-deployment can also be a challenge.
 - Significant effort is often required to communicate proposed system functions and operations to project stakeholders.
 - Achieving consensus on system requirements may take significantly longer than initially anticipated due to the variety of needs to be addressed across all participating agencies.
 - Before proceeding with the development of an ICM system, it is essential that the stakeholders be able to describe why the proposed system is needed and what the goals of the system are.
 - Post-deployment operations and maintenance should be kept in mind when designing an ICM system. This includes identifying in advance funding sources and regional agreements and policies for operations and maintenance.
 - A careful choice of procurement mechanism is required for the design team to carry out its assigned tasks effectively.
 - Significant resources are required at the local agency level to integrate corridor management into daily operations.
 - Accelerating the development of an operations plan enables full account to be taken of existing unconnected, but related processes, and helps partners to start visualizing their role in the new environment.
- **System operations and maintenance**
 - Operations and maintenance personnel should be adequately trained prior to the launch of an ICM system.
 - Team meetings should be regularly scheduled to continually improve processes and procedures as the operations of an ICM system matures.

- The implementation of freeway ramp metering and traffic signal control plans should ideally be automatic.
- Posting of messages on freeway and arterial changeable message signs generally requires approval from TMC operators.
- Under non-incident conditions, arterial availability should be constrained to provide local mobility.
- Changes to signal timing plans should be constrained to no more than once over 15 minutes to allow the recommended action plans to be fully implemented and to avoid creating too many disturbances in system operations.
- Changes in freeway ramp metering rates should be considered as part of the development of active detours.
- **Performance metrics**
 - Performance measures and evaluation criteria to be used during system operations should be considered very early in the planning process and kept as a priority throughout design and implementation. This will typically require an early and committed involvement from stakeholders in the design discussions.
 - Mobility measures should drive the development of response plans for freeways and arterials.
- **Freeway and arterial detection**
 - Adequate detection coverage is key for successfully developing accurate simulation models.
 - A turnkey arterial detection solution would typically only consider detector configuration issues and/or detection firmware upgrade or configuration. A short-term solution may add to the considerations the installation of new lead-in cables into signal controller cabinets and new traffic detectors. A medium-term solution may also consider the installation of new conduits, while a long-term solution may add the installation of new signal controllers.
- **Supporting data**
 - Data inputs for signal and ramp metering plans are needed early in the design process.
- **Analysis, modeling, and simulation studies**
 - An AMS analysis 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.
 - An AMS analysis allows corridor managers to “see around the corner” and discover optimum combinations of strategies, as well as conflicts or unintended consequences that would otherwise be unknowable before implementation.
 - An AMS analysis enables corridor managers to understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.

- An AMS evaluation framework provides corridor managers with a long-term capability to continually improve the implementation of ICM strategies based on experience.
- **Outreach and marketing**
 - Getting marketing involved early is key to identifying the audience, in addition to helping developing a consistent message.

