Integrated Corridor Management (ICM) Program

Major Achievements, Key Findings, and Outlook

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16. Abstract The purpose of this Integrated Corridor Management (ICM) Program Overview Report is to provide an executive level synopsis of the United States Department of Transportation (USDOT) ICM demonstration project (specifically) and program in general, including an explanation of the ICM concept and program structure, key accomplishments and findings, future needs, and the outlook for national deployment. Additionally, the report addresses questions agencies may have about planning and deployment of ICM and where to find additional resources to learn more about ICM.		
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LIST OF ACRONYMS

Acronym	Definition
Aimsun	Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks
AMS	Analysis Modeling and Simulation
ATCMTD	Advanced Transportation and Congestion Management Technology Deployment
ATDM	Active Transportation Demand Management
BCR	Benefit/Cost Ratio
BRT	Bus Rapid Transit
CALTRANS	California Department of Transportation
ConOps	Concept of Operations
DART	Dallas Area Rapid Transit
DIRECT	Dynamic Intermodal Routing Environment for Control and Telematics
DMS	Dynamic Message Signs
DSS	Decision Support Systems
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GIS	Geographic Information Systems
HOT	High Occupancy Vehicle
ICM	Integrated Corridor Management
ICMS	Integrated Corridor Management Systems
ITS	Intelligent Transportation Systems
IVR	Interactive Voice Response
KTT	Knowledge and Technology Transfer
MOD	Mobility on Demand
MPO	Metropolitan Planning Organization
NITTEC	Niagara International Transportation Technology Coalition
ROW	Right-of-Way
SANDAG	San Diego Association of Governments
SOV	Single Occupancy Vehicle
SR	State Route
SyRS	System Requirements Specification
TMDD	Traffic Management Data Dictionary
TMC	Transportation Management Center
TSMO	Transportation Systems Management & Operations
USDOT	United States Department of Transportation
UTA	Utah Transit Authority

EXECUTIVE SUMMARY

Integrated Corridor Management (ICM) offers improvements in the efficient movement of people and goods through institutional collaboration and aggressive, proactive integration of existing infrastructure and systems along major corridors. This report is an executive level synopsis of the United States Department of Transportation (USDOT) ICM demonstration projects (specifically) and program in general, including an explanation of the ICM concept and program structure, key accomplishments and findings, future needs, and the outlook for national deployment. This report can also double as a starting point if you are considering ICM deployment in your region. This report references key considerations, documentation, evaluation findings, and other resources that are useful for ICM planning, deployment, and operations. Some of the key takeaways for ICM are as follows:

- It is important to differentiate that ICM is not traditional "detouring," but rather, a holistic approach to enable the corridor, and not just a route, to absorb the impact of an atypical event (e.g., an hours-long shutdown or newsworthy major event, and not just a local fender bender).
- ICM fosters communication, collaboration, and trust among network operators that is leveraged to provide event response far beyond what corridors had initially.
- A full scale Integrated Corridor Management System (ICMS) deployment is not needed to initiate ICM in a corridor. Corridor stakeholders should not be afraid to plan big but deploy incrementally as resources become available.
- Improved ICM data sets are useful to identify trends in corridor events. Those event trends coupled with improved coordination among corridor network operators are proving helpful to identify planning needs for corridors and gain funding support for needed capital improvements.

Highlighted in this report are the two ICM demonstration sites; the I-15 corridor in San Diego, California, and the U.S. 75 corridor in Dallas, Texas; both began operational implementation circa 2013. An evaluation[1] of these projects found that the improved interagency cooperation and coordination brought about by going through the ICM process was a big success. Both San Diego and Dallas created a fundamental paradigm shift in the management of their respective corridors by creating strong multi-jurisdictional partnerships that set the foundation for a regional corridor management mindset – based on a platform of strong institutional, technical, and operational integration. Key findings that emerged from the evaluation of these demonstrations include the following benefits:

- Regional operations awareness of corridor congestion and incidents improved significantly through regional data sharing.

[1] Battelle, Integrated Corridor Management Initiative: Demonstration Phase Evaluation.

- Incident reporting details improved substantially in both regions.
- Corridor operators reported better situational awareness of corridor operating conditions, although there were opportunities to improve.
- Incident and congestion specific traveler information provision improved.
- While employing different levels of human involvement, the Decision Support System (DSS) at both sites proved to be valuable for better situational awareness, decision-making, and response coordination.

The evaluation team faced several challenges in capturing and validating actual ICM impacts. Several other regional improvement projects, including infrastructure capacity expansion projects, were implemented in parallel with the ICM projects in both regions. Thus, it is to be expected that there were broader impacts and improvements that changed the dynamics of the corridor operations before and after ICM. The mobility analysis was driven primarily from the results of the post-deployment modeling and simulation activity, since a before-after analysis using field data was not pursued due to lack of sufficient ICMS activations and the lack of comparable incidents representing before and after ICM deployment. In addition, the modeling tools used in San Diego and Dallas were different from each other, making it difficult to draw a comparison between the two sites. This report also highlights several challenges in applying benefits and costs analysis to an ICMS relating to the potential tendency to underestimate ICM benefits and overestimate ICM costs. Agencies should understand these evaluation challenges as they move forward with ICM planning and implementation efforts.

Further insights and lessons learned are also captured from thirteen (13) ICM Deployment Planning Grant sites that were awarded pre-implementation grants circa 2015. Several other important outcomes of the ICM program are indicative of its success, including the emergence of locally-funded ICM planning and deployment efforts and the sponsorship of additional ICM research activity (for example, NCHRP projects or State DOT research not specifically funded by USDOT). These activities provide another indication that the ICM concept is becoming more accepted as good practice. While national deployment of ICM is far from complete, motivation to deploy ICM has been established and embraced among many regional mobility managers across the country and there is considerable effort to include ICM in Transportation Systems Management and Operations (TSMO) planning.

This report also discusses the current state of the practice in ICM and conveys how ICM deployments can help to lay a foundation for future transportation advancements. Finally, next steps are described that include Knowledge and Technology Transfer (KTT) activities to support mainstream deployment informed by today's ICM practitioners.

CHAPTER 1. INTRODUCTION TO ICM

Traditionally, operations in urban transportation corridors are handled independently by each transportation network operator within a corridor, focused on their individual systems rather than the corridor as a whole. For example, the State DOT would focus on the freeway system that they own and operate, and the city DOT focuses on their arterial system and managing the signals that they own, while the transit operator manages their fleet that operates in the same corridor, but autonomously, without regard to traffic disruptions on the freeway or arterial system or the actions of the State or city operators. These agencies are mostly *reactive* to any incidents on other systems. They may collaborate or interact to some extent to deal with incidents or pre-planned events occurring within the corridor, but each transportation network operator mostly handles day-to-day operations independently, without communication with other transportation network operators. As congestion becomes heavier and incidents increase within corridors, this independent operation of transportation networks is becoming less effective in meeting the transportation needs within a corridor.

The vision for ICM is that transportation networks will realize significant improvements in the efficient movement of people and goods through institutional collaboration and aggressive, proactive integration of existing infrastructure and systems along major corridors. Through an ICM approach, transportation professionals manage the corridor as a multimodal system "whole" and make collaborative operational decisions for the benefit of the wider corridor.

BACKGROUND

In 2006, the USDOT initiated the ICM Demonstration Program to research the integration of the operations of all transportation networks (e.g., freeway, arterial, transit, rail, etc.) within a corridor, to maximize the effectiveness of their use and to mitigate the effect of incidents that affect the movement of people, goods, and services within the corridor. This integrated operation of corridor transportation networks became fundamental to the development of Integrated Corridor Management Systems (ICMS). After a national search for candidate corridors conducted through a competitive 3-stage process, the

Integrated Corridor Management Provides:

- Communication, collaboration, and trust among network operators that goes far beyond what regions had initially
- Consensus business rules and agreements for corridor operations
- Integrated, active management approach
- A cross-network understanding of corridor operations that did not exist before
- Expanded network data sets and data sharing that did not exist before; better integration
- Identification of network/corridor problem areas and consensus support for resolving those problems

USDOT initiated the first ICMS with deployment projects in two corridors – U.S.75 in Dallas, TX and I-15 in San Diego, CA. Evaluations of these ICM demonstration projects were completed in 2017. Additionally, the USDOT provided seed funding to 13 more deployment planning sites to further facilitate ICM deployment throughout the country. All the ICM sites were surveyed to elicit their key concerns and findings with planning, developing, and deploying ICM. A summary of these program activities and their outcomes will be discussed in this ICM Program Overview Report. Additionally, the USDOT is providing guidance, based on outcomes of the ICM program, to assist agencies in implementing mainstream ICM and creating supporting analysis tools, approaches, and technical standards.

This report is organized as follows:

- Chapter 1 is the introduction.
- In Chapter 2, the major ICM research program achievements are described, including key findings from each phase of the program, including subsections on:
    - Foundational Research
    - Initial Deployment Efforts (the Pioneer corridor site process)
    - Promoting ICM Deployment (planning grants)
    - Ongoing ICM Knowledge Transfer
- Next, Chapter 3 provides a short discussion of the overarching findings and outcomes of the ICM program.
- Chapter 4 conveys how ICM deployments can help to lay a foundation for future transportation advancements and contains high-level suggestions for research and knowledge transfer activities.
- Appendix A provides more depth on the important topic of ICM Decision Support Systems (DSS), including challenges, constraints, and suggestions for research.
- Appendix B provides a question-and-answer format for frequently asked questions about the ICM program. **Readers may find this section particularly useful in answering straightforward FAQs that we've heard at our workshops and meetings.**
- Appendix C is the acknowledgements section.

CHAPTER 2. ICM RESEARCH PROGRAM ACHIEVEMENTS AND FINDINGS

The ICM program began with two main objectives 1) to demonstrate and evaluate pro-active integrated approaches, strategies, and technologies for efficient, productive, and reliable operations; and 2) to provide the institutional guidance, operational capabilities, and ITS technical methods needed for effective Integrated Corridor Management. This chapter discusses how these objectives were met. The major phases of the USDOT ICM program are shown in Figure 1.

The USDOT initiated the ICM Program to research the integration of transportation networks within urban travel corridors. The first phase of the program was the foundational research phase, discussed briefly in Chapter 2, which involved research into the institutional, operational, and technical integration of individual corridor networks and development of ICM strategies to facilitate this integration; the goal was to see what would be needed in terms of cooperation, harmonization, and utility when formerly stove piped agencies would work in concert. Next, corridor tools and ICM strategies (e.g., ramp metering, congestion pricing, cross jurisdictional signal coordination and optimization, transit priority, and enhanced traveler information) were developed along with a framework created to model, simulate and analyze the strategies. After this initial research, the program solicited actual corridor stakeholders through a 3-stage competitive funding process to develop concepts for integrated operation of their corridor networks, analyze them to determine potential benefits, and then demonstrate them. Because these agencies were breaking new ground, their corridors were referred to as “Pioneer sites.” The Pioneer site process is described later in this chapter. Briefly, Stage 1 began with the development of concepts of operations (ConOps) and system requirements in eight urban areas. Stage 2 involved analysis, modeling and simulation (AMS) of three corridor networks (Dallas, San Diego, and Minneapolis). Stage 3 consisted of awarding two sites full deployment grants; U.S.75 in Dallas, TX, and I-15 in San Diego, CA, thereby providing “proof of concept” demonstrations.

