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Elements of Business Rules and Decision Support Systems within Integrated Corridor Management: Understanding the Intersection of These Three Components

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LIST OF ABBREVIATIONS AND ACRONYMS

ATMS	advanced transportation management
ARTS	area rapid transit system
ATIS	advanced traveler information system
ARM	automated records management
ATM	active traffic management
AZTech	Arizona Technical Regional Partnership
CM	corridor management
CAD/AVL	computer aided design/audio visual
CCTV	closed circuit television
CAD	computer aided design
CHP	California Highway Patrol
CSC	corridor sharing committee
CSMP	corridor systems engineering plan
COMPASS	computerized optimization model for predicting and analyzing support systems
ConOPS	concept of operation
DART	Dallas Area Rapid Transit
DMS	dynamic message aystem
DOT	Department of Transportation
DRISI	Division of Research, Innovation, and System Information
DSS	decision support system
EV	emergency vehicle
FHWA	Federal Highway Administration
GLIDE	green link determination
HOT	high-occupancy toll
HOV	high-occupancy vehicle
ICM	integrated corridor management
ICMS	integrated corridor management system
IMTS	intermodal transportation management
IRP	incident response plan
IT	information technology
ITS	intelligent transportation systems
IVR	interactive voice response
KITS	Kimley-Horn Integrated Transportation System(s)
LRT	light rail transit
MOU	memorandum of understanding
MPO	metropolitan planning organization
NCTCOG	North Central Texas Council of Governments
NPS	network prediction system
O&M	operations and maintenance
NTTA	North Texas Tollway Authority

LIST OF ABBREVIATIONS AND ACRONYMS (CONT.)

PAC	Policy Advisory Committee
PATH	Partners for Advanced Transportation Technology
RMS	ramp meter station
RTMS	Regional Transit Management System
RTSS	Real-Time Simulation System
PEMS	Performance Engineering Management System
SANDAG	San Diego Association of Governments
TCC	Technical Coordinating Committee
TLSP	transport layer security protocol
TMC	traffic management center
TMS	traffic management system(s)
TOAR	traffic operations analysis report
TRANSCOM	Transportation Operations Coordinating Committee
TxDOT	Texas Department of Transportation
USDOT	United States Department of Transportation
XML	extensible markup language

CHAPTER 1. INTRODUCTION

The purpose of this guidance document is to provide a fundamental explanation of the "decision support system" (DSS) concept and the relationship of DSS systems and business rules to the integrated corridor management (ICM) community. The document will provide examples and background within and beyond transportation, as well as a clearly organized discussion concerning the elements of business rules and DSS within ICM corridors.

An ICM system is a multimodal transportation management system designed to enhance the accessibility and efficiency of traveler infrastructure (routes and modes, but also information) by directing travelers in the short term to alternative routes and/or modes in a transportation corridor. A corridor is herein defined as a unique travel "wedge" or linear corridor that is anchored by a major highway and supported by a network of alternative routes and modes (e.g., commuter bus, rail, bike, transit, etc.). Inter-regional commute trips and intra-regional "bustle" trips that originate near to (and therefore, are considered "anchored by") the major spine highway, are said to be germane to the "travel shed" of that corridor boundary; that is, they would *not* go out of their way to use another spine highway to travel "downtown" and back.

A DSS is an information system that supports organizational decisionmaking and, in the case of an ICM, assists in multimodal transportation operation decisionmaking in real-time (Lukasik et al, 2011). To assert a multimodal transportation management structure and control the operation of all participating agencies, "business rules" are required. Business rules are predefined and agreed-upon organizational and inter-agency permissions, constraints, or criteria that bind the participating agencies and affect the DSS solutions.

This document is not a step-by-step guide to developing business rules, criteria, or algorithms (or code) to be implemented within a DSS. Extensive search, contacts, canvassing, and discussions have not turned up detailed specifications of business rules as part of DSS within an ICM (and transportation) domain. Consequently, general principles are outlined for the reader. The document is also not a *detailed* overview of ICM or DSS history, development, and current state. There are numerous other documents whose focus is on these topics (and several of them are cited in the appropriate areas below). This guidance document attempts to provide an overview of the intersection of these three components, which is an often-overlooked area, and we hope the information provided below is helpful.

DEVELOPMENT OF GUIDANCE DOCUMENT

This document is divided into five chapters, each focused on the business rules as related to DSS for managing integrated corridors.

- **Chapter 1. Introduction.** This chapter provides the overall purpose, objectives, guidance document overview, intended audience, and a *brief* background of ICM, DSS, and business rules.

- **Chapter 2. Guidance for business rules and DSS within the context of ICM.** This chapter describes how DSS was developed in the two U.S. Department of Transportation (DOT) demonstration sites, Dallas and San Diego, as well as how users interact, communicate, and coordinate with colleagues and agencies.
- **Chapter 3. Case studies and lessons learned in ICM with emphasis on DSS and relevant business rules.** This chapter describes operators' strengths, limitations, biases, and lessons learned from site implementation.
- **Chapter 4. Examples of operational decisions with and without business rules constraining options.**
- **Appendixes.** Listing the phases of initiative ICM and resources for the development of concept of operation, and interagency agreement approaches and examples.

INTENDED AUDIENCE

This guidance document presents information on DSS and ICM with a focus on proper business rules. It is intended to be used by practitioners, managers, and designers who have varied levels of decisionmaking authority, ranging from leading initiatives to operations supervisors to shift workers; therefore, they will face a variety of challenges, including overcoming interagency and inter-jurisdictional communication issues, or being fully familiar with decision processes in the context of transportation management. These staff members will be from varied backgrounds, including those who are new to transportation.

BACKGROUND

This section provides a *brief* overview of ICM, DSS, and business rules. It is meant only to give a high-level overview and introduction with references to more detailed documents about ICM and DSS for the interested reader to pursue. This background is necessary to provide the foundation for discussion of these three topics and the role of business rules.

Integrated Corridor Management

The ICM concept has been defined in the San Diego Concept of Operations report as:

> . . . the operational coordination of multiple transportation networks and cross-network connections comprising a corridor and the coordination of institutions responsible for corridor mobility. ICM programs provide better information, coordination of network junctions, proactive management of capacity and demand, advanced technologies and systems, and improved institutional arrangements. ICMS is a "system of systems," i.e., a transportation management system (TMS) that connects the individual network-based TMS, provides decision support, and enables joint operations according to a set of operational procedures agreed to by the network owners. ICMS facilitates ICM programs to meet corridor needs and realize the ICM vision. (San Diego Pioneer Site Team (2008), page 1-1).

ICM has been a concept for over 10 years but was not fully vetted and implemented until the U.S. DOT "ICM Initiative" was undertaken to identify several "pioneer sites" and ultimately award full demonstration rights to Dallas, TX, and San Diego, CA.

Managing an integrated corridor is possible if agencies take advantage of telecommunications, internet, software, and information technology (IT) capabilities as well as, and perhaps most importantly, the increasing availability of archived and real-time "big data." Together, these resources allow agencies' traffic management systems to archive and share data in real-time (or compare it to historical precedence) to enhance their ability to monitor, react to, and even predict traffic conditions to inform motorists and system operators of any severe delays and the options available for either avoiding problem areas or mitigating the cause.

Use of the term "integrated" implies the need for interagency and interjurisdictional cooperation and the ability for proactive traffic management systems to share information with corridor agencies and service providers. ICM sites are complex environments characterized by constant upgrades of technology along with the concomitant demands (e.g., monitoring ongoing traffic operations, responding to emergencies and unpredictable weather, communicating with partner entities and the public) on operators, transportation planners, managers, and designers. Such an environment also calls for constant decisions to be made at the individual and organizational level along with proper protocols for communication between entities.

Decision Support Systems

DSS are primarily computer-based information systems that originally were developed in the management and organizational decisionmaking arenas. They are typically used to sort, rank, or choose alternatives. These DSS operated at the operational and planning levels and were used by upper management to plan strategic and long-range approaches. For more historical information and a detailed bibliography on DSS, which is outside of the current scope of this report, see Marakas (1999); Turban, Aronson, and Liang (2008); and Burstein and Holsapple (2008). A DSS consists of three major components:

- Expert Rules.
- Prediction (Model).
- Evaluation.

Because only Dallas and San Diego were fully implemented at the time of this report, this guidance document focuses on those two regional ICM sites as examples.

Business Rules

A key component of successful transportation systems management is that all relevant agencies both leverage their operating powers as well as achieve administrative efficiencies and cost savings. The communication and coordination of information sharing capabilities can promote interoperability. Too often, the work of the agencies unnecessarily overlaps due to the lack of an interagency cooperation agreement, leading to redundancies. This inefficiency due to lack of interagency cooperation can result in higher administrative and congestion costs.

This guidance document outlines elements of business rules and DSS used in ICM to ensure efficient operations and interagency cooperation.

When discussing DSS, business rules, ICM, and how these concepts tie together, it can often be confusing. One analogy that may help describe this complex relationship hails from chess. In a game of chess, there are several components: the chess board, pieces, rules, and strategies for using those pieces within the rules (see Figure 1 for an example chess board).

Figure 1. Photo. Example of a chess board.

Similarly, we can map these components onto the DSS and business rules within the ICM space:

- The ICM corridor can be thought of as the chess board where the pieces interact, decisions are made, and overall context is provided within the geographical constraint of the board, or in the context of ICM, the "corridor."
- The managers, operators, agencies, and organizations involved in the ICM corridor can be thought of as the chess pieces as they are the "moving parts" on the game board/corridor.
- Business rules are the pre-agreed game rules by which these individuals and agencies (pieces) interact. In the chess analogy, a bishop can move diagonally any number of unimpeded spaces, a pawn can move one space forward, etc.
- The DSS contains the strategies to beneficially utilize these rules. In other words, knowing the rules of how the entities interact is not enough, just like knowing the rules that govern pieces on a chess board does not make someone a chess champion. Combining these rules within the chess board context in a most beneficial way to succeed is one way of defining strategy.

Another example could be a hospital operating room. DSS have been in use in hospital operating rooms for many years, evolving from "management systems" over recent decades. There are many task-related rules in place merely to record a patient's vital signs. Various professionals follow protocols to take and monitor the patient's temperature, blood pressure, oxygen level, heart rate, respiration, etc. In case of failure of one or more of these functions, the surgeon plans decisions relating to the operating procedure and makes the necessary adjustments.

In the transportation management arena, we are advocating that traffic management systems have a decision support system that automates much of the necessary decisionmaking based on conditions. But, within this context, it is crucial to have these decisions align and be consistent with agreed-upon policies, procedures, control plans, interagency agreements, and protocols of the lead and cooperating agencies.

Integrated Corridor Management, Relevant Components, and Recent Implementations

ICM is an integrated network of freeway, arterial, transit, and parking facilities, among other transportation networks. Real-time situational awareness on the entire network and all constituent parts is required to make proper decisions. To meet this goal, interagency cooperation is needed.

> The existing agencies do very well with day-to-day operations. What causes problems with the corridor operations are atypical non-recurring events, such as incidents, and even atypical recurring conditions. Multijurisdictional responses were not being attempted before ICM (Spiller, et al. 2014, page E-4).

ICM gives agencies the opportunity to operate together by sharing information pertaining to incidents, construction, special events, transit, parking, and traffic flow data internally and externally. The shared information is used to improve situational awareness, corridor performance, and real-time alternatives for transportation users, enabling them to manage their trip plans (Miller et al., 2015). Figure 2 lists characteristics of a transportation network where an ICM could be effective:

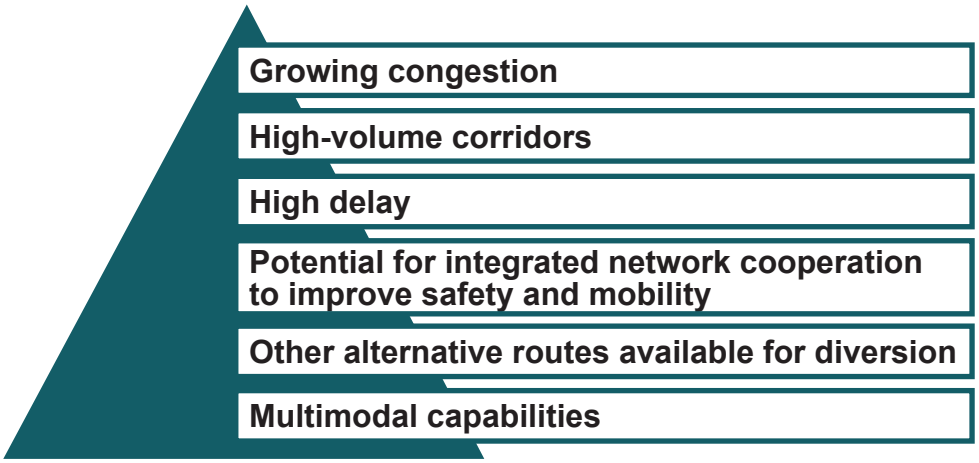


Figure 2. Diagram. Characteristics of transportation highway networks where integrated corridor management can be an effective approach.

However, the Federal Highway Administration's (FHWA) *Integrated Corridor Management Implementation Guide* (Gonzalez et al., 2012) suggests the leaders of each agency answer these questions before they engage in an ICM project:

- Why the ICM is needed?
- How will ICM address the problem?
- How will ICM benefit the users as well as the partners?

As noted above, to date, the San Diego I-15 and Dallas US 75 corridors are the only two fully operational U.S. DOT-funded ICM demonstration sites with DSS systems. However, elements of ICM concepts have been developed and tested in several other locations:

- New York/New Jersey/Pennsylvania – since the mid-1980s, this region has cooperatively championed the TRANSCOM regional authority, which has grown to include a coalition of no less than 16 regional transportation agencies in New York, New Jersey, Pennsylvania, and Connecticut. TRANSCOM was the first de facto ICM-styled, coordinated, multiregional coalition.
- Minneapolis – the I-394 corridor was a U.S. DOT Pioneer Site for Stages 1 and 2 of the Federal ICM program. The corridor is bounded by Highway 55 on the north and Highway 7 on the south, and is ripe with advanced and robust infrastructure, highway traveler information systems, and real-time data.
- Phoenix – The Maricopa Association of Governments champions the ICM strategic plan for I-10, Loop 101, and potentially the I-10/I-17 "spine" connector. "AZTech" is a strong partner in developing the management partnership of many agencies, cities, and local authorities (Spiller,et al. 2014).

ICM improves communication by supporting coordination among agencies such that they share incident, construction, and special event data and information as well as making changes to benefit the corridor's operation through a data interfacing platform (i.e., a common operational and visualization platform) that can be integrated into the agency's existing software. A DSS, as a major component of ICM, supports the operation of agencies participating in the integrated corridor system by potentially recommending traffic operations strategies, traffic control plans, and response plans and actions and by disseminating information based on prevailing conditions within the transportation corridor.

As ICM builds upon regional management, it requires the expansion of existing agreements among institutions to improve corridor operation. Operations are coordinated through the ICM network, where participating agencies share data and information while making changes that benefit overall corridor operations and performance. An example of this would be operations personnel adjusting traffic signals and ramp meters to take advantage of capacity on other facilities; e.g., funneling travelers to parallel roads, or high-occupancy toll (HOT) lanes or bus rapid transit, as needed. A properly deployed DSS can also compare real-time data against historical data to predict short-term corridor performance problems to recommend (and

implement) responses that select the most beneficial combination of ICM strategies *before* the actual predicted breakdown, as in, "why wait for the actual problem?"

Business rules are rules or agreements that define or constrain some aspect of operations, decisionmaking, and strategy, among several organizations. A DSS that incorporates business rules will incorporate agreements with relevant entities when making these recommendations.

To expand the agreement to facilitate multi-agency collaboration, the first step is identifying the ICM partners. ICM partners can be listed in multiple major categories as shown in Figure 3. Due to multi-agency collaboration, ICM has a wide range of applications which require agencies' coordination, cooperation, and communication. For example, the following list notes areas of deployment in the Dallas ICM:

- Responsive traffic signal system.
- Arterial street monitoring system.
- Agency, Bluetooth, and third party data.
- Transit signal priority.
- Transit parking management.
- Real-Time transit vehicle information.
- Freeway and high-occupancy vehicle (HOV) systems management.
- Weather system reporting.
- Decision Support System.
- 511.

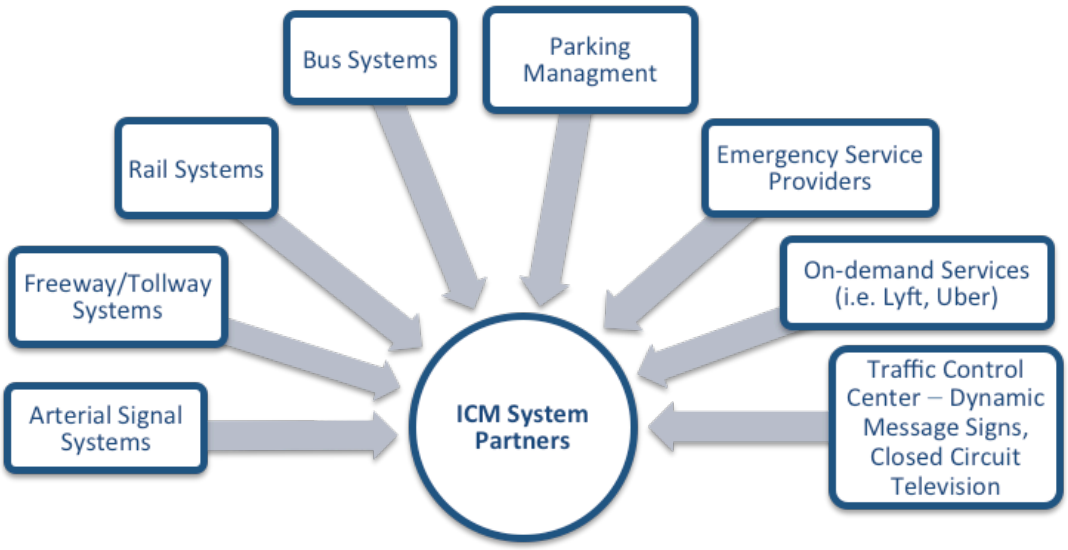


Figure 3. Illustration. Integrated corridor management system partners.

By its nature, ICM consists of the corridor sub network as well as the corridor itself. For instance, the Dallas ICM demonstration site on US-75 is illustrated in Figure 4, where the black line represents the corridor influence area. "The primary criteria were to select a congested corridor where there are both transit and other alternative routes available for diversion in the case of an incident. US-75 is fully built out, with no ability for new capacity additions" (Spiller, et al. 2014, page E-3). The corridor network includes a freeway with continuous frontage roads, managed HOV lanes, the Dallas North Tollway, 167 miles of arterials, a bus network, a light rail network, 900 signals, multiple traffic management centers (TMC), and a regional advanced traveler information system.

