Final Report

Dallas Integrated Corridor Management (ICM) Demonstration Project

www.its.dot.gov/index.htm
Final Report — August 13, 2015
FHWA-JPO-16-234

Source: Dallas Area Rapid Transit, 2012

U.S. Department of Transportation

Produced by
Dallas Integrated Corridor Management (ICM) Demonstration Project
U.S. Department of Transportation
Intelligent Transportation Systems Joint Program Office
Federal Highway Administration
Federal Transit Administration

Notice

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-16-234		

4. Title and Subtitle Final Report: Dallas Integrated Corridor Management (ICM) Demonstration Project	**5. Report Date** August 13, 2015 **6. Performing Organization Code**
7. Author(s) Miller, Kevin; Bouattoura, Fariel; Macias, Roberto; Poe, Chris; Le, Minh; Plesko, Todd;	**8. Performing Organization Report No.**
9. Performing Organization Name And Address Dallas Area Rapid Transit 1401 Pacific Avenue Dallas, TX 75202	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH61-06-H-00040
12. Sponsoring Agency Name and Address U.S. Department of Transportation ITS Joint Program Office 1200 New Jersey Avenue, SE Washington, DC 20590	**13. Type of Report and Period Covered** Final Report, October 2006 to January 2015 **14. Sponsoring Agency Code** HOIT-1

15. Supplementary Notes
Source of picture on cover is Lisa Rising on behalf of Dallas Area Rapid Transit.

16. Abstract
The Dallas Area Rapid Transit (DART) is leading the US-75 Integrated Corridor Management (ICM) Demonstration Project for the Dallas region. Coordinated corridor operations and management is predicated on being able to share transportation information on highways, arterials, transit, weather, and incidents. The ICM system utilizes the existing Texas Department of Transportation (TxDOT) Center-to-Center standards based communication infrastructure, and provides direct connections to agencies not on the Center-to-Center network via a web-based interface known as SmartNET. The ICM system uses SmartNET as the main graphical user interface for the ICM stakeholders to create, edit, and view events in the corridor and region, view current conditions of field devices and congestion on the roadway network, and coordinate responses to incidents within the corridor.

This final report covers the project's process and results for the various phases of the ICM program, lessons learned, and recommendations for others implementing ICM.

17. Key Words	18. Distribution Statement
Integrated Corridor Management, ICM, Decision Support System, Lessons Learned, Systems Engineering	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	37	N/A

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

Acknowledgements

The Dallas Area Rapid Transit would like to thank Steve Mortensen of the Federal Transit Administration, Brian Cronin, Robert Sheehan, and Dale Thompson of the Intelligent Transportation Systems Joint Program Office, Neil Spiller and James Colyar of the Federal Highway Administration, and others from the United Stated Department of Transportation for their leadership and assistance throughout the ICM program.

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1 Executive Summary

The Dallas Area Rapid Transit (DART) led the US-75 Integrated Corridor Management (ICM) Demonstration Project for the Dallas region. Coordinated corridor operations and management is predicated on being able to share transportation information on highways, arterials, transit, weather, and incidents. The ICM system utilizes the existing Texas Department of Transportation (TxDOT) Center-to-Center standards based communication infrastructure, and provides direct connections to agencies not on the Center-to-Center network via a web-based interface known as SmartNET. The ICM system uses SmartNET as the main graphical user interface for the ICM stakeholders to create, edit, and view events in the corridor and region, view current conditions of field devices and congestion on the roadway network, and coordinate responses to incidents within the corridor.

The Integrated Corridor Management (ICM) Project fundamentally changes how transportation agencies in the US-75 corridor collaborate to move more people and vehicles through the corridor, respond to incidents, and provide better travel information to travelers, who can make better decisions about how and when to travel in the corridor.

This document is the final project report for the US-75 Integrated Corridor Management System (ICMS) Demonstration Project in Dallas, Texas. This report includes an overview of the system engineering phases of the project, the results and lessons learned, and recommendations for others implementing ICM.

2 Project Background

The Integrated Corridor Management System (ICMS) is a component based system which supports corridor management by sharing internal and external incident, construction, special event, transit, parking, and traffic flow data, and utilizes this data to provide operational planning and evaluation through decision support.

Keeping in mind the vision of the ICM project, "Operate the US-75 Corridor in a true multimodal, integrated, efficient, and safe fashion where the focus is on the transportation customer", the management and operations of the corridor and the ICM is a joint effort involving all the stakeholders.

The daily operation of the corridor is coordinated through the existing arrangements and information is exchanged through the Center-to-Center project along with an information exchange system known as SmartNET, which distributes event information and response plan recommendations for incidents that have occurred within the US-75 Corridor. Staff has been assigned by the corridor stakeholders to support daily operations, develop response plans, analyze system deficiencies and needs, and provide general administration.

Communications, systems, and system networks have been integrated to support the virtual ICMS corridor command center. Voice, data, video, information, and control have been provided to all agencies based on the adopted protocols and standards for the sharing of information and the distribution of responsibilities. The ICMS supports the virtual nature of the corridor by connecting the member agency staff on a real-time basis via communications and other Intelligent Transportation Systems (ITS) technologies. While all the ICM operational strategies are available for evaluation by the Decision Support System (DSS), only a subset of these strategies have been activated consistent with traffic signal timing plan deployment.

A key to implementing coordinated ICM operations and response is the development of pre-approved response plans. A comprehensive effort to develop the response plans has been led by the ICM Operations, Decision Support and Arterial Monitoring Systems Committees. After consideration by the group, it was determined that varying event types and locations would require different response scenarios depending on location and transportation impact. As a result, the following approach was used:

- Frequently occurring event types, recurring areas of congestion and high frequency locations for incidents were considered
- The corridor was divided into multiple sections and directions
- Response strategies were identified
- Event impact indicators (such as queue length and number of lanes affected) were identified

Using this approach, response plans were developed for each segment of US-75 northbound and southbound. There are up to four response plans for each segment to address the following strategies:

- Minor Incident: Short Diversion to Frontage Road
- Major Incident: Long Diversion to Frontage Road
- Major Incident: Diversion to Frontage Road and Greenville Ave (arterial)
- Major Incident: Diversion to Frontage Road and Greenville Ave (arterial) and Transit

The appropriate strategy to use in the event of an incident is determined based upon the magnitude of the event impact indicators as follows:

- Number of affected lanes on US-75 (including HOV lanes)
- Speed on US-75
- Queue length on US-75
- Speed on frontage road diversion route
- Speed on Greenville Ave. diversion route
- Current utilization of nearby park-and-ride lot
- Current utilization of Red and Orange light rail transit (LRT) lines

Table 1 is a matrix that shows the relationship between the strategies and the transportation condition parameters.

Table 1: DSS Rules for Response Plan Development

Strategies	No. Affected Lanes General Purpose and HOV	Main Lanes		Speed Frontage Road (on Diversion Route) (mph)	Speed Greenville Ave. (on Diversion Route) (mph)	Prediction Measures of Performance	Park and Ride Utilization	Light Rapid Transit Utilization	Weather
		Speed (mph)	Queue Length Derived from Avg. speed (mi.)						
Minor Incident: Short Diversion to Frontage Road (FR.)	≥ 1	< 30	0.5 < Q <1	> 20	N/A	N/A	N/A	N/A	(2)
Major Incident: Long Diversion to FR.	≥ 1	< 30	Q ≥ 1	> 20	N/A	(1)	N/A	N/A	(2)
Major Incident: Diversion to FR. and Greenville Avenue (GV.)	≥ 2	< 30	Q ≥ 1	< 20	> 20	(1)	N/A	N/A	(2)
Major Incident: Diversion to FR. and GV., Transit	≥ 2	< 30	Q ≥ 4	< 20	< 20	(1)	< 85%	< 85%	(2)
Major Incident: Diversion to FR. and GV., Transit	≥ 2	< 30	Q ≥ 4	< 20	< 20	(1)	> 85%	> 85%	(2)
Return to Normal	< 1	> 30	Q < 0.5	NA	NA	NA	NA	NA	NA

Notes:

1. The prediction measures of performance (MOPs) to be used in response plan development are still being assessed as to validity and value. The four measures under assessment are: travel time; number of travelers, travel delay and travel distance.
2. The use of weather conditions as a consideration in response plan development is not currently implemented but is a potential enhancement being considered for the future.

2.1 Key Stakeholders

The stakeholders for the project include:

- Dallas Area Rapid Transit
- City of Dallas
- City of Richardson
- City of Plano
- Town of Highland Park
- City of University Park
- North Central Texas Council of Governments
- North Texas Tollway Authority
- Texas Department of Transportation – Dallas District & Traffic Operation Division

2.2 Background of Corridor

This US-75 Corridor contains Dallas' first major freeway completed around 1950. This section of freeway was totally reconstructed with cantilevered frontage roads over the depressed freeway section and re-opened in 1999 with a minimum of eight general-purpose lanes. The freeway main lanes carry over 330,000 vehicles a day, with another 20,000-30,000 on the frontage roads. Concurrent-flow, high-occupancy vehicle lanes are operated by TxDOT within the freeway median in the northern section of the Corridor.

