Integrated Corridor Management:

Implementation Guide and Lessons Learned

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16. Abstract

This implementation guide is intended for use by adopters of integrated corridor management (ICM) approaches and strategies to address congestion and travel time reliability issues within specific travel corridors. It introduces the topic of ICM and identifies the type of information system, the integrated corridor management system (ICMS) that is used to support transportation network managers and operators in applying ICM.

The guide discusses typical issues (lessons learned) that arose during the U.S. Department of Transportation's (U.S. DOT's) research initiative, where the U.S. DOT partnered with eight transportation agencies in large metropolitan areas (known as "Pioneer Sites") to research effective means of implementing ICM approaches in their major travel corridors. Each of the Pioneer Sites used a systems engineering approach to define the needs for ICM within their corridor and the needs and requirements for an ICMS to support ICM. Two of the original eight Pioneer Sites were selected to serve as Pioneer Demonstration Sites, where an actual ICMS was built, operated, maintained and evaluated to assess how effective ICM strategies were in improving the flow of traffic within the corridor.

The guide offers suggestions for each stage of an implementation effort for an ICMS, to assist other agencies in benefitting from the research done to date and from the experiences of the Pioneer Sites. In addition to the material covered in the guide itself, there are extensive references to other documents and source material that can assist ICM adopters in successfully applying these concepts for their regions. Please note that this Version 2.0 of the ICM Implementation Guide and Lessons Learned supersedes Version 1.0 of the ICM Implementation Guide and Lessons Learned published in February of 2012. At the time the version 1.0 guide was written, the Dallas and San Diego ICM Pioneer Sites were still in the system definition and design stages of the project lifecycle. This version 2.0 update of the guide provides additional lessons learned and examples through the full implementation of the Dallas and San Diego ICM Pioneer Site projects.

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Abstract

This implementation guide is intended for use by adopters of integrated corridor management (ICM) approaches and strategies to address congestion and travel time reliability issues within specific travel corridors. It introduces the topic of ICM and identifies the type of information system, the integrated corridor management system (ICMS) that is used to support transportation network managers and operators in applying ICM.

The guide discusses typical issues (lessons learned) that arose during the U.S. Department of Transportation's (U.S. DOT's) research initiative, where the U.S. DOT partnered with eight transportation agencies in large metropolitan areas (known as "Pioneer Sites") to research effective means of implementing ICM approaches in their major travel corridors. Each of the Pioneer Sites used a systems engineering approach to define the needs for ICM within their corridor and the needs and requirements for an ICMS to support ICM. Two of the original eight Pioneer Sites were selected to serve as Pioneer Demonstration Sites, where an actual ICMS was built, operated, maintained and evaluated to assess how effective ICM strategies were in improving the flow of traffic within the corridor.

The guide offers suggestions for each stage of an implementation effort for an ICMS, to assist other agencies in benefitting from the research done to date and from the experiences of the Pioneer Sites. The guide is only one of a set of documents that the U.S. DOT intends to publish to provide guidance and advice to prospective adopters of ICM. In addition to the material covered in the guide itself, there are extensive references to other documents and source material that can assist ICM adopters in successfully applying these concepts for their regions. It is important to note that both sites are continuing to operate and make enhancements to their ICM deployments, as well as expanding the system to other corridors within their respective regions.

Please note that this Version 2.0 of the ICM Implementation Guide and Lessons Learned supersedes Version 1.0 of the ICM Implementation Guide and Lessons Learned published in February of 2012. At the time the version 1.0 guide was written, the Dallas and San Diego ICM Pioneer Sites were still in the system definition and design stages of the project lifecycle. This version 2.0 update of the guide provides additional lessons learned and examples through the full implementation of the Dallas and San Diego ICM Pioneer Site projects.