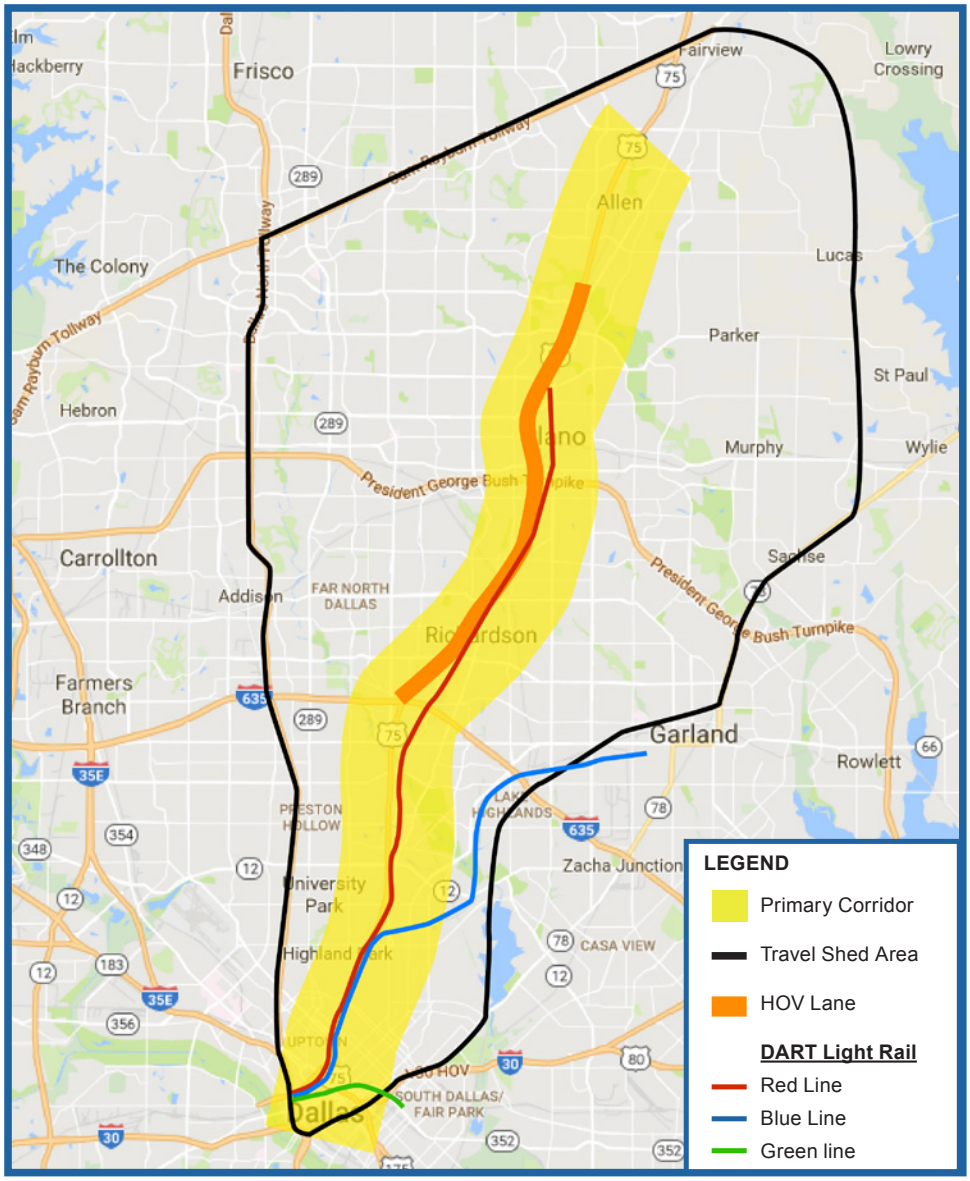


Figure 4. Map. US-75 corridor network, Dallas integrated corridor management demonstration site.

(Source: Google© Map Data, March 27, 2017)

The San Diego demonstration site on I-15 is illustrated in Figure 5.

> The I-15 corridor is a 21-mile freeway segment in San Diego County. This corridor is a regionally significant segment of I-15 from State Route (SR) 52 in the City of San Diego to SR 78 in the City of Escondido. The corridor also includes the portion of SR 163 from SR 52 to I-15 in the City of San Diego. The I-15 corridor is presently an eight- to ten-lane freeway within the corridor boundaries, with additional auxiliary lanes throughout the corridor. Near the southern section and within the median of I-15 from SR 56 is a two-lane reversible, high occupancy toll (HOT) facility. Known locally as the I-15 Express Lanes, this eight-mile, barrier-separated facility operates in the southbound direction during the a.m. peak period, northbound during the p.m. peak period, and all day (northbound) during the weekend. The existing I-15 corridor can be split into three distinct segments: north, middle and south as shown in Figure 5 (San Diego Pioneer Site Team, 2008. Page 3-1).

The role of DSS in the general ICM context is to:

- Receive data from an information exchange system (e.g., Dallas SmartNET/SmartFusion).
- Evaluate various response plan options.
- Provide recommended plan to ICM coordinator, partner agencies, and information exchange system, which then make the ultimate decision and carry out appropriate strategies.

Following confirmation of candidacy, the first step to initiate an ICM is to develop the concept of operation (ConOps). Appendix B provides a list of references for how to develop a ConOps and examples. "The ConOps does not delve into technology or detailed requirements of the ICMS, but it does address the operational scenarios and objectives, information needs, and overall functionality. The ConOps must also address the "institutional" environment in which integrated corridor management must be deployed, operated, and maintained" (San Diego Pioneer Site Team (2008), Page 1-3). To develop the concept of ICM operations, a sequential order process is suggested by the San Diego I-15 ICM team. The components of this procedure are as follows:

1. System vision.
2. System goals and objectives.
3. Operational concept.
4. Approaches and strategies.
5. User needs.
6. Implementation issues.
7. Institutional framework.
8. Operational scenarios.

Figure 5. Map. I-15 corridor network, San Diego integrated corridor management demonstration site.

(Source: San Diego Pioneer Site Team 2008)

Figure 6 illustrates the Dallas ICM overview. The development of the system requirements incorporated the user needs that had been identified during the concept of operations development. Any operational evaluations that are conducted to assess the potential benefits of the system would then be based on strategies and approaches identified in the original concept of operations (Dion and Skabardonis, 2015). More information about the different phases of the ICM initiative can be found in Appendix A.

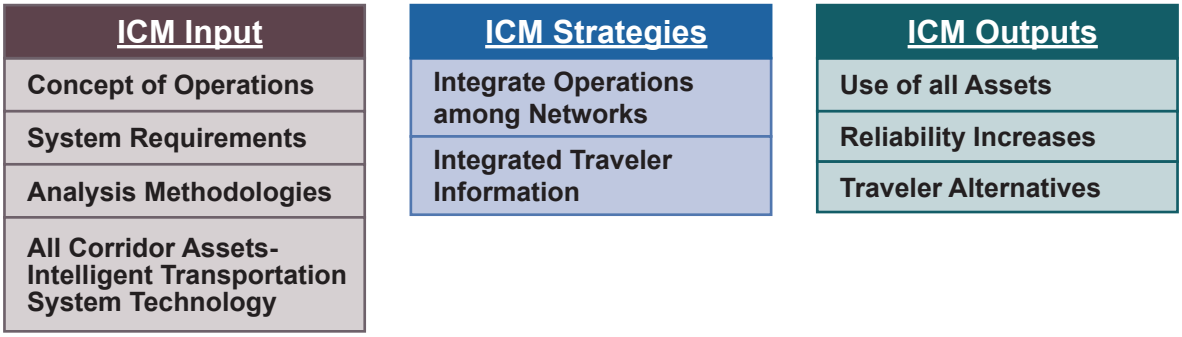


Figure 6. Illustration. Integrated corridor management overview.
(Source: Dave Carter, 2007)

Overview of Decisionmaking and Decision Support System Design

Why do we need DSS? Humans are prone to numerous biases that affect decisionmaking and can benefit from a support structure.

Factors Affecting Decisionmaking

Decisionmaking is a complicated process with a myriad potential influences that should be considered. These influences can affect the decisions of individual operators, including those who are in leadership positions and drive overall organizational strategies. They also are part of the motivation for utilizing DSS (i.e., avoiding many of these biases or influences). Torma-Krajewski et al. (2010) and Kelly (1999) identified a variety of factors that can impact an operator's decisionmaking, many of which can lead to sub-optimal outcomes:

- Fatigue (including sleep deprivation).
- Stress, often related to perceived or real-time pressure.
- Erratic eating habits (leading to high or low blood sugar).
- Caffeine.
- Lack of information, conflicting information, and uncertainty.

Stress can negatively influence decisionmaking and should be mitigated when possible. Robinson, et al. (2017) found that decision makers under stress can exhibit a variety of behaviors. For example, they may:

- Seek out certainty, be less tolerant of ambiguity, and look for fast choices.
- Experience greater conflict in social interactions.
- Develop "tunnel vision" (narrowed perception due to sensory overload).
- Experience distorted perception.
- Have a decreased ability to handle complex or difficult tasks.
- Focus on short-term survival goals, sometimes at the expense of long-term benefits.
- Choose riskier alternatives.

For these human factors, a DSS offers an objective – not subjective – analysis to a situation and promotes one or more equally objective solutions.

Understanding Common Decisionmaking Biases

Understanding Framing. A very common decisionmaking bias involves people reacting differently to information depending on the phrasing, context, or "framing." (Tversky et al., 1981) This bias can have profound impacts on a transportation system, especially when switching or transitioning operations during a major incident or emergency if the personnel do not adjust their thinking appropriately. A strategy to mitigate this bias is to change labels, colors, or codes to indicate clearly the context has changed (e.g., from normal operations to emergency operations). A DSS can provide guidance on proper label switching and information dissemination depending on the "mode" of operation. In addition, one should be aware of how information is presented and whether it may be framed in a negative or positive way.

Understanding Confirmation Bias. People often favor or seek out information that confirms a prior hypothesis or belief. This is known as "confirmation bias" (Wason, 1968). This bias can affect operations when operators and managers focus more on data that support an initial approach or only listen to opinions that support their plans. Thus, operators may not seek out alternate explanations and inadvertently ignore other useful information. Instead, the correct decisionmaking process or a properly deployed DSS would be to sample the full range of both negative *and* positive possibilities rather than just the positive ones.

Understanding Anchoring Bias. Individuals have the tendency to rely on the first piece or limited pieces of information when planning or forming an estimate. This is known as "anchoring" (Ariely, 2008, Tversky et al.,1973). This bias often manifests itself in operational situations where the first incoming field reports will drive estimates or the more salient images will affect planning. To mitigate this bias, one should be careful about weighting early or limited information and generate alternative or counterfactual options. Another option is to constantly refine estimates as data becomes more reliable over time (Robinson et al., 2017). A DSS can handle the updating of information and properly weigh it to compensate for this bias.

Decision Support Systems—High-level History and Relevant Approaches on Implementation and Management

Decisions are not made in a vacuum, a concept which is often lost in the design and implementation of DSS. This is particularly relevant in the case of ICM and the overlay of business rules for operations, where various entities can affect one another during the process (e.g., local roads being congested during rush hour due to an incident on the highway).

How Do Decision Support Systems Help Overcome Bias?

DSS can be defined traditionally as computer-based information systems that support business or organizational activities and can be fully computerized, human powered, or a combination of both (Robinson, 2016). DSS can also occur in a range of technology levels, from mechanical to digital. Figure 7 illustrates the evolution and examples of DSS, which began with decision support tools that facilitated decisionmaking tasks (before being developed to larger, more complex decision support systems).

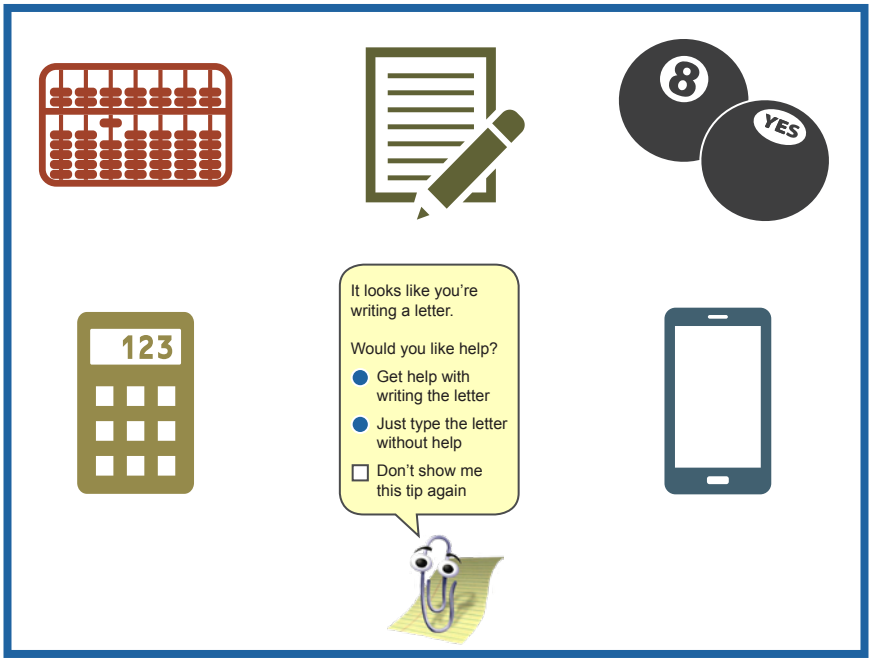


Figure 7. Illustration. Examples of decision tools.
(Source: Robinson, 2017)

Within a transportation context, one can think of a traffic simulation model as an example of a tool that supports data analysis. It is not a system, per se, but rather produces information that supports the process of making decisions. A range of decision support tools are deployed within a transportation context and will continue to be used to manage and control traffic as well as coordinate amongst staff members and outside stakeholders.

Markalas (1999) defined three components that are often considered to be integral to a DSS:

a) The data/knowledge base.

b) The model (criteria and decision context).

c) The interface.

It seems most implementations neglect the context (which in this case can be the business rules governing agency interactions). The current effort focuses on this very important component of DSS.

The word "integrated" can also be used to describe an effective DSS implementation; it represents the unification of all parts within the context of decisionmaking. A DSS is particularly useful for unstructured or semi-structured problems or a litany of biases and problems that occur every day. DSS have been successfully developed for a variety of fields, including clinical decision support and medical diagnosis, finance, business management, agricultural contexts, law enforcement and the military.

DSS in Broader Transportation Areas. As the transportation network and control centers have become increasingly complex, a DSS can play a greater role in optimizing the efficient and safe movement of people and products. The following passage highlights the burgeoning amount of new data streams and expanding complexity facing operations personnel that demands various decision support systems:

> In the world of transportation systems operations, emerging infrastructure-based sensor technologies and in-vehicle technologies are providing new data streams to support transportation operations decisionmaking. Increasingly complex and capable system control technologies and traveler systems present transportation managers with a broader range of potential actions to impact system performance. In many cases, this includes a new capability to act with increasing precision with a shorter response time. At the same time, there is an emerging recognition that in complex systems individual mode control decisions cannot be made independently. Any single modal decision may impact broader system performance positively or negatively. This leads to the consideration of how concurrent decisions may be made across modal, facility, institutional and jurisdictional boundaries to optimize performance across the entire multimodal transportation system (Lukasik et al. (2011), page 3-1).
>
> Most existing DSS identified were associated with freeway management systems – from a "lessons learned" perspective, these deployments can be extrapolated to future multimodal systems (Lukasik et al., 2011, page 3-4).

The application of DSS in transportation as stated by Lukasik et al. (2011) has variety of developments in real-time traffic management but not limited to:

- Accident response strategy assessments.
- Online travel information systems.
- Predictive travel time calculations.
- Dynamic route guidance.
- Adaptive ramp metering using predictive traffic congestion algorithms.
- Intelligence-based Transit DSS.
- Dynamic emergency vehicle routing.
- Emissions management.
- Urban and interurban congestion management.
- Security threat mitigation and large-scale evacuation management.

DSS technology and methodologies can be categorized into five major groups (Power, 2001 2003; Lukasik, 2011). Figure 8 outlines the DSS methodologies. Discussing these technologies/ methodologies is out of the scope of this report, but further information can be found in Power (2001, 2003).

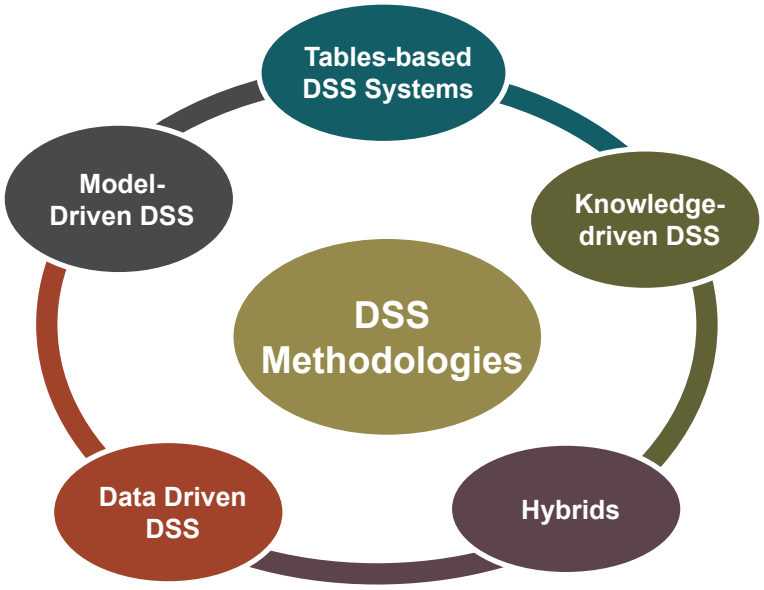


Figure 8. Illustration. The DSS technology and methodologies.

The following list with transportation ICM appropriate examples was based on Lukasik (2011):

- Table-based DSS (e.g., Toronto Computerized Optimization Model for Predicting and Analyzing Support Scenarios {COMPASS}, Kansas City Scout, Georgia DOT NaviGAtor) are data tables or spreadsheets with predefined response plan recommendations and require little or no processing, modeling or analysis. Some may include basic logic to analyze data in the tables, while others are purely lookup tables.
- Knowledge-driven examples include:
  - » Expert Systems (e.g., the Caltrans Advanced Transportation Management System (ATMS), St. Louis Gateway Guide). Response plans are based on a set of pre-defined rules and the DSS requires an expert system engine.
    - › Custom Rules-based Systems (e.g., Oregon DOT Transport, Pace Transit Operations Decision Support Systems). The Custom Rules DSS uses specific rules to determine response plans, making it similar to the Expert System DSS. The main difference between the two is that rules are custom built rather than having an expert system engine.
  - » Event Scenario Matrices (e.g., Lake County Passage, Michigan ATMS, New Jersey ATMS) identify events on the roadway using a plane coordinate system, and users can respond to the events using the predefined ITS field devices along the roadway in the area.
- Model-Driven DSS incorporate on-line simulation tool integration (e.g., Singapore – Green LInk DEtermination (GLIDE) Traffic Control System, Madrid, Beijing, Milan).
- Data Driven DSS are a form of support system that focuses on utilizing internal and sometimes external data to aid in the decisionmaking process. Sometimes this comes in the form of a data warehouse, e.g. a database designed to store data in such a way as to allow for its querying and analysis by users.
- There are also hybrids of the "Model Driven" and "Data Driven" models.

The **"Five Rights."** Lessons have been learned from many of these fields, and DSS has worked across several domains within them. For example, Figure 9 illustrates a brief list of "five rights" to keep in mind when implementing a DSS design (U.S. Department of Health and Human Services).

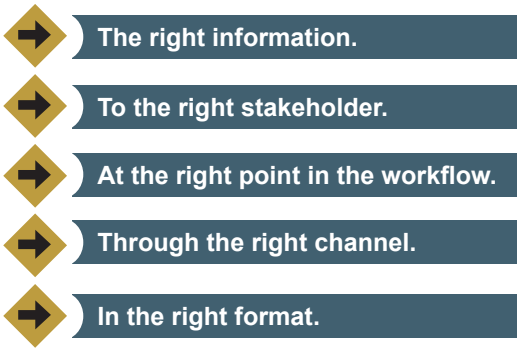


Figure 9. Illustration. "Five Rights" of a decision support system design.

Proper Design and Use of Decision Aids. Decision aids (such as DSS) can help with data processing and improve overall decision quality. This can offset some of the typical biases that arise when making decisions.

Robinson et al. (2017) found that decision aids have a variety of advantages, including:

- Minimizing the influence of biases (such as confirmation bias) on decisions.
- Forcing structure and consideration of alternatives as well as quantitative weighing of options.

However, the same study also found several disadvantages that one should keep in mind when employing decision aids, including:

- Discounting intuition and experience.
- Lack of use regarding inaccurate recommendations.
- Lack of adaptation in unusual circumstances.
- Increased decision time, and difficult to evaluate.

Despite these potential pitfalls, properly designed decision aids can be valuable assets to an operator in the TMC.

Business Rules: Context and Constraints for Implementing Decision Support Systems Interagency Agreements

A key component of successful transportation systems management is that all the agencies involved leverage their operating powers, achieve administrative efficiencies, and function cost effectively. Communication and coordination can promote interoperability, which supports these objectives. Too often, however, agencies conduct overlapping activities due to the lack of an interagency cooperation agreement. Such inefficiency can result in higher administrative and congestion costs.

This guidance document outlines elements of business rules and DSS used in managing integrated corridors to ensure efficient operations and interagency cooperation. By establishing a framework for sharing information and data and for collaborating, the duplication of data collection and extra delays caused by congestion can be reduced. Gordon (2011) found that significant value can be obtained with:

- The right leadership.
- Strong strategic planning.
- Evaluation of the current case.
- Solid contract management.

To achieve organizational change across multi-agency functions requires a holistic strategic plan. Strategic planning to develop business rules commonly includes several major steps:

- Determine the need for ICM.
- Determine the lead agency and point of contact.
- Elect a committed board to assist with planning and design.
- Define the vision.
- Define resources and categorize them by duration (short and long term) and type (service, or support fund).
- Define stakeholders with an opportunity for public-private partnering.
- Plan outreach activities and follow up.
- Define capabilities of each agency.
- Evaluate the existing plans, rules, and services.
- Conduct detailed planning for all possible scenarios: daily operations, freeway incident, arterial incident, transit incident, special event, and major disaster.
- Determine where there is a need for interagency communication and operation improvement and prioritize them (consider all possible scenarios).
- Identify the best way to create a collaboration where there is a need.
- Decide based on the feedback obtained from the board of committee and stakeholders.
- Allocate the resources.
- Gain approval from each agency's authority.