The Corridor also contains the first light-rail line constructed in Dallas, part of the 20-mile DART starter system, opened in 1996. The Red and Orange Line now expands into cities of Richardson and Plano and passes next to the cities of Highland Park and University Park. This facility operates partially at grade and partially grade separated through deep-bored tunnels under US-75. There is also another rail line, the Blue Line, which operates in the US-75 Corridor near downtown Dallas and extends along the eastern edge of the Corridor boundary. In the downtown, there is also a connection from these lines to the regional commuter rail line that extends to downtown Fort Worth.

In general, the arterials are on a grid pattern and US-75 is aligned in a north-northwest direction. The arterial street system consists of several major north-south arterial streets. These primary streets are typically spaced on one-mile spacing and serve as primary travel routes and potentially serve as alternate routes for traffic diverted from the freeways and toll road. The key north-south arterials in the US-75 Corridor are:

- Jupiter Road
- Plano Road
- Abrams Avenue / Gaston Road
- Skillman Avenue / Live Oak Avenue
- Alma Road Custer Road
- Coit Road
- Greenville Avenue
- Hillcrest Road
- Preston Road

There are also several key east-west arterials. While many of these carry significant traffic, these arterials are critical for moving traffic between the north-south routes, especially for diversion purposes. The key east-west arterials are:

- McDermott Road
- Spring Creek Parkway
- Park Boulevard
- Plano Parkway
- Campbell Road
- Arapaho Road
- Belt Line Road Spring Valley Road
- Forest Lane
- Royal Lane
- Walnut Hill Lane
- Northwest Highway
- Lovers Lane
- Mockingbird Avenue

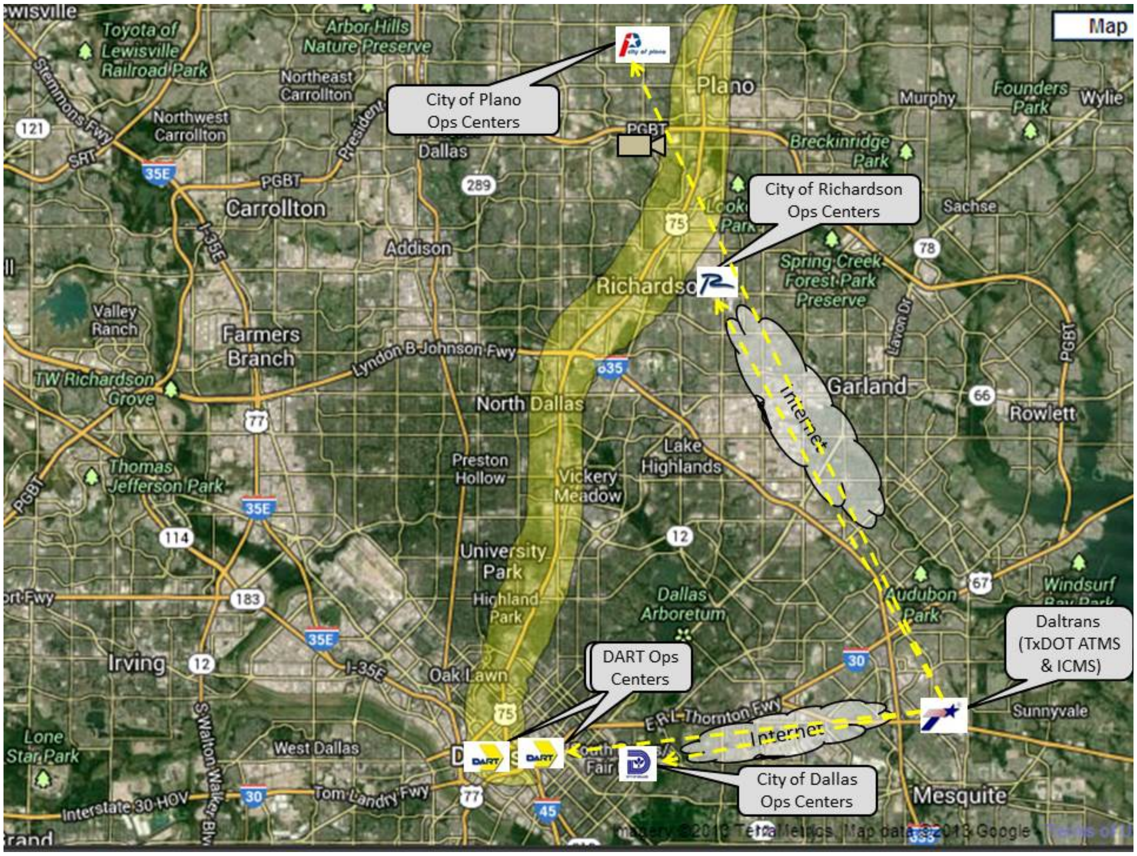

Figure 1: Corridor Overview (Source: Dallas Area Rapid Transit)

This ICM demonstration project has allowed the operating agencies along the corridor to manage the transportation network as an integrated asset and provide travelers with personalized, real-time information enabling them to make better decisions about how to travel along the corridor. The effort is designed to collaboratively engage the planning, technology and infrastructure resources of the various cities and government jurisdictions along the corridor from Dallas, north to SH 121 in Plano (approximately 28 miles), in improving mobility along the entire corridor instead of the traditional approach of managing individual assets to solve local mobility needs. By applying ICM, the operating agencies along this section of the corridor manage it as an integrated asset in order to improve travel time reliability and predictability by empowering travelers through better information and more transportation choices.

ICM Systems

The ICM system is comprised of three major subsystems, as shown in Figure 2 below. One of the main components of the ICM System is SmartNET/ SmartFusion, which gathers data from a variety of sources and delivers it to multiple destinations. Information is gathered from transportation systems, emergency management systems, dispatch systems for law enforcement, and other types of systems. The ICM System then makes this information available via a web server to traditional users such as Traffic Operations Centers, the Media, and Agency and public websites. The main purpose of the Dallas ICM System is to:

- Provide an integrated platform for coordinating responses to incidents, construction, and special events in the corridor;
- Provide an information exchange tool based on center-to-center standards, and Traffic Management Data Dictionary (TMDD);
- Provide a data fusion engine for the corridor to feed information to the regional 511DFW systems;
- Provide DSS real-time information on incidents, construction, special events, transportation network status, and device status throughout the corridor; and
- Provide a response plan coordination tool for multiple agencies to coordinate actions in responding to incidents within the corridor.

SmartNET is a web-based Graphic User Interface that enables transportation management centers, police, emergency responders, and any organization in the SmartNET network to share important information with each other, such as the location and status of major incidents, resources deployed, planned event activities, and construction areas.

Implemented over the Internet, the ICM System via the SmartNET/ SmartFusion subsystems allows operators to obtain information through a GIS-based map display, and to enter information through easy-to-use, intuitive menus that incorporate drop-down menu based input screens. The ICM System includes a center-to-center messaging system to make information sharing easier with sources such as freeway/signal management systems; probe based tracking systems, computer-aided dispatch systems, and information dissemination systems such as 511 and other websites. The power of the ICM System is it:

- Helps agencies efficiently plan and use resources ;
- Helps agencies plan and use resources during “normal” times;
- Shares critical information among responders and decision makers during emergencies; and
- Provides a conduit to the public for traveler information; and it serves as a multi-purpose data warehouse.

The other main subsystem of the ICM System is the DSS which is driven by the decision rules developed by the stakeholders, expert system, prediction modeling and evaluation components to recommend the plan of actions associated with specific events within the corridor. The involved agencies will be notified of the events along with the suggested recommendations for consideration and deployment.