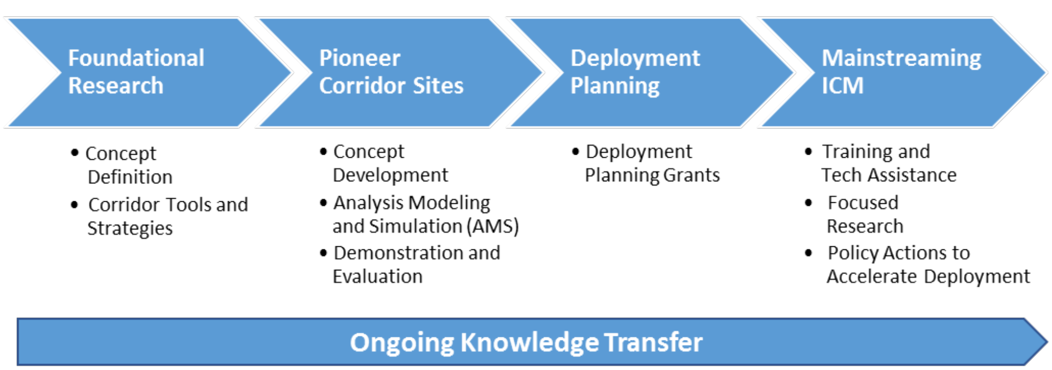

Figure 1. Chart. Major phases of the USDOT ICM research program.
(Source: USDOT)

Building off the successful Pioneer site process, USDOT initiated an ICM Deployment Planning Grant Program. The USDOT provided 13 sites up to $200,000 per site to enable those areas to develop "pre-implementation" documents (e.g., ConOps, Systems Engineering, and Project Management plans) and begin active planning for integrated corridor management systems, requiring 20% match by the local jurisdiction. This program also provided an opportunity for USDOT to test the effectiveness of the knowledge and technology transfer products (KTT) and activities that had been developed to date. The grant program results are discussed in Chapter 2 under "Promoting ICM Planning and Deployment."

As shown in Figure 1, knowledge transfer activities have been an ongoing part of every program phase. The final phase of the ICM research program is referred to as "Mainstreaming ICM" and consists of the continued knowledge transfer of ICM concepts, methods, tools, and products, to encourage the adoption of ICM into everyday transportation planning, project development, and operations. Mainstreaming activities also include focused research to assist with deployment challenges and policies to encourage deployment, such as establishing ICM as an eligible or even preferred project type in various deployment grant programs. More information on the original research plan can be found on USDOT's ICM website[2]. To learn more about ICM and view materials developed as part of the ICM Initiative, visit the ICM Knowledgebase[3].

FOUNDATIONAL RESEARCH AND ICM CONCEPT

The original concept of ICM was defined in a white paper entitled "Conceptualizing Integrated Corridor Management". This paper is included as Appendix A in the "Integrated Corridor Management: Implementation Guide and Lessons Learned (February 2012)." [4] That historical document defines the original ICM concept of operations and identifies some early "startup" lessons learned. **However, be advised that we intend to publish an updated companion executive summary called "Mainstreaming ICM: An Executive Level Primer" in late 2019 which intends to address the questions "how do we get started," and "how and why should our region invest in ICM," and, for that matter, "what constitutes a 'candidate' ICM region?"** We strongly encourage startup regions to pair this document, which explains to executives *what* ICM is, with that one that is planned, which will explain how to adopt ICM in your region.

The ICM concept paper hypothesized or envisioned that managing a corridor in an integrated fashion requires corridor network operators to develop strategies in four areas and implement those strategies in one or more areas. The four areas include:

- Demand Management

[2] https://www.its.dot.gov/research_archives/icms/icm_plan.htm

[3] ICM Knowledgebase is available at https://www.its.dot.gov/research_archives/icms/knowledgebase.htm.

[4] https://rosap.ntl.bts.gov/view/dot/3375

- Load Balancing
- Event Response
- Capital Improvement

Within the first three strategic areas (demand management, load balancing, and event response), corridor operators can develop control strategies (tactics or actions) and procedures for implementing those strategies. For the capital improvement area, corridor operators do not develop control strategies; instead, recommendations for capital expenditures for facility improvements are identified and pursued. Corridor operators may be able to implement some recommendations (e.g., the installation of ITS) more easily than others.

One example of an envisioned strategy for ICM is having the ability to quickly enable load balancing during an unplanned major congestion event on a freeway. For example, if a chemical spill occurs on the freeway, operators would have the capability to quickly enact not only preapproved *route shifts* to divert traffic onto arterials, commonly known as pre-determined detours, but also to enact preapproved *mode* shifts amongst the stakeholder groups to initiate remediation without delay. Further, in addition to enacting (and *enabling* the detours with options and signal progression, et al) the road detours, the stakeholders simultaneously notify travelers of available transit options and encouraging alternate travel times to accommodate their planned trips. It is important to differentiate that this is not traditional "detouring," but rather, a holistic approach to enable the corridor, and not just a route, to absorb the impact of an *atypical* event, e.g., an hours-long shutdown or newsworthy major event, and not just a local fender bender. **This concept makes use of the term "travel shed." Think of a "watershed." In a travel shed all trips (instead of tributaries) combine to absorb the closed freeway and all trips are candidates to be messaged to avoid it in the first place, or pro-actively enabled to get around it.** A travel shed, therefore, is defined to be the area subsumed by a cordon, such that all trips therein would otherwise orient to the subject anchor highway if not for the congestion or the propensity for even a minor event on that facility to induce bumper to bumper gridlock, thus requiring the adjacent arterials, cross streets, signals, and systems to mitigate and absorb the subject ICM event. The focus should be on moving travelers through the corridor, not just vehicles. Thus, the real-time advantage of ICM is not simply to identify a detour route, but to inform and empower all corridor travelers to take advantage of the implemented management strategies. The management strategies may include encouraging mode shift, traveler information messages, signal progression, "opening" HOV lanes if necessary, adjusting (or suspending) ramp metering or part-time shoulder use, and/or relaxing peak hour travel and parking restrictions during the duration of the event. Once the event has subsided, and the anchor highway returns to nominal condition, then individual traffic and transit systems return to their normal day to day operation. Travelers are kept informed about the best trip options every step of the way. These types of strategies were demonstrated with varying degrees of success by the Dallas and San Diego demonstration sites.

One final idea; think of ICM in terms of an *unplanned* special event. A planned special event, like a college or pro game day, or a route-closing parade, requires multi-agency coordination, many stakeholders, and a great deal of pre-planning to mitigate the traffic impact. It effectively shuts down a region, or at least consumes it, sometimes for hours. Consideration is given to changing signals, or opening or closing ramps, or appropriating reverse lanes, or invoking dynamic messaging, and enabling all manner of special activities to absorb the special event, including to promote use of transit (e.g., bus bridges) and subway (where available) to mitigate the crowds. But what if that planned event were to occur, in essence, without planning? ICM, which is most effective in peak periods, and for already-congested corridors, constantly "searches" for *atypical* congestion, often caused by an immediate non-recurring event or even beyond-normal recurring patterns. The decision support system (DSS – see Appendix A for a fuller explanation) subsequently – and in real-time – recommends and then invokes the best of several alternate mitigation plans, sort of if the "unplanned" event had been planned all along. The many agencies' pre-discussed "business rules" (also explained further below) and mitigations are begun immediately, and not, as in the past, subject to delay from discussion, inaction, and approvals needed up the chain, which would only serve to exacerbate an already-impacting event. The incident still occurs, and is still impacting, but whether a "planned" event, or an "unplanned" incident, but mitigated by ICM, it is respectively lessened.

PIONEER CORRIDOR SITES DEVELOPMENT AND DEMONSTRATION

This section describes the results of the Pioneer site process, including the initial concept development work; the analysis, modeling and simulation (AMS) activity; deployment of their initial concepts; and the independent evaluation.

Confirming the Initial Concept and Baseline Requirements

The Pioneer Sites initially included eight regions (Dallas, Houston, Minneapolis, Montgomery County MD, Oakland, San Antonio, San Diego, and Seattle) that helped to mold the original operational concept of ICM. These regions submitted an initial ConOps and System Requirements outlining their vision of ICM and an ICMS. This initial work helped researchers to develop consensus on what ICM may include. These efforts identified that a successful ICM would include, among other things, the ability to:

- Manage the corridor as a system rather than individual assets
- Enable travelers to make informed travel decisions and dynamically shift modes during a trip
- Reduce travel delays, fuel consumption, emissions, and incidents
- Improve travel time reliability and predictability
- Optimize existing transportation infrastructure along a corridor, making transportation investments go farther

Figure 2 depicts the original ICM Pioneer Sites summary of strategies anticipated for their ICMS deployment. The Pioneer Sites ConOps and Requirements work helped confirm what a successful ICMS may include for each region.

Information Distribution

Site	Manual information sharing	Automated real-time data	Automated real-time video	Information clearinghouse	Pre-trip ATIS	En-route ATIS	Incident management system	Monitoring device shared control	ATIS database for external ISPs
Dallas		●	●	●	●	●	●		
Houston	●	●	●	●	●	●	●	●	
Minneapolis	●	●	●	●	●	●	●		●
Montgomery County	●	●	●	●	●	●	●		
Oakland					●	●	●		
San Antonio	●	●	●	●	●	●			
San Diego	●		●	●	●	●			
Seattle	●	●	●	●	●	●	●		●

Network Junctions

Site	Transit Signal Priority	Emergency Vehicle pre-emption	Multi-modal electronic payment	Transit hub connection protection	Multi-agency incident mgmt.	Ramp meters and traffic signals	Traffic signals and rail crossings
Dallas	●		●		●		
Houston	●	●	●		●	●	
Minneapolis	●	●			●	●	
Montgomery County			●		●		
Oakland	●	●	●	●	●	●	
San Antonio	●						
San Diego		●	●	●	●	●	
Seattle	●				●	●	●

Route/Mode Shifts

Site	Freeway to arterial—signal timings	Arterial to freeway—ramp metering	Modify transit priority parameters	En-route ATIS for route shifts	En-route ATIS for modal shifts	En-route ATIS for inter-modal shifts	Bus re-routing for major incidents
Dallas	●			●	●	●	
Houston	●	●	●	●	●	●	
Minneapolis	●	●	●	●	●	●	●
Montgomery County	●			●	●	●	●
Oakland	●	●	●	●	●	●	
San Antonio	●		●	●	●	●	
San Diego					●		
Seattle	●	●		●			