Consideration for ICM in a corridor (i.e., as a congestion or incident-driven mitigation) is typically led by a regional agency, such as a State DOT, a metropolitan planning organization (MPO) or a transit authority, that has responsibility for overseeing a transportation plan in the subject corridor. An early confirmation that said corridor is even an ICM candidate corridor can be made by viewing the U.S. DOT report *ICM Candidate Corridor: Implementation Guide and Lessons* (Gonzalez et al., 2012).

Another early step in initiating an ICM system is to select a stakeholder that will manage the process, such as scheduling meetings to discuss planning, activities, issues, and risks. The U.S. DOT ICM website (http://www.its.dot.gov/research_archives/icms/index.htm) offers many sources to assist stakeholders in developing a managed corridor system. The "ICM Knowledgebase" (http://www.its.dot.gov/research_archives/icms/knowledgebase.htm) is also a good source for presentations, newsletters, and fact sheets on ICM.

All potential stakeholders should be invited early in the process (Gonzalez et al., 2012). Their level of involvement will be up to them; however, it is advisable to keep those who decide not to participate informed as the efforts progress. The success of the program is highly dependent on the level of engagement and interest among agency leadership because ICM-related activities require the commitment of time and resources. It's advisable for each key operating agency to have a champion who understands ICM and the concept of corridor operation and could lead a diverse team, communicate well, and commit time to the effort (Gonzalez et al., 2012).

The planning and development process should include transportation planners, modelers, and operations personnel from various partner agencies. These stakeholders are key to understanding the context. They can provide guidance into the types of performance measures needed as well as assisting the organization in understanding how best to track and evaluate system performance to ensure it remains focused on the established goals. When working with multiple agencies, it is also important for terminologies and acronyms to be well defined, understood, and agreed upon among stakeholders. Educating stakeholders and maintaining their engagement over time is another leadership task critical for the success of the program. Routine evaluation of the risks, benefits, and implications of each strategy by the leaders is required. One example of risk could be compatibility of the technology and data collection format, which are necessary for agencies to exchange certain data elements. However, any changes on the interface and type of data being shared could cause problems.

In accordance with sharing information and data across the system, any future technology enhancement regarding data collection must be compatible amongst all agencies.

Proficiency of the program over time can be a challenge. Planning efforts should focus on ensuring the program is successful enough to run over the long-term, not just for the short period of time that funding is available. One way to facilitate motivation and resource sharing could be through peer exchange workshops bringing representatives with the knowledge of ICM implementation in other regions to share their experience (Markiewicz et al., 2016).

To improve interagency operational power, agencies need to share information (including the names of vendors, contract terms and conditions, and points of contact for each group) and real-time data. The traffic management center (TMC) needs integrated information from the State DOT, county sheriff's department, safety/service patrol, closed-circuit television cameras, detection systems, other TMCs, agencies, etc. Based on the pioneer sites' experience, to eliminate confusion, stakeholders' roles and responsibilities should be documented. For formal agreements among agencies, one or more business cases can be defined, each of which should include an executive summary with the key point of agreement followed by a defined scope and potential duplication of resources and staff, potential monetary value, role, and interagency demand and management of resources (Gordon, 2011). Although not mandatory, agencies may consider developing an agreement such as a memorandum of understanding to share information or services. More information about interagency agreement approaches can be found in Appendix C. The Dallas/Fort Worth regional comprehensive intelligent transportation (ITS) agreement is attached to this document as an example (Appendix D).

The expected operation of the ICM corridor under each possible scenario must be defined in detail. An expanded description of each scenario solution should be provided in detail and broken down to the responsibility of each agency (more information is available in the *Concept of Operations for the I-15 Corridor in San Diego, California* (Page 5-1 Chapter 5 – Operational Scenarios). Dallas and San Diego defined their scenarios in general categories as follows:

- Daily operation or non-event based operation.
- Moderate and major freeway incident.
- Major arterial incident.
- Major transit incident.
- Planned special events.
- Major disaster.

The effect of these capabilities can span the institutional and operational processes; however, agencies must be alert to the impact of duplication when creating a new collaborative system. The new business rules should be approved by the agency's executive leadership, although an agency may choose to require additional approvals (Gordon, 2011). Regular assessment of whether the intended business rules meet the goals for the managed corridor is necessary. In addition, an emphasis on transparency when establishing the rules and strategies will reduce any future confusion when it comes to implementation.

To stimulate realistic operations strategies, the board or committee must constantly work to enhance their understanding of respective capabilities, authorities, and limitations. Examples of limitations could be funding or maintaining trained staff and qualified leadership.

CHAPTER 2. GUIDANCE FOR BUSINESS RULES AND DECISION SUPPORT SYSTEMS WITHIN INTEGRATED CORRIDOR MANAGEMENT IMPLEMENTATION

This chapter will provide general guidance for the necessary components to develop business rules to be incorporated into a decision support system (DSS) for integrated managed corridors. As mentioned previously, the goal is not to provide detailed specifications or algorithms that someone can "plug" into a developmental DSS. Through searching, scanning, extensive conversations with contacts, and an expert panel review, there have been no documents to date that we deem to be detailed, code-level descriptions of business rules for integrated managed corridors with respect to a DSS, per se. Consequently, herein we focus on principled guidance to endorse that "business rules" should be at least implicit understandings on developing necessary components of integrated corridor management (ICM). Business rules incorporate, either by inference or actual documentation, interagency agreements, organizational and committee structures, and even tacit agreements to share information, resources, and decisions, etc. that can be used as building blocks for success.

Attaining and maintaining a successfully integrated and managed corridor that facilitates "the safe movement of persons and goods, with minimum delay, throughout the region of influence" depends on the human operator interacting with the transportation management center (TMC) systems and devices as well as other operators, managers, and agencies. One way to improve this relationship between the user and technology is through user-centered system design. The goal is to increase efficiency, comfort, safety, and ease-of-use. When applying human factors principles and procedures to TMC operation and design, Robinson, et al. (2017) and Nowakowski, Green, and Kojima (1999) identified several areas of emphasis:

- Focus on human requirements.
- Collect data on and analyze the functions, tasks, and human/machine systems.
- Make use of design principles that reduce human error.
- Employ design principles that increase human performance.
- Apply principles of job design, user aids, and data presentation.
- Use the principles of anthropometry.
- Apply principles and standards for displays and controls.
- Adhere to workplace design principles and standards.
- Design user interfaces with information systems.

If user-centered design areas are emphasized in designing and operating a TMC, several benefits will result: First, the tasks (e.g., monitoring accidents) and functions (e.g., communicating with partner entities) of the operators will be developed based on the total system, second, any deficiencies in the system will be discovered early on, and third, the use of human resources will be optimized.

HOW TO DEVELOP A DECISION SUPPORT SYSTEM WITHIN AN INTEGRATED CORRIDOR

The DSS identifies sudden or pending nonrecurring events (e.g., incidents or weather) or atypical recurring congestion-beyond-the-norm via predictive modeling. This modeling compares "that which should be" to that which is forming, thereby triggering broad response strategies. A DSS constantly mines real-time data (e.g., detectors, incidents, speeds, warnings, and weather) and evaluates and rates the response plan alternatives for recommendation to the ICM coordinator or team to identify the highest rated plan and associated mitigations. For example, in the San Diego and Dallas deployments, each DSS averages from one to five response plans per week. Monthly debriefs evaluate the systems' success and recommends any fine-tuning that might be needed.

There is no one DSS template. San Diego and Dallas, and indeed many other regions formed or forming, have developed unique approaches, any one of which satisfies the function of a DSS. A DSS can be simple or complex depending on the users' needs, the data available, and the corridor's model. A simple DSS could be a set of written incident response plans that agencies consult when an incident occurs. For the sites that the scan team visited, more-complex systems were in use and are discussed below" (Spiller et al., 2014).

> **Overview of "Dallas" vs. "San Diego"** – The Dallas ICM system uses an *expert rules system* to select a pre-agreed response plan based on numerous variables (e.g., location, time of day, and lanes affected) and *then uses a real-time model to validate* that the selected plan will provide a benefit. The San Diego system relies on its real-time model much more and allows the model to use engineering principles and algorithms to generate a response plan for an event within the corridor. The system has the capability to be fully automated or fully manual in responding to the event. (Spiller et al., 2014, page 7-1)

The Dallas ICM process is designed to collaboratively engage the planning, technology, and infrastructure resources of the various cities and government jurisdictions along the corridor. An overview of DSS has been reproduced from the *Dallas Integrated Corridor Management (ICM) Demonstration Project* (Miller et al., 2015) as shown in Figure 10.

> The Dallas DSS (Figure 10) provides candidate response plans to the SmartFusion (Smart Urban Freight Solutions) subsystem based on network conditions received from the SmartFusion subsystem, prediction analysis, and on a rule-based assessment of the recommended response plans. The subsystem consists of three major components: expert rules, prediction (model), and evaluation. In response to an incident, the process begins with the expert rules and the

model collecting information on corridor performance and incidents from the data fusion system. The model develops an assessment of the current roadway operations based on the data received from the data fusion system. In addition, the model periodically forecasts the current and predicted performance of the network based on the current conditions and sends them to the expert rules system. Given the information about the current conditions of the network and the predicted performance of the network, the expert rules develop candidate response plans that are delivered to the ICM coordinator via the DSS dialog. The ICM coordinator approves or rejects the candidate response plan from the recommendation of the expert rules. If the ICM coordinator approves the validation decision, then the DSS pushes candidate response-plan information to the involved agency users for plan implementation. The expert rules collect the users plan readiness status and plan decision from the DSS dialog.

After implementing the ICM coordinator's plan decision, each agency user confirms the plan's operational status. The plan is terminated once the event owner agency user or the ICM coordinator closes the event in the ICM System (Spiller, et al. 2014, page 7-1).

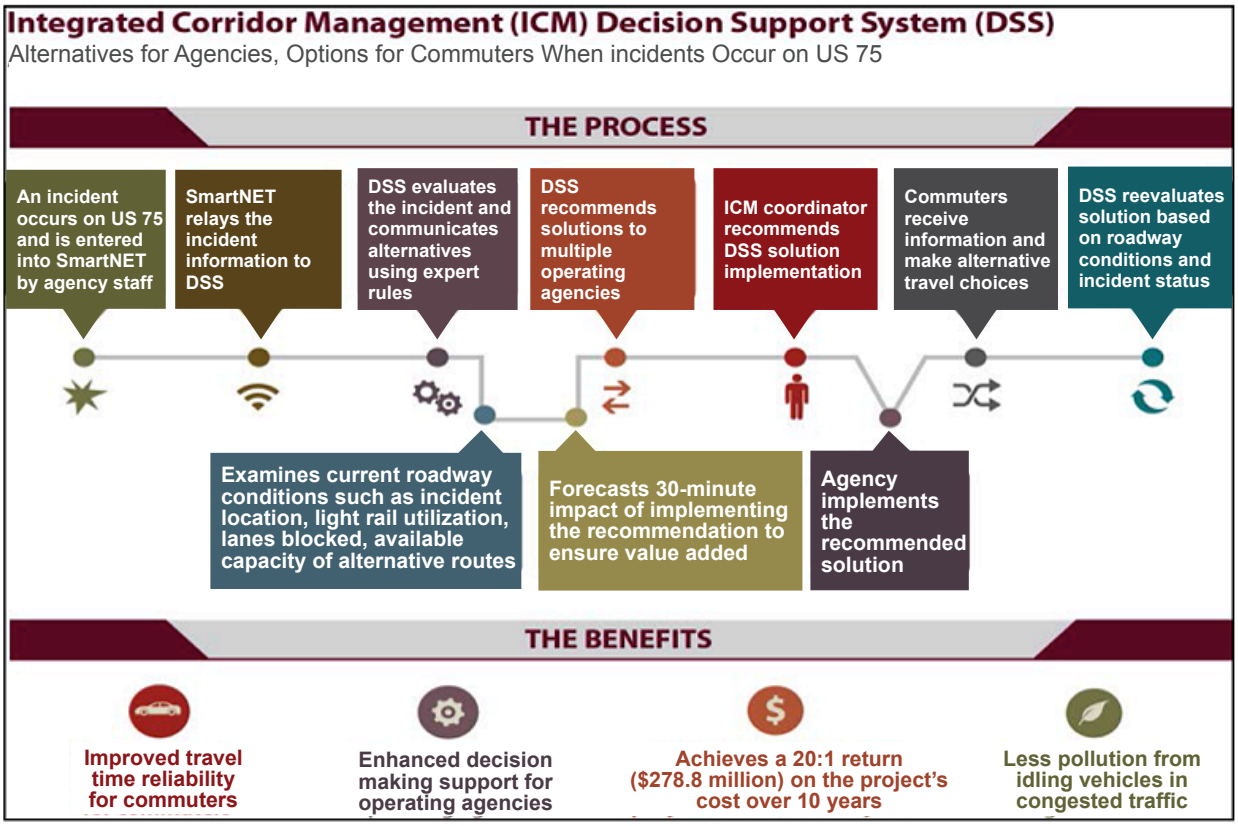


Figure 10. Diagram. Decision support process used by Dallas Area Rapid Transit.
(Source: Miller et al. 2015, Final Report-Dallas Integrated Corridor Management (ICM) Demonstration Project)

More information about DSS Analysis Test Plans and the specific qualitative and quantitative data required is described in the *Dallas Decision Support System Analysis Test Plan* (Lee, 2012).

San Diego – A key element of San Diego's ICM project includes the implementation of a real-time dynamic DSS. The system uses predictive capabilities to aid stakeholders in managing and operating the corridor proactively and is composed of seven key system components, including an on-line real-time simulation analysis and network predictive system and the application of a dynamic rule-based strategy assessment engine to generate real-time response plan strategies.

The DSS collects information on current network conditions by taking in data from an array of ITS and modal management systems, including, but not limited to, traffic signal systems, ramp metering, transit management, and freeway management systems located along the corridor. Data also includes hundreds of traffic volume and speed detectors in the roadway infrastructure and automated passenger counters and location data from transit systems, video camera feeds, and changeable message signs. Through the DSS data fusion engine, if changes in demand (based on incident or recurring conditions) are measured that meet pre-established thresholds (e.g., a minimum change in speed on the freeway of 10 mph less than free flow), the DSS generates a set of response plans containing recommended strategies to manage the congestion. The DSS assesses the impacts of the response plans on the level of service; volume-to-capacity ratio; and speed 15, 30, 45, and 60 minutes in the future. With the DSS response plan evaluation engine, a set of response plans are evaluated and scored using a traveler, not vehicular, delay-based algorithm to derive the scores for each plan when compared to the "do nothing" case. ("Do nothing" is the base scenario where no new actions would be taken along the corridor and devices maintain normal operations.) The response plan with the best score, representing the most congestion relief, is recommended for implementation. Once response plans are recommended, the affected agencies are notified, and the specific assets associated with a given response plan are implemented (e.g., en-route and pre-trip traveler information, corridor ramp metering, and signal coordination on arterials with freeway ramp metering). The implementation of the preferred response plan can be set to automated implementation or implementation upon approval.

Because the DSS is dynamic, it does not contain a set of predefined response plans. It was designed and built to take a performance-based approach to corridor operations and management. The business rules engine drives how response plans are implemented, how or what key actions the response plans should include, and under what conditions. The engine reflects agreed-upon regional and corridor-level operational principles discussed and set by the ICM partners. This includes, for example, how the assets available on the corridor will be used in response to certain conditions or setting constraints to reflect localized operational demand conditions (e.g., traffic cannot be rerouted onto certain arterials during school

zone hours). After a plan is implemented, the DSS continues to forecast traffic conditions. As conditions change, the system continues to monitor the extent of the congestion based on the total distance upstream of the event to the end of the congestion. As congestion continues or grows, the system will re-evaluate and generate new response plans to ensure that the best strategy continues to be applied. Once the congestion starts to dissipate and the upstream length of the congestion is reduced, the system steps out of the response plan and places the device back into the normal operations for that time of day (Spiller, et al. 2014, page 7-3).

HOW TO DEVELOP AGREEMENTS: RULES TO CONSIDER WITHIN OPERATIONAL CONSTRAINTS

Levels of Formality for Agreements

For any operational project that involves multiple agencies, interagency agreements are required to manage the system and coordinate responses to any incident. These agreements can form the basis of business rules that are incorporated into the DSS, so it is advantageous to spend some time discussing ways of developing them and providing general guidance. The following examples of interagency agreements have been suggested by I-210 ICM initiatives that may need to be developed and could be useful in outlining business rules (Dion, Butler, Xuan, 2015).

The level of formality depends on the relationship among agencies and can be set as they desire. There are instances of agencies cooperating with very few formal agreements. Instead, the interactions are set based on principles and common goals in their concepts of operations, and then these are used to guide solutions on an ad hoc basis. On the other extreme, some agencies may establish very detailed agreements that try to address the range of possible situations that may arise (or develop a new agreement for each situation). Figure 11 shows potential elements of multiagency agreements.

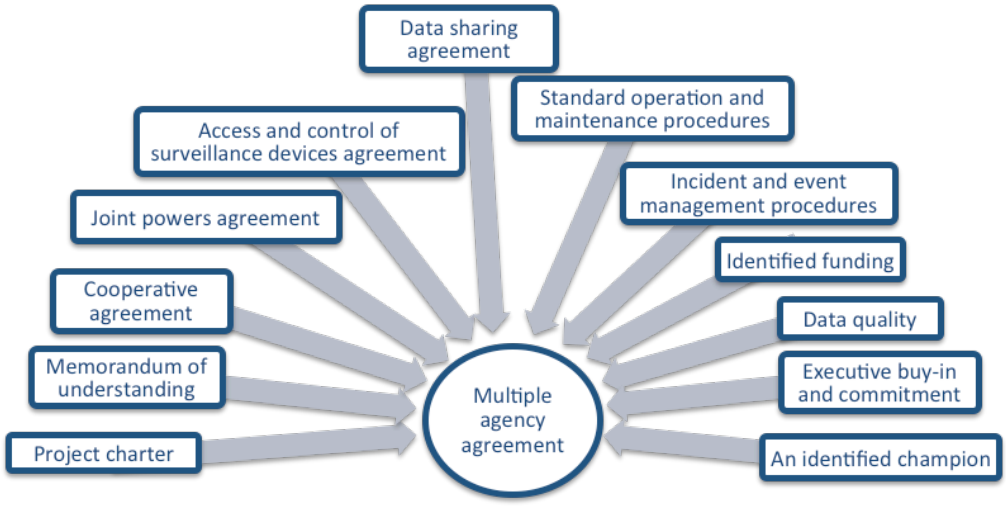


Figure 11. Diagram. Potential elements of a multiagency agreement.

Table 1 provides examples of the various stakeholders and potential formal agreements that may be established when developing business rules. This was originally formulated as a variety of interfaces for the DSS users, but it also is indicative of the different components (for more background, see Dion, Butler, and Xuan, 2015, p. 157, 10-10 Institutional Agreements).

Table 1. Example stakeholders and potential formal agreements that should be established when developing business rules.

Agreements and Protocols with Information Collection Systems
• Caltrans uses the Performance Management System (PeMS) as its main system for collecting, processing, and visualizing freeway flow data. • Traffic detection and traffic signal control systems operated by Caltrans (TransSuite), Los Angeles County (the Kimley-Horn intelligent transportation system software, or "KITS"), the cities of Pasadena (i2tms, QuicNet Pro, and SCATS®), Arcadia (TransSuite), Duarte (KITS), and Monrovia (KITS). • Bluetooth data collection systems operated by local agencies. Current systems include those operated by Pasadena and Arcadia. • Transit operations management systems used by Metro Bus, Metro Rail, Foothill Transit, Pasadena Transit, and any other participating local transit agencies. • California Highway Patrol and its computer-aided dispatch (CAD) system. • Local law enforcement agencies and their dispatch systems. • Parking management systems used by operators of park-and-ride facilities participating in the project.
Agreements and Protocols for Device Control Systems
• Traffic signal control systems operated by Caltrans (TransSuite), Los Angeles County (KITS), the cities of Pasadena (i2tms, QuicNet Pro, and SCATS), Arcadia (TransSuite), Duarte (KITS), and Monrovia (KITS). • Caltrans uses an advanced traffic management system (ATMS) to control ramp meters on freeway on-ramps and connectors as well as post messages on freeway changeable message signs. • Systems used by local agencies to post messages on dynamic message signs operating along arterials.