Chapter 1. Introduction to the ICM Guide

Overview

Integrated Corridor Management (ICM) is a promising tool in the congestion management toolbox that seeks to optimize the use of existing infrastructure assets and leverage unused capacity along our nation's urban corridors. ICM is defined as a collection of operational strategies and advanced technologies that allow transportation subsystems, managed by one or more transportation agencies, to operate in a coordinated and integrated manner[1]. With ICM, transportation professionals manage the transportation corridor as a multimodal system rather than taking the more traditional approach of managing individual assets.

Beginning in 2006, the U.S. DOT partnered with eight "Pioneer Sites" in an initiative to develop, deploy, and evaluate ICM concepts in our Nation's busiest corridors—the ICM Pioneer Sites are listed in Figure 1. Because of practical limitations, only two of the initial eight sites (those identified with an asterisk) were selected to deploy and operate and maintain ICM systems (ICMS). The U.S. DOT ICM Initiative aims to advance the state of the practice in transportation corridor operations to manage congestion. This initiative is providing the institutional guidance, operational capabilities, Intelligent Transportation Systems (ITS) technology, and technical methods needed for effective ICMS.

Figure 1. U.S. DOT ICM Pioneer Sites

Dallas, Texas*
Houston, Texas
Minneapolis, Minnesota
Montgomery County, Maryland
Oakland, California
San Antonio, Texas
San Diego, California*
Seattle, Washington

* ICM Pioneer Demonstration Sites

ICM can be viewed as the evolution of ITS technologies: first, agencies deployed individual devices; next agencies deployed separate modal systems; and now agencies are working on multi-modal integration in ICM. ICM can improve corridor travel by integrating existing ITS devices and systems, including assets operated by different agencies, into a proactive solution designed to manage demand and capacity across all travel modes. This evolution to ICM brings operational benefits as well as the challenges of technical complexity and interagency coordination. The purpose of this ICM Implementation Guide is to provide information to ICM "early adopters" on how to plan, develop, deploy, operate, and maintain an ICMS. This guide addresses both the benefits and challenges by explaining the ICM project process and conveying firsthand knowledge and experience from the ICM Pioneer Sites.

The target audience for this guide is public-sector transportation project managers who wish to implement an ICMS in their region. Note, that this guide is not a "how to" manual on Systems Engineering for an ICMS. The Systems Engineering process is used as the framework for the ICMS project process; however, the breadth of the Systems Engineering process is too extensive to cover comprehensively for ICM in a short guide of this type. This guide describes the phases in the system life cycle and the associated ICMS deliverables, focusing on how the ICM Pioneer Sites addressed each phase.

The U.S. DOT ICM initiative is a multi-stage effort spanning several years. In the first stage, the eight Pioneer Sites developed their Concept of Operations and System Requirements Specification. In the second stage three sites—Dallas, Minneapolis, and San Diego—were selected to model the potential impact of ICM on their

corridors. In the third stage two sites—Dallas and San Diego—were selected as ICM Pioneer Demonstration Sites to design, build, operate, and maintain their respective ICMSs and evaluate the impact on the corridors.

- The goal of this guide is to further the ICM program toward the ultimate goal of empowering future locations to implement ICM and seeks to fulfill the following set of objectives for the reader: Use the applicable steps and deliverables from the Pioneer Site Process;
- Focus on measures and benefits, including performance monitoring and performance management;
- Understand ICM operations and maintenance (O&M);
- Adhere to existing Federal Highway Administration/Federal Transit Administration (FHWA/FTA) rules, policy, and guidance—for example, the FTA Policy and FHWA Rule on ITS Architecture and Standards Conformity;[2]
- Provide references to other guidebooks for more detail on ITS and Systems Engineering; for example, the FHWA Systems Engineering for ITS Handbook[3] and the FHWA/ California Department of Transportation (Caltrans) Systems Engineering Guidebook for ITS: Version 3.0;[4] and
- Identify some unique challenges of ICM implementation.

This guide advises a potential ICM adopter both on the references the site should use from its region and on the appropriate references from Pioneer Sites and Standards Development Organizations. Several examples are included, as well as some templates. The appendices contain additional information to assist the reader, such as a list of acronyms and abbreviations and a bibliography of references and resources.