Manage Real-time/Short-term Demand/Capacity

Site	Lane use control	Transit- or emergency-only lanes	Adjust transit headways	Temporary transit service	Temporary parking lots	Temporarily rescind HOV/HOT	Temporarily increase HOV	Meter or close ramps	Truck-only lanes	Coordinate WZTC schedules	Variable speed limits	Modify toll/HOT pricing	Modify transit fares	Modify parking fees	Variable truck restrictions	Commercial traffic restrict/re-route
Dallas			●		●	●	●							●		●
Houston		●	●	●	●	●		●				●	●	●	●	●
Minneapolis	●	●	●	●	●	●		●		●	●	●	●	●		
Montgomery County	●		●	●		●				●						
Oakland										●						
San Antonio		●	●	●									●			
San Diego	●		●	●		●	●			●		●				
Seattle		●			●				●							

Long-term D/C

Site	Low-cost infrastructure changes	Re-rout rail transit	Special work hours during events	Peak spreading	Ride-sharing
Dallas	●		●	●	●
Houston					
Minneapolis					
Montgomery County					●
Oakland			●		
San Antonio					
San Diego			●	●	●
Seattle	●				

[Key: ● Planning to implement in ICMS]

Figure 2. Chart. Anticipated ICM deployment strategies for each concept development corridor location. (Source: USDOT)

Highlights of the Analysis, Modeling, and Simulation (AMS) Activity

The first activity for the pioneer sites was defining the initial concepts for ICM strategies in their networks. After this step, three pioneer sites (Dallas, TX, San Diego, CA; and Minneapolis, MN) undertook analysis, modeling, and simulation (AMS) to explore whether applying ICM strategies (such as ramp metering, congestion pricing, signal optimization, transit priority, and enhanced traveler information) to a transportation corridor in a truly active and integrated manner could improve mobility, reliability, and environmental impacts of transportation corridors. The three sites examined the implications of implementing a host of ICM strategies applied under conditions of varying demand along a transportation corridor. The analyses encompassed freeway, arterial, and transit facilities along the defined corridors and examined effects of ICM strategies applied under conditions of high, medium, and low demand. The AMS assessed the effects of ICM strategies both with and without traffic incidents (the largest cause of unexpected congestion) and other scenarios.

Findings across all three sites indicated that ICM would increase reliability and reduce travel time, delays, fuel consumption, and emissions in transportation corridors. Findings also indicated that benefits result when otherwise "stovepipe" agencies combine to cross-share information, resources, and solutions that benefit all. Further, the benefits of ICM appear to scale with travel demand and are especially meaningful under scenarios that unexpectedly constrain supply, such as traffic incidents.

One of the defining features of the ICM AMS methodology is that it helps agencies to understand system dynamics at the corridor level. It uses corridor-level performance metrics (e.g., trip-end travel times and systemic congestion metrics) rather than facility-level metrics (e.g., queues and delays on one facility) to evaluate and understand corridor performance. This is accomplished through the combined use of multiple classes of available modeling tools. Three classes of modeling tools – macroscopic, mesoscopic, and microscopic – are considered essential components of the AMS methodology and were used for this analysis. Figure 3 presents a graphical depiction of the geographic scope and interrelationships between these tools.

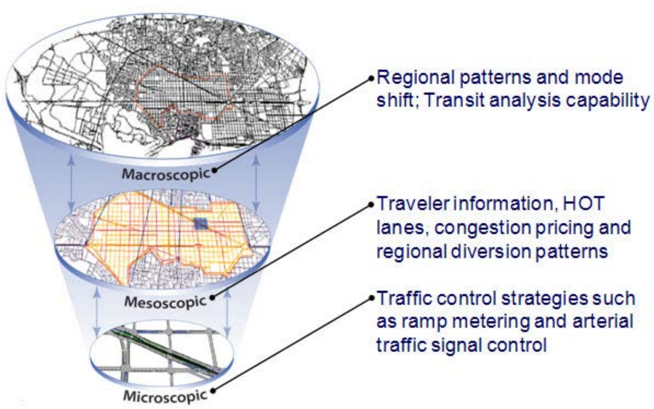

Figure 3. Chart. Geographic Scope and Analysis Capabilities of AMS Tools *(Source: USDOT, September 2009.)*

A major accomplishment of the ICM AMS work is that it generated improved analysis tools and methods for corridor analyses. These tools and methods assist system operators with analyses in five areas: mobility, reliability and variability of travel time, emissions, fuel consumption, and benefits and cost comparison.

The ICM technologies assist operators in gathering expanded data sets useful in managing corridor networks. Through the ICM AMS tools, this data is fused to provide managers with insight on conditions across the full travel shed of the corridor. Operators use this data and work together to implement predefined strategies and coordinate operations to manage the multimodal networks more efficiently and can provide truly "actionable" information to travelers such that they can alter trip (start) times, route choices, and mode choices on a sufficient scale to "soften" congestion hotspots, spreading demand more evenly across the network.

Conducting ICM AMS offers the following benefits[5]:

- **Invest in the right strategies.** The analysis offers corridor managers a predictive forecasting capability that most lack today to help them determine which combinations of ICM strategies are likely to be most effective and under which conditions.
- **Invest with confidence.** The 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.
- **Improve the effectiveness/success of implementation.** With this analysis, corridor managers can understand in advance what questions to ask about their system and potential combinations of strategies to make any implementation more successful.

The analysis provides a long-term capacity for corridor managers to **continually improve implementation** of ICM strategies based on experience.

Summary of the ICM Demonstration Sites

This section contains a summary of the two selected Pioneer ICM demonstration sites (Dallas and San Diego), including a description of the transportation corridor characteristics and needs, project partners, a corridor study area map, the proposed ICM strategies, and a discussion of the status of ICM operations in their regions.

Summary of the Dallas ICM project

A 28 mile stretch of the U.S.75 corridor in the Dallas-Fort Worth region (shown below in Figure 4) was selected as the demonstration site in Dallas.[6] The Dallas-Fort Worth region

[5] *Source: Integrated Corridor Management Modeling Results Report: Dallas, Minneapolis, and San Diego.*

[6] Source: Concept of Operations for the U.S.-75 Integrated Corridor, Dallas, Texas, March 2008.

was ranked as the 11th most congested region in the U.S.[7], with an expected population growth of one million residents every eight years.

Partners for the Dallas ICM project included:

- Dallas Area Rapid Transit
- City of Dallas
- Town of Highland Park
- North Central Texas Council of Governments
- North Texas Tollway Auth.
- City of Plano
- City of Richardson
- Texas DOT
- City of University Park

The U.S.75 Corridor serves: 1) commuter trips into downtown Dallas, via the freeway, bus routes, light-rail line, and arterial streets; 2) a significant number of reverse commuters traveling to commercial and retail developments in the northern cities and neighborhoods; 3) regional traffic during off-peak periods; and 4) interstate traffic into Oklahoma, since the freeway is a continuation of Interstate 45. The corridor also is a major evacuation route and experienced significant volumes during the Hurricane Rita evacuation in 2005. In Dallas, the inability to expand the freeways or arterials as a method to reduce delays caused by bottlenecks and incidents or to improve travel time reliability created a need to explore alternative congestion reduction strategies. Several features of the corridor study area made it an exemplary ICM testbed: an eight-lane freeway with continuous frontage roads, a concurrent-flow, High-Occupancy Vehicle (HOV) lane, light-rail line, transit bus service, park-and-ride lots, major regional arterial streets within approximately two miles of the freeway, toll roads, bike trails, and Intelligent Transportation Systems (ITS). The layout of the transportation network provided opportunities for strategic traffic diversion onto under-utilized frontage roads, arterials, or transit.

The originally envisioned strategies conceived by the Dallas ICM Team included:

- Decision-Support System
- Actionable traveler information
  - Interactive Voice Response (IVR) 511
  - Website
  - Email alerts
  - Comparable travel times
- Rerouting of traffic
  - Coordinated timing and adaptive signal control
- Mode Shift
  - Parking management
  - Real-time service adjustments

[7] Source: Schrank, D., B. Eisele, T. Lomax, and J. Bak, 2015 Urban Mobility Scorecard, 2015.

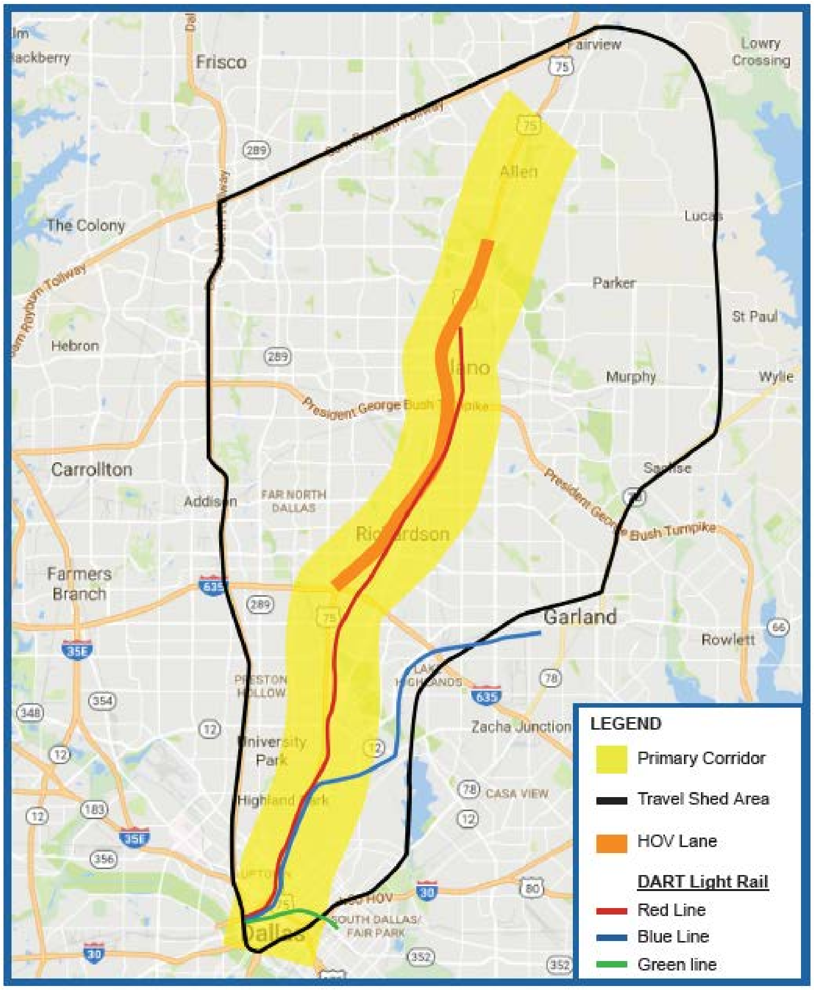

Figure 4. Chart. U.S.75 corridor network, Dallas integrated corridor management demonstration site. (Source: Google© Map Data, March 27, 2017)

The Dallas ICM team proposed an ICMS consisting of three main components including decision support, data management, and user interface functionality. Their system is still largely in place, although these components have changed from that which was originally envisioned. Perhaps the most visible change is that the Dallas ICM "champion" changed from Dallas Area Rapid Transit (DART) to TxDOT, for reasons that the project centered on the highway – U.S. 75 – over the rail line. The data management system, originally called SmartNet was replaced with a next generation product version called EcoTraffic and is still in operation. The data is shared among network operators through the 511 system. Originally, the corridor data was being collected from seven agencies; however, that has now expanded to over 30 agencies. The real-time ICM data is no longer limited to the U.S.75 corridor subnetwork and is being actively used to support regional operational activities. Additionally, Dallas subsequently received a USDOT Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Grant in 2017 that will help to improve access to DART ride-sharing services, thereby improving access to DART stations, and helping to further enhance ICM mode shift capabilities.