The DSS provides candidate response plans to the SmartFusion subsystem based on network conditions received from the SmartFusion subsystem, prediction analysis, and on a rule-based assessment of the recommended response plans. The DSS consists of three major components:

- Expert Rules
- Prediction (Model)
- Evaluation

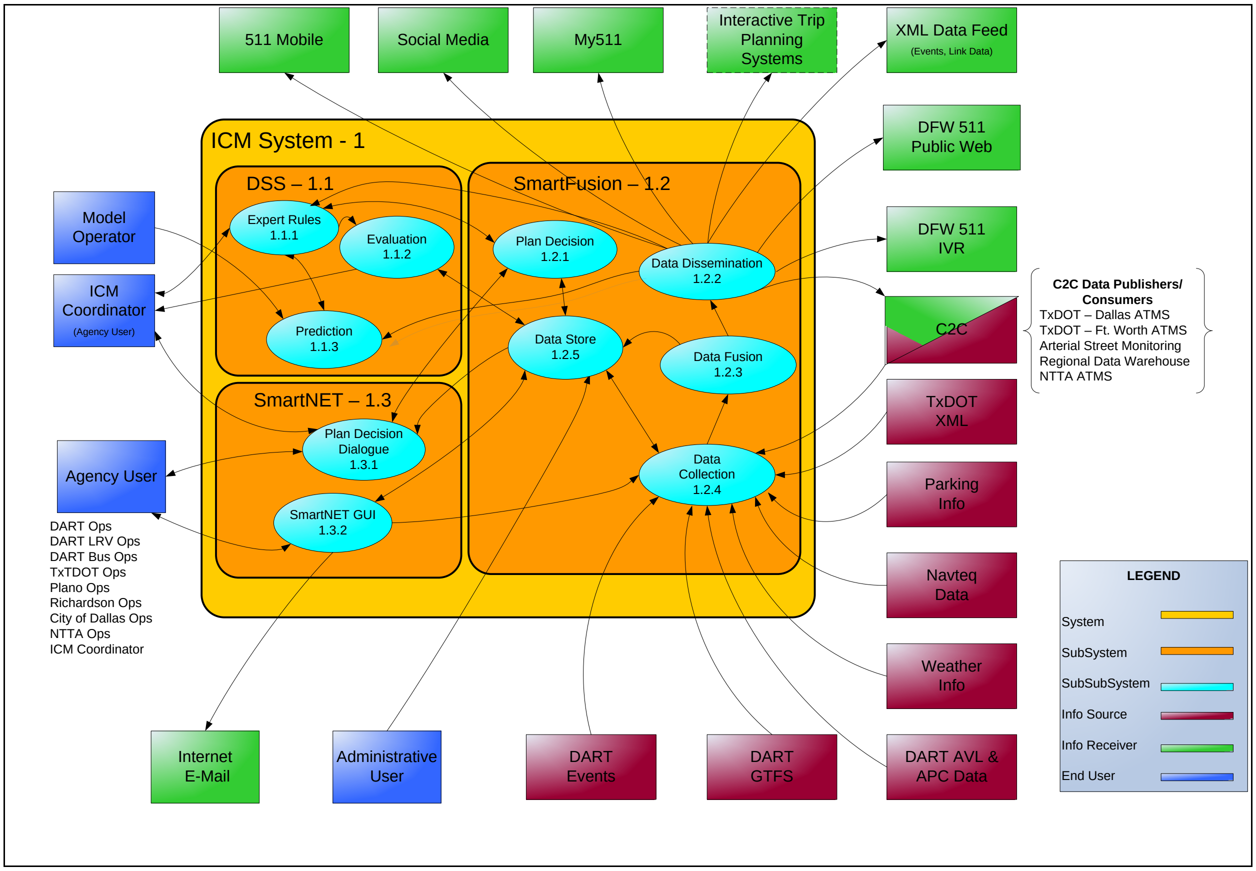

Figure 2: ICMS High-Level Conceptual Diagram (Source: Dallas Area Rapid Transit)

In response to an incident the process begins with the Expert Rules and the Model collecting information on corridor performance and incidents from the Data Fusion component of the SmartFusion subsystem.

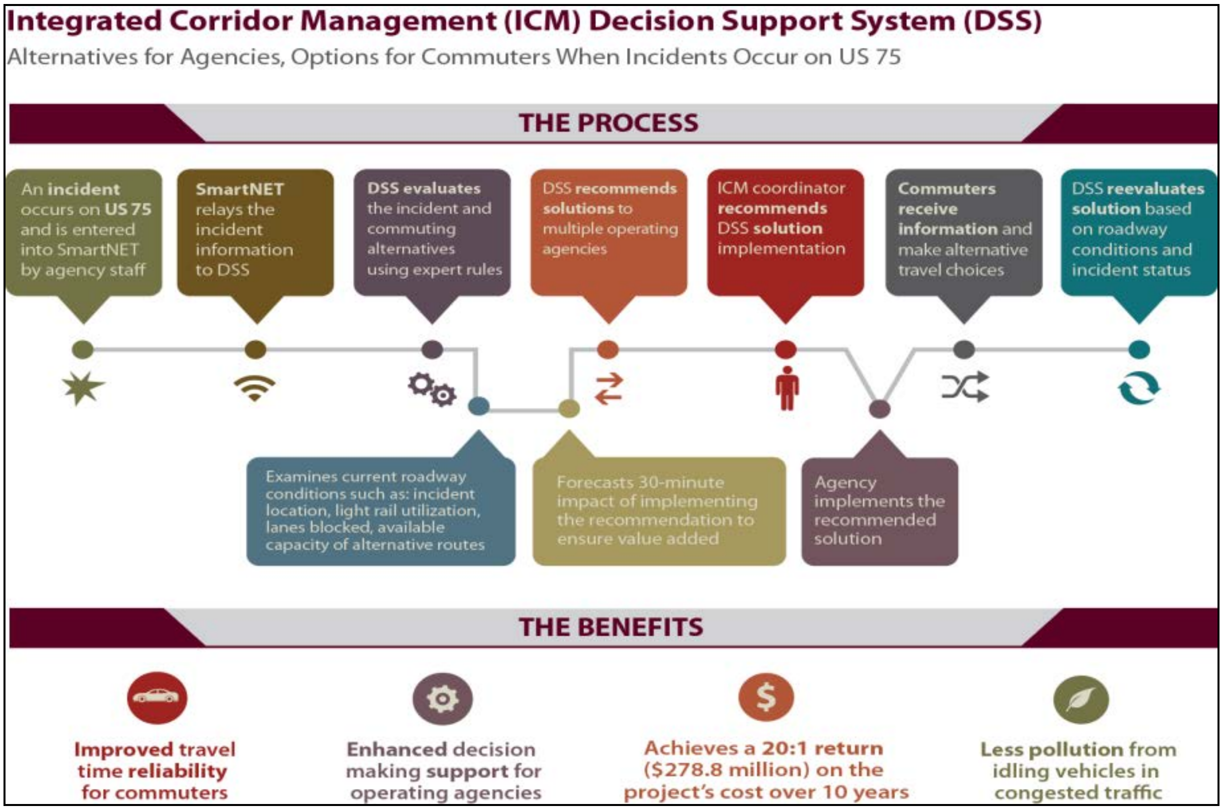

Figure 3: Decision Support Process (Source: Dallas Area Rapid Transit)

The Model develops an assessment of the current roadway operations based on the data received from the Data Fusion component. In addition, the Model periodically forecasts the current and predicted performance of the network based on the current conditions and sends them to the Expert Rules component.

Given the information about the current conditions of the network and the predicted performance of the network, the Expert Rules selects candidate response plans, which were develop by the operating agency stakeholders based on their expert knowledge and experience, and are delivered to the ICM coordinator via the DSS dialog. The ICM coordinator approves or rejects the candidate response plan from the recommendation of the Expert Rules.

If the validation decision is approved by the ICM coordinator, then the DSS pushes candidate response plan information to the involved agency users for plan implementation.

The Expert Rules collects the users plan readiness status and plan decision from the DSS dialog.

After implementing the ICM coordinator's plan decision, each agency user confirms the plan's operational status. The plan is then terminated once the event owner agency user or the ICM coordinator closes the event in the ICM System.

In an ICM corridor, commuters receive information that encompasses the entire transportation network to help them make better decisions about how to travel in that corridor.

Over 400 Response Plans have been developed and approved to date. Response plans are still being developed and revised as experience is gained. The pre-approved response plans are consolidated and available to Dallas ICM partner agencies via the internet for reference in real time during response plan implementation as well as off line for assessment and refinement.

Informing travelers

The project includes the Dallas –Fort Worth "511" real-time traveler information system and supports integrated operation of the US-75 corridor. The ICM System collects information on the current travel conditions on freeways, frontage roads, arterial streets, DART rail, park-and-ride lots, and the high occupancy vehicle (HOV) lane.

The 511 System has three basic subsystems: a Telephone platform, Public Web Site, and a personalized travel information system. The Interactive Voice Response (IVR) system allows travelers to dial "511" and receive real-time transportation information for the DFW region. The Public Web Site (www.511dfw.org) provides a web portal for transportation information for the region, and includes the ability for travelers to sign-up and receive personalized traveler information through the My511 feature of the website. Personalized traveler information includes alerts on specific routes or transit routes that the traveler has set up in their account on My511.