Potential Partners in Forming Agreements and Business Rules

Partnership with the key relevant transportation agencies is a necessary step in order to advance ICM implementation. A list of potential partners may include:

- U.S. Department of Transportation (DOT).
- State DOT.
- Metropolitan planning organization (MPO) (e.g., the North Central Texas Council of Governments).
- Transit agencies (e.g., high-occupancy vehicles (HOV), high-occupancy toll (HOT), rail, bus, etc.).
- Freight.
- County or City public works or transportation agencies that own arterials and signals.
- Local agencies responsible for parking, commuter or rideshare organizations, traveler information or 511 providers.
- Public safety services such as law enforcement, fire department, towing companies.
- Local universities.
- Toll agencies
- Private sector.

Communication amongst different partners is a vital component of an ICM implementation and can be done with a variety of interfaces and infrastructure. For example, the Dallas ICM uses the existing infrastructure from the Texas Department of Transportation (TxDOT) center-to-center system (a software system to facilitate sharing of traffic management related information and control of ITS field devices between TMCs which have a variety of different management systems). This provides direct connection to agencies not on the system with a web-based interfaced known as the information exchange system. This system interface is used for ICM stakeholders to develop and view events in the corridor as well as ascertain current conditions of field devices and congestions. It also allows for coordinating responses to incidents within the corridor. Other ICM communications platforms being tested use "the cloud" interface.

Regulatory Context

A proactive, collaborative, and strategic approach to public and private stakeholder partnerships is a key component for the successful implementation of an ICM system. Engaging these partners in developing business rules to incorporate into the DSS is critical.

Enabling Authority. An enabling authority should coordinate with all participating agencies and stakeholders. The type and level of authority varies based upon the respective agencies' roles in the system.

Policy Board (Composition, Voting, and Officers). Each participating agency or stakeholder should be able to choose its role. However, support personnel and representatives are required for each of them. Because the success of the ICM project relies on effective leadership, it is important that the selected key policy board has these features illustrated in Figure 12.

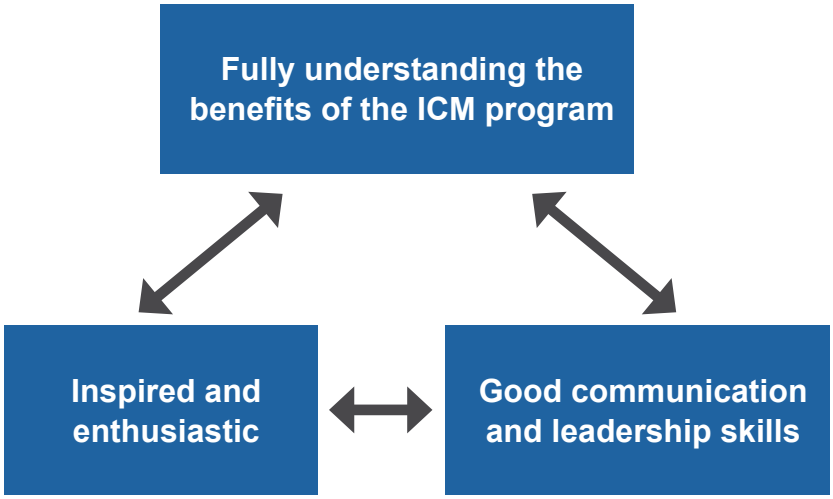


Figure 12. Diagram. Key features of a policy board.

Advisory Committees. The name and number of committees will vary depending on the needs of the specific program. Figure 13 shows examples of developed committees at various implementation sites (Dion, Butler, Xuan, 2015; Gonzalez, 2012; San Diego Pioneer Site Team, 2008).

Each committee may contain subcommittees. The membership should consist of members from local jurisdictions, transit agencies, first-responding agencies, software developers, system integrators, etc.

This section provides an overview of the regulatory and committee structure of a typical managed, integrated corridor. It also provides suggestions for the types of representatives and communication vehicles (e.g., committee meetings) one may want to tap in order to gather business rules and protocols, interagency agreements, and other documents that are helpful in incorporating business rules into the DSS.

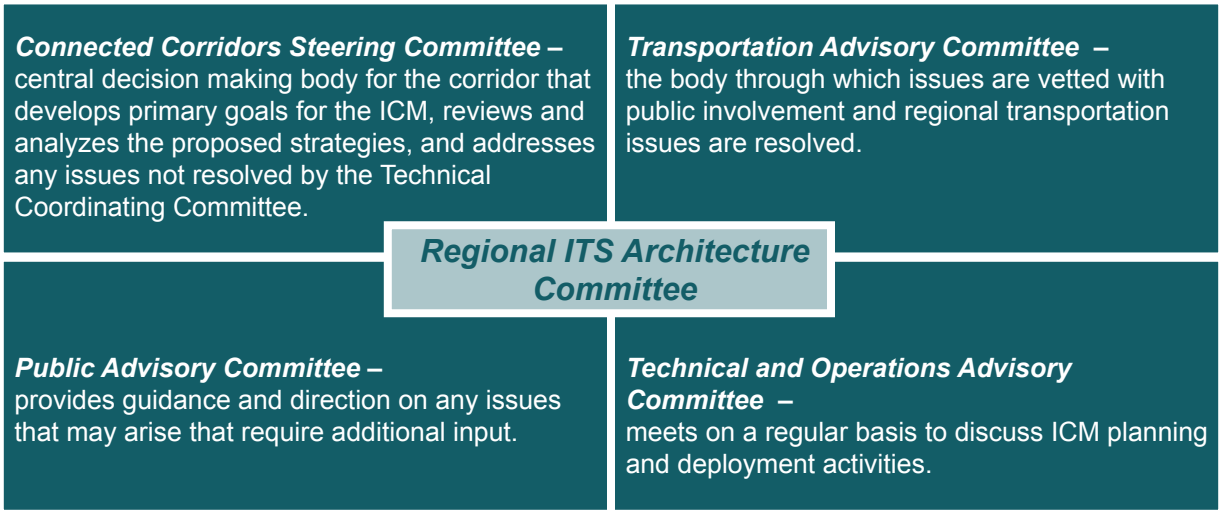


Figure 13. Diagram. Functions of a regional intelligent transportation systems architecture committee.

Communication Approaches

Communication amongst various stakeholders in a managed, integrated corridor is critical to successful implementation. It involves bringing together multiple agencies that utilize a variety of methods and heterogeneous systems (Gonzalez, 2012).

In the Dallas ICM effort, daily operation is coordinated through protocols and arrangements. Information is exchanged through the center-to-center project along with SmartNET (an information exchange system). SmartNET then distributes event information and response recommendations to the appropriate staff. (For more information, see the *Dallas Integrated Corridor Management (ICM) Demonstration Project Final Report*, by Miller, et al., 2015). For this section, we want to highlight the role this communication system plays in connecting the various stakeholders and utilizing pre-existing arrangements that were established to aid in implementation. These arrangements (or business rules) form the context and structure of the communications component to the ICM. They may be institutional protocols, memoranda of understanding between the agencies, etc. These elements contain a range of tools and systems that transform data into information that operators can use to make decisions.

> "A clearly defined process that guides work and encourages communication, often using a systems engineering approach, can be beneficial to achieving the ICM goals."
>
> — Koorosh Olyai
> Assistant Vice President
> Mobility Programs Development
> Dallas Area Rapid Transit

This information includes:

- Computers for storing and processing the large amounts of data.
- Communications networks.
- Display devices to present information to decisionmakers.
- Storage databases.
- Devices for manual entry of data.
- Communication devices for information exchange.
- Data warehousing.
- Algorithms for data quality and aggregation.

The information sharing components are critical for efficiently implementing DSS recommendations. These also can be based on strict protocols that were pre-established during the ICM development process (and can potentially be automated by incorporation into the DSS). Operators can provide travelers information about conditions through several means:

- **Media feeds** – These include information feeds to local media, such as radio and television stations, but may also include in-vehicle devices or smartphone apps.
- **Dynamic message signs (DMS)** – These are on-road signs that provide information about conditions to the traveler (including travel time, emergency situations, transit status, etc.).
- **Highway advisory radio (HAR)** – This is a radio medium to provide more detailed information that may be contained on DMS.
- **5-1-1 systems (voice)** – These systems can provide general messages and traffic information to the driver via a telephone voice interface (although many places are restricting phone use while driving).
- **Traffic and transit web sites** – Internet-based websites that provide traffic-related information.
- **Mobile application.**

In addition to this range of options, operators can use outreach campaigns and publicity releases. Figure 14 shows the range of approaches to communicating with the public. This range of media and approaches can all be subject to business rules and protocols amongst agencies on coordinated responses and information sharing. These rules or protocols can provide a context (with boundaries) to recommendations from a DSS that generates media- or messaging- related guidance. For example, many messages for non-recurring events (both planned and unplanned) are coordinated with public safety personnel. This coordination often has set interagency agreements governing how messaging is coordinated, which can be formulated into constraining business rules (Noblis, June 2008).

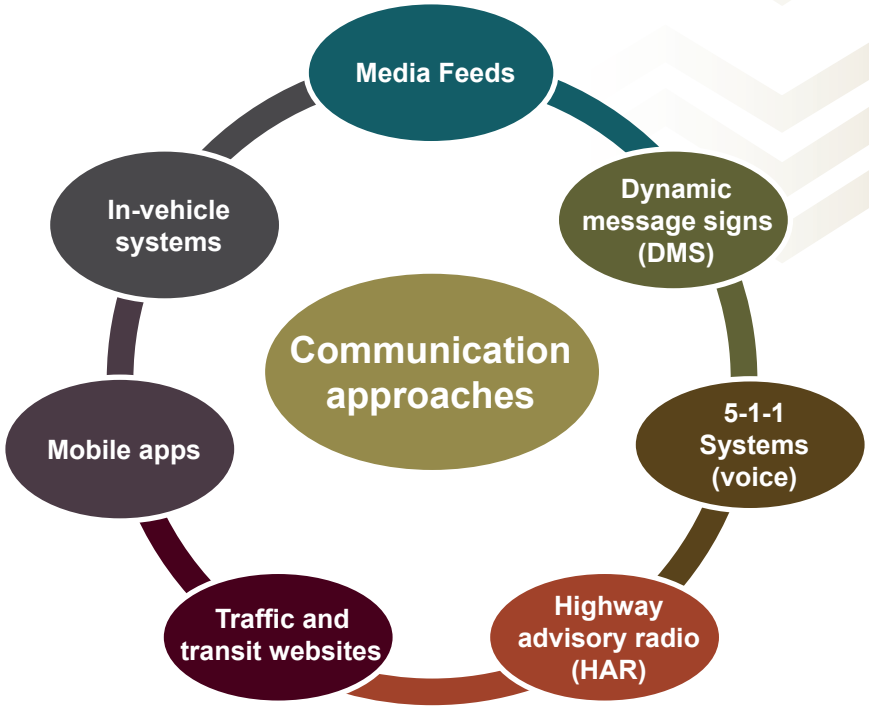


Figure 14. Diagram. Approaches to communicating with the public.

Contingencies Based on Level of Interagency Cooperation

The use of business rules in DSS (and decisionmaking in general) can be guided by each area's unique level of interagency cooperation and formal agreements. There are some regions or areas where all interactions, decisions, and protocols are clearly defined and explicitly stated. In contrast, there are examples in areas such as freight where staff at the operational level have developed relationships and make decisions based on overall principle and the strategic plans of the agencies, but formal agreements have never been developed. Instead, there is an institutional knowledge of who to reach out to when an incident occurs and what common goals are in place that then can be operationalized at the implementation level. Both approaches have advantages and disadvantages, and are not mutually exclusive (there can be a combination). The approach adopted will depend on the context.

STRUCTURAL CONCERNS

The main concerns for each site might vary depending on the nature of their system. For instance, Table 2 outlines issues identified by the I-15 corridor stakeholders. It highlights three areas, but we will focus on the institutional issues which are most relevant to business rules in DSS.

Table 2. Institutional issues relevant to business rules in the I-15 decision support system.

Technical Issues
• Data archiving and accessibility for future analyses. • Modifying/updating San Diego regional intelligent transportation system architecture to bring it into alignment with I-15 integrated corridor management system (ICMS) concept. • Use of regional transit fare system (Compass Card) across multiple transit service providers. • Expansion of functionality for 511 advanced traveler information system.
Operational Issues
• Enhancing transit capacity in response to planned events and major incidents. • Implementing bus signal priority for transit on arterials. • Coordinating different operating systems across agencies to work together (e.g., I-15 freeway on-ramp metering signals with adjacent arterial traffic signals). • Fully integrating commercial vehicle operations into I-15 ICMS concept.
Institutional Issues
• Establishing policies and arrangements with private entities (parking, information service providers, and major employment centers along the I-15 corridor). • Compatibility of virtual corridor transportation management center responsibilities for I-15 ICMS corridor stakeholders with their conventional responsibilities. • Expansion of set of organizational stakeholders as part of the I-15 Corridor Management Team beyond those that are only transportation-focused (e.g., public health agencies). • Enhanced level of inter-organizational coordination and integration among corridor stakeholders.

Source: San Diego Pioneer Site Team, 2008.

The following provides examples of institutional and technical constraints that may affect the implementation of a proposed ICM system in California (for more detail, see Dion, Butler, Xuan, 2015).

Table 3. Institutional and technical constraints that may affect the proposed I-210 integrated corridor management implementation.

Institutional Constraints
• Due to liability issues, jurisdictional policies may not allow recommendations of specific diversion routes to be communicated to travelers. • Several local jurisdictions impose restrictions on the routes that truck traffic may take across their network. This may be due to various reasons, such as the desire, to reduce safety risks, noise in residential neighborhoods, pavement damages, etc. • Some jurisdictions may impose constraints on traffic signal operations during specific periods. • Various regulations may govern the operation of changeable message signs. • Strict regulations govern the design and installation of traffic signs and road markings. Many agencies have established operational procedures defining what to do in specific situations. • Different jurisdictions may have different requirements and regulations regarding the use of information technologies.
Technical Constraints
• Inadequate traffic detection may exist at various locations within the corridor. • A variety of traffic signal control equipment with varying capabilities is in use within the corridor. • Various centralized traffic signal control systems are used throughout the corridor. • Not all traffic management centers are staffed 24 hours per day, 7 days per week. • Transit agencies may not have the necessary equipment to track vehicle occupancy and relevant operational metrics in real-time. • Park-and-ride facilities may not be equipped with the necessary equipment to track facility occupancy in real-time. • Suitable communication or control capabilities may not exist with all existing or desired field devices.

Additional Levels of Approval

This part can be categorized as:

- **Institutional:** Additional approval is required for coordination and collaboration between various agencies and jurisdictions
- **Operational:** Agreement among all operating agencies is required on operational strategies to manage the total capacity and demand of the corridor.
- **Technical:** Additional agreement is required for the sharing and distribution of information, and system operations and control.

Various cooperative agreements are required to support system operations. Key agreements include:

- Traffic Signals/Ramp Meter Support and Update – Establish guidelines, processes, and communication protocols between the agencies when changes to signal timing/ operations and ramp meter rates are planned.
- Planned Events and Update – Establish guidelines, processes, and communication protocols when an agency is planning construction events, sports events, or other major events that will have traffic impacts along the mainline, and/or ramps, and/or arterials.

Source: Connected Corridors: I-210

Staffing and Budget Limitations

As with any new program, staffing requirements must be considered. Agencies have staffed ICM in a variety of ways. Many add ICM duties to existing staff members' responsibilities (e.g., existing Dallas Area Rapid Transit operations staff was given additional duties). However, the agency did fund one full-time equivalent to serve as the ICM coordinator for the US-75 corridor.

In general terms, operations have continued as part of the ongoing operational roles of the agencies involved. System support for ICM has been outsourced to private companies for the development and ongoing operation and maintenance of the software and hardware used for ICM programs. However, depending on staffing constraints, technical capabilities could be provided by any combination of public agencies and/or private companies. This should be considered a long-term commitment for an ICM program. (Spiller et al. 2014, page ES-3)

The operational needs for an integrated corridor management system (ICMS) are further explored in the white paper "Conceptualizing Integrated Corridor Management."

The "Conceptualizing Integrated Corridor Management" white paper (Noblis, 2008) discusses 23 possible operational needs of an ICMS. The unique number and title of each need are listed below:

1. Need for communication with transportation network users.
2. Need for interactive communication with colleagues.
3. Need for standard definition of customary operations.
4. Need for transportation system operators and public safety organizations to coordinate.
5. Need to manage the supply of services to match demand.
6. Need to have competent and well-trained staff.
7. Need to monitor the location and status of vehicles within corridor management agency fleet(s).
8. Need to visualize information.
9. Need to share control of devices within a corridor.
10. Need to monitor the effectiveness of control tactics implemented in the corridor.
11. Need to understand demand for transportation services.
12. Need to monitor threats to the corridor.
13. Need for corridor performance measures.
14. Need for impact assessment tools.
15. Need to archive data.
16. Need for descriptive data about corridor infrastructure.
17. Need to have a quality information processing infrastructure.
18. Need to monitor corridor status.
19. Need for real-time or near real-time information.
20. Need for non-real-time data (e.g., sample data).
21. Need to collect and process data in real-time or near real-time.
22. Need to monitor the status of the physical transportation infrastructure.
23. Need to have quality physical infrastructure.

The white paper provides a detailed description of each of these needs listed above and the following actions are recommended:

- Make a list of resources to finance the project.
- Try to find a way to make profit with the newly developed system to be able to fund ongoing operation (for example, develop a smartphone app).

The Los Angeles I-210 Pilot system identifies the following key groups of individuals to be involved in the operation of the ICM system (Dion, Butler, Xuan, 2015):

- ICM corridor manager.
- ICM system manager.
- Core system operators.
- Information providers/consumers.
- Technical advisory and management committee.
- Connected corridors steering committee.
- Caltrans traffic management center operators.
- Caltrans operations division staff.
- County/city traffic management staff.
- Transit dispatchers.
- First responders.

Maintaining Balance among Participating Jurisdictions

Once agreements are established and business rules are ready to be incorporated into recommended decisions, it is important not to assume the task is complete. Agencies, structures, and context continue to change, and the agreements can quickly become outdated. One should consider these agreements to be living documents that continue to reflect the current operational environment (and not as a snapshot in time from when it was established). They must be revisited and updated as needed (Gonzalez et al., 2012). Getting agreements is difficult, but so is constantly having to update it, a process which requires board and governing body approvals. Once a blanket agreement is in hand, it is best to consider operations and maintenance manuals as living documents.

Establishment of New Partnerships

Interjurisdictional and interorganizational coordination and integration among corridor stakeholders is necessary for the establishment of new partnerships.

- Invite all potential agencies from the beginning.
- Motivate by educating them about the benefit of the system to them.
- Keep them motivated.
- If they decide not to be a part of the team, keep them in the loop, they may decide to join later in the process.
- Give them a leadership role like chairing committees will be helpful.

DIFFERENCES IN INSTITUTIONS

Every ICM implementation site will have its own unique landscape, culture, and set of institutions. This context will shape the agreements and partnerships that are formed, along with the "personality" of that ICM implementation. It is out of the scope of this guidance to outline all of the different characteristics of potential partners and structures of managed, integrated corridors. However, we would like to highlight several categories of which to be mindful when establishing interagency agreements and eventual business rules for decision making. Figure 15 depicts some of the many ways that agencies may differ in their oversight duties.