Whereas, an automated Decision Support System (DSS) is no longer officially in operation, many of the DSS plan elements are still used to respond to events. During the one-year ICM system test period, the network operators quickly learned which plans would be recommended (i.e., “triggered”) for implementation by the DSS based on certain traffic conditions. Once they learned what plans would likely be recommended by the DSS, they did not feel it was cost effective to continue making minor incremental changes to the data model and operating the DSS. Finally, there are no dedicated ICM coordinators or staff. The resultant scaled-down ICM system did not require a full-time staff position for operations. The ICMS coordinator role now occurs in an ad hoc fashion at times of greatest need. The current system changed from the original vision for the ICMS; however, the changes have resulted in a system that is easier and more cost effective to support within the corridor. **The Dallas Team has proved that even a scaled down version of an ICM DSS, when used by capable network operators, can effectively manage the corridor**.

Dallas stakeholders consider the improved collaboration among network partners to be one of the most valuable outcomes of the Dallas ICM project. The partners gained a greater understanding of each other’s operational needs and they learned new operational strategies to better relieve congestion in the corridor. The capture and sharing of the operational data opened the eyes of the network operators to new approaches for congestion relief. Even though the Dallas stakeholders did not maintain or enhance the system as originally intended, the network operators believe that the ICMS is an overall benefit to their corridor. Some of the operators report that they would still like to have the DSS in operation along with a dedicated ICM coordinator. However, funding for a full-time staff position is currently not available.

Summary of the San Diego ICM project

The I-15 corridor is an eight- to 10-lane freeway, providing an important multimodal connection between San Diego, CA, and destinations to the northeast. It is one of three primary north-south transportation corridors in San Diego County and is the primary north-south highway in inland San Diego County, serving local, regional, and interregional travel. The corridor is a heavily utilized regional commuter route, connecting communities with major regional employment centers. It is located within a major interregional goods movement corridor, connecting Mexico, counties in California, and Las Vegas, Nevada.

Partners for the San Diego ICM project included:

- San Diego Association of Governments (SANDAG)
- California Department of Transportation(CALTRANS)
- City of Escondido
- Metropolitan Transit System
- North County Transit District
- City of Poway
- City of San Diego

The corridor study area, shown in Figure 5, consists of the freeway, including managed/ High-Occupancy Toll (HOT) lanes and general-purpose lanes, frontage roads, bus rapid transit (BRT), park-and-ride lots, and regional arterial streets. The current operations on

I-15 include two center-median lanes that run along 8 miles of I-15 between SR 163 in the south and Ted William Pkwy (SR 56) in the north. These center-median lanes are reversible HOV lanes that operate in the southbound direction in the AM peak period and in the northbound direction during the PM peak period. The current operations also allow Single Occupancy Vehicles (SOV) to utilize the roadway for a price, thereby operating as HOT lanes.

Current weekday traffic volumes range from 170,000 to 290,000 vehicles on the general-purpose lanes of I-15; approximately 20,000 vehicles use the I-15 Express Lanes during weekdays. Analysis of corridor conditions show that typical weekday demand along this linear corridor is high, largely due to the limited number of freeway alternatives. Analysis of historical data on this corridor shows that 10 percent of the days in the year experience major incidents under conditions of high demand.

Figure 5. Chart. I-15 ICM Corridor, San Diego, CA
(Source: USDOT)

The goals of the I-15 ICM initiative were to 1) increase corridor throughput, 2) improve travel time reliability, 3) improve incident management, and 4) enable intermodal travel decisions. Stakeholder agencies defined performance measures to support analysis in areas of mobility, travel time reliability, and emissions and fuel consumption.

The originally envisioned strategies conceived by the San Diego ICM Team included:

- Automated DSS
- Actionable traveler information
  - 511 (phone and website)
  - Comparable travel times
- Managed lanes
- Rerouting of traffic

    - Coordinated timing and responsive signal operations
    - Coordinated ramp metering and traffic signals
    - Wayfinding roadway signs for diversion routes
- Mode shift
    - Bus rapid transit
    - Transit signal priority
    - Real-time transit information

The San Diego region implemented and still operates an advanced form of a DSS that enabled automated response plan implementation including ramp-metering controls and signal system timing changes on arterials. The San Diego stakeholders developed business rules and parameters that govern the development of response plans. A response plan generation and evaluation process is triggered by the DSS business rules performance thresholds which can be adjusted and considers loss in capacity (when captured during event and entered by TMC operators via the Caltrans event system) and observed drops in speeds. The system is also designed to start a response plan process manually. The San Diego system predicts the impact of the proposed response plans with the aid of traffic simulation tools and selects the best response plans that meets the system activation and implementation thresholds.

During the ICM demonstration phase, the San Diego region continued to make significant investments in transit, highway, and arterial systems along this corridor to maximize ITS benefits while focusing on data sharing. These investments required the ICM team to continually re-calibrate the decision support system and responses. In some ways, it was difficult to separate the impacts of traditional upgrades in the corridor from "strictly ICM centric" successes. Nevertheless, the San Diego ICM team felt that there were both measurable benefits and institutional benefits to deploying the ICM strategies. The San Diego ICM stakeholders identified needs to optimize operational coordination of multiple transportation networks and cross-network connections to improve corridor mobility within the region. Because the frequency of traffic incidents increases during periods of high demand, the impacts of these incidents are more widespread (i.e., more travelers affected, increased environmental impacts associated with more travelers idling).

The San Diego ICM Team found that the benefit/cost ratio (BCR) for their system goes up as activations go up; however, the ultimate point of corridor operations is to keep the activations low by keeping traffic running smoothly. The ICMS provides network operators with new tools to isolate corridor trouble spots and resolve any congestion related issues in those locations to minimize incident occurrences. This in turn keeps activations lower. ***Ultimately, the San Diego team has found that ICM is a valuable mitigation tool, and its greatest value may be the improved ability to manage low probability – high impact events.***

San Diego also found that interagency collaboration was enhanced and is key to improving corridor operation; this type of collaboration did not exist before the ICM project. ***For San Diego, ICM is a fundamental change in the traffic management paradigm that has offered a more detailed understanding of the corridor and its operations***.

Key Findings from the Independent Evaluation of the two Demonstration Projects

The Dallas U.S.75 and San Diego I–15 projects were the first of their kind in the country and required original research and development prior to implementation. These sites have different characteristics and used different analysis models and methods. Several other regional improvement projects including infrastructure capacity expansion projects were implemented in parallel with the ICM projects in both regions. Thus, it is to be expected that there were broader impacts and improvements that changed the dynamics of the corridor operations before and after ICM. Initially during the evaluation period, only a small number of incidents required ICM response activations. The lack of sufficient activations did not allow for a completely objective empirical assessment of the impacts of ICM. Because of this, the findings from the evaluation were supplemented with the AMS modeling results and other sources of information to meet the goals of the evaluation project. The AMS modeling tools used in San Diego and Dallas were different from each other; specifically, each was promoted and tested on its own merits. The Dallas ICMS used the DIRECT mesoscopic modeling tool while the San Diego ICMS used the (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) Aimsun microscopic modeling tool. The AMS team used these respective tools for conducting their analysis at the two locations, and those results were in turn used by the independent evaluator in the mobility and benefit cost analyses. This makes it difficult, if not incorrect, to draw a direct comparison between the two sites. Readers are encouraged to study the deployments and assess the outcomes of both sites if considering ICMS implementation. The key findings are provided below[8]:

- ***The interagency cooperation and coordination was a big success.*** Both San Diego and Dallas created a fundamental paradigm shift in the management of their respective corridors by creating strong multi-jurisdictional partnerships that set the foundation for a regional corridor management mindset – based on a platform of strong institutional, technical, and operational integration. The San Diego ICM lead agency, the San Diego Association of Governments (SANDAG) continues to engage regional stakeholders to review and continue to improve ICM performance. Dallas continues to enhance coverage and improve their regional data exchange for information sharing. It is interesting to note that San Diego, led by SANDAG, took a more ambitious approach and was willing to try new things. Meanwhile, Dallas, initially led by DART, and later by TxDOT, took a more conservative approach to using new concepts for real-time traffic management. In the end, both approaches were valid and both teams provided great value to the evolution of ICM.
- ***Operators reported better situational awareness of corridor operating conditions, although there were opportunities to improve***. Overall awareness of corridor congestion and incidents improved significantly through regional data sharing. Incident reporting improved substantially in both regions compared to the pre-ICM period. However, in Dallas, stakeholders raised the point that there were gaps in arterial data due to outdated equipment and systems issues and that the corridor speed data did not always match with

[8] Battelle, Integrated Corridor Management Initiative: Demonstration Phase Evaluation, Final Report Draft, August 2017.

actual field conditions. Operators at both sites believed that construction and maintenance information could have been shared in a more timely and consistent manner.

- ***Incident and congestion specific traveler information provision improved.*** Both sites saw a significant increase in the number of posted dynamic message signs (DMS) and travel time messages post-ICM along with improved incident-related notification to travelers.
- ***The DSS at both sites proved to be valuable for better situational awareness, decision-making, and response.*** A DSS offers impartial evaluation of congestion events and recommends an objective course of action(s) from which to choose. A DSS determines appropriate strategies and responses based on sophisticated performance monitoring and key performance indicators. The DSS detects anomalies as well as return to normal conditions. Additionally, the DSS monitors the availability of corridor devices, provides stakeholders with optimized response plan recommendations, and evaluates the impact of proposed response plans. The DSS at both sites facilitated better awareness of transportation system conditions through the respective data fusion systems and response plans contributing to the provision of better traveler information. The San Diego DSS offered automated response plan implementation across jurisdictional boundaries including ramp-metering controls and signal system timing changes on arterials. The San Diego system predicted the impact of the proposed response plans with the aid of a traffic simulation tool and selected the best response plans that met the system activation and implementation thresholds. The Dallas system initially offered similar features as San Diego, with the exception of their response plan implementation needing to be confirmed by the ICMS coordinator and local agency representatives. Stakeholder agencies in Dallas maintained the authority to decline the requested response plan actions (e.g., signal timing changes) from the DSS. This happened only rarely, but to be fair, one may never know if declining one or more DSS-recommended response plan affected the duration and intensity of an individual event. After one year of operation, the Dallas stakeholders felt that they had learned enough about which plans may be recommended under certain traffic conditions and they chose to discontinue the operation of the DSS, in part due to the cost of maintaining the DSS data model. Dallas learned that manual decision support is a feasible option, if funding for the maintenance of a data model is not available. It should be noted that Dallas did originally intend to ultimately use automated response plan implementation once operators gained trust and a level of comfort with DSS response plan recommendations. The real-time traffic modeling caused some delay in getting response plans implemented. Dallas used a mesoscopic model in part because they had a large travel shed which included a large arterial network. The level of resolution of the network and vehicles is important because the larger the network, the greater the model execution time.
- ***The traveler response surveys taken well after the projects concluded indicated mostly positive results on traveler information awareness, utilization, behavioral response, and overall satisfaction.*** Travelers in both San Diego and Dallas reported higher awareness of where to find traveler information and higher utilization of traveler information post-ICM. San Diego travelers did not report a higher propensity to change behavior in response to traveler information, while Dallas travelers did. While there were some exceptions, generally travelers expressed overall satisfaction with traveler

information sources post-ICM. It is empirically difficult for most people to realize and appreciate that what might have been a significant delay (e.g. one hour's delay due to a hugely impacting crash, etc.) was "only" a lesser delay (say, half that) due to the success of an ICM-mitigated event. That person, stuck in traffic for half-again as long as they would normally have been, might not understand that their plight could have been even worse; i.e., they are still "upset at traffic."