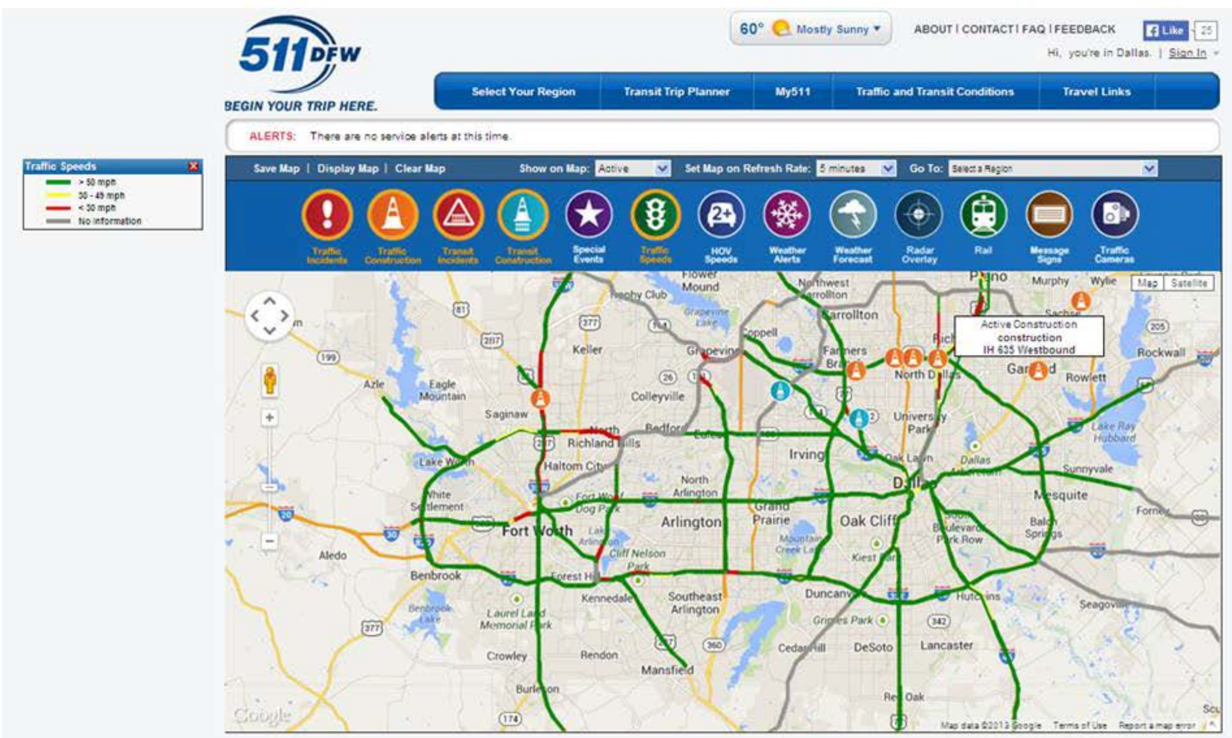

Figure 4: 511DFW Website (Source: Dallas Area Rapid Transit)

The US-75 ICM project includes the first 511 system in the State of Texas. As part of the cooperation between the local agencies in Dallas -Fort Worth led by Dallas Area Rapid Transit and the State of Texas, the 511DFW system utilizes the 511 dial-in number for a nine county region around the Dallas-Fort Worth (DFW) area.

The information in the 511 DFW system is received from many public transportation agencies in the Dallas – Fort Worth region. Traffic management centers monitor and provide traffic condition information to the 511 DFW system. Staffs at these centers receive highway condition information from police and transportation officials, motorist assistance patrol drivers, 911 calls, construction crews, traffic cameras and roadway sensors. Transit information comes from public transportation agencies. Weather conditions, forecast information and alerts are provided by a 3rd Party weather information provider.

The 511DFW website provides transportation users within the DFW area real-time information on roadway conditions, transit, and weather information. This includes a Transit Trip Planner, which allows users to plan a trip anywhere within the region and the system will recommend multiple trips using all transit carriers in the region. This may include trips with transfers between bus, train, and light rail and utilizing the three transit carriers within the region.

The IVR system provides a voice responsive system for travelers to dial "511" in the region and request real-time information on traffic conditions, transit trips, parking availability, weather conditions, and airport information.

3 Systems Engineering

The Dallas ICM Team's approach was consistent with the system engineering process which is proven to greatly improve the chances of a successful system deployment by reducing the risk of unnecessary or unrealistic requirements, while validating that user needs (functional, political and budgetary) are met by the system.

Our team used an iterative approach by building on previous work at each step of the project. In Stage 1 we developed our Concept of Operations and High-Level Requirements. As we began the Stage 3 Demonstration phase, we worked with the USDOT to refine our High Level Requirements to complete the Detail Requirements, High Level and Detailed Design; once those were completed we began implementation of the ICMS.[1] Since this project was a Design, Build, Operate and Maintain type of contract – some of the implementation, especially the DSS, used an iterative methodology. Since some of the systems and concepts of the ICM were new, we approached those using an iterative process in order to reduce risk, and to deliver a working system.

This project used all phases of the System Engineering process, as shown in Figure below, as prescribed by the Federal Highway Administration (FHWA) recommended methodology. Our Systems Engineering Management Plan (SEMP) was developed and approved by USDOT, and

[1] During Stage 2 the Dallas team applied the ICM modeling and analysis capabilities developed in the ICM Initiative to model proposed ICM strategies. The modeling work and outcomes helped Dallas to refine the ICM strategies and ICMS requirements.

assisted the team with defining the tools, processes and procedures we used throughout the project.

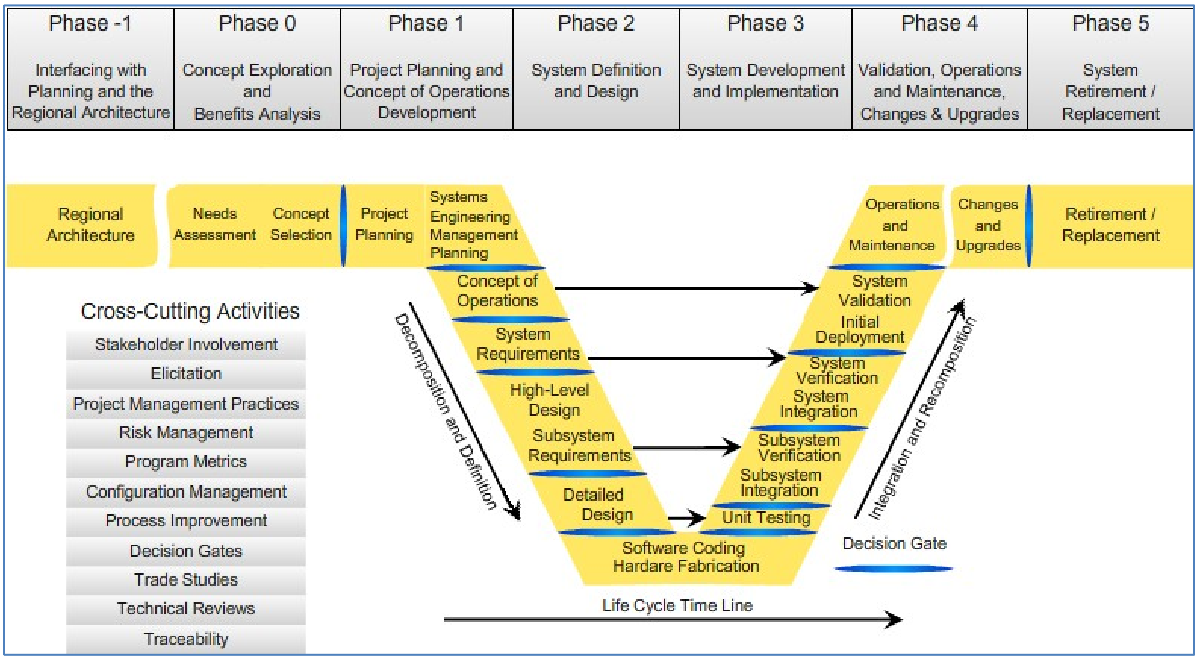

Figure 5: System Engineering Process (Source: FHWA California Division Systems Engineering Guidebook for ITS v 3.0, https://www.fhwa.dot.gov/cadiv/segb/views/process/index.cfm)

3.1 System Goals and Objectives

The US-75 corridor is an integrated transportation system – managed and operated collectively – in order to maximize its efficiency to corridor travelers.

The Vision Statement for the Corridor, as stated in the Concept of Operations, is to "Operate the US-75 Corridor in a true multimodal, integrated, efficient, and safe fashion where the focus is on the transportation customer." Using the Vision Statement as a starting point, the US-75 Steering Committee developed four primary Goals for the ICM, and discussed the Objectives and Strategies for each of the Goals. These Goals and Objectives, shown in Table 2 below, are interrelated such that activities and strategies oriented towards attaining one of the Goals will likely impact the attainment of other Goals and Objectives.