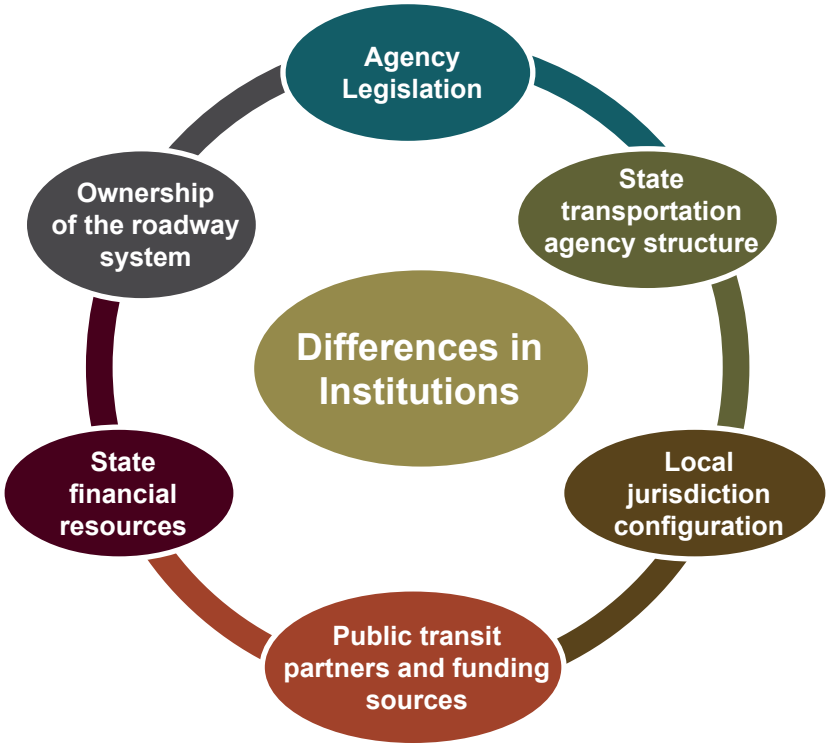


Figure 15. Diagram. Illustration of the many ways in which agencies may differ.

- *Differences in agency legislation* (at the State, county, or city levels), laws, and funding sources. State agencies may have completely different structures and funding concerns than city or county agencies. These factors should be considered.
- *Differences in State transportation agencies.* Each DOT has its own unique character, ways of operating, leadership direction, etc. Culture in an organization and leadership presence should not be underestimated in impacting business rules and operational execution.
- *Differences in local jurisdictions.* Similarly, the local context and partners will influence the types of agreements made. Does the local jurisdiction work well with the local branch of the State DOT? Do they have the same goals?

- *Differences in Public transit partners and funding sources.* Transit partners are key to a successful ICM implementation, and they are the most seasoned at developing multimodal and multijurisdictional agreements.
- *Differences in State financial resources.* These resources can have a large impact on the type of ICM, its DSS, and the ability to enact agreed upon response plans. If there are not enough resources, then the response plans may not be practical and coordination will be inhibited.
- *Differences in ownership of the roadway system.* This is often overlooked, but different segments of the roadway system can have different owners with a range of goals. And, it is not unusual for those goals to be in conflict at times. Consequently, ownership rights and goals can impact the success of the ICM, as well as how flexible the business rules can be with respect to partner priority and coordination.

CHAPTER 3. CASE STUDIES AND LESSONS LEARNED IN INTEGRATED CORRIDOR MANAGEMENT WITH EMPHASIS ON DECISION SUPPORT SYSTEMS AND RELEVANT BUSINESS RULES

Integrated corridor management (ICM) provides information that covers the entire transportation network to help commuters make better decisions about how to travel in that corridor. This section focuses on best practices in ICM deployment with respect to decision support systems (DSS) and business rules.

SAN DIEGO AND DALLAS

As mentioned in the previous chapter, agreements and memoranda of understanding among agencies, known as business rules, are structural and key elements of success within the context of ICM. However, few determinate examples exist. Nevertheless, even implicit rules must exist for agencies to share data, resources, and—most importantly—real-time action plans. The sections below explain how the San Diego and Dallas ICM demonstration sites operated with either documented or implicit "business rules."

Business Rules

Dallas. The business rules for Dallas were initially based on a regional ITS cooperative agreement that was expanded to an operations and maintenance agreement, as described by Spiller et al. (2014, page 9-1):

> A blanket ITS cooperative agreement for the region was in-place and used as a starting point by the ICM stakeholders for this project. The ICM program was a part of the transportation improvement project to ensure regional support by the Council of Governments. An operations and maintenance (O&M) document was developed cooperatively among all the operating agencies in the corridor during the operations phase of the ICM demonstration. The ICM O&M Manual has the potential to act as a more detailed agreement.

The Dallas stakeholder team included:

- Dallas Area Rapid Transit (DART).
- Cities of Dallas, Plano, University Park, Highland Park, and Richardson.
- North Central Texas Council of Governments (NCTCOG).
- North Texas Tollway Authority (NTTA).
- Texas Department of Transportation (TxDOT) – Dallas District Traffic Operation Division.
- Three Universities (Texas A&M, Southern Methodist University, and University of Texas – Arlington) are also involved.

These agencies and stakeholders have been participating in incident management and regional training for many years (Spiller et al, 2014. Page E-2). They have established multiagency working groups and committees to promote multiagency cooperation, including an ICM steering committee, ICM operations committee, and an ICM 511 committee. Within the region, the North Central Texas Council of Governments (NCTCOG) includes a transportation committee and an ITS committee. The stakeholders' committee was also created as a multijurisdictional oversight and advisory committee. It was noted that interjurisdictional challenges included identifying ongoing capital sources, maintaining operational capacity, and funding maintenance activities.

DART was initially selected as lead agency.

> Existing operations staff is used for the daily operation of the system. The ICM coordinator, provided by DART, leads the ICM responses. The DART high-occupancy vehicle (HOV) operations team is co-located with TxDOT at the DalTrans facility. The other operating agencies (i.e., DART bus, light rail, North Texas Tollway Authority, and cities) operate out of their normal operations center (Spiller et al, 2014. Page E-3).

San Diego. In San Diego, the foundational documents were more numerous and included a project charter and MOUs:

> Throughout the project process several documents have been undertaken and are anticipated to be completed as they pertain to the data collection/documentation, lessons-learned experienced through the ongoing operations. Initial related documentation included the completion of a project charter, followed by the completion of individual [memoranda of understanding]. Such documents provided high-level guidance on needed coordination and cooperation. During the design and development of the [integrated corridor management system (ICMS)], the focus turned to the needed operational consensus. Such agreements were documented through agency-level memorandums, which served as the platform for an ICMS operational framework document. The operational framework establishes and sets the conditions for using the individual network assets under the ICMS environment and reflects input/agreement by all partner agencies (Spiller et al, 2014. Page E-30).

The ICM implementation was also not without interjurisdictional challenges:

> There is no one specific challenge that stands out since all challenges experienced were generally dependent on each other. However, the observation to share is that the greatest challenge was associated with ensuring that the project partners received appropriate transportation, engineering, and operational input, which was then translated into the software design process during the [integrated corridor management system] design (Spiller et al, 2014. Page E-30).

According to Spiller et al. (2014, page E-31), the San Diego ICM Team established these multiagency working groups/committees:

- Weekly meetings: operational review (all project team partners).
- Biweekly meetings: Core Project management team (San Diego Association of Governments (SANDAG) and consultant teams).
- Monthly meetings: project development team (all partners, including management level).

In addition:

> The City and County Traffic Engineer's Council and The City and County Transportation Advisory Committee (city engineers and public works directors) are used as standing committees that were established back in the late 1990s, which generally provide the venue for recommendation and discussion on multi-agency, project/program-related efforts, and SANDAG region-wide strategies. SANDAG staff used these committees as a sounding board for input and discussion throughout the ICM project. These committees report to and provide recommendations to our Transportation Committee (policy).
>
> SANDAG serves as project/contract lead. Contract staff is involved, but for providing project development, coordination, operational/technical support, and ICM system interface, design, and implementation. All other agencies have committed appropriate staff to participate (Spiller et al. 2014, page E-31).

Decision Support System Development

A main component of each of the U.S. Department of Transportation (U.S. DOT) ICM demonstration projects was the development of a unique DSS to facilitate decision-making activities and operations in order to minimize the impacts of their respective congestion challenges. The San Diego and Dallas ICM Pioneer Sites were the very first sites to deploy ICM systems with a combination of DSS methodologies. These methodologies included table-based, expert systems, event scenario matrices, custom rules-based systems, and systems that were model driven or data driven. These types of DSS had been implemented in different intelligent transportation systems (ITS) projects across the country. The lessons learned from these efforts as well as an assessment of which methodologies work best under certain conditions had been documented by the U.S. DOT in a report titled *Assessment of Emerging Opportunities for*

Real-Time Multimodal Decision Support Systems in Transportation Operations: Concept Definition and Current Practice. According to this report, each site had unique conditions; therefore, it was necessary to explore the appropriate methodologies based on the regional differences.

Dallas. Dallas implemented a customized, rules-based DSS that was built on an expert system approach with an event scenario matrix. The San Diego site also used a rule-based methodology with incident response parameters and knowledge-based information on roadway geometry and device locations to generate response plans. The rules were created with operator inputs. Overall, DSS uses the strategy responses developed by the stakeholders, expert systems, prediction modeling, and evaluation components to recommend plans of action associated with specific events (Table 1). Although not explicitly detailed, these approaches should incorporate business rules given the coordination needed amongst different entities.

The DSS is part of the design development stage of an ICM. Figure 16 shows the Dallas ICM phases of development.

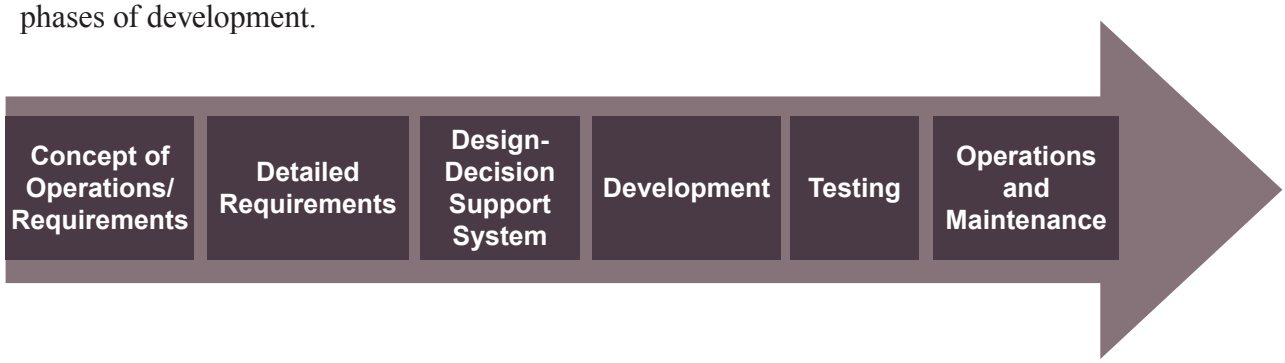


Figure 16. Diagram. Dallas integrated corridor management phases.
(Source: Miller et al., 2015)

The Dallas ICM developed a set of pre-approved response plans, which can be a type of business rules based on agreements between agencies. These response plans were seen as key to implementing coordinated ICM operations and responses. There were several committees tasked with developing these response plans (namely, ICM operations, decision support, and arterial monitoring systems). The group would discuss certain event types and locations that would require different response scenarios depending on the location and transportation impact. Although not explicitly stated in the Dallas ICM reports, it is implied that these response scenarios could very well involve key stakeholders, who represented different agencies, as well any agreements or protocols. The following approach was used to develop the response plans:

- Event types that occurred frequently, as well as locations with recurring congestion or high incident frequency.
- Event impact indicators (for example, queue length and number of lanes affected).
- The corridor was divided into multiple sections.
- Identification of response strategies.

The report lists magnitude-of-event indicators that stakeholders used to develop appropriate strategies in response to incidents, including:

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

Note that several of these indicators are related to local roads, park-and-ride lots, and transit operations. Each partner would have its own magnitude-of-event protocols to incorporate information sharing and cooperation. Table 4 depicts decision strategies for minor and major incidents and delay.

Table 4. Example of decision support system rules for response plan development.

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

NA = not applicable.

(Source: Miller et al., 2015)

The Dallas DSS consists of expert rules, prediction, and evaluation. The operating agency stakeholders provide candidate response plans based on their experience and knowledge, which are then selected by the expert rules system. Note that these operating agencies would have their own protocols, and the DSS could be enhanced by including these agreements (i.e., business rules) to enact select response plans as well as implementation. At the next stage, a candidate response plan is submitted to the ICM coordinator, who decides whether or not to enact it. This would also be an area where business rules could have a significant impact on plan selection. For example, if the DSS regularly submits plans that are not realistic due to constraints based on interagency agreements, then the ICM coordinator will not be as likely to rely on it for future decisions. After selection, the response plan is then pushed to agencies for implementation.

Dallas has developed and approved over 400 response plans, with more currently being written and revised as a result of experience. The ICM processes provide partner agencies with the pre-approved response plans both in real-time via the Internet during response plan implementation as well as offline for assessment and refinement. Figure 17 depicts an overview of Dallas DSS analysis from hypothesis to evaluation. For more information, please refer to the *Dallas Decision Support System Analysis Test Plan*.

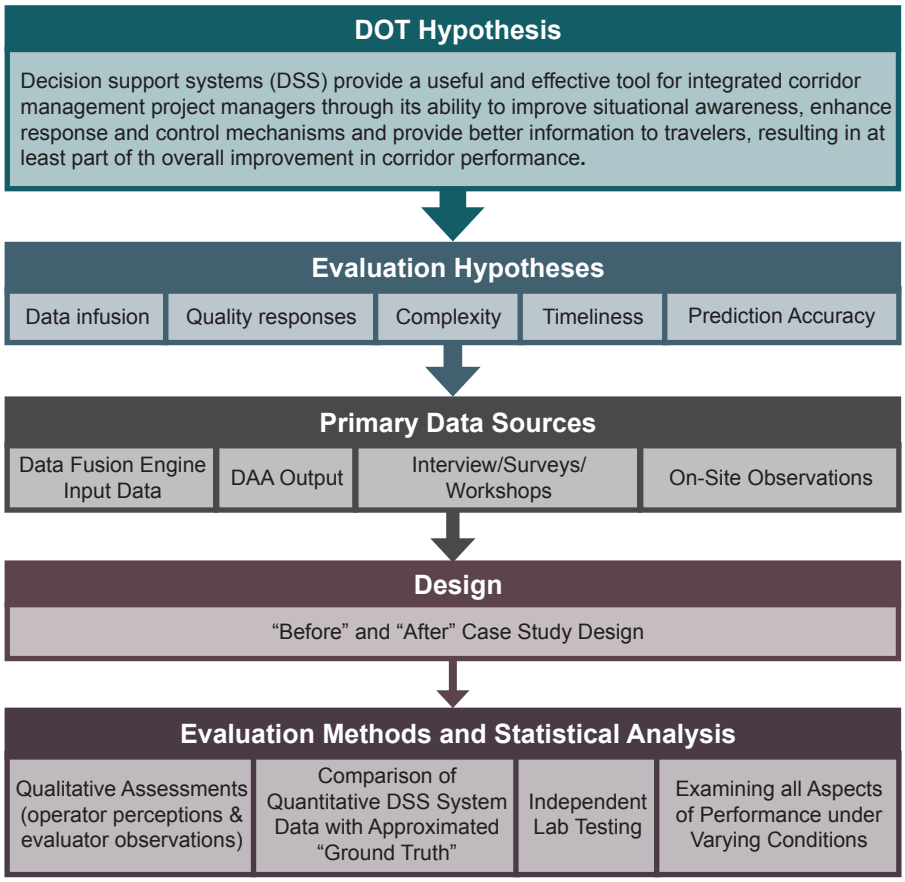


Figure 17. Diagram. Overview of a decision support systems analysis.
(Source: Lee et al., 2012)

San Diego: In contrast, the San Diego ICM already had a decisionmaking system based on enabling the sharing of information across agencies. But, the application needed to integrate this information into actionable control strategies—an element which was lacking. The DSS attempted to fill this gap by providing data integration capabilities with a decision-making process for developing response plans. Unlike pre-DSS practices, this new tool incorporates coordination among corridor stakeholders, which is a significant and important development. Note the referenced actions are being coordinated and not carried out in isolation. This implies some sort of agreements need to be built into the decision-making process, either at the response development stage or at the response selection stage.

Figure 18 illustrates the list of contracted tasks for the California Partners for Advanced Transportation Technology (PATH):

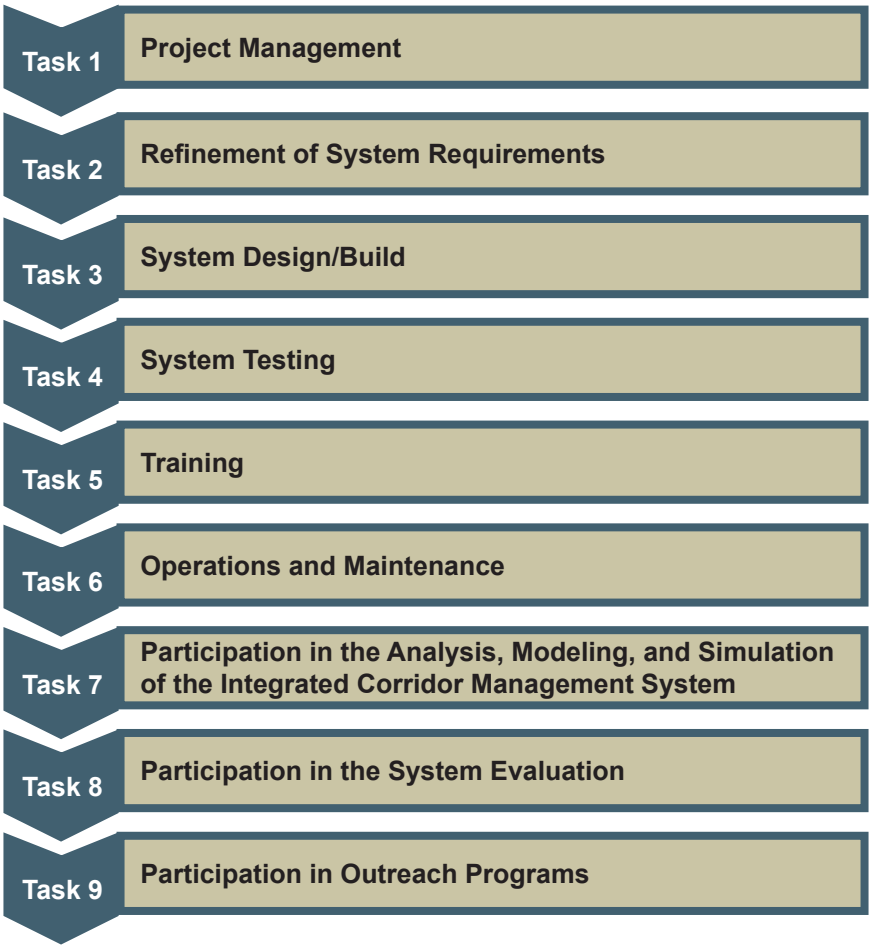


Figure 18. Diagram. Partners for Advanced Transportation Technology tasks.

One of the objectives was to develop the DSS, the network prediction system (NPS), and the real-time simulation system (RTSS). (Dion, Skabardonis, 2015)

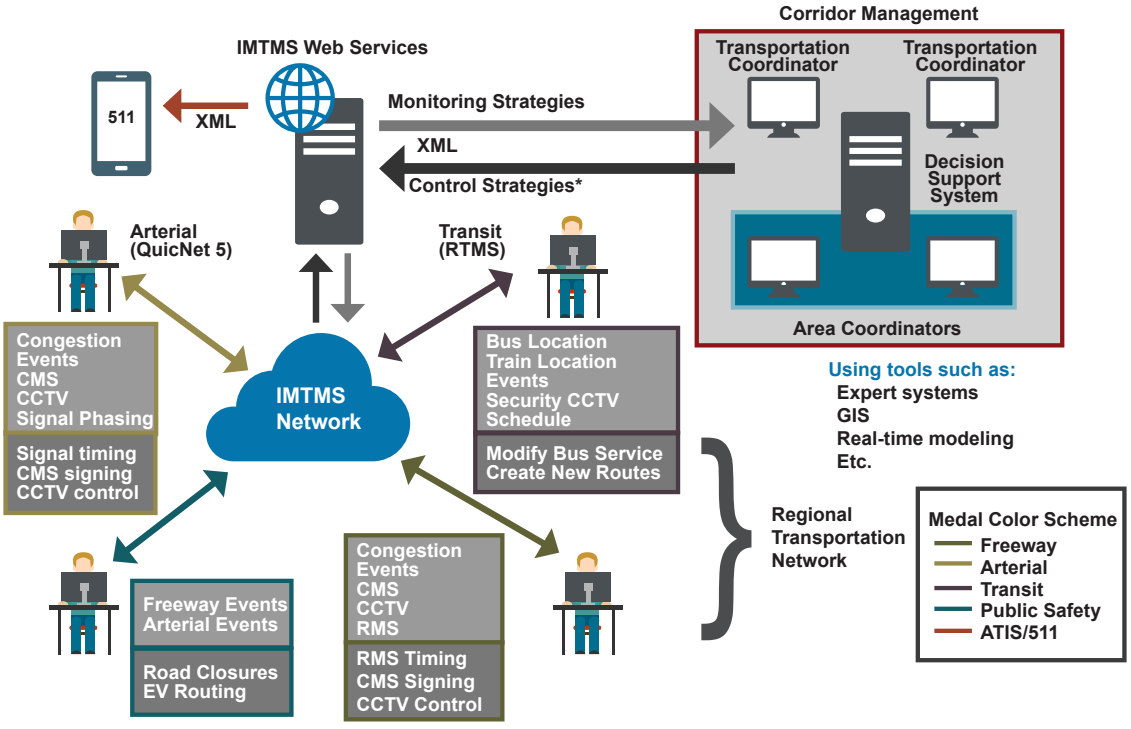
Network Prediction System (NPS) – developed as part of the ICM demonstration to support DSS operations and used to predict origin-destination flows within the I-15 corridor.