- ***Alternate route diversion was demonstrated, but transit mode shift did not happen as expected.*** Overall, alternate *vehicle* route diversion was a success but transit mode shift (shift from other modes to transit) in the wake of incidents was not observed. The lack of transit mode shift was influenced by inherent constraints in mobilizing (particularly) rail cars and headways, and by not having an immediately available surplus of operators and manpower. Also, regional policies (at both sites) restricted the ability of transit partners to be overly flexible and immediately reactive to ad hoc events, compared to, say, the capability of a highway department or public works department to make on-the-fly tweaks to detours, signals, and diversions. Even beyond these supply-side considerations, the inherent nature of traveler behavior may have prevented meaningful transit mode shifts, particularly when those who normally drive are not familiar with the transit alternative, are concerned about parking, or do not want to leave their vehicles away from home.
- ***Corridor mobility performance improved during ICM activations.*** In San Diego, travel time improved with peak period savings ranging from 250 to 1,300 person-hours during ICM activations. San Diego travel time reliability also improved by an average of 368 hours per Southbound AM peak period activation and 569 hours per Northbound PM peak period activation. In Dallas, travel time marginally improved with peak period person-hour savings ranging from 6 hours to 262 hours. Travel time reliability marginally improved by an average of 109 hours in Dallas for each Northbound PM peak period ICMS activation (there was no travel time reliability improvement in the southbound direction).

  Capturing and validating actual mobility performance improvements proved to be quite challenging for the evaluators. The mobility analysis was driven primarily from the results of the post-deployment modeling and simulation activity, since a before-after analysis using field data was abandoned due to lack of sufficient ICMS activations and the lack of comparable incidents representing before and after ICM deployment. Results also depend on the existing level of saturation within a corridor. Keep in mind that the results in these two sites do not lend themselves to an apples-to-apples comparison. Two different models were used to derive these results and the calibration and validation of the models can make a big impact on the outcomes. Readers are encouraged to look at both methodologies and models carefully before drawing any conclusions.
- ***Safety and Air Quality impacts were neutral.*** Consistent with the primary objective of ICM to improve mobility, the safety and air quality impacts of both demonstration projects were neutral.

- ***ICM projects present challenges to traditional benefit-cost analyses and the proper interpretation of results.*** Using the assumptions documented by the evaluators, the benefits estimated for San Diego's ICMS easily exceeded costs, whereas the break-even point (1:1 ratio) for Dallas's ICMS was contained within the expected range for the benefit cost ratio. For San Diego, the benefit cost ratio ranged from 2:1 to 9:1 (based on the original 17 response plan implementations during the demonstration period) for different scenarios representing different levels of ICMS activation and system effectiveness for a 20-year horizon. For Dallas, the benefit cost ratio ranged from 0.55:1 to 1.64:1 (based on the original 35 response plan implementations during the demonstration period).

  The results for either site could have changed dramatically based on the impacts of the incidents recorded in the corridor. One major incident could have altered the result significantly. ICM also has significant intangible benefits including the successful regional partnerships and the establishment of a joint corridor management mindset, enhanced regional traveler information and 511, ongoing collaboration and information sharing, and traffic signal coordination programs for arterials. These intangible benefits are difficult to quantify and were not considered in the benefit cost analysis. Just as for the mobility analysis, the benefit-cost study depended heavily on the results of the post-deployment modeling and simulation activity. Again, due to the use of different modeling assumptions between the sites, readers should be aware that the benefit cost ratios should not be compared and are not truly indicative of the cost effectiveness of the projects. More information on ICMS benefit cost analyses challenges can be found below in the section on "ICMS Evaluation Benefits and Costs Analysis Insights".

In the end, Dallas and San Diego demonstration sites had different overall outcomes. The original vision for an ICMS was a fully automated software and hardware system that could make automated decisions about real-time operational changes needed to manage congestion within a defined corridor network. These decisions would be guided by real-time network data collected and analyzed by data models incorporated into DSSs for corridor network management.

The San Diego demonstration site achieved a mostly automated DSS that, based on established business rules set by the stakeholders, can generate, evaluate, recommend, and implement a finite set of response plans, with minimal manual intervention. This is in line with the original vision for ICMS implementation and the system seems to work well, although the system required a lengthy period of tuning to find the correct performance improvement thresholds for system activation. In that sense, the human intervention comes in the form of establishing the response plan parameters and decision rules and policies for activating the system.

The Dallas ICMS demonstration varied from the original vision, in that it required human confirmation to implement response strategies that were recommended by the DSS. The Dallas DSS was partially automated and like San Diego's DSS included the ability to analyze, evaluate, and recommend a finite set of preapproved response plans. The Dallas DSS differed from the San Diego DSS by requiring individual operator approval and implementation of recommended response plans. Dallas currently uses human decision support. Dallas demonstrated that the human-in-the-loop solution is a viable option. If

ICMS is implemented in this fashion, operations staff need to be instructed, trained, and supported in having ICM responsibilities as a key part of their job descriptions.

The key takeaway from the DSS experiences of San Diego and Dallas is that there is no one-size-fits-all DSS. Each DSS is unique to its corridor and user needs, and needs to account for the advantages and disadvantages of automation vs. human involvement in the choice of the DSS operating model. Many of the ICM deployment planning grant sites are initially focusing on human-centric methods of deploying ICM.

ICMS Evaluation Benefits and Costs Analysis Insights

Review of the demonstration sites independent evaluation revealed several things about ICMS as evidenced from the benefits and costs analysis. Computed benefits depended on DSS activations, and no benefits were derived if the DSS was not activated. Such an assumption under-estimates the benefits of ICMS, including the benefits of decisions that Traffic Management Center (TMC) operators may make outside of the system using their improved situational awareness, which may prevent an unnecessary activation, as well as the benefits that can be attributed to the decisions of travelers responding to the combined, integrated information.

Review of the costs side of the equation reveals the difficulty of properly attributing the costs associated with upgrading network systems to be ICMS-compatible. Costs associated with implementation and operations of the DSS are clearly ICMS-related, as well as any communications upgrades that are necessary to share operational information between infrastructure and service operators and owners. Costs expended to upgrade individual agency networks, however, must be carefully evaluated to determine if the expense should be attributed to ICMS. For example, an interface upgrade that is necessary to connect with the ICMS would likely be counted as an ICMS expense, while the addition of traffic monitoring equipment needed to fill gaps in coverage would likely not be considered an ICMS expense, or at least not exclusively an ICMS expense. While the additional traffic monitoring equipment certainly supports the ICMS operations, its primary purpose is to provide monitoring for the individual network. Analysts must be careful to document these assumptions when conducting a benefits or benefit-cost analysis for a potential ICMS, since the natural tendency may be to underestimate the benefits and overestimate the costs.

PROMOTING ICM PLANNING AND DEPLOYMENT

To promote ICM as an operational framework that is routinely considered in cities across the country, the ICM concept needs to be mainstreamed into the transportation planning and programming processes of States, Metropolitan Planning Organizations (MPOs), transit agencies, cities, and other operating agencies. The third major ICM program phase involved a competitive grant and solicitation process[9] designed to jumpstart the concept. USDOT sought applications for federal funding (with local match) from multiple sites

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[9] Integrated Corridor Management Deployment Planning Grants, A Notice by the Federal Highway Administration, Federal Register, 2013-26057, 11/01/2013.

across the U.S. with candidate corridors suitable for conducting ICMS deployment planning. The solicitation only covered planning activities, with the expectation that funding of future deployment of an ICMS in their regions would be covered by the States and regional/local agencies.

The thirteen sites were selected from 33 candidate proposals. Originally, only ten awards were intended by the announcement, but a congruence of money "asked for" and funds available allowed for thirteen awards. These grant sites were required to produce one or more of the following deliverables as a part of their agreement:

- ICM Concept of Operations
- ICM System Requirements Specifications (SyRS)
- ICM Analysis, Modeling, and Simulation (AMS) Plan
- ICM AMS Activity Findings Report
- ICM Implementation Plan

It was intended that once they developed the required pre-implementation documents, they would be ready to move on their own merits and funding towards implementation of their projects. The sites were asked to provide a grant-ending report summarizing the effectiveness of the KTT products that they had access to in supporting their ICM development efforts, as well as provide lessons learned and recommendations for further knowledge transfer activities. Figure 6 on the following page maps the 13 selected sites, shown as red circles, along with the original Pioneer sites. The Pioneer sites taking part in each of the three program stages are shown, including the eight concept development sites (green), the three AMS sites (orange), and the two demonstration sites (blue). Note that the corridors in Minneapolis, Dallas, and San Diego are shown as overlapping circles since they took part in multiple program stages.