Table 2: Goals and Objectives of the US-75 ICM

Goals	Objectives
Increase corridor throughput – The agencies within the corridor have done much to increase the throughput of their individual networks both from a supply and operations point of view, and will continue to do so. The integrated corridor perspective builds on these network initiatives, managing delays on a corridor basis, utilizing any spare capacity within the corridor, and coordinating the junctions and interfaces between networks, in order to optimize the overall throughput of the corridor.	• Increase the vehicle person throughput of the US-75 corridor. • Increase transit ridership, with minimal increase in transit operating costs. • Maximize the efficient use of any spare corridor capacity, such that delays on other saturated networks may be reduced. • Facilitate intermodal transfers and route and mode shifts • Improve pre-planning (e.g., developing response plans) for incidents, events, and emergencies that have corridor and regional implications.
Improve travel time reliability - The transportation agencies within the corridor have done much to increase the mobility and reliability of their individual networks, and will continue to do so. The integrated corridor perspective builds on these network initiatives, managing delays on a corridor basis, utilizing any spare capacity within the corridor, and coordinating the junctions and interfaces between networks, thereby providing a multi-modal transportation system that more adequately meets customer expectations for travel time predictability.	• Reduce overall trip and person travel time through the corridor. • Improve travel predictability. • Maximize the efficient use of any spare corridor capacity, such that delays on other saturated networks may be reduced. • Improve commercial vehicle operations through and around the corridor. • Increase travel time reliability (i.e., lower the 95% travel time)
Improved incident management - Provide a corridor-wide and integrated approach to the management of incidents, events, and emergencies that occur within the corridor or that otherwise impact the operation of the corridor. The approach includes planning, detection and verification, response and information sharing, so that the corridor returns back to "normal" more quickly.	• Provide/expand means for communicating consistent and accurate information regarding incidents and events between corridor networks and public safety agencies. • Provide an integrated and coordinated response during major incidents and emergencies, including joint-use and sharing of response assets and resources among stakeholders, and development of a common policies and processes. • Continue comprehensive and on-going training program – involving all corridor networks and public safety entities – for corridor event and incident management. • Reduce secondary crashes

Goals	Objectives
Enable intermodal travel decisions - Travelers must be provided with a holistic view of the corridor and its operation through the delivery of timely, accurate and reliable multimodal information, which then allows travelers to make informed choices regarding departure time, mode and route of travel. In some instances, the information will recommend travelers to utilize a specific mode or network. Advertising and marketing to travelers over time will allow a greater understanding of the modes available to them.	• Facilitate intermodal transfers and route and mode shifts • Increase transit ridership • Expand existing ATIS systems to include mode shifts as part of pre-planning • Expand coverage and availability of ATIS devices • Obtain accurate real-time on the current status of the corridor network and cross-network connections

These corridor-wide goals and objectives have a general premise in the travelers' (i.e., "customers'") perspective of only one surface transportation system; and that the public generally is not concerned with which jurisdiction or agency is responsible for the road or transit network on which they are currently traveling. As taxpayers and fare/toll payers, they want and deserve a safe and reliable trip – one that provides a consistent level-of service with minimal congestion, and is predictable in terms of travel time. Travelers also need accurate and timely information so that they can make informed decisions before and during trips. Table 3 maps these goals against the various corridor needs (as discussed in the Concept of Operations).

Table 3: Mapping of Goals against Corridor Needs

Problems and Needs	Goals: Increase corridor throughput	Improve travel time reliability	Improved incident management	Enable intermodal travel decisions
Corridor based approach among agencies and modes.	●	●	●	
Improved coordination, cooperation and integration among stakeholders	●		●	
Improved interagency information sharing			●	●
Improve demand balance among facilities		●		●
Reduce non-recurring incidents	●	●		
Improve incident management process			●	
Data warehousing	●		●	●
More standardization and system interoperability within and between all stakeholders		●	●	
Accurate real-time information on the operations of all networks including travel time		●		●
Improved operational coordination of networks in the corridor, particularly at junctions (including multi-modes)	●	●	●	
Accurate models to simulate corridor operation under various scenarios.	●	●		●
Joint use of resources and infrastructure (e.g., service patrols, DMS)	●	●	●	
Improved in-reach and public outreach	●	●	●	●
Funding sources for corridor initiatives including the O&M				
Increased transit usage	●			●
Improved corridor wide incident management			●	●
Performance measures for screening, monitoring and evaluating corridor-based strategies and operations				●
Information Sharing both Inter-agency and with the Public	●		●	●
Provide tools for Real-time operation of the system	●		●	●

3.2 System Definition and Design Process

For System Definition and design we used a Structured Analysis process based on Yourdon-DeMarco. This process helped the team with a repeatable consistent process for defining the system, documenting the system requirements and design parameters, and providing rigor to the systems engineering process.

Structured Analysis views a system from the perspective of the data flowing through it. The function of the system is described by processes that transform the data flows. Structured analysis takes advantage of information hiding through successive decomposition (or top down) analysis. This allows attention to be focused on pertinent details and avoids confusion from looking at many irrelevant details. As the level of detail increases, the breadth of information is reduced. The result of structured analysis is a set of related graphical diagrams, process descriptions, and data definitions. They describe the transformations that need to take place and the data required to meet a system's functional requirements.

The structured analysis approach develops perspectives on both process objects and data objects.

Our approach to structured analysis and design included:

- Context diagram
- data flow diagrams, and
- A data dictionary.

The data flow diagrams (DFDs) are directed graphs. The arrows represent data, and the rounded rectangles represent processes that transform the data. A process can be further decomposed to a more detailed DFD which shows the sub processes and data flows within it. The sub processes can in turn be decomposed further with another set of DFDs until their functions can be easily understood. The DFDs model the structure of the system as a network of interconnected processes composed of functional primitives. The data dictionary is a set of entries (definitions) of data flows, data elements, files, and data bases. The data dictionary is partitioned in a top down manner. They can be referenced in other data dictionary entries and in data flow diagrams.

3.3 System Development and Implementation Process

Since this project included existing technology and new technology, multiple development processes were followed. For existing technology that was configured and deployed, a standard waterfall development methodology was utilized. For the new technology components, especially the Decision Support System, a spiral methodology was utilized.

For a spiral methodology, we used several phases to develop and deploy the systems. For the DSS the first stage was using a basic expert rules engine to select a response plan based on location, speeds, and basic traffic variables. The second stage of the DSS utilized more real-time transit information. The final stage of the DSS integrated the use of a real-time model to validate and assist in selection of the best response plan for current conditions.

3.4 Validation Process

Overall, the testing of the system revealed very minor technical defects. The majority of the enhancement and change requests were due to operational use of the system. For instance, the SmartNET GUI was later modified to streamline the response plan actions; this was discovered during an Operational Test of the system prior to Go-Live. The Operators participating in the Operational Test found the system to function as expected, but requested several changes that would make their jobs more efficient.

This process was invoked during the stakeholders requirements definition process to confirm that the requirements properly reflected the stakeholder needs and to establish validation criteria (i.e., that the right system has been built). This process was also invoked during the transition process to handle the acceptance activities; for the Dallas ICM Demonstration, this phase was known as the System Acceptance Test (SAT).

3.4.1 System Testing

As a part of the Dallas US-75 ICM Demonstration Project, the Dallas ICM team developed an acceptance test plan for verifying the requirements of the ICMS.[2] As stated in ISO/IEC 15288:2008: The purpose of the validation process is to provide objective evidence that the services provided by a system when in use comply with stakeholders' requirements, achieving its intended use in its intended operational environment. This process performs a comparative assessment and confirms that the stakeholders' requirements are correctly defined. Where variances are identified, these are recorded and guide corrective actions. System validation was ratified by stakeholders.

Technical reviews are essential to insure that the system being developed will meet requirements, and that the requirements are understood by the development team. For the Dallas ICM Demonstration Project, several formal and informal technical reviews were performed, utilizing IEEE STD 1028-1997 IEEE Standard for Software Reviews:

- Requirements Walkthroughs;
- Preliminary Design Review (PDR);
- Critical Design Review (CDR);
- Test Readiness Reviews (TRRs).

3.4.1.1 Requirements Walkthrough

The Dallas ICM team conducted a requirements walkthrough with the USDOT and its representatives to ensure that both had a common understanding of what will be built and what capabilities the proposed system will actually be deployed.

[2] The acceptance test plan was used to test the ICMS, not to validate the data provided by external sources. Thus, if the data is erroneous and the ICMS reports the erroneous data in an accurate and timely manner, then the ICMS has performed successfully.

3.4.1.2 Preliminary Design Review

At the completion of the 40% design a Preliminary Design Review (PDR) was conducted to obtain verification/ approval of the system architecture design. The goals of the PDR were to:

- Verify the technical content of the architectural design document and its interfaces are complete and traceable;
- Ensure the selected design methodology has been followed in producing the architectural design;
- Obtain approval from the DART Program Manager to proceed into detailed design.

3.4.1.3 Critical Design Review

After completion of approximately 90% of the detailed design and prior to system build, a Critical Design Review (CDR) was conducted to ensure the design fulfills the requirements. The CDR served as a baseline for all deliverables. The goals of the CDR were to:

- Verify the technical content of the System Design Document are complete and its functions traceable to requirements;
- Ensure the selected design methodology has been followed in producing the detailed design;
- Obtain approval from the DART Project Manager; the team will proceed into the implementation phase.