Real-Time Simulation System (RTSS) – developed as part of the ICM demonstration to support DSS operations and used to manage and execute corridor simulations.

Source: Dion, Skabardonis, 2015

Figure 19 depicts the underlying concept for a DSS. Dion and Skabardonis (2015) note that the diagram:

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



ATIS = advanced traveler information system. CAD = computer aided dispatch. CCTV = closed-circuit television. CMS = changeable message sign. EV = emergency vehicle. GIS = geographic information system. IMTMS = intermodal transportation management system. RMS = ramp meter stations. RTMS = regional transit management system. XML = extensible markup language.

Figure 19. Diagram. Decision support system concept.
(Source: Dion, Skabardonis, 2015)

Note that the DSS would receive information from various transportation systems, which could include protocols and procedures for interagency interactions. It is also possible that these interagency agreements and business rules were not incorporated (or incorporated inconsistently) because each agency may only be supplying the information relevant to their system. Figure 20 shows an example response plan concept from the San Diego ICM demonstration project report.

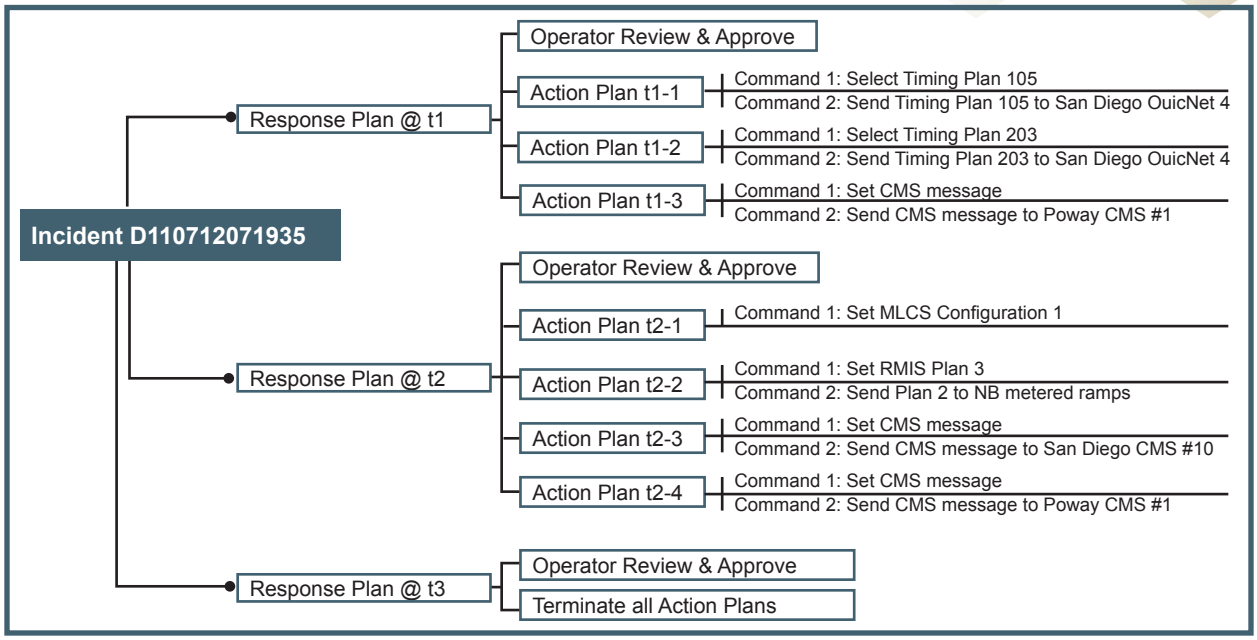


Figure 20. Diagram. Response plan concept from the San Diego integrated corridor management demonstration project report.
(Source: Dion, Skabardonis, 2015)

The following description is from the San Diego ICM report:

> [The diagram] illustrates the conceptual process for the generation and execution of response plans. Response plans would be generated when requested for a specific incident location, type, severity, and impact, based on the time of day and other operational parameters. Each response plan would consist of one or more action plans, with each action plan consisting of one or more commands. Single commands would be recommended actions for a specific system in a specific jurisdiction. The DSS was envisioned to be an Expert System or equivalent table-driven application that would make decisions based on information available in various databases and a series of "if-then" statements describing the business rules for corridor operations under specified conditions.
>
> When responding to an event, the DSS was to be further instructed to keep monitoring travel conditions within the corridor and issue updated recommendations when necessary. This would allow the DSS to account for unforeseen changes in travel patterns or other events affecting corridor operations in addition to the original event (Dion, Skabardonis, 2015).

Figure 21 and Figure 22 represent elements of Dallas ICM demonstration and implementation, respectively. Figure 23 depicts multiple stage implementation of ICM.

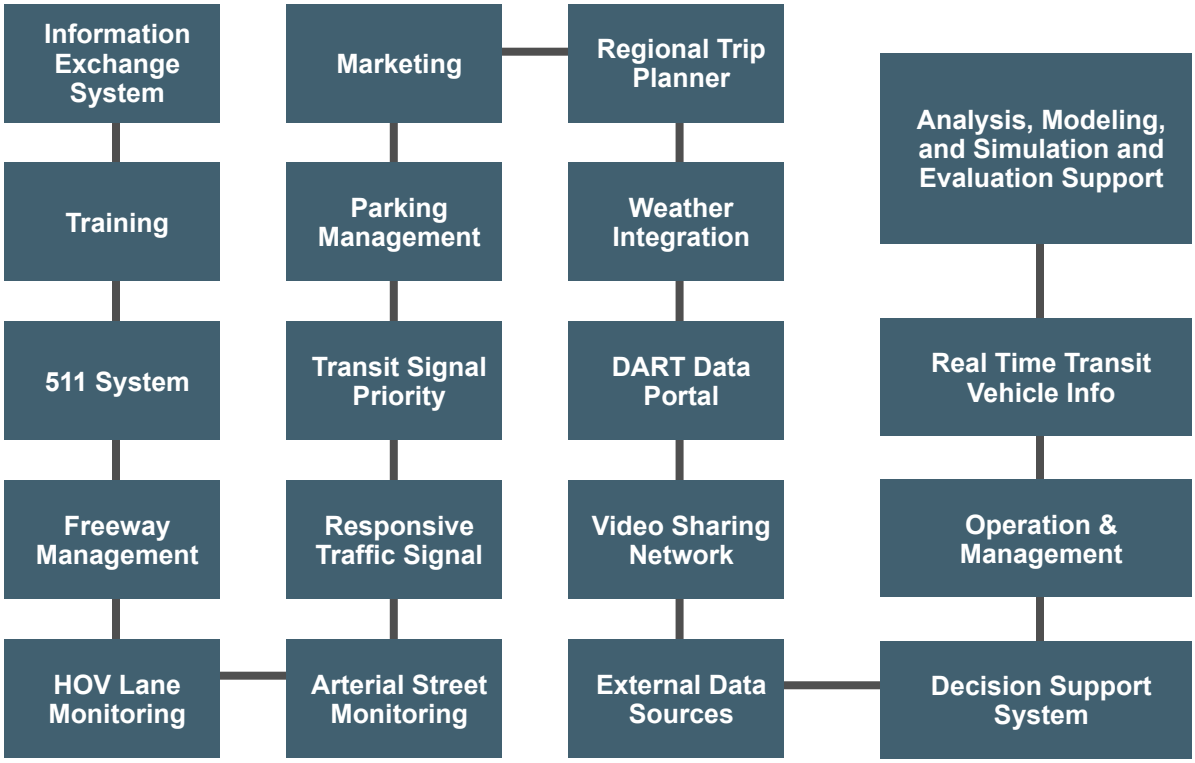


Figure 21. Diagram. Elements of the Dallas integrated corridor management demonstration.

Figure 22. Diagram. Integrated corridor management multiple stage implementation.

Dallas Implementation – Real Time Transit Vehicle Information	• Vehicle location. • Time to arrival at next stop. • Transit schedule. • Available capacity to carry additional passengers.
Dallas Implementation – Parking Management	• Park & ride lots along light rail transit Red Line. • Monitor availability at each Park & Ride lot. • Publish to 511 System. • Publish to Texas Department of Transportation dynamic message signs. • Integrate with the decision support system.

Dallas Implementation – 5-1-1 DFW (Dallas-Fort Worth)	• Multi-modal traffic and transit information disseminated through:
	  • A public web site.
	  • Interactive voice response (IVR)
	  • A mobile website and mobile application
	  • My511 (Web, IVR, alerts)
	  • Social Media

Dallas ICM Strategies	• Prioritize non-recurring congestion based on historical crash data. • Identify available alternatives for route/mode diversion along the corridor. • Route diversion strategy (minor incident). • Route diversion strategy (major incident). • Mode diversion strategy (major incident). • Combined route and mode diversion strategy. • Advanced traveler information (all scenarios).

Figure 23. Diagram. Elements of the Dallas integrated corridor management implementation.

Expected Timeframe

Dallas:

- ConOps and requirements done over a one- to two-year period.
- AMS phase was done over 18 months.
- Development and deployment phase was completed in three years.
- The program began in October 2006.
- Became operational in April 2013.

San Diego:

- Kickoff – February 2010 – Completion of project management documentation and definition of system requirements February 2010 – March 2011.
- Coordination with partners to define operational framework and interdependencies – April through December 2011.
- Design of ICMS – mid-2011 through March 2013.
- System shakedown and testing – March 2013 through January 2014.
- ICMS placed into full operations – February 2014.

OTHER GRANT SITES

This section gives a brief overview of ICM and potential business rules-related issues in several of 13 sites selected to receive ICM grants in 2015 from the Federal Highway Administration (FHWA). They were required to use the funding towards pre-implementation activities; e.g., development of systems engineering plans and concepts of operations, et al. Table 5 lists the 13 sites, their respective lead agencies, and their respective ICM project corridors.

Table 5. Federal Highway Administration 2015 ICM Grant Award Sites

State	Lead Agency or City	Corridor Description
Arizona	Maricopa County	I-10 through the Phoenix metro area and multiple east-west parallel routes.
California	Caltrans	I-210 on a 22-mile section from the 134/210 interchange near downtown Pasadena to the Foothill Boulevard Interchange in La Verne.
California	Contra Costa County	SR-4 in the city of Hercules from I-80 to I-680.

Table 5. Federal Highway Administration 2015 ICM Grant Award Sites (continued)

State	Lead Agency or City	Corridor Description
Florida	Broward County	I-95 on a 25-mile section in Broward County. Commuter rail, transit bus service, inter-city rail (including Amtrak) park & ride lots and bike trails.
Maryland	Maryland State Highway Administration	Three corridors connecting Washington, DC and Baltimore: I-95, MD 295 (the Baltimore-Washington Parkway), and US 1 between MD 32 and I-695.
New Jersey	New Jersey Department of Transportation (DOT)	New Jersey Turnpike (I-95), Garden Parkway and US 1 and US 9 from Woodbridge (south) to the Holland Tunnel (north).
New York	City of New York	In the New York/New Jersey metro area, the corridor includes sections of Route 495 (the Long Island/Queens-Midtown Expressway) and crosses midtown Manhattan, the Lincoln Tunnel and the Queens-Midtown Tunnel.
New York	Niagara International Transportation Technology Coalition	I-90 within the Buffalo-Niagara region, including the Peace Bridge and the I-190/I-90 interchange to the south and the I-190/I-290 interchange to the north.
Oregon	City of Portland	I-84 from downtown Portland encompassing over 45 square miles. Light rail and streetcar routes. Local streets. Bus and bike routes.
Texas	City of El Paso	IH-10 from US-54 to Loop 375, US-54/IH-110 from IH-1 to Loop 375. This project is 16 miles combined. Bus routes.
Texas	City of Austin	IH-35 between US 183 and SH 71.
Utah	Utah Transit Authority and the Utah DOT	Major north-south roadways, representing approximately 25 miles, from downtown Salt Lake City to Lehi City, including I-15, State Street and Redwood Road. Commuter rail services.
Virginia	Virginia DOT	Northern Virginia east-west corridors including I-66, SR 7, US 29, US 50 and SR 267. The Virginia Railway Express Manassas line, Metro Silver and Orange lines, commuter bus routes, and commuter parking lots.

Source: Federal Highway Administration, "The U.S. Department of Transportation Announces $2.6 Million in Grants to Expand Real-Time Travel Information in 13 Cities." Available at: https://www.fhwa.dot.gov/pressroom/fhwa1504.cfm

As of 2017, most of these sites have now completed or are near completion of their pre-implementation activities. In the context of this report, the Los Angeles I-210 ICM deployment is notable because the Los Angeles deployment team built on lessons learned from the Dallas and San Diego prototype demonstration projects. Future ICM deployments can also be expected to build on these earlier efforts and advance the state of the practice in DSS and business rules.

Dion, Butler, and Xuan (2015) illustrate their concept of how a fully developed ICM system would work in Figure 24 and explain it as follows:

> The large blue box at the bottom of the diagram represents the transportation corridor being managed. Within the box, the seven smaller blue boxes show the various transportation system elements. The primary functions of the proposed ICM system, as outlined in the figure, are as follows:
>
> - Data collection /validation/fusion.
> - System operational assessment.
> - Determination of asset availability.
> - Evaluation and Selection of Management Strategies – Evaluations would be conducted by a Decision Support System (DSS) drawing strategies from rules or playbooks describing potential supply-side and demand management solutions. Figure 8-11 shows a conceptual representation of the DSS operations.
> - Strategy execution.
> - Information warehousing.
> - Traveler information applications.
> - Feedback control loop.

For purposes of this paper, we shall focus on the DSS element, especially the selection and evaluation of management strategies. Figure 24 indicates a variety of components that fit into the DSS, but does not note the incorporation of business rules through interagency agreements, etc.

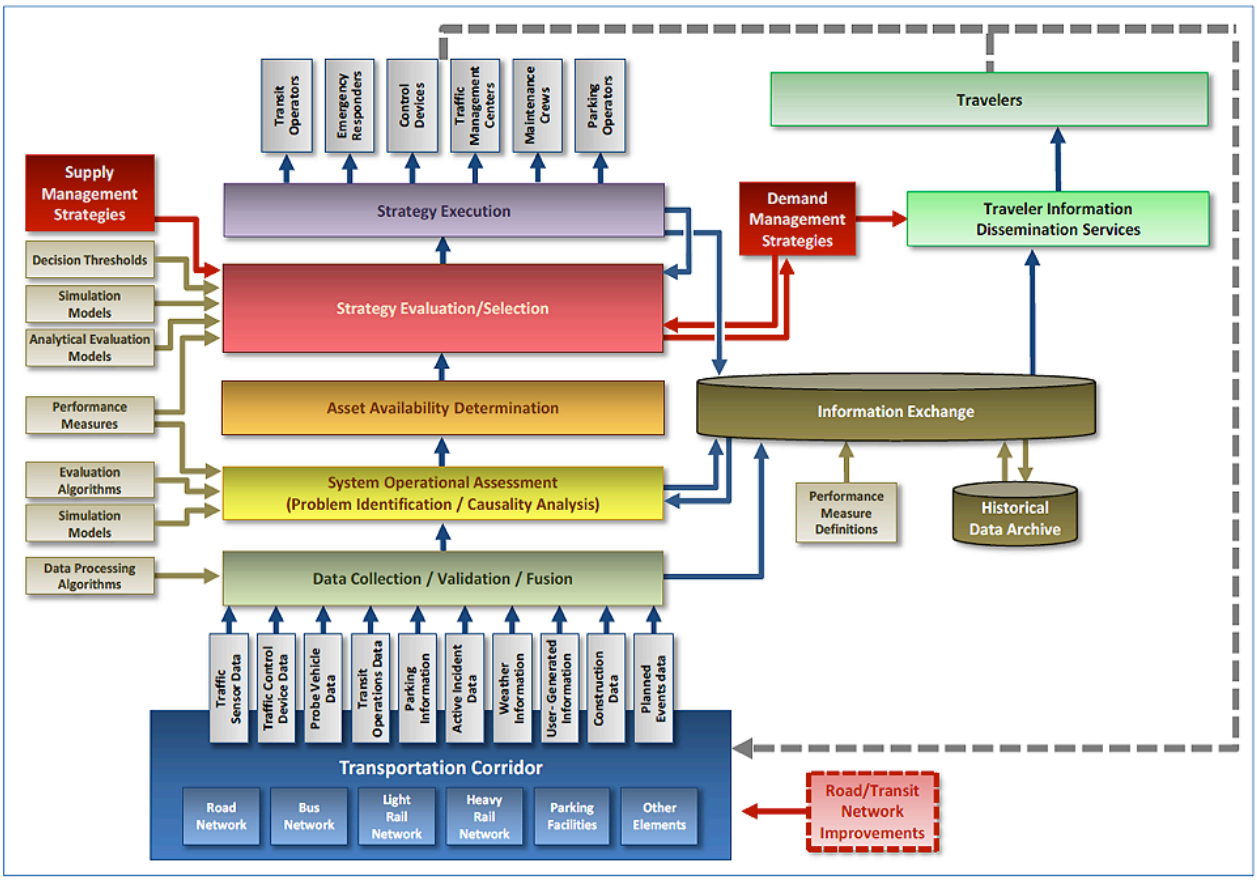
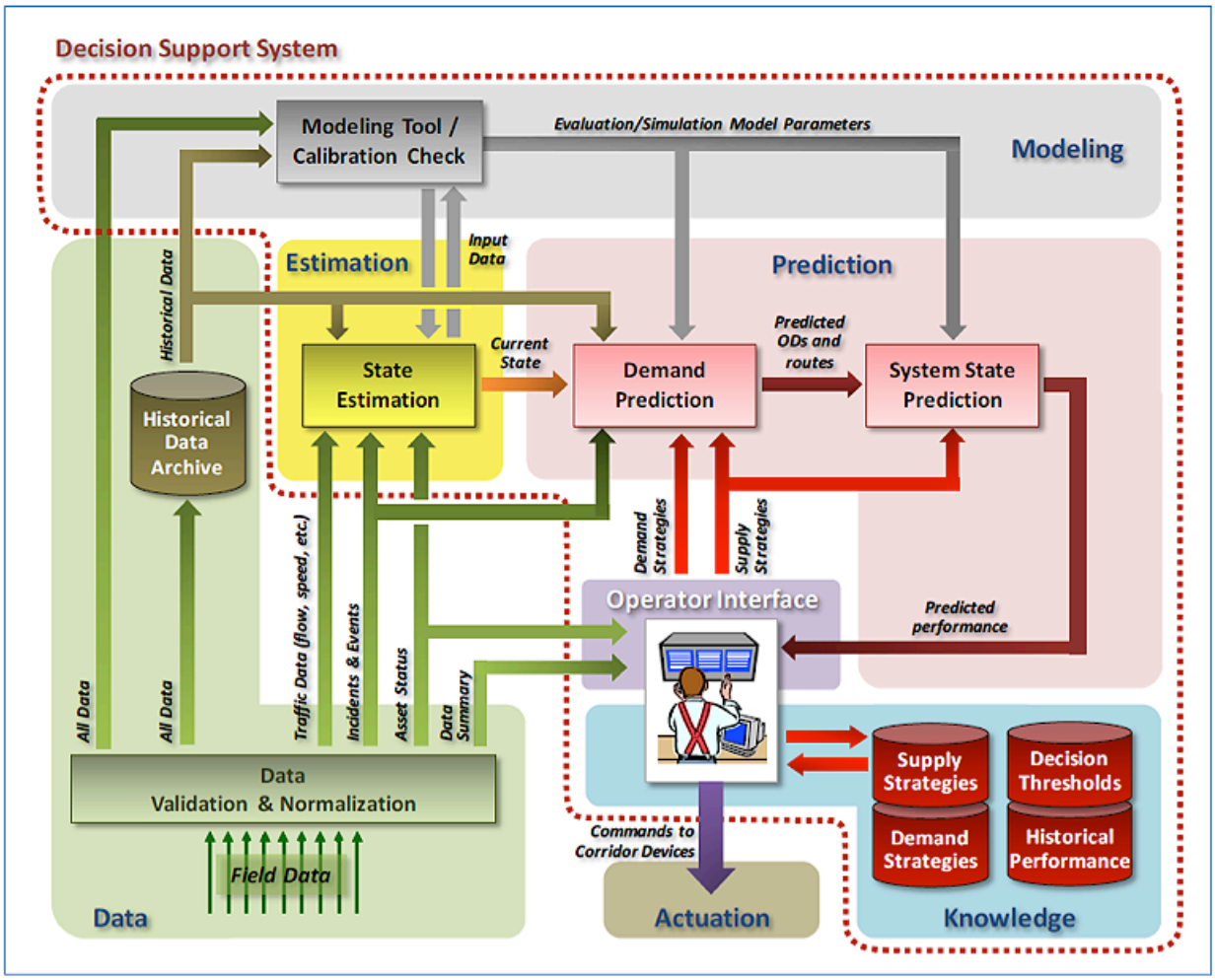


Figure 24. Diagram. Functional view of a fully developed integrated corridor management system.
(Source: Dion, Butler, Xuan, 2015)

Figure 25 illustrates an operational concept for a decision support system. It contains a diagram of the decision support system which would evaluate and select appropriate management strategies for implementation. Several key functionalities were listed, including:

- State estimation.
- Demand and system state prediction.
- Operator interface.
- Knowledge development.
- Modeling tool maintenance.