REFERENCES

- [1] *Managing Congestion with Integrated Corridor Management*. Document FHWA-JPO-07-025, U.S. Department of Transportation, 2007.
- [2] *Integrated Corridor Management Initiative – Program Plan Update*, U.S. Department of Transportation, February 2006. Available at <http://www.its.dot.gov/icms/workplan.htm>, accessed January 22, 2015.
- [3] L. Neudorff, J. Harding, and L. Englisner. *ICMS Concept of Operations for a Generic Corridor*. Document FHWA-JPO-06-032, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., April 2006.
- [4] L. Neudorff, J. Harding, and L. Englisner. *Integrated Corridor Management: ICM Implementation Guide*. Document FHWA-JPO-06-042, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., April 2006.
- [5] V. Alexiadis. *Integrated Corridor Management Analysis, Modeling and Simulation (AMS) Methodology*. Document FHWA-JPO-08-034, Research and Innovative Technology Administration, U.S. Department of Transportation, Washington, D.C., March 2008.
- [6] W.B. Zhang. *Study of Integrated Corridor Management for San Francisco Bay Area I-880 Corridor*. Report UCB-ITS-PRR-2008-30, California PATH, University of California, Berkeley, November 2008.
- [7] S. Mortensem. *Integrated Corridor Management*. Presentation prepared for the ITS America Annual Meeting 2010, U.S. Department of Transportation, May 2010.
- [8] Federal Highway Administration and Federal Transit Administration, *Systems Engineering for Intelligent Transportation Systems: An Introduction for Transportation Professionals*. Publication FHWA-HOP-07-069, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., January 2007.
- [9] Federal Highway Administration and Caltrans, *Systems Engineering Guidebook for Intelligent Transportation Systems, Version 3.0.*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., November 2009.
- [10] *Concept of Operations for the I-15 Corridor in San Diego, California*. Document FHWA-JPO-08-009, ITS Joint Program Office, Research and Innovative Technology Administration, U.S. Department of Transportation, Washington, D.C., March 2008.
- [11] *System Requirement Specification for the I-15 Integrated Corridor Management System (ICMS) in San Diego, California*. Document FHWA-JPO-08-044, ITS Joint Program Office, Research and Innovative Technology Administration, U.S. Department of Transportation, Washington, D.C., March 2008.
- [12] Cambridge Systematics, Inc. *Analysis, Modeling and Simulation Results for the I-15 Corridor in San Diego, California*. Research and Innovative Technology Administration, U.S. Department of Transportation, Washington, D.C., September 2010.

- [13] *IEEE Guide for Developing System Requirements Specifications*. IEEE Standard 1233, Institute of Electrical and Electronics Engineers, Inc., 1998 Edition.
- [14] V. Alexiadis. *Integrated Corridor Management Analysis, Modeling and Simulation (AMS) Methodology*. Document FHWA-JPO-08-034, ITS Joint Program Office, Research and Innovative Technology Administration, U.S. Department of Transportation, Washington, D.C., March 2008.
- [15] Cambridge Systematics, Inc. *Analysis Modeling and Simulation for the I-15 Corridor in San Diego, California: Experimental Plan*. Report prepared for the U.S. Department of Transportation, Cambridge Systematics, Oakland, California, November 2009.
- [16] M. Papageorgiou, H. Hadi Salem, and J-M. Blosseville. *ALINEA: A Local Feedback Control Law for On-Ramp Metering*. In *Transportation Research Record*, Vol. 1320, 1991, pp. 58-64.
- [17] S. Cho, J. Zhu, G. Chockalingam, and R. Cruz. *Comparative Analysis Report of Ramp Metering Algorithms*. California Institute for Telecommunications and Information Technology (Calit²), University of California, San Diego, November 2011.

APPENDIX A: LIST OF ACRONYMS

AMS	Analysis, Modeling, and Simulation
ATMS	Advanced Traffic Management System
ATTS	Arterial Travel Time System
BRT	Bus Rapid Transit
CAD	Computer-Aided Dispatch
Caltrans	California Department of Transportation
CCTV	Closed-Circuit Television
CHP	California Highway Patrol
CMS	Changeable Message Sign
CPS	Congestion Pricing System
DSS	Decision Support System
EOC	Emergency Operations Center
FSP	Freeway Service Patrol
GUI	Graphical User Interface
HOT	High-Occupancy Toll
HOV	High-Occupancy Vehicle
HTTP	Hypertext Transfer Protocol
ICM	Integrated Corridor Management
ICMS	Integrated Corridor Management System
IMTMS	Intermodal Transportation Management System
ITS	Intelligent Transportation System
LCS	Lane Closure System
MLCS	Managed Lane Control System
MTS	Metropolitan Transit System
NCTD	North County Transit District
NPS	Network Prediction System
NWS	National Weather Service
PATH	Partners for Advanced Transportation Technology
PeMS	Performance Measurement System
PM	Post Mile
RAMS	Regional Arterial Management System
REMS	Regional Event Management System
RMIS	Ramp Meter Information System
RTMS	Regional Transit Management System
RTSS	Real-Time Simulation System
SANDAG	San Diego Association of Governments
SDRMS	San Diego Ramp Metering System
SPS	Smart Parking System
TSS	Transport Simulation Systems
TMC	Traffic Management Center
XML	Extensible Markup Language