3.4.1.4 Test Readiness Reviews (TRRs)

The Dallas ICM team held Test Readiness Reviews prior to each major testing milestone, including sub-system testing, integration testing, and system acceptance testing. The Test Readiness Review process is an extract of the overall quality assurance process. The purpose of the Test Readiness Review is to provide the stakeholders with the assurance that the software has undergone a thorough test process and is ready for turnover to the next test phase. The scope of the Test Readiness Review is to inspect the test products and test results from the completed test phase for completeness and accuracy, and to verify that the test cases, test scenarios, test scripts, environment, and test data have been prepared for the next test phase. Test Readiness Reviews were held for each sub-system of the overall ICM System.

Prior to beginning the System Acceptance Testing, an Acceptance Test Readiness Review was held. The review was a formal test readiness review conducted following successful completion of the Integration Test and Performance Test, and was used to brief the stakeholders of the previous test results, the known deficiencies and bugs prior to beginning SAT.

For the SAT, all scripts were performed by the development team and verified by the stakeholder team by witnessing the test being run. Comments were provided for any tests regarding business process, unexpected results, or defects.

The table below summarizes the test cases employed for user acceptance testing and the test results obtained for each test case (as discussed in the Test Report).

Table 4: SAT Results

Test Case ID	Date Tested	Tester	Pass /Fail	Severity of Defect	Summary of Defect	Closed prior to Production Release?	Comments
SN1	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	Pass for CCTV, DMS, and Detectors. Will be tested for Parking, Vehicle Location at a later date.
SN2	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	Stakeholders recommended that Exchange Server be used instead of local e-mail client for sending e-mail alerts.
SN3	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	
SN4	3/19/2013	Fariel Bouattoura	Pass	Minor	Missing data feeds to be added at later date, once available	Yes	Step 5: Weather layer will not be added to SmartNET. Navteq data currently not on arterials – will be added and tested at a later time.
SN5	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	Stakeholders to provide needed reports at a later Operations Committee meeting.
SN6	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	Stakeholders to discuss Alarms and filtering at a later time.
SN7	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	

Test Case ID	Date Tested	Tester	Pass /Fail	Severity of Defect	Summary of Defect	Closed prior to Production Release?	Comments
SN8	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	
SN9	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	Traffic signal data currently not planned.
SN10	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	
SN11	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	1.0.1.20 requirement needs to be modified since data in DSS originates in SmartFusion. Review other requirements associated with DSS to ensure consistency.
SF1	3/18/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	
SF2	3/18/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	Steps 9, 10, 11 SmartNET Map was used instead of Public Web map
SF3	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	
SF4	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	
SF5	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	
SF6							Not tested due to parking management project incomplete. Will test at a later time.

Test Case ID	Date Tested	Tester	Pass /Fail	Severity of Defect	Summary of Defect	Closed prior to Production Release?	Comments
SF7							Traffic Signal data will not be added to the project, due to Center-to-Center (C2C) plug-in project delay.
SF8	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	DART to provide new color code for blue line.
SF9	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	Remove ambiguity of requirements 1.20.530 from “Incident Response Plan” to “Incident Response Record”
SF10	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	
SF11							Alarms will be re-done with stakeholder recommendation s.
SF12							Sending data to C2C removed from scope at decision of stakeholders.
SF13	3/19/2013	Fariel Bouattoura	Pass	N/A	N/A	Yes	
DS1	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS2	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS3	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS4	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS25	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	

Test Case ID	Date Tested	Tester	Pass /Fail	Severity of Defect	Summary of Defect	Closed prior to Production Release?	Comments
DS30	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS35	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS55	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS65	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS90	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS100	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	
DS120	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	Validation of Prediction model is needed. Test only showed data exchange and a result provided by Prediction system
DS125	3/20/2013	Roberto Macias	Pass	N/A	N/A	Yes	

3.4.2 ICM Operator Drill

Prior to hard launch of the system, an ICM operator drill was conducted. During the drill a typical incident and response plan process was used to let the operators use the system and to evaluate their knowledge of the process, the system, and to ask questions. The drill was very valuable for the operators and the development team. The operators had to use the real system to respond to an incident, instead of seeing the system. The hands-on use of the system provided the operators the opportunity to make small changes to the user interface and process prior to go-live.

The feedback received from the operators allowed the developers to make changes to the system so that it was more user friendly and would be more useful for the operations of the corridor.

3.4.3 Change Management

When changes are requested by the users, a change management process is followed. As part of the system deployed, a pre-production environment was configured which allowed all changes to be tested prior to promotion to the production environment. A pre-production environment mirrors the existing production environment, so changes can be tested and impacts to the entire system can be determined. This process ensures that the production system will experience minimal downtime during maintenance and promotion of changes.

3.5 Operations and Maintenance Process

The Operations and Maintenance (O&M) Plan describes how the ICMS will be used in daily transportation operations and maintenance activities. The Plan addresses the activities needed to effectively operate the US-75 Corridor in a coordinated, multi-modal basis including:

- System operational vision, goals, objectives and strategies
- Agencies who will be responsible for operations and maintenance
- The capabilities of the operating agencies
- Systems and tools that will be involved in operations and maintenance
- Policies and procedures that are to be used in operations and maintenance
- Daily operational activities and procedures
- Operating and Maintenance Costs and Funding Sources
- How system performance will be measured
- An organizational framework for ongoing management and coordination
- Actions needed to transition to full operations including training needs

The Operations and Maintenance Plan is separate from operating manuals and maintenance manuals used in daily operations by agencies or provided by system or component developers or suppliers. Those documents describe detailed procedures, whereas this Plan describes resources, organization, responsibilities, policies, and activities.

3.6 Lessons Learned from the process

Systems Engineering (SE) is about iteration, and learning and improving the previous work completed by the team. Specifically, the Dallas ICM stakeholders learned the following from following the SE process:

- ➢ Rigor (strict precision) is the goal of the SE process
  - Define the process you will use well in your SEMP
  - Follow the process so everyone knows what is happening and to manage expectations
  - Know the disciplines that will be needed (software development, incident response expertise, etc.)
  - Ensure quality of products
- ➢ A multi-agency system that utilizes data from multiple sources needs strict configuration management to identify changes in both the ICMS and the individual supporting systems that might affect current and future operation.

4 Demonstration Results

The operations of the ICM System during the 18 month demonstration project included a 6-month soft launch period, and a hard launch which began on October 28, 2013[3]. The yearlong demonstration project was extended through December 2014 due to the system upgrade of the Advanced Transportation management System (ATMS) software at the Daltrans facility during the month of October 2014. The Dallas ICM operating agencies continued to use the system after the demonstration period ended.

The following map displays the incidents which occurred in the corridor, and triggered a response plan by the Decision Support System by location. The map shows the cross-streets along the US-75 corridor, and the number of response plans implemented by direction and cross-street.

[3] Some features or peripheral systems continued to be added after the hard launch, such as the LRT parking management system, LRT real-time passenger load information system, additional implementable DSS response plans, and DSS prediction capability.