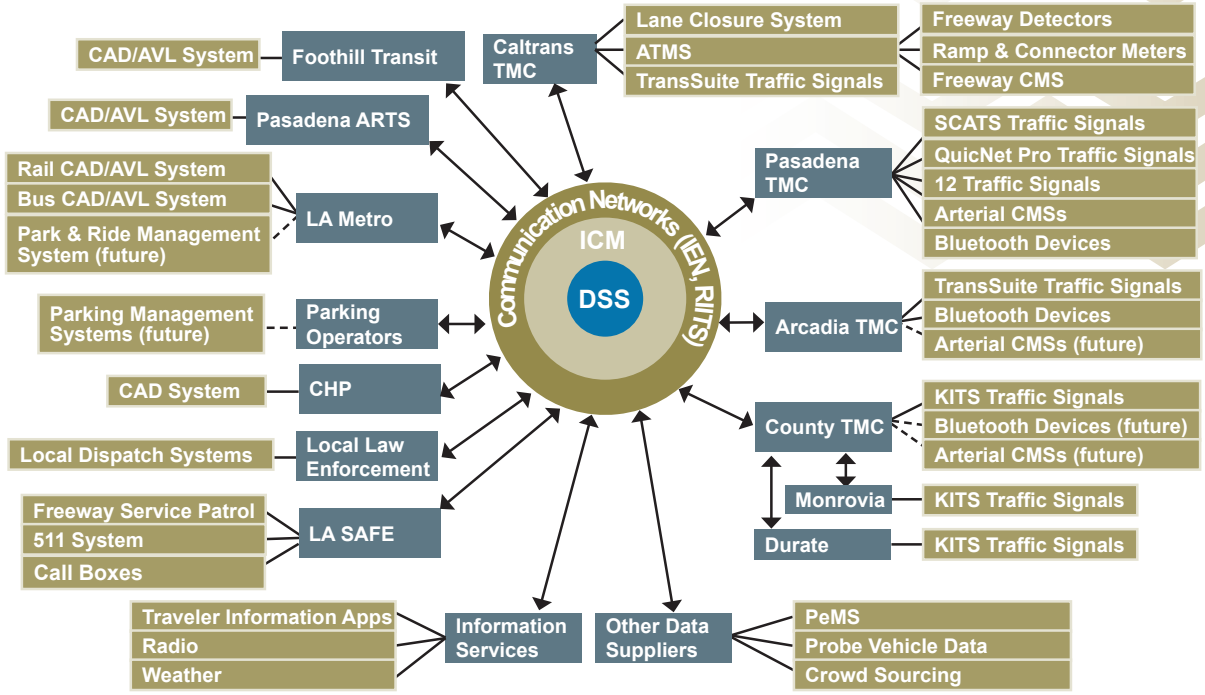


OD = origin/destination

Figure 25. Diagram. Operational concept for a decision support system.
(Source: Dion, Butler, Xuan, 2015)

Similar to the earlier diagram, there is not a specific area showing the importance of incorporating business rules into system development. The description mentions operators making selections amongst recommended scenarios, so it is possible that this is where the incorporation of interagency agreements and business rules occurs. If so, the load on the operator could be reduced by preemptively removing conflicting recommendations that do not work efficiently in the coordinated environment.

As noted in chapter 2, communication is a vital component of both proper ICM development as well as DSS implementation. Figure 26 presents a preliminary, high-level concept for an ICM deployment on I-210 Los Angeles. Note the range of partners and stakeholders, including roadway and transit operators, law enforcement and first responders, information providers, parking operators, and other data providers. Also note the vital role both communications networks and DSS support, located at the center of this diagram, play.



ARTS = area rapid transit system. ATMS = advanced transportation management system. CAD/AVL = computer-aided dispatch/automated vehicle location. CHP = California Highway Patrol. CMS = changeable message sign. KITS = Kimley-Horn Intelligent Transportation System Software. PeMS = (Caltrans) Performance Measurement System. TMC = traffic management center.

Figure 26. Diagram. I-210 pilot integrated corridor management preliminary high-level architecture.

(Source: Dion, Butler, Xuan, 2015)

The range of partners also indicates the opportunity for incorporating various interagency agreements and business rules for operating as part of the DSS development process, although this was not indicated in the original concept. However, Table 6 mentions business rules as part of the response planning stage.

Table 6. Business rules for the three areas of integrated corridor management implementation on I-210 in Los Angeles, California.

Periodical Corridor Operational Assessment
• The decision support system (DSS) predicts how traffic conditions will evolve over the next hour if patterns are maintained. If an unusual system occurs, then it is flagged and brought to the attention of the manager.
Initial Impact Assessment
• Once there is an identified incident, the DSS predicts traffic impact if nothing is done and becomes the base of evaluation for response plans.
Response Planning
• The DSS develops a plan to address the situation. An initial assessment of traffic management devices is done to determine which can participate in the response. Business rules by corridor stakeholders are then used to develop several candidate response plans. The plan with the best overall corridor performance projections is then recommended.

CHARACTERISTICS OF SUCCESSFUL INTEGRATED CORRIDOR MANAGEMENT IMPLEMENTATIONS

Effective Leadership

A key component of any successful organizational plan is engagement among knowledgeable leadership and staff who are capable of operating and creatively applying decisions in unpredictable, complex environments.

Integrated thinking about capabilities across all areas—understanding the benefits, risks, and implication of different scenarios—must become a standard practice for leaders. Engagement opportunities among transportation control centers and both public and private agencies will promote leadership skill development. Leaders need to be motivated and have the time and resources to become more familiar with all partners. Peer exchange workshops are a great way to achieve the culture shift necessary to support an integrated operation. Bringing representatives with the knowledge of ICM implementation in other regions can provide the training for staff new to the concept.

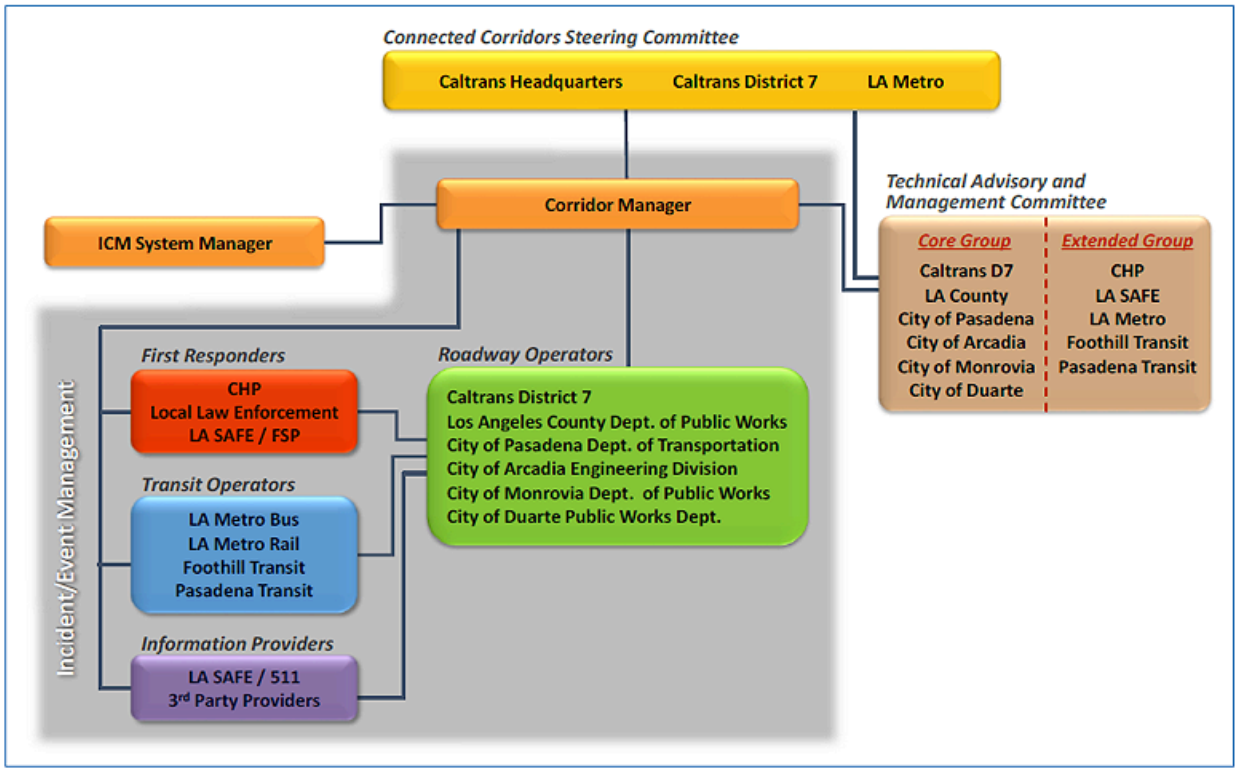
Cooperative Working Relationships with Federal, State, and Local Agencies

As noted in Gonzalez, et al., (2012), trying to manage the complexity of an ICM implementation is a serious challenge. It entails bringing together multiple agencies that use a diverse set of operations methods. Further, a range of subsystems that must be coordinated often exist within agencies. It is important to increase communication and organization to ensure that all project partners agree about expectations. A systems management approach is also useful when developing and organizing this highly complex structure. The systems engineering approach often entails the development of a plan that all stakeholders agree to early in the project process. It provides a common understanding of how work will be managed and supports tracking systems development activities from one phase to another. This same approach can be used in developing interagency agreements, which can then be incorporated into the DSS.

In their evaluation of stage 3 of the ICM deployment on I-210 in Los Angeles, Dion, Butler, and Xuan (2015) identified the following key groups of individuals as part of an institutional framework:

- **Corridor Manager (CM).** The corridor manager (CM) is expected to have control and authority over his or her agency. This will not extend to other agencies. Traffic managers from each agency are expected to retain control and decision authority over their respective agencies. The CM's major task is to oversee and assess the functionality of the individual systems connected to the ICM system as a whole. The CM also ensures that stakeholders carry on the actions that have been agreed upon.
- **Core System Operators.** These individuals have the responsibility for making final decisions to accept or reject ICM traffic control recommendations when automated control is not available.

- **Information Providers/Consumers.** These agencies provide information to or use information produced by the ICM system, such as first responder and transit agencies.
- **ICM System Manager.** This individual has responsibility for system maintenance and repairs. It is advisable for the individual to be chosen from the agency that houses the system's servers. This individual will be directly responsible for the ICM servers' maintenance and will follow up on identified maintenance and repair activities conducted by other agencies.
- **Technical Advisory and Management Committee.** This is a committee with representatives from each agency that has a role in the operation of the ICM system. Responsibilities could include evaluating the change requests for ICM system operations, counseling on operational issues, advising corridor stakeholders on jurisdictional issues, assessing system performance against established performance metrics, and identifying potential system improvements.
- **Connected Corridors Steering Committee.** This is a committee made up of representatives from major public and private partners who address funding, legal, operational, and organizational issues. It is also the committee's responsibility to develop a strategic vision and plans for system implementation and enhancement. Figure 27 illustrates the hierarchy of the I-210 connected corridor steering committee.



CHP = California Highway Patrol. ICM = integrated corridor management.

Figure 27. Diagram. Hierarchy of the I-210 connected corridor steering committee.
(Source: Dion, Butler, Xuan, 2015)

Figure 28 is another example of institutional framework of the San Diego I-15 ICM system in California.

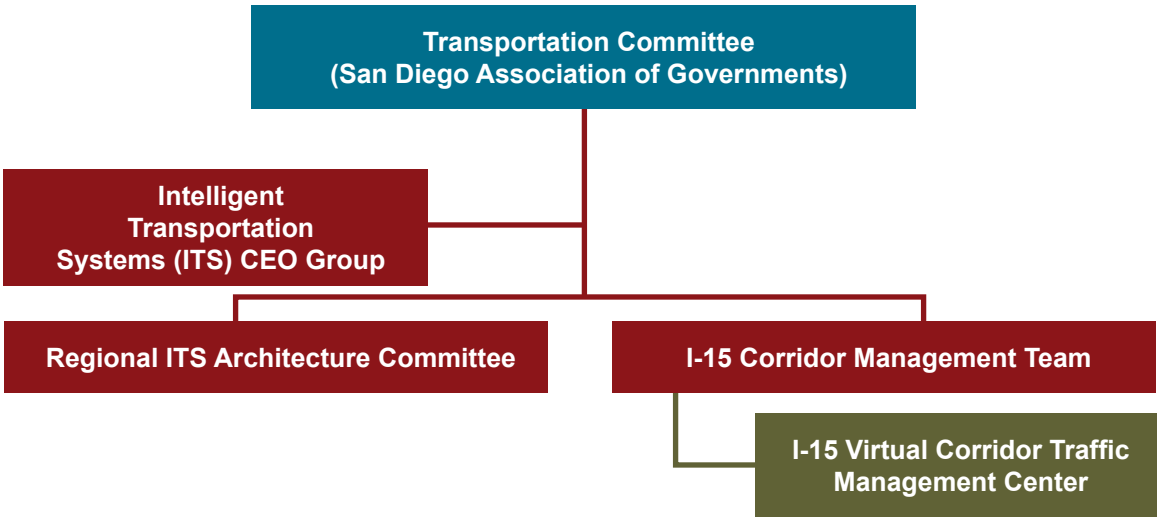


Figure 28. Diagram. Institutional framework for the I-15 integrated corridor management system.

Program Enhancement Strategies

Enhancement strategies directly emanate from innovations in ideas, personnel management, and leadership development. Here are a few examples of how to improve ICM system reliability:

- Improve engagement among agency leadership and staff.
- Enhance situational awareness of staff with respect to program capabilities.
- Prepare a directory of key people that includes a contact number, department, role, and locations.
- Increase the capacity to monitor and macro-manage operations of the staff and, if applicable, the contractor performance too.
- Identify and implement new tools to reconcile expenditures with deliverables.
- Conduct comprehensive assessments of whether the intended business rules meet the goals of ICM.

Performance measures are another way to evaluate the success of the ICM strategies and operation. How to select proper performance measures that are related to the ICM goals and objectives have been explained in detail in the FHWA document Concept of Operations for the I-15 Corridor in San Diego, California.

Staff Expertise

Staffing is an important consideration for any new program, and agencies have staffed ICM efforts in a variety of ways. These can include hiring new staff or adding ICM duties to existing staff.

The lead coordinator is the personnel or office which serves as the daily manager of operations overseeing the status of ongoing daily ICM deployment. He or they review and inspect the resultant response plans. An ICM deployment may or may not have a lead coordinator identified as such; however, by some measure, one person or one office from one of the member agencies is probably filling this role by rote. The lead coordinator is also the person or office that one calls to inquire about the ICM operation or program. This person may or may not be the champion previously described, or necessarily an employee of the lead agency.

The lead coordinator may retain prior job duties for his or her employer. It is probable, however, that those job duties (new or continuing) would naturally tailor to serve this purpose anyway, only now on behalf of the affiliated ICM agencies (Spiller et al. 2014, page 3-3).

LESSONS LEARNED AND COMMON MISTAKES

Due to the complex environment of an integrated, managed corridor, as well as the ever-changing technological and organizational landscape, there are a variety of lessons learned from common mistakes that agencies have encountered in their implementation sites. It is our hope that these lessons can be passed along for the benefit of an agency considering incorporating business rules into a DSS for their regional integrated corridor project.

It should be noted that many of these topic areas are broad and may go beyond just the business rules and interagency agreement included in this guidance document, but are mentioned for their potential impact in the larger landscape. For example, in a final report on the Dallas ICM, the authors stated that the lessons learned focused mainly on larger institutional issues and relationships that are universal to any region considering an ICM (Miller, et al., 2015). It is important to build on existing institutional arrangements in an attempt to build consensus, developing clearly defined roles and responsibilities along with tempered expectations. Within these boundaries, establishing clear business rules as part of the decision process can facilitate operations. Figure 29 shows the recommendations to enhance DSS.

Figure 29. Infographic. Recommendation to enhance a decision support system.

Table 7 summarizes lessons learned from the ICM implementation pilots. The following sections draw heavily from reports, presentations, and experiences from the Dallas and San Diego ICM implementation sites (Miller et al., 2015, Dion and Skabardonis, 201,5 Gonzalez et al., 2012).

Table 7. Lessons learned from the integrated corridor management implementation pilots.

Project Management & Stakeholder Engagement & Planning
• ***Division of labor.*** There is too much work that requires many qualities—transportation policy, planning, local context, information technology, systems engineering, telecommunications, people, and meeting dynamics—for one project manager to make decisions without input. Because finding all of the attributes in one person may be nearly impossible, the San Diego Integrated Corridor Management (ICM) Team found that a dual project management mechanism can work very well. This can mean decisions are separated out into specialty areas with more than one manager overseeing distinct components. This type of structure can set boundaries or business rules that route a decision through the appropriate branch, and rules of coordination are set up to clearly demarcate responsibility and priority when there is the inevitable disagreement. » Roles should be clearly documented to avoid any confusion.
• ***Communication.*** Invite all the potential stakeholders early in the process and give them the ability to choose their level and type of involvement. Keep them informed about the decision and the progress even if they decide not to participate, they may decide to become part of the project as they see the progress. Their participation will be key to developing interagency agreements and protocols for developing robust business rules. » "Maintaining regular communication with partner agencies throughout a project is critical, as continuous information exchange fosters understanding and perspective." – F. Dion and A. Skabardonis. (2015) San Diego I-15 Demonstration Integrated Corridor Management System PATH Report on Stage 3: Site Demonstration and Evaluation. Sponsored by Caltrans DRISI. Rep. UCB-ITS-PRR-2015-03.
• ***Needs and goals.*** Stakeholders should be able to describe the necessity and goals of the integrated corridor for their transportation network before proceeding with the development of an ICM system. These needs and goals can then be used to develop priorities and constraints on the decision-making process, incorporating all of the agency's perspectives. » The Dallas ICM project staff suggested that stakeholders should envision the ultimate working system, determine resources needed, define roles and responsibilities, deal with institutional issues, identify funding sources, and execute regional agreements and policies from the beginning.
• ***Leadership support.*** The support of each stakeholder's executive leadership is a necessary component in the success of the project as is formulating the proper implementation of decisions based in the context of interagency business rules. If leadership does not endorse the agreements made, then it is unlikely subordinates will implement them properly.
• ***Documentation.*** Integrated corridors are complex environments with a range of different players. In some cases, it may be tempting to just "wing it," operating with a contact list that one reaches out to every time a new situation arises. This can often lead to reinventing the wheel each time a recurring situation needs a decision, and it also opens up stakeholders to the potential of confusion and misinterpretation based on implied roles and relationships. It may also leave unclear how best agencies can contribute and support one another.

Table 7. Lessons learned from the integrated corridor management implementation pilots (continued).