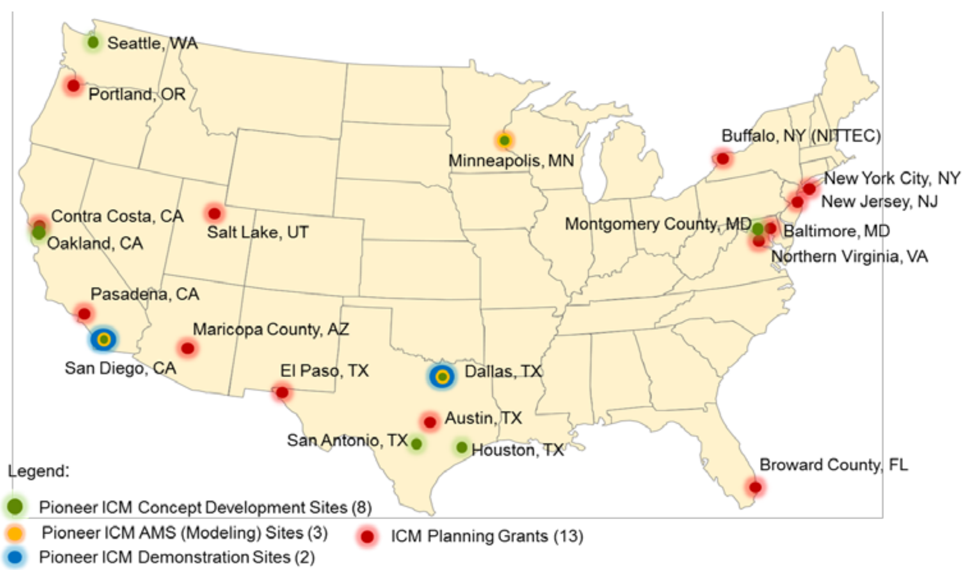

Figure 6. Chart. ICM Pioneer Site and Implementation Planning Grant Site corridor locations. (Source: USDOT, 2018)

After most sites had completed the required deliverable products identified within their cooperative agreements, the USDOT undertook a KTT survey to gather lessons learned and recommendations from the grant recipients. The survey revealed that ICM Deployment Planning Grants were successful in encouraging agencies to systematically plan and implement ICM strategies in the grantee's respective corridors. Grantee sites and stakeholder agencies appear to be committed to some form of ICM deployment; however, there are challenges:

- Planning and implementing ICM takes time, particularly if an educational process is needed to get everybody on the same page.
- Funding remains a challenge. Most sites are just getting preliminary implementation funding identified at this point.
- ICM projects face stiff competition for funding, and must compete against other traditional or transportation systems management and operations (TSMO) projects.
- Need to determine methods for comparing and measuring traveler-focused, multi-modal performance information.
- Stakeholders may not understand how to define their "corridor" boundaries, and corresponding travel sheds, to achieve a comprehensive, multimodal, cross-network "system of systems". Some stakeholders will not understand the importance of the travel shed as "the boundary of all last-mile trips that have a high feasibility of using the subject facility (e.g., a freeway)". Experience also reveals that ICM corridors tend to expand in geographic scope as new mode/route alternatives are identified for the travel shed, or traffic patterns change due to the addition of new capacity.
- Due mostly to funding concerns, it appears that incremental ICM deployment is the most likely viable path forward (rather than a single, large project).
- Incremental deployment may be preferable from a risk management perspective, but runs the risk of losing momentum as time goes on and personnel change.
- Related to this uncertainty, many grant recipients were not sure what the end-state ICMS would look like for their corridor.

ONGOING ICM KNOWLEDGE TRANSFER

While previous KTT products and activities (such as guidance, workshops, studies and presentations, articles, and peer exchanges) have been part of every program phase and successful in communicating the ICM concept and promoting deployment, more knowledge transfer activities and resources are needed to mainstream ICM and encourage further adoption. The final ICM program phase places an emphasis on knowledge and technology transfer. KTT products and activities that have been completed to date includes guidance, workshops, studies, presentations, articles, and peer exchanges. Future USDOT ICM work will primarily consist of these kinds of knowledge transfer activities at future new candidate regions, along with focused research for specific questions affecting implementation.

As part of the ICM Program, the USDOT engaged leaders from peer locations implementing ICM today, including representatives from the demonstration sites and early adopter locations, in the development of the content and format for KTT resources to ensure usefulness and practicality. More information on available ICM KTT resources can be found on the ICM Web page at https://www.its.dot.gov/research_archives/icms/index.htm *or a related fact sheet at* https://www.its.dot.gov/factsheets/pdf/ICM_KTT_V5.pdf.

Resource Type - the following types of KTT resources are available in the ICM Knowledgebase and are linked by topic area below.

- Guidance
- Studies/Analysis results
- Lessons Learned
- Sample documents/templates
- Presentations
- Outreach support products
- Articles
- Videos

Mainstreaming ICM. As mentioned earlier, be advised that we intend to publish an updated companion executive summary called "Mainstreaming ICM: An Executive Level Primer" in late 2019 which intends to address the questions "how do we get started," and "how and why should our region invest in ICM," and, for that matter, "what constitutes a 'candidate' ICM region?" We strongly encourage startup regions to pair this document, which explains to executives *what* ICM is, with that one that is planned, which will explain how to adopt ICM in your region.

The grant recipients provided the USDOT with valuable information on ICM lessons learned, informational needs, and KTT suggestions or recommendations.

CHAPTER 3. OVERARCHING FINDINGS AND OUTCOMES OF THE ICM PROGRAM

Below are some of the overarching findings and outcomes of the ICM Program that have been identified throughout the evolution of the program. Some findings are anecdotal. For example, one original cynic of the ICM program, a network operator in Dallas, later conveyed his frustration that he knew ICM had made improvements in his corridor, but it was hard to prove that quantitatively. Another anecdotal statement heard was along the lines of "how much better our respective agencies are in understanding each other's strengths and weaknesses." **Measuring objective ICM benefits may be one of the larger problems to solve in promoting ICM deployment. However, there is no denying the subjective anecdotal successes that agencies are reporting.**

GUIDING DEPLOYMENT OF ICM SUPPORTING INFRASTRUCTURE

ICM brings a new level of corridor cooperation and data sharing that helps involved stakeholders coordinate the operations of their individual systems to achieve regional goals. Most of the supporting ICM infrastructure (coordinated ramp metering, real-time transit information, traffic signal timing improvements, parking management, 511, etc.) are designed to improve traffic conditions as stand-alone systems. By enhancing or upgrading these systems to support ICM, regions will likely make incremental improvements to corridor operations, even before an ICMS is turned on. This may result in a reduction in delay and duration of corridor incidents prior to the ICMS implementation, which may then ironically reduce measurable benefits when the ICMS is implemented. Deployers need to be aware of this, because a lack of measurable benefits may ultimately influence decision-making. While these stand-alone ICM support systems can make improvements in the corridor even without ICM, the collaboration and coordination among network operators brings an extra level of corridor management that could not be achieved without ICMS planning and implementation.

ICM promotes a change towards proactively managing corridor traffic considering the traveler first, instead of agency systems or jurisdictional boundaries. With the focus being on travelers, rather than just drivers, emphasis should be placed on determining methods for comparing and measuring traveler-focused, multi-modal performance metrics and information.

Collaboration among ICM partners planning to implement an ICMS provides a deeper understanding of corridor infrastructure needs and offers supporting data that can be used to upgrade their corridor infrastructure in a well-organized and efficient manner. These types of capital improvements are likely to improve corridor operations even before the ICMS is implemented. Additionally, once the ICMS is operational, it can assist operators in further isolating corridor trouble spots that may need additional capital improvements.

LOCALLY-FUNDED ICM PLANNING AND DEPLOYMENT

Based on initial USDOT ICM efforts, various States and regions throughout the country have begun funding their own ICM planning and implementation projects and have begun applying USDOT concepts on their own corridors. Identifying funding for ICM has been a challenge, however the surveyed regions have realized value in the ICM initiative, and they are working to insert ICM funding into their normal planning processes. In California, transportation agencies are actively planning to deploy ICM in several "Connected Corridors" throughout the State. One example is the U.S. 50 corridor from the City of West Sacramento into El Dorado County[10]. Another example is in Pennsylvania in the I-76 integrated corridor management project[11] between the Pennsylvania Turnpike and the U.S. 1 interchanges. These self-funded activities provide another indication that the ICM concept is becoming more accepted as good practice and represents another important outcome of the program.

WHAT HAVE WE LEARNED FROM ICM?

What makes corridor management "integrated"? Does the collaboration among corridor partners make the system *institutionally* integrated or does the DSS make the system *operationally* integrated? A technical (hardware and software) solution is not always the most reliable metric in measuring system problems. The human interaction in developing the logic of the system is also necessary for system development. **The New York City ICM stakeholders - one of the thirteen deployment planning grant sites – cited the decades-long success and example of TRANSCOM in emphasizing the human centric viewpoint of ICM for their corridor.** TRANSCOM developed organically, by rote, and over time, beginning in 1986. A coalition of sixteen (16) transportation and public safety agencies, spanning NY, NJ, and CT, and including bridge, subway and port authority agencies, *needed* to integrate and cooperate to enable everyone's success, because one major impacting event in one silo would reverberate to all. In such cases, it can be a more feasible option to maintain human interaction to make the system work more efficiently and fulfill requirements in a more cost-effective manner.

PROMOTING ADDITIONAL ICM RESEARCH ACTIVITY

An important outcome of the ICM program is that it has stimulated research activity, including non-federally funded research to be conducted by outside organizations and researchers. For example, several NCHRP projects have been funded to research various aspects of ICM. Examples include:

- NCHRP 03-81 [Completed]: Strategies for Integrated Operation of Freeway and Arterial Corridors

- NCHRP Project 20-68A, Scan 12-02 [Completed]: Advances in Strategies for Implementing Integrated Corridor Management (ICM) (Domestic Scan)

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[10] Source: http://www.dot.ca.gov/dist3/departments/planning/icm.htm.

[11] https://www.dvrpc.org/connections2040/publiccomment/pdf/2016AmendmentAnalysis.pdf;
I-76 Corridor Management: Opening Lanes and Offering Options to Regional Mobility , presentation (Dec. 2017) http://www.larson.psu.edu/assets/docs/TESC-presentations/5C-I76-integrated-corridor/5C-Draft.pdf.

- NCHRP 03-121 [Active]: Incorporating Freight, Transit, and Incident Response Stakeholders into Integrated Corridor Management (ICM): Processes and Strategies for Implementation
- NCHRP 708-124 [Anticipated 2018]: Quantifying the Impacts of Corridor Management

In addition, State DOT's have partnered with universities to research various ICM topics, including evaluation and analysis modeling and simulation activities. The I-210 pilot ICMS project, which includes a partnership between Caltrans, PATH, and LA Metro, is an example of a project that meets these criteria. The I-210 Pilot is located on a 22-mile section of the I-210 freeway (the Foothill Freeway) in the San Gabriel Valley in Los Angeles County.

The DSS topic has received a lot of research attention, because it can be complex, yet is so fundamental to ICM. The research on DSS expands beyond the ICM context into the general transportation management environment. Several workshops have been held on this DSS topic. One recent workshop[12] produced notes that included a prioritized list of recommendations for research on the topic of DSS. DSS for ICM is a challenging and important topic with many facets. Appendix A provides more detail on some of the issues and challenges associated with DSS for ICMS and offers some suggested research and areas for improvement.

[12] For example, see Decision Support Subsystem Requirements for the Next Generation Traffic Management Systems and Centers (TMCs), https://transportationops.org/publications/decision-support-subsystem-requirements-next-generation-traffic-management-systems-and, meeting held Jan 07, 2018, Transportation Research Board.

CHAPTER 4. OUTLOOK: CONNECTING ICM TO THE FUTURE

Many view ICM as a natural extension of ITS capabilities that focuses on integrating the various pieces. In other words, ***ICM ties together the various ITS systems for individual networks and agencies***. Using this logic, ICM should continue to evolve to encompass new and improved ITS technologies and applications. ICM can also be viewed as an advanced form of transportation systems management and operations (TSMO). As such, ***regions should consider incorporating ICM into their TSMO plans.*** A few of the deployment planning grant sites have already done so, in some cases prioritizing ICM investments over other operational needs. The ICM program and FHWA's Active Transportation and Demand Management (ATDM) program share many common features between them. They are both considered active; they both involve monitoring the system, assessing system performance; evaluating and recommending response strategies or dynamic actions; and finally implementing the response plan or dynamic actions. The process is continuous so that minor adjustments can be made as plans are implemented, depending on the reaction of traffic to the implemented response.