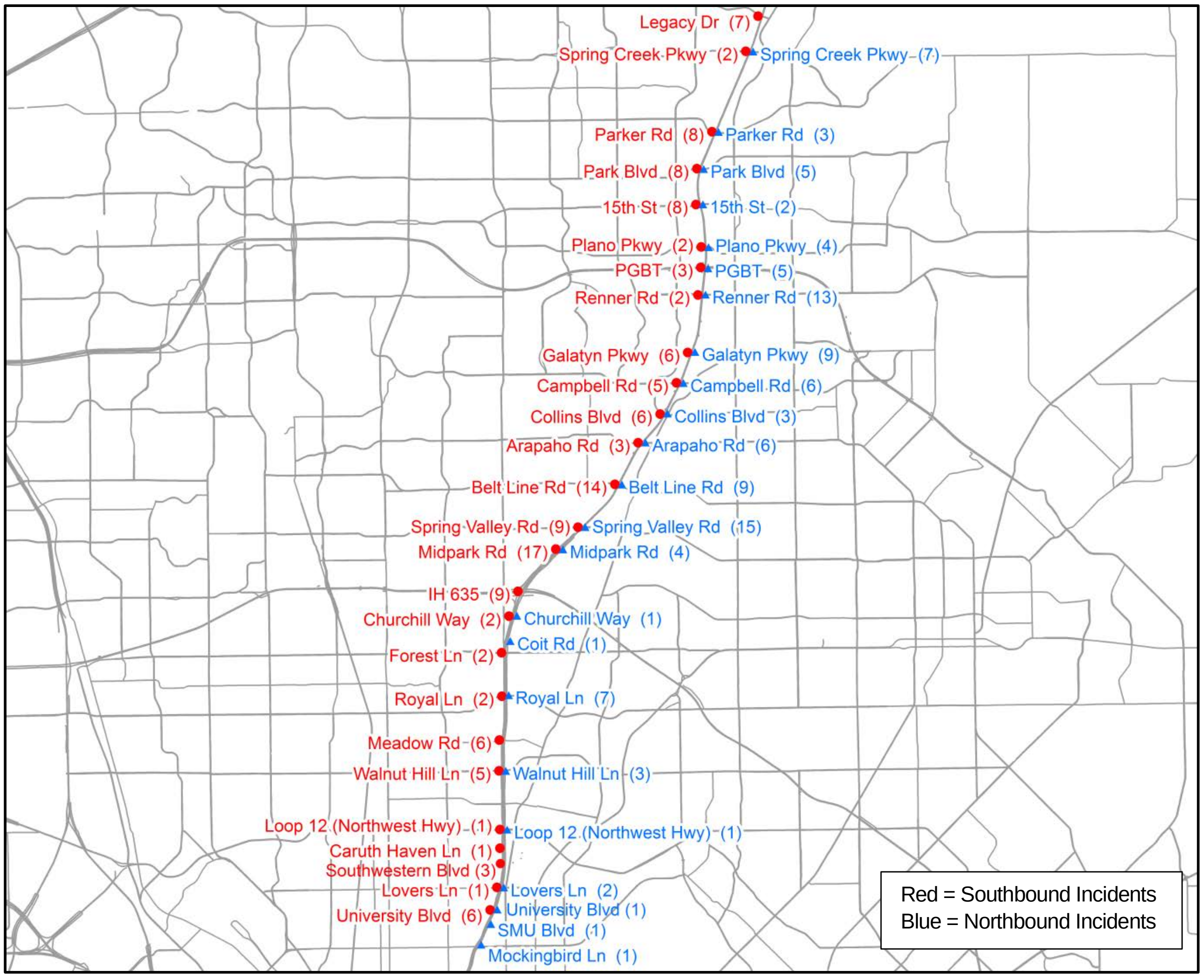

Figure 6: Response Plans implemented during the Demonstration Phase by direction and location. (Source: Dallas Area Rapid Transit, December 2014)

The following table and chart displays the number of incidents within the corridor by month and the number of response plans recommended by the system for implementation. In October 2014, at the end of the demonstration phase, TxDOT upgraded their ATMS software at the Daltrans facility. Data from TxDOT on incidents, freeway speed data, and infrastructure status data was unavailable from the system during this time. The demonstration phase of the project was extended through December 2014 to compensate for this downtime.

Table 5: Response Plan Recommendations during Demonstration

Year	Month	Events During Operating Hours (6a – 6p)	Plan Recommendations	Implementable Plans	Information only plans
2013	October-13	131	34	5	29
	November-13	73	21	0	21
	December-13	101	24	8	16
2014	January-14	134	34	9	25
	February-14	94	21	4	17
	March-14	159	29	3	26
	April-14	104	27	6	21
	May-14	112	41	2	39
	June-14	155	15	3	12
	July-14	114	12	3	9
	August-14	122	18	N/A	N/A
	September-14	130	26	8	18
	October-14	N/A	N/A	N/A	N/A
	November-14	48	3	1	2
	December-14	50	14	3	11

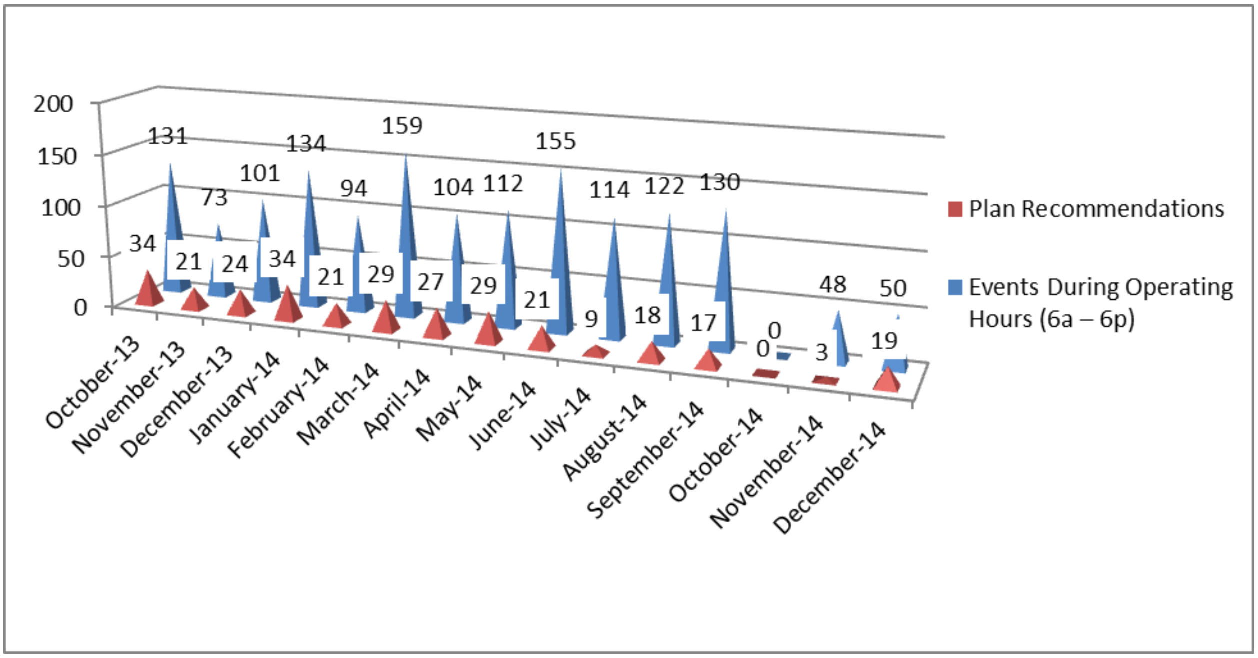

Figure 7: Response Plan Recommendations during Demonstration (Source: Dallas Area Rapid Transit)

The other major operational component of the ICM demonstration project is the 511DFW system. During the 18 months of the operations, the usage of the 511 system has been relatively consistent. Consistent marketing and public information on the system has not been robust, which has limited the exposure of the 511 system to the public. Personalized 511 services, through the My511 features were limited to 243 subscriptions by the end of the demonstration period. The 511 program is being expanded to include a Mobile App for smartphones and devices, which we believe will increase the usage and exposure of the 511 system. The following table shows the usage of the 511 system by month during the demonstration phase.

Table 6: 511DFW Usage

Month	Unique visitors (website)	Number of visits (Website)	Pages Views (Website)	Hits (Website)	Total Calls IVR
Oct-13	16,271	19,191	395,531	1,624,544	13,855
Nov-13	7,007	8,600	334,246	923,949	13,860
Dec-13	3,594	4,460	319,113	596,901	18,437
Jan-14	1,283	1,743	237,759	316,854	12,468
Feb-14	1,203	1,577	219,327	293,708	11,298
Mar-14	1,306	1,641	261,226	339,763	12,765
Apr-14	1,050	1,518	2,088,350	2,145,592	11,677
May-14	857	1,241	439,038	488,951	12,303
Jun-14	848	1,219	531,951	576,580	11,867
Jul-14	1,011	1,372	247,795	306,555	10,816
Aug-14	808	1,068	224,595	273,987	10,857
Sep-14	861	1,121	235,142	283,414	10,698
Oct-14	1,122	1,517	253,476	323,621	11,686
Nov-14	1,113	1,385	214,963	276,126	10,824
Dec-14	1,051	1,310	233,355	293,264	11,086

5 Lessons Learned

This section provides a discussion of the main lessons learned for the project and recommendations for others considering Integrated Corridor Management, with lessons learned on each phase of the project provided in the subsections below.

The lessons learned for the overall project deal mostly with the institutional issues and relationships which any region considering ICM should address. ICM programs should build on existing institutional arrangements; this is a key to building consensus. By setting expectations, and defining roles and responsibilities, regions can address the institutional issues of ICM from the beginning of the program. For ICM programs to be successful all agencies involved need to be committed to the program, and have some benefit to their agency in order for ICM programs to succeed.

The easiest way for an ICM program to begin is through data sharing. This could be as simple as discussing operations or deploying a system to share data among agencies. Our suggestion for starting and building an ICM program is to plan and discuss how you want the system in the short term, but also plan for future expansion and consider the geographic region, systems involved, agencies, and applications that might be needed for a future ICM. ICM must be in your regional ITS strategic plan, so that agencies are committed and understand how the program fits into the overall ITS strategy for their region.

5.1 Concept of Operations/ Requirements

The Concept of Operations and Systems Requirements phase is used to envision the ultimate working system. This includes determining who is in charge up front; the resources needed by each agency, and preparing regional agreements and policies in advance. Our experience shows that regions should not start unless there is realization that the partners will have to fund this in the future.

Stakeholders must be involved at all stages of development, and invest their time and thoughts into the Concept of Operations. This is done to ensure that the stakeholders understand and agree on what the system will be, what agency needs it will fulfill, and how it will impact their operations. One of the important factors of any change in operations and system is to identify how success will be calculated, and how it will be measured. Stakeholders must agree to what is a realistic goal for ICM, and can and how will it be measured.