An important component of ICM is Analysis, Modeling, and Simulation (AMS). The use of AMS provides ICM adopters with the means to assess operational strategies before they are implemented and to continuously monitor changing conditions and operational effectiveness. The AMS methodologies used for ICM receive their own special treatment in the ICM AMS Guide. The ICM AMS Guide has been incorporated into the Federal Highway Administration (FHWA) Traffic Analysis Toolbox (Volume XIII) and Traffic Simulation Guidelines. Implementers of ICM are well served to consider the ICM AMS Guide in its entirety.[5]

How to Use This Guide

Chapters 1 and 2 of this guide introduce ICM and the potential complexity of deploying systems to support it. These chapters also explain the distinction between ICM and an ICMS. Chapter 3 of this guide provides some insight on what it takes to implement an ICMS including suggestions for management of the process, highlights of recommended practices and ICMS challenges, testimonials, lessons learned, and examples from the Pioneer Site implementations.

In chapter 3, sections 1 through 7 follow an intentionally similar format. Each section provides information on one of the seven phases of an ICMS implementation. The length of time needed to complete each phase of an ICMS implementation depends on the size and complexity of the project. Because of a potentially longtime to complete implementation phases, the sections were designed to be read independently as the project progresses.

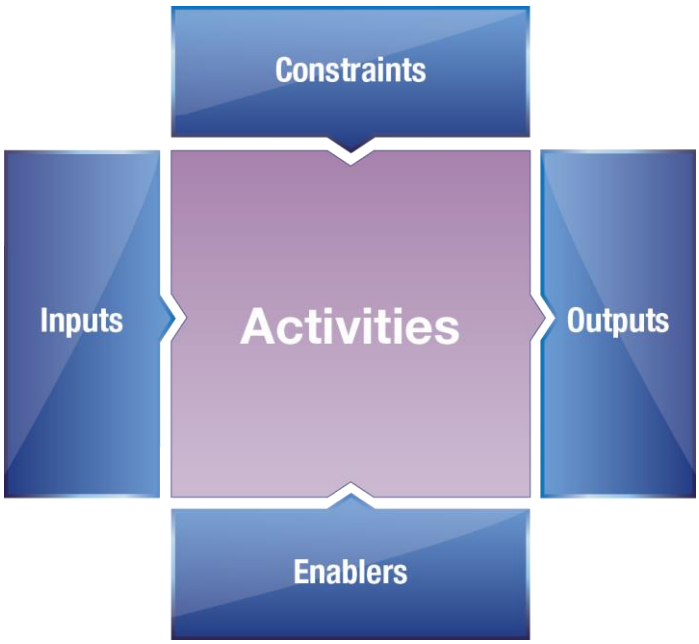
Each section starts with a brief summary of the project phase and then each phase description contains the following information areas—manage for quality, resources, process highlights, questions to answer, lessons learned, and example. This convention should aid the reader in understanding the process and will provide

consistency for the reader in using the guide as a reference throughout the process by tying together the different phases using similar themes. These six information areas are described below.

Manage for Quality

Each Manage for Quality section provides guidance on the management structure for each implementation phase, describing important activities for which the leader of the given phase will be responsible. Each Manage for Quality section also includes a graphic showing some of the typical planning/development activities that will occur in each phase of the ICM implementation (note that the diagram is in the Highlights section in a few instances). See Figure 2 for the overall generic structure diagram.

Figure 2. Generic Structure Diagram



[Source: Modeled after: *Systems Engineering Guidebook for Intelligent Transportation Systems, Version 3.0,* U.S. DOT, November 2009.]