Connected vehicle applications, particularly those related to mobility, are clearly within the scope of an ICMS, and the data collected from the connected vehicles can be used as additional data to be fused in the DSS. The ICM concept is also embedded in deployment grant programs such as the ATCMTD program. The ICM program accomplishments and outcomes described in this paper provide a solid foundation for future work in making these connections on a practical level.

Practitioners desire more practical, how-to guidance for planning, implementing, and operating ICM systems. Table 1 provides a listing of current research needs and KTT recommendations. These needs were gathered from the 13 deployment planning grant recipients, the ICM demonstration sites and evaluation report, interviews with ICM developers, and the experience of the authors with the ICM program. The needs and recommendations are not prioritized.

The ICM program has been a cornerstone to the evolution of traffic management programs such as ATDM, ATCMTD, and Mobility on Demand (MOD). The core functionality of the ICMS and the collaboration among an expanded set of corridor and now regional partners has greatly improved the chances of success of current and future mobility management systems. National deployment of ICM is far from complete; however, the program has gained visibility across the country as regions are introduced to the benefits of ICM. Motivation to deploy ICM has been established and embraced among regional mobility managers across the country.

Table 1. ICM Research Needs and KTT Recommendations (Based on Stakeholder Inputs)

1. Guidance on evolutionary paths for ICM deployment.
2. DSS options and incremental development guidance, business rules, lessons learned, playbooks, and examples.
3. Improving DSS response and strategy activation times.
4. Further DSS improvements including more robust transit strategies/Mobility on Demand (MOD)/etc.
5. Guidance on mainstreaming ICM into overall transportation planning, programming, and project development processes. Institutional framework to promote collaboration and integration.
6. Continued assessment of evolving and new ICM strategies.
7. Support for peer-to-peer exchange mechanisms among ICM planners and implementers; to allow sharing of ideas, approaches, lessons learned, and plans.
8. Knowledge, skills, and abilities guidance for traffic operations center operators to support ICM. How do the new ICM tools/strategies enhance rather than compete with the demands of existing operator responsibilities?
9. Guidance on funding opportunities and examples or case studies; how have other regions done it. Information on creative funding opportunities. Helpful hints on long-term operations and maintenance arrangements and funding.
10. Evaluation and Performance:
    a. How to prioritize, quantify, monetize, and measure ICM benefits.
    b. Guidance on how to test the baseline and measure the improvement in ICM.
    c. Demonstrate built-in performance monitoring and evaluation reporting (what was predicted by the model vs. what occurred).
    d. Provide updated benefits information and benefit-cost data that applies to a range of urban areas and operational conditions.
    e. Updated guidance on ICM performance management, related multimodal performance measures including return on investment.
11. Efficient tools for sharing and integrating operational data across multiple agencies.
12. Investigating the potential to expand ICM from a “corridor” mindset to a “regional” mindset – incorporating multiple corridors into a regional management framework.

APPENDIX A. DECISION SUPPORT SYSTEMS

ICM could not exist absent the recent advent (a decade or so) of "big data," or, extremely large data sets that may be analyzed computationally to reveal patterns, trends, and associations, especially relating to human behavior and interactions. Big data is often characterized by the 3Vs: the extreme *volume* of data, the wide *variety* of data types and the *velocity* at which the data must be processed. **Based on those criteria, the DSS will recommend a response plan and communicate it to network operators for review and approval. The ultimate goal of an ICM automated system would be to have the DSS assess corridor needs and independently implement plans to the benefit of corridor operations.**

Decision Support Systems (DSS) exist in research libraries, water, sewer and electrical grids, in medicine, and in financial and military communities, etc., to not only aggregate huge lists of data, but more importantly, to assist humans in creating computer-speed analysis, alternatives, and decision making. DSS is a key component of an ICMS. The ICM DSS basically involves the collection of data and information describing the corridor or portions of the corridor that are experiencing disruptions in traffic flow. Based on the information collected and analyzed, it develops real-time response plans, and communicates them among corridor partners, and then implements them to help mitigate the traffic flow disruptions.

Like any other system, the DSS can be implemented using a range of solutions. To save time and money an initial DSS implementation may very well be a solution that leverages human resources. This appears to be an increasingly popular first phase for DSS implementation. Human network operators within the corridor work to develop ICM response plans based on their experience within the corridor. The developed response plans may or may not benefit each network operator and they are free to implement the plans based on their own needs and projected benefits.

With time, corridor partners can improve the DSS structure leading toward a more automated system. Corridor data can be collected, stored, and analyzed based on an increasingly more sophisticated set of decision criteria.

DSS DEVELOPMENT

The decision support system (DSS) can be thought of as a chess board where the pieces interact and decisions are made. The board itself is the geographical constraint of the ICM region and corridor. The chess pieces can be thought of as the the managers, operators, agencies, and organizations (e.g., stakeholders) involved in the ICM corridor; each one having its own special talents but also restrictions; for example, a bishop can move diagonally any number of unimpeded spaces, but a pawn can move only one space forward. However, each are needed to advance the game. ICM business rules are the pre-agreed "chess rules" by which these individuals and agencies (pieces) interact. And like innumerous chess strategies, the DSS contains the ICM strategies to beneficially utilize these rules. In other words, knowing the rules of how the entities interact is not enough, just like knowing the basic rules that govern pieces on a chess board does not make someone a chess champion. Combining these rules within the chess board context in the most beneficial way to succeed is one way of defining strategy.

Developing requirements for a DSS is a logical incremental step in moving forward with an ICM system. It is clear from lessons learned during implementation of DSS in Dallas and San Diego that there is still a lot to be learned from developing a DSS. As each region is different, with different partners, road networks and complementary agencies, there is no "off the shelf" DSS that is one size fits all. Possible approaches include improving an existing DSS engine or developing a new DSS using software in the loop, machine learning, and Artificial Intelligence.

Like shopping at a store, a DSS can pick from previously agreed upon signal timing programs (e.g., a.m versus p.m. versus mid-day, etc.) or dynamic ramp metering programs, or any of pre-programmed DMS messages, et al, to build and select response plans. In San Diego it was estimated that there are well over a million potential combinations of plans, although to be fair, a more concise number of plans were ever considered. This information, along with preferences, restrictions, and guidelines based on incident severity, real time traffic conditions, incident location and other information, is entered into a **business rules engine**, which is guided by each agency's capabilities or constraints. The rules engine will then suggest response strategies, compared to the "do nothing alternative" for corridor events. These response plans will optionally be evaluated (scored) by running a predictive simulation using a micro model of the corridor. This simulation predicts the resulting benefit on the corridor based on the potential response plan implementation. The best plan is forwarded. The results of this simulation and the basic ordering provided by the rules engine is also used to present an ordered list of response plans for operators to approve or decline. Why might an operator choose to decline his agency's part of the plan? Maybe he or she knows of a competing challenge, like a water main break, or disruption to school loading or unloading, or a localized outage or similar constraint. "Declines" don't happen very often but they remain a failsafe in some cases.

Keys to developing a DSS in a corridor include:

- Establishing a multimodal detour policy (includes transit and pedestrians safely accessing a detoured transit vehicle, for example)
- Addressing data needs:
    - Forming a corridor data policy
    - Forming agreements with third parties and sharing real-time, multimodal construction zone information across agencies (e.g., One regional TSMO Program investment is improving a local agency entry tool for Right-of-Way (ROW) construction that will deploy statewide; a second service is expanding from a Geographic Information System (GIS) layer to an online data service coordinated among several local agencies Multimodal ICM corridor)
- Building corridor partnerships to foster event and demand management

Some of the cited constraints for DSS development[13] include:

- The DSS will need to consider the traffic rerouting strategies being offered by current mapping systems. The rerouting that they offer creates dynamic traffic patterns that the DSS will need to assess on the fly to make accurate recommendations.
- A DSS may not consider certain jurisdictional rules about what can be communicated to travelers (e.g., some jurisdictions do not allow for direct diversion messages with instructions to be communicated, instead favoring less specific messages). This can have a major impact on the efficiency of a traveler information dissemination strategy recommended by a DSS.
- Many jurisdictions may restrict truck use on certain roads. A DSS that has not incorporated this information and interagency agreements regarding truck traffic would not differentiate the traveler type. A properly calibrated DSS should incorporate this into the recommendation protocol to separate out vehicle travelers from truck traffic in any diversion or messaging suggestion.
- Local jurisdictional constraints may exist on the use of traffic signals and diversions at certain times. For example, in San Diego there were safety concerns about traffic being diverted past schools around school start and end times. These concerns and restrictions are contextual constraints that the DSS should be accounting for when providing recommendations.
- For traveler information posted to DMS, there are often regulations regarding the structure and format of messages. This should be incorporated into the DSS recommendations. Although constraining the message content and structure to conform to local signs and protocol is likely part of the DSS development, additional rules for types of messages and phasing frequency based on traffic speed may be the type of agreed upon use that is not usually incorporated.
- Something as simple as TMC staffing is another area where not all jurisdictions operate in the same way. Recommendations should incorporate whether staff from other facilities are available to coordinate with and if not, is there another representative or agency that can step in?

ONGOING DSS IMPROVEMENTS AND SUGGESTED RESEARCH

There are several universities and private companies that continue to refine DSS for ICM. Some of the needed improvements noted by ICMS deployment regions include:

- **Finding a way to make the DSS plan implementation process more efficient,** because agency approvals may be required to confirm DSS plan implementations.
- **Considering various ways for DSS to make changes during incidents**, for example change from 4-phase to 2-phase signal operation along frontage roads.

[13] Robinson, Emanual et al., Elements of Business Rules and Decision Support Systems within Integrated Corridor Management: Understanding the Intersection of These Three Components, FHWA-HOP-17-027, October 2017.

- **Campaigning for the development of a region-wide program** that would set a path for building the ICM infrastructure systems and DSS at a regional level once manual processes have been implemented, practiced, continuously improved, and proof of concept established, within a corridor.
- **Writing draft system requirements documents** that outline the use of a DSS that deploys specific response plans for select types of events. The plan is to classify each event to varying degrees of severity where a select set of response strategies would be available for implementation. An automated strategy could be as simple as deploying messages that notify travelers of downstream incidents, such as weather-related messages (e.g., "Watch for Ice on the Road") triggered by weather sensors.
- **Defining baseline business rules.** There is not a one-size fits all proposition when it comes to DSS. All regions have unique needs where DSS is concerned. However, it would be nice to have a baseline set of business rules to improve upon.
- **Understanding the benefit of having a shared TMC** so many operators are already collocated and can coordinate quickly for human-centric DSS solutions.
- Understanding that heavily automated DSS is not necessary to realize benefits.
- **Realizing the role of DSS will evolve over time** as operational collaboration around real-world needs helps to define value-added roles for these kinds of tools and systems.
- Recognizing that currently, in this complex multi-agency environment, the emphasis likely needs to be on **human-centric strategies** while the more experimental DSS are still being tested.
- Understanding that heavily automated DSS strategies **need more research and testing** before they can effectively advance ICM in a corridor.
- **Adding to the Traffic Management Data Dictionary (TMDD) standards** for them to meet the ICM and DSS requirements. There is a general need for harmonization of nomenclature.
- **Developing guidance** is also needed for how and what data can be displayed publicly versus data that is sensitive and could raise security implications.
- **Addressing cybersecurity** is one of the concerns that needs to be addressed regarding ICM.
- **Improving DSS machine learning** capacity.
- **Achieving full or nearly full DSS automation** will include the willingness of the partners to accept progressively automated levels of ICMS.