5.2 Detailed Requirements

Once the Concept of Operations and Systems Requirements were completed, the next step was to refine and finalize the detailed requirements prior to design. As part of the project's SEMP, we documented our methodology for developing and de-composing requirements. Requirement development should be iterative. Agencies developing requirements should start with the user needs to define the high-level requirements of the system and then decompose the requirements to a more detailed level.

One of the more important activities is to develop action verbs list and definition. This ensures that everyone has the same understanding of what the requirement and words mean. The key attributes of a well-formed requirement are that it is necessary, unambiguous, complete, correct, feasible, and verifiable. Requirements must trace back to their source, so that stakeholders can see what led to their inclusion in the System Requirements Specification. Stakeholders must understand the requirements, agree that the specific statement of the requirement matches their understanding of what their needs involve, and concur that the requirements all have the key attributes (necessary, unambiguous, complete, correct, feasible, and verifiable) before the development process proceeds.

One of the issues our team faced in tracking and developing requirements is that tools available to develop and document requirements are not easily available. Commercial products are available, but are expensive and may not meet your needs. We ended up developing an Access database with customized interfaces for the requirements phase which used the action verb lists, the subsystem names and various standard terms to have the database engine write the requirements for the team. This allowed multiple authors to write requirements, such that all requirements were written in the same format with the same words. This database was then used for traceability during the design, development, and testing phases.

5.3 Design

As with all phases of the systems engineering process, the design development should be iterative; designers should start at high-level and continue to develop more and more detail. Our approach included prototyping user interfaces, and providing process diagrams to the stakeholders so that they could understand the design more easily, especially for non-technical people.

The design process we followed included the following activities:

1. Define the Architecture
    - Define a consistent logical architecture – capture the logical sequencing and interaction of system functions or logical elements
    - Partition system requirements and allocate them to system elements with associated performance requirements – evaluate commercial off-the-shelf (COTS) solutions that already exist
    - Identify interfaces and interactions between system elements (including human elements of the system) and with external and enabling systems
    - Define verification and validation criteria for the system elements
2. Analyze and Evaluate the Architecture
    - Evaluate COTS elements for compatibility with the design

- Evaluate alternative design solutions using the selection criteria established
- Support definition of the system integration strategy and plan

3. Document and Maintain the Architecture
    - Document and maintain the architectural design and relevant decisions made to reach agreement on the baseline design
    - Establish and maintain the traceability between requirements and system elements.

5.4 Development

Once the design phase is completed and the design is approved, the development phase began. Our approach to development included showing the system during early stages and having mock ups of the software being developed so that users and stakeholders can envision the system and corrections can be done early in the process.

As part of our hardware design, we decided to include a pre-production and production environment. The pre-production environment is helpful for development and future enhancements, and can be used to demonstrate and test any changes prior to promotion to the production environment.

The development team for the ICMS included multi-vendors, which can be a challenge to manage and coordinate. It is recommended that a lead system integrator be decided so that technical decisions can be done by a single entity – instead of multiple vendors developing software without coordination. Our lessons from this experience include:

1. Other development needs to be well coordinated, especially if deployment of hardware in the field will impact the schedule and the availability of systems to test. Our system was designed to include automatic vehicle location (AVL) and automatic passenger counting (APC) information from transit, but those systems and data were not available until after the soft-launch.

2. Interfaces can have a tremendous impact on the development time, and the way the system works. In several instances, the interfaces to systems were found to be insufficient because they did not include the expected data. For instance, the TxDOT C2C interface did not include lane by lane information, so a separate interface was required to be developed for another system which did provide that information.

3. Since multiple vendors were developing systems, it is important to understand everyone's schedules so that the completion of the overall system can be completed on schedule.

5.5 Testing

As previously discussed, multiple steps in the testing phase were completed. This included unit testing by the developers, integration testing by the development team, and system acceptance testing. Our experience shows that the development team should provide results of all previous unit and integration testing, prior to final integration testing. Prior to Systems Acceptance Testing, the developers should provide walkthrough and training of the system. Stakeholders should observe and run test scripts for SAT, and provide a consensus decision by all agencies that system was accepted and ready for operations. Lastly, operations should begin once all punchlist items are fixed.

5.6 Operations and Maintenance

For operations and maintenance of the system, stakeholders should realize that the system is always evolving -- crash patterns and travel patterns change due to construction, the economy changes, and the transportation network changes. During the final months of the demonstration project, the TxDOT ATMS software was replaced with a new version. This caused data to be unavailable for almost a two-month period. This demonstrates that the stakeholders need to be flexible and understand that ICM is a process, and it takes time.

6 Conclusions

Over the 18 month operations phase of the project, the ICM system has performed well and provided benefits to the stakeholder agencies and to the public within the region. The ICM system has provided the operators a better picture of the transportation environment within the corridor by providing data on all modes and agencies activities. The coordination of response plans for incidents has improved as the system is used more frequently and the maturity of the data, DSS, and operational processes have evolved.

The stakeholder agencies have agreed to continue to support and fund the continuing operations of the ICM and 511 systems for the region. Other agencies within the region have also asked to be a part of the system and integrate their data into the ICM and 511 systems.

7 Recommendations

The USDOT has used the ICM demonstration project to further the knowledge and provide technology transfer on the ICM program. There are tools which are needed by the industry to improve these types of programs and provide for a standardized approach to deploying ICM systems. Based on the experience the Dallas team has received over the 8 years of the ICM program, we would recommend the following:

- System engineering tools are needed for development of the requirements and design of transportation systems. Our team developed a requirements tracking database, and utilized Visio for drawing detailed data flow diagrams. A tool is needed which provides standard templates and databases for ICM systems, similar to the SET-IT tools developed for the connected vehicle program, which automatically tracks the diagramming to elements within the requirements database.
- Document templates for all phases of the system engineering lifecycle are needed, so that future ICM projects do not need to invent content and formats. During the ICM demonstration project, the FHWA Systems Engineering website was used for reference, however, some phases of the process do not have sample documents and templates that were needed. The Dallas team utilized other industry templates for documents and processes.

8 List of Acronyms and Glossary

- ATIS – Advanced Traveler Information System
- ATMS – Advanced Transportation Management System
- ARDT – Arterial Detection Subsystem
- AVL – Automatic Vehicle Location
- C2C – Center-to-Center
- CAD – Computer Aided Dispatch
- CCTV – Closed Circuit Television
- Con Ops – Concept of Operations
- DalTrans – Dallas Transportation Management Center
- DART – Dallas Area Rapid Transit
- DMS – Dynamic Message Sign
- DNT – Dallas North Tollway
- DSS – Decision Support System (also Decision Support Subsystem)
- ERD – Entity Relationship Diagram
- ETC – Electronic Toll Collection
- FHWA – Federal Highway Administration
- FTA – Federal Transit Administration
- FTP – File Transfer Protocol
- GIS – Geographic Information System
- HOV – High Occupancy Vehicle
- HTTP – Hypertext Transfer Protocol
- HTTPS – Hypertext Transfer Protocol Secure
- ICD – Interface Control Document
- ICM – Integrated Corridor Management
- ICMS – Integrated Corridor Management System
- IEEE – Institute of Electrical and Electronics Engineers
- INCOSE – INternational Council On System Engineering
- INFR – Infrastructure
- ISP – Information Service Provider
- ITS – Intelligent Transportation System
- IVR – Interactive Voice Response
- JMS – Java Messaging System
- LBJ – Lyndon Bayne Johnson
- LRT – Light Rail Transit
- LRV – Light Rail Vehicle
- MS/ETMC – Message Set for External TMC to TMC Communication

- MOD – ICM Model Subsystem
- NCTCOG – North Central Texas Council of Government
- NTTA – North Texas Tollway Authority
- P&R – Park & Ride
- PARK – Parking Management
- PDA – Personal Data Assistant
- PGBT – President George Bush Turnpike
- RITA – Research and Innovative Technology Administration
- RTC – Regional Transportation Council
- SAN – Storage Area Network
- SOAP – Simple Object Access Protocol
- SNMP – Simple Network Management Protocol
- SMS – Short Message Service
- SMTP – Simple Messaging Transport Protocol
- SRS – System Requirement Specification
- SSL – Secure Sockets Layer
- TCIP – Transit Communication Interface Protocol
- TCP – Transmission Control Protocol
- TLS – Transport Layer Security
- TMDD – Traffic Management Data Dictionary
- TRE – Trinity Railway Express
- TxDOT – Texas Department of Transportation
- USDOT – United States Department of Transportation
- VXML – Voice eXtensible Mark-up Language
- W3C – World Wide Web Consortium
- WDMS – Web-based Database Management System
- WSDL - Web Services Description Language
- XML – eXtensible Mark-up Language

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