Project Management & Stakeholder Engagement & Planning (continued)
Consequently, developing clearly worded, legal agreements such as memoranda of understanding) will help in the development of clear rules that constrain the decision-making process. » "Legal agreements, such as memoranda of understanding, generally need to be established between agencies to enable them to support each other." – F. Dion and A. Skabardonis. (2015) San Diego I-15 Demonstration Integrated Corridor Management System PATH Report on Stage 3: Site Demonstration and Evaluation. Sponsored by Caltrans DRISI. Rep. UCB-ITS-PRR-2015-03. • ***Evaluation and performance measures.*** Most decision support systems (DSS) do not have a mechanism to actually evaluate the performance of a system after a decision is made. Newer generation DSS are beginning to properly incorporate this "self-reflective" ability. The use of business rules within a DSS can also be evaluated so that either refinement or replacement can occur depending on outcomes. Involvement of transportation planners and modelers, along with operations personnel, can provide valuable input into the selection of relevant performance measures to best track system performance against established goals. • ***Sustainability.*** Long-term commitments are key to the success of the project. These commitments must go beyond principles and ideas and include financial support so that the DSS system can continue. Given the context with respect to stakeholders, agreements, and priorities can continually evolve, then having the proper resources to update the system with these new components is critical. • ***Planning.*** Proper planning is essential throughout the ICM development and implementation process. With respect to business rules in DSS, proper planning is necessary to incorporate the range of agreements and stakeholder interests into the decision-making process. » Experiences from the Dallas ICM site can be summarized with a pithy statement of plan big, start small, be flexible, plans are plans, and be prepared for unexpected events. » To develop essential political buy-in of concepts and funding, proper planning is necessary.
Operations, Maintenance, and Testing
• ***Training.*** Provide proper training for operations and maintenance personnel prior to the launch of an ICM system. With respect to the DSS and business rules, relevant staff should be familiar with the DSS as well as constraints that are being incorporated into it based on interagency agreements with regional partners. • ***Meetings and communication.*** Regular team meetings are essential to enhance processes and procedures as the operation of an ICM system matures. This includes keeping lines of communication open with partners, and providing feedback between agencies with respect to implementation and operation decisions. This regular interaction will make it easier to modify and adjust the agreements that are then utilized as context for the DSS.

Table 7. Lessons learned from the integrated corridor management implementation pilots (continued).

Operations, Maintenance, and Testing (continued)
• ***Sustainability.*** As with the project management section above, post-deployment operations and maintenance funding, as well as regional agreements and policies should be identified when designing an ICM system. Even after a successful implementation, there are maintenance and upkeep costs. Specifically focusing on the DSS and incorporating business rules, these agreements and relevant partners will likely evolve. Consequently, having a budget and resources for keeping the system current and performing well are critical. • ***Evaluation and ongoing measurement.*** One should select proper performance measures and evaluation criteria very early in planning stage with the help of transportation planners and modelers. These measures than can be refined and continuously implemented throughout the lifespan of the ICM. As noted above, DSS are generally lacking in self-evaluation capabilities. But, new generations are incorporating this functionality and staff can assist in this process by monitoring and evaluating the effectiveness of decisions made and utilization of business rules. If there are cases where recommended decisions ran counter to the preset agreements and boundaries of business rules, then the DSS system can be reviewed for areas of improvement on future recommendations.
Design & Development
• There are several components to developing an ICM relevant to business rules that can be incorporated into ICM: » Data sharing is a good start point. One needs to have a variety of data and indicators that are of high quality. » According to San Diego ICM experience, data collection and processing as well as proper usage of post-deployment data can be one of the most time consuming aspect of ICM system planning and design. • ***Communication during development*** Proper communication of proposed system functions and operations is vital. Yet, this is a challenging problem not just for an ICM, but also for the DSS being used by the ICM. How do all of the stakeholders and users know what went into the contextual, business rules component incorporated into the DSS? Is it functioning properly? What changes were made as it was updated? » "Significant effort is often required to communicate proposed system functions and operations to project stakeholders." – F. Dion and A. Skabardonis. (2015) San Diego I-15 Demonstration Integrated Corridor Management System PATH Report on Stage 3: Site Demonstration and Evaluation. Sponsored by Caltrans DRISI. Rep. UCB-ITS-PRR-2015-03. • ***General agreement.*** Achieving general agreement across all participating agencies may take longer time than planned due to variety reasons.

CHAPTER 4. EXAMPLES OF OPERATIONAL DECISIONS WITH AND WITHOUT BUSINESS RULES CONSTRAINING OPTIONS

The goal of this section is to provide the reader with several examples of a decision recommendation and the importance of incorporating a business rules filter. This can provide guidance to the operator or decision maker with respect to setting constraints for decisions to be implemented based on the underlying context of interagency coordination (the chess board along with move rules noted in chapter 1). Examples have been generalized, but are based on actual response scenarios in situations that occur on corridors where an integrated corridor management (ICM) system has been applied.

EXAMPLE 1

A minor incident occurs on the main highway. The decision support system (DSS) may suggest diverting traffic to parallel frontage roads for X amount of time until after the incident clears.

- Recommendation without incorporating business rules: The DSS may recommend only diversion, without regard for the frontage road capacity, authority, or coordination.
- Recommendation incorporating business rules: The DSS may recommend diversion, but with a prioritized order of frontage roads based on information provided by the local agency overseeing those roads. In addition, there may be a recommendation for the operator to contact counterparts and provide appropriate information for a coordinated response (including possibly local law enforcement to intervene in traffic direction, signal timing adjustments, messaging with media partners, etc.).

EXAMPLE 2

A major incident or unplanned event occurs on the main highway. The DSS may suggest diverting traffic to parallel frontage roads as well as strategic arterials for X amount of time until after the incident clears.

- Recommendation without incorporating business rules: The DSS may recommend only diversion, without regard for the frontage road or arterial roads capacity, authority, or coordination.
- Recommendation incorporating business rules: The DSS may recommend diversion, but with a prioritized order of frontage and arterial roads based on information provided by the local agency overseeing those roads. There may be a coordinated protocol for routing through agreed upon arterials. In addition, there may be a recommendation for the operator to contact counterparts and provide appropriate information for a coordinated response (including possibly local law enforcement to intervene in traffic direction, signal timingadjustments, messaging with media partners, etc.).

EXAMPLE 3

A planned event in the downtown area will cause expected delays and heavy congestion. The DSS may suggest (in addition to diversions onto detours of frontage roads and arterials) diverting travelers to public transportation as a mode switching strategy.

- Recommendation without incorporating business rules: The DSS may recommend messages that encourage travelers to use public transportation. But, without coordinating with the local transit authority, there may not be enough resources (e.g., trains and busses) to handle the excess numbers.
- Recommendation incorporating business rules: The DSS may recommend messages that encourage travelers to use public transportation. But, in this situation, protocols are incorporated into the recommendation that include proper messaging and utilize the coordinated channels established with transit partners as well as local agencies overseeing roads. There would also be guidance about interacting with agreed upon liaisons to coordinate increased capacity during the diversion times. In addition, the DSS would have information about agreed-upon protocols, updates on planned outages for the transit partners (e.g., rail work), and other contingencies that would yield a more informed recommendation.

APPENDIX A: THE FOUR PHASES OF THE INTEGRATED CORRIDOR MANAGEMENT INITIATIVE

The four phases of the integrated corridor management (ICM) initiative according to Dion and Skabardonis (2015) is presented in this section. Figure 30 illustrates an overview of the ICM initiative phases. For further detail please refer to the San Diego I-15 Demonstration Integrated Corridor Management System PATH Report on Stage 3: Site Demonstration and Evaluation, which is the source of the information presented in this appendix. References cited from the original report are at the end of this section.

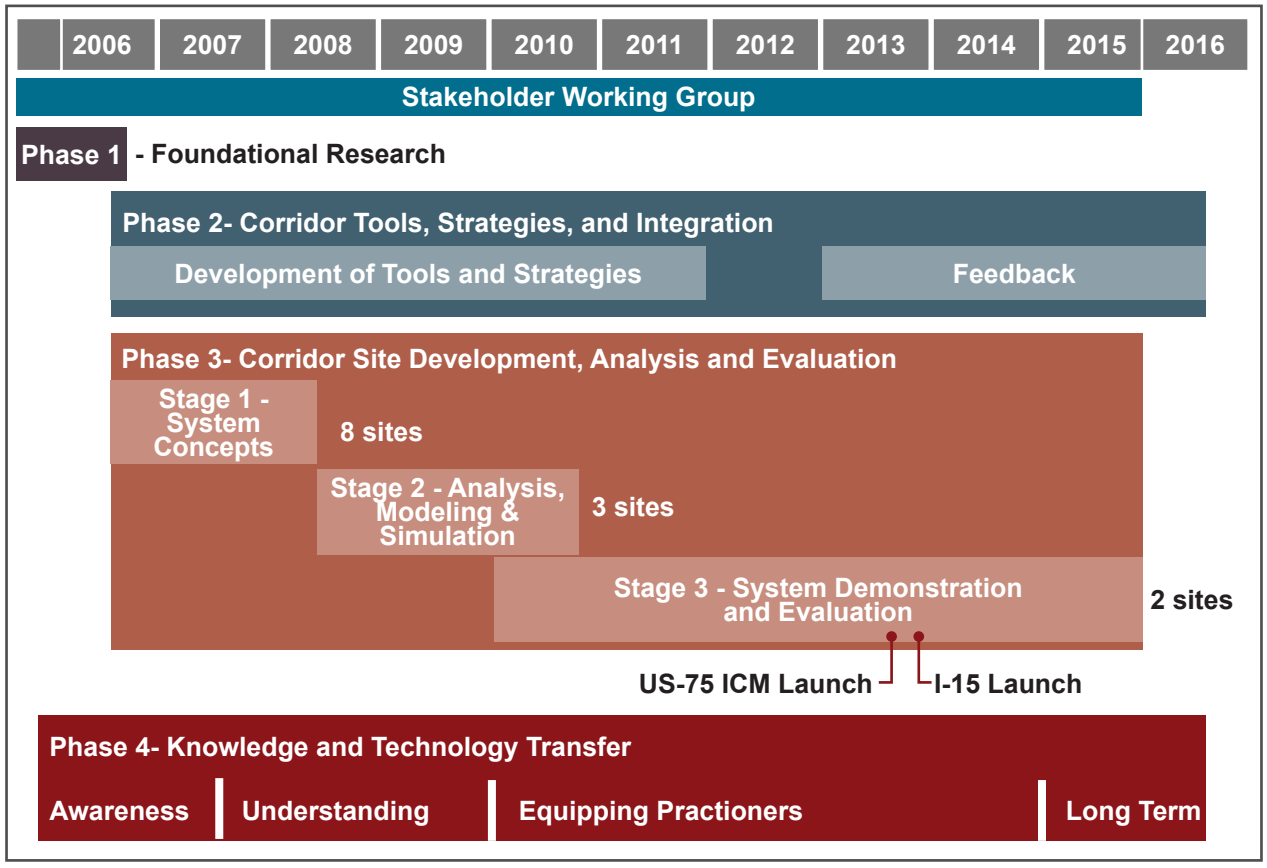


Figure 30. Diagram. U.S. Department of Transportation integrated corridor management initiative timeline.
(Dion and Skabardonis, 2015, p. 7)

PHASE 1: FOUNDATIONAL RESEARCH

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

Key activities that were conducted during this phase include:

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

PHASE 2: CORRIDOR TOOLS, STRATEGIES, AND INTEGRATION

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

Key activities conducted during Phase 2 of the initiative include:

- Refinement of the ICM strategies identified in Phase 1
- Development of a framework to analyze, model, and simulate the ICM strategies

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

PHASE 3: CORRIDOR SITE DEVELOPMENT, ANALYSIS, AND DEMONSTRATION

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

Stage 1: Concept Development

During this stage, stakeholders from each of the selected pioneer sites were tasked with developing a concept of operations and preliminary system requirements for the ICM system they would be deploying on their respective corridors, using the generic concept of operations that was developed in Phase 1 of the initiative as a guide. Sample data from each site were also provided to the U.S. Department of Transportation (U.S. DOT) to assess data availability and the suitability of each proposed ICM corridor for conducting modeling and simulation evaluations.

Each document first inventoried existing transportation systems and described the operational performance of these systems. Each document then identified the goals and objectives of the proposed ICM system, the strategies to be pursued for improving corridor operations, the user needs and asset requirements for the proposed system, how the system was envisioned to operate under various scenarios, and the eventual responsibilities of system stakeholders. The system requirements that were subsequently developed further identified and defined the different Intelligent Transportation System (ITS) components that would need to be integrated along each corridor. The resources for preparing a Concept of Operations is provided in Appendix B.

Stage 2: Analysis, Modeling, and Simulation

Under this stage, the corridors were first modeled according to the analysis, modeling, and simulation (AMS) framework that was developed in Phase 2. For each corridor, key ICM strategies from the Concept of Operations developed in Stage I were then selected for modeling and analysis to assess the range of expected benefits associated with each proposed system.

Table 8 lists the various management strategies that were modeled and evaluated for each corridor. Depending on the corridor, various combinations of strategies aimed at improving traveler information, traffic management, HOV/HOT operations, and transit management were considered.

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

Table 8. Integrated corridor management strategies considered in analysis, modeling, and simulation evaluations.

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

More detail about Stage 2 is available in the San Diego I-15 Integrated Corridor Management (ICM) System: Stage II (Analysis, Modeling, and Simulation) report, which can be accessed at: https://merritt.cdlib.org/d/ark:%252F13030%252Fm5z039tp/2/producer%252FPRR-2010-09.pdf

Stage 3: Demonstration and Evaluation

This stage, which was expected to last three to four years, consisted of the development, implementation, and operational evaluation of an actual ICM system on each corridor. A first goal was to demonstrate the application of institutional, operational, and technical integration approaches in the field. A second goal was to document the operational benefits associated with each system and the implementation issues encountered during system development and implementation to assist with future ICM system deployments along other corridors.

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

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

Each of the above tasks are described in detail in the chapter 6.1 of the *San Diego I-15 Demonstration Integrated Corridor Management System PATH Report* on Stage 3: Site Demonstration and Evaluation report.

On phase 3, specific activities associated with each deployment site included:

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

PHASE 4: INTEGRATED CORRIDOR MANAGEMENT OUTREACH AND KNOWLEDGE AND TECHNOLOGY TRANSFER

The goal of Phase 4 of the ICM Initiative was to equip corridor managers and operators around the country with a comprehensive resource set to help them develop, implement, and evaluate prospective ICM systems.

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

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

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APPENDIX B: RESOURCES FOR PREPARING A CONCEPT OF OPERATIONS

A Concept of Operations is a key document to be used in the development of an ICM. It is vital to have a clear understanding of the purpose and structure before beginning development of such a document. The following list of resources provide a starting point as well as fundamental elements to include in a well-crafted Concept of Operations.

- *Developing and Using a Concept of Operations in Transportation Management Systems.* (FHWA-HOP-07-001 - 2005) available (5/30/2017): https://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/conops_tms_handbook.pdf
- *Guide to the Preparation of Operational Concept Documents.* (ANSI/AIAA G-043-2012). American National Standards Institute, 1992. This report gives guidelines for creating a Concept of Operations document.
- *Concept of Operations for the US-75 Integrated Corridor in Dallas, Texas.* (FHWA-JPO-08-004- 2008) available (5/30/2017): https://ntl.bts.gov/lib/30000/30400/30409/14390_files/14390.pdf
- *Concept of Operations for the I-15 Corridor in San Diego, California* (FHWA-JPO-08-009-2008) available (5/30/2017): https://ntl.bts.gov/lib/30000/30300/30311/14395_files/14395.pdf
- *Concept of Operations for the I-394 Corridor in Minneapolis, Minnesota.* (FHWA-JPO-08-006- 2008) available (5/30/2017): https://ntl.bts.gov/lib/30000/30300/30310/14392_files/14392.pdf
- *Concept of Operations for the I-880 Corridor in Oakland, California* (FHWA-JPO-08-003 -2008), available (5/30/2017): https://ntl.bts.gov/lib/30000/30700/30766/14389.pdf
- *Concept of Operations for the I-270 Corridor in Montgomery County, Maryland.* (FHWA-JPO-08-002 -2008), available (5/30/2017): https://ntl.bts.gov/lib/30000/30300/30312/14388_files/14388.pdf

APPENDIX C: INTERAGENCY AGREEMENT APPROACHES

This section has been extracted from "Assessment of Emerging Opportunities for Real-Time, Multimodal Decision Support Systems in Transportation Operations Task 4 Concept of Operations." For more detail on each part please refer to the original report.

1. **Definition and Explanation of Terms**- have clear definition of all terms documented, such as:

   Emergency Vehicle Preemption (EVP) – Devices on emergency vehicles communicate with devices at traffic signals to provide a green traffic signal phase for emergency vehicles approaching an intersection.

2. **Purpose of MOU**, Project Description, and Project Governance

   a. **Purpose.** The MOU should serve the following purposes:

      1) Confirm support from all project partners, particularly local support for freeway elements;

      2) Articulate key operations and maintenance (O&M) principles for continuing project development;

      3) Clarify ownership, O&M, and management responsibilities;

      4) Clarify the distribution of costs and funding sources;

      5) Outline the framework for multi-agency cooperation, collaboration, and conflict resolution;

      6) Identify which Smart Corridor devices will be made part of the ICM project; and

      7) Signify the ongoing commitment of the project partners to deliver the project and make it a success.

   b. **Governance**

      It is the intent that all technical and operational matters be resolved among the partnering agencies at the lowest working level. For instance, the I-80 integrated corridor management activities will be directed through three bodies of governance, in the following order of hierarchy, from low to high:

      Technical Coordinating Committee (I-80 TCC)

      Corridor Steering Committee (I-80 CSC)

      Policy Advisory Committee (I-80 PAC)

3. **Project Goals & Objectives**

4. **Operations Strategies and Principles**

   a. **Operational Scenarios & Lead Agencies** - illustrates the operational strategies that will initially be deployed as part of the I-80 ICM Project and the agencies that will take the lead in implementing the strategies.

      Normal Operations

      Incident / Special Events Management

   b. **Operating Principles** - day-to-day transportation management and operational activities along the corridor

5. **Equipment Ownership & Maintenance** - delineates the ownership and operations responsibilities.

6. **Project Development Principles**

   a. **Project Documents**

      i. To design the project:

         1) **Project Report:** Defines the purpose and need for the project, identifies the alternative selected, describes how that alternative was decided upon, and describes how consensus was reached among stakeholders.

         2) **Environmental Document:** For a capital project to proceed, it must receive official federal, state, and environmental approvals as well as consensus from all the stakeholders and the public.

         3) **Corridor Systems Management Plan (CSMP):** Overall corridor operational conditions, existing and future conditions, list of future projects, and recommendations.

         4) **Concept of Operations Report (Con Ops):** Concept for proposed system, user-oriented operational description, operational needs, system overview, operational and support environment, operational scenarios, summary of impacts.

         5) **Traffic Operations Analysis Report (TOAR):** Existing traffic conditions, proposed alternatives, traffic forecasts, modeling results.

      ii. To govern the implementation of the project

         1) **Project Implementation Plan:** Document identifying the staging and commissioning of each I-80 ICM project element (TOS, TLSP, ARM, and ATM).

2) **Operations and Maintenance (O&M) Plan:** Operational scenarios and cost of operations, maintenance and management for each city along the corridor.

3) **Incident Response Plan (IRP):** Overall incident response plan that defines various incident scenarios and procedures for managing traffic congestion during incidents, including signal flush plans.

4) **System Integration Plan:** Specifies the procedures, methods and strategies to implement the required project elements based on project documents and system requirements.

5) **Configuration Management Plan:** Details the process to establish and maintain the integrity and control of software and hardware products.

6) **Outreach Plan:** Outlines strategies to disseminate periodic project information and updates to various stakeholders.

    a. Construction

    b. System Integration

    c. Implementation & Initial System Evaluation

    d. Regular Operations & Maintenance

    e. Configuration and Change Management

7. **Costs & Funding -** The project most likely is funded by various fund sources for the different phases of the project – Project Development, Construction, and Operation & Maintenance phases. Funding for each phase should be outlined.

8. **Future MOU Modifications -** The MOU could be a legally non-binding document. However, revisions to this MOU may be requested by the Technical Coordinating Committee (TCC) and approved by the Corridor Steering Committee (CSC). Revisions may also be recommended by the CSC.

9. **Need for Additional Agreements -** New maintenance agreements or amendments to existing maintenance agreements could be developed and executed as necessary to address maintenance arrangements, liabilities, or any other legal issues.

APPENDIX D: INTERAGENCY AGREEMENT EXAMPLES

[1] *These are complete references from the original document (I-15 ICM Demonstration: Stage 3 PATH Report, 2015) and provide numerous examples of interagency agreement structure and content.*

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