APPENDIX B. QUESTIONS AGENCIES MAY HAVE ABOUT ICM

This section provides a listing of frequently asked questions about ICM along with answers and explanations where possible.

- **Is my region conducting ICM or some other corridor or freeway management practice?**
  - **Because ICM is a response-triggered strategy, it does not replace management of construction projects or day-to-day operation to maintain a highway or even a system**, in the sense that <u>nominal</u> recurring delays, fender benders, highway service patrols, occasional rain, ramp metering, HOV hours and restrictions, et al, already exist. Rather, the USDOT's informal definition of ICM is not merely a one-off local-incident traffic detour, or even a traffic incident management (TIM) program or plan, or a pre-planned construction or special event mitigation plan with a detour(s), but a real-time multi-agency collaboration **"response to a severe sudden and non-conforming event"** that necessitates concurrent cross-agency response to that atypically forming incident. It invokes several layers of route and/or mode management and pertains to major atypical events that would otherwise, and suddenly, cause hours of delay or be newsworthy in their random severity. ICM is "event driven" in real time, as exhibited by the San Diego and Dallas experiences that only a few candidate ICM events were triggered each week. It is neither a months long construction mitigation plan, nor is it a special event plan, nor a routine TIM response. ICM requires the pre-agreed support of as many adjacent and complementary agencies as possible, with their resources, in the guise of state, county, and local street systems, signal departments, transit and commuter programs and resources, media and ITS-related partners all working together. There are myriad other non-ICM highway and freeway management practices that are practiced more or less solely on the "trunk" facility, like ramp metering, HOV lanes, ATDM, speed harmonization, part time shoulder use, standard highway service patrols, and highway lane-and queue-attention, et al, that <u>by and of themselves, do not constitute ICM</u>. For example, a simple detour off the trunk highway, through side streets, and back onto the highway, is not ICM in the purest sense, unless remediation is promoted to the entire region, in real time messaging, with transit incorporation, and multi-agency involvement. ICM employs route- <u>and</u> mode-alternative diversions, including reformatting the openings, closings, timings, and messages of those diversions during the impacting event, and then returning them to nominal operation once the event has subsided.

- **Is a Decision Support System (DSS) necessary to achieve integrated corridor management? Can I deploy an ICMS without a DSS?**
  - Although transportation management decisions are always necessary to manage a corridor effectively, you do not necessarily need a DSS to achieve integrated corridor management. Particularly in less complex corridors with fewer traveler

options, TMC operators may be able to handle the decision-making needed to implement basic ICM strategies. However, for a complex corridor with lots of modal options and diverse traffic conditions, you should consider the benefits and costs of a DSS to assist with managing your corridor as a network. Implementing a DSS is a large undertaking and should not be taken lightly. You may want to start with a more basic system that has various tools to show transportation operators what the traffic conditions are or are predicted to be in the near future and build from there. Ultimately, some level of DSS automation is usually necessary to reduce the workload on TMC operators.

- **What benefits can I expect from ICM without a DSS?**
  - Every situation is different, but without a DSS, you will be relying on human operators and operations staff to communicate with operators from the other agencies and make coordinated decisions regarding control and information strategies that may be required under incident, construction, high demand, or special event conditions in the corridor. Benefits are expected to be greater where disciplined pre-planning has been performed to identify alternate routes, signal changes, and possibly modal shifts to accommodate the corridor traffic as much as possible. Network operators should go through the ICM process to develop consensus incident response plans for the response "playbook". This process helps operators better understand other network operations and the impacts that these systems can have on the corridor. Ideally, the operations agencies in your corridor will have a frequently updated "common operating picture" of the conditions in the corridor, so that they can act according to the same information.

- **If ICM is only for major crashes, and extremely high demand/congestion, or emergencies, then are there any benefits for more routine incidents and day to day variability?**
  - To some extent, the answer to the question depends on the concept of operations you and your stakeholders have for managing your corridor, as well as network and transportation characteristics, such as resiliency and overall level of congestion. If you decide to set a performance or disruption threshold that is high prior to implementing various response strategies, then you will not invoke the strategies as often as you would with a lower performance threshold (as shown by San Diego).
  - One of the proven benefits of ICM is that there is an increased awareness of even nominal incidents in the corridor as well as visibility into daily traffic conditions. This situational awareness assists in managing day to day variations and routine incidents, but strictly speaking, ICM only invokes for the worst of the worst events.

- **Can I deploy an ICMS incrementally?**
  - Yes, absolutely. In fact, building your ICM capabilities incrementally is likely a given with limited budgets and competition of various projects in your region for funding. The Dallas and San Diego sites implemented an ICMS in a relatively short

amount of time; however, they were specifically funded by USDOT to do so. Incremental deployment will also provide more time to advance your DSS capabilities in a gradual fashion.

- **If ICM is so beneficial, why did the Dallas stakeholders stop using the ICM DSS?**
  - Collectively, Dallas stakeholders are still supportive of the ICM program and use many of the capabilities brought to the region with the demonstration program. However, the DSS implementation in Dallas had several limitations, including the need for multiple layers of human intervention before a response plan could be implemented. Additionally, several infrastructure changes and major new roads within the corridor network during the demonstration period resulted in a need to update the predictive data model. Since no stakeholder stepped forward to lead and fund the effort that would be needed to update the model, Dallas stakeholders decided it was in their best interest to discontinue use of the DSS for real-time operations. Also, during the ICM test phase, the Dallas network operators learned a great deal about the types of response plans that were most effective in their corridor and felt less reliant on the predictive data model.

- **Is an overall ICM champion still needed?**
  - It never hurts to have an articulate and politically savvy champion for ICM within your region, but perhaps it is more important to have individual agency proponents for the key ICM stakeholders associated with the corridor you want to manage. Initially, in Dallas, DART was the champion agency (and ICM host) but over time that duty transferred to TXDOT. In other locations the city, MPO, or regional authority may be the champion, and not always the DOT. ICM represents a different mindset as compared to traditional network operations, so it helps in the early stages to have many champions to make the case for change. Gradually, as ICM becomes more accepted as a standard practice, the need for champions will lessen. To mainstream ICM into the transportation planning and programming processes, the leadership of each stakeholder organization must be supportive of ICM and understand what it means to their agency. Given the realities of staff turnover and attrition, there is a need within each agency to have multiple personnel knowledgeable and supportive of ICM, at various job levels and spanning planning, operations, and project management responsibilities.

- **Why is it that the benefit-to-cost ratios projected from the evaluation of the demonstration sites were not higher?**
  - The final evaluation report for the ICM demonstrations showed a range of benefit-to-cost ratios for San Diego from 2:1 to 9:1 and Dallas from *0.55:1 to 1.64:1*. See the evaluation final report for more information. The ranges were based on varying assumptions for activations over a 20-year horizon and relied heavily on simulation modeling work that was done for the post deployment AMS activity, which relied on a static weighting of incident types and frequencies. Only the incidents in the AM or

PM peak were considered in the analysis. The B-C ratios would be higher if all incidents, including those outside the peak periods, were considered. The ratios would be even higher if the overall frequency of incidents increased over the 20-year horizon. The weighting and characteristics of various incident types, based on cluster analyses, would not remain fixed over 20 years and would have to be recalibrated from time to time to improve the accuracy of the analysis.

- Because of methodological difficulties, the evaluators did not try to monetize other realized benefits such as traveler or operator satisfaction, improved situational awareness, improved agency collaboration, and other institutional benefits. In addition, individual network benefits that may be attributed to ICM enhancements were excluded from the analysis. **Therefore, the benefit-to-cost ratios under-represent the true benefits of the ICM demonstrations.**

- **What advances have been made since the time the ICM systems of Dallas and San Diego were designed and implemented that current deployers can take advantage of?**
  - Advances include more research on and experience with DSSs, improved simulation modeling capabilities, the availability of a rich set of new ICM strategies that can be leveraged from connected and cooperative vehicles and shared use mobility concepts such as MOD[14]. In addition, more consultants have experience with ICM planning and implementation than were available at the time the systems of Dallas and San Diego were being designed. Beyond that, the availability of third-party data on network traffic conditions made available from Crowdsourced applications such as WAZE, INRIX, or HERE has grown substantially in the last few years. These applications enable arterial network coverage to be much more robust than in the past.

- **Why should we implement ICM in our region? How will I know when we are ready to begin?**
  - FHWA has a *flyer* entitled "10 Attributes of a Successful ICM Corridor"[15] that suggests when a region is candidate for ICM.
  - Working in collaboration with other agencies, integrated corridor management promotes a change towards proactively managing corridor traffic considering the traveler first, instead of agency systems or jurisdictional boundaries. The San Diego and Dallas ICM deployments demonstrated the benefits of this approach.
  - Discussing the concept of integrated corridor management and potential strategies with other stakeholders can begin right away, while serious project planning and deployment of ICM systems in your corridor should wait until you have visibility

[14] See also the MOD Operational Concept Report, FHWA-JPO-18-611, September 2017 https://rosap.ntl.bts.gov/view/dot/34258 Last accessed December 2018

[15] https://www.its.dot.gov/factsheets/pdf/ICM_10Attributes.pdf

into operational status and conditions of each important network within the corridor. In addition, corridors with current or predicted congested conditions and variability in traffic conditions plus viable alternative modes and routes to the freeway are better candidates for integrated corridor management.

- **Where should I go for help?**
  - Many ICM initiative deliverables were produced during the program that may serve as a reference or example for others interested in deploying the concept. A great place to start would be to search the FHWA Office of Operations website and/or the Joint Program Office of ICM knowledgebase. In addition, USDOT plans to provide ongoing KTT support through facilitated workshops and other targeted assistance.
  - **For more information contact the ICM Program Manager in the FHWA Office of Operations or the USDOT Intelligent Transportation Systems Joint Program Office website: keyword, ICM or related.**

APPENDIX C. ACKNOWLEDGEMENTS

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- Maricopa County, Arizona
- California Department of Transportation (Caltrans)
- Contra Costa County, California
- Broward County, Florida
- Maryland State Highway Administration (SHA)
- New Jersey DOT
- City of New York
- Niagara International Transportation Technology Coalition (NITTEC), vicinity, Buffalo, New York
- City of Portland, Oregon
- City of El Paso, Texas
- City of Austin, Texas
- Utah Transit Authority and the Utah DOT (UTA and UDOT)
- Virginia DOT
- Dallas, Texas
- San Diego, California

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