These graphics are adaptations from the Systems Engineering Guidebook for ITS[6] and are tailored for an ICM implementation. Each graphic includes **inputs**, **activities**, and the resulting **outputs** for each phase of the project. Outputs of one project phase often become inputs to the next project phase and may be seen on the graphic for the next project phase. The graphics also include **constraints** on the project phase, which are typically items that control or impose limits on the work (e.g., laws, rules, guides, and standards). Stakeholders may want to add additional controls, inputs, or outputs that they deem necessary. The graphics also identify the physical **enablers** or resources that facilitate the activities. Many activities identified in the graphics correspond to typical project planning and development activities (e. g., feasibility studies, simulation and modeling, regional ITS architecture), so no explanation is provided in this guide for those activities. However, for those activities that may be new to some implementers, the guide provides guidance and or resources to assist readers with those activities.

Resources

Each section of the guide provides a list of key resources. A brief summary of the resource is provided as it relates to each project phase. For detailed information on each resource, the reader should access the endnotes, which provide specific page, appendix, and template references.

Highlights

Each section includes a phase highlights section that provides information on and examples of some of the more challenging and perhaps less well-known activities in each project phase. These activities were specifically included to help implementers understand the less well-known ICM implementation concepts.

Questions to Answer

Each section includes questions that stakeholders should address during reviews of the project or prior to completion of each phase. Stakeholders may want to add to the list to satisfy their own unique project needs.

Lessons Learned

Each section includes lessons learned from the ICM Pioneer Site implementations. These lessons learned provide some insight into challenges that ICM implementers may encounter and recommendations for implementing solutions.

Pioneer Site Example

Finally, each section includes a featured example of work performed during the ICM Pioneer Site implementations. These examples are not intended to be recommended practice; however, they do provide a perspective on work that the sites performed. Considering these were pioneer projects, future ICM implementers may want to consider adopting process improvements for future implementations.

The guide highlights each Pioneer Site example in a separate box set apart from the text of the guide as shown below.

> Pioneer Site Example

Throughout the text there are other examples both from the Pioneer Sites and from other sources that are highlighted in this manner.

Note: This guide does assume some understanding of project management and systems engineering. It is strongly recommended that both project management and systems engineering expertise be available to ensure project processes are conducted correctly.

Chapter 2. Understanding Integrated Management of Transportation Corridors

This chapter explains the main concepts and benefits of Integrated Corridor Management and Integrated Corridor Management Systems. Additionally, this chapter gives some perspective on how to manage the complexity of an Integrated Corridor Management System.

What Is Integrated Corridor Management?

Integrated Corridor Management is the operational coordination of multiple transportation networks and cross-network connections comprising a corridor and the institutional coordination of those agencies and entities responsible for corridor mobility.[7] It will transform the manner in which transportation networks are managed within a corridor, enabling agencies to see the *overall* impact of *multimodal* transportation network management decisions and to optimize the movement of people and goods within the corridor instead of just on individual networks.

> *"The overall ICM process is extremely helpful in bringing together multi-modal stakeholders to discuss the organization and management of corridor resources to achieve operational efficiencies for corridor transportation."*
>
> Koorosh Olyai
> Assistant Vice President
> Mobility Programs Development
> Dallas Area Rapid Transit

The integration of operations among all transportation networks within a corridor is one solution to the growing congestion problem and its resulting mobility reductions within urban transportation corridors. Integration maximizes the effectiveness of operations and mitigates the effect of incidents that affect the movement of people and goods within the corridor. This integrated operation of corridor transportation networks is the subject of a major U.S. DOT initiative known as Integrated Corridor Management. Without ICM, each transportation network operator reacts to changes in demand or capacity in the manner permitted by the operator's network management system. The freeway operator, for example, might post messages on dynamic messaging signs located sufficiently before an incident to divert travelers from one freeway to another (if possible) or to the arterials that allow operators to bypass the incident. However, if the arterial network operators are not expecting this additional volume on their roads, their networks may become congested, and delays may build. Similarly, transit bus operators cannot prepare for or encourage travelers to shift to their mode of transportation, since they are not expecting any reason for increased demand. With an effective ICM approach in place, however, the transportation system operators in the corridor would be able to take a series of actions that could mitigate the effects of increased demand or reduced capacity on the entire corridor.

> *"ICM provides the opportunity to proactively improve and maximize the performance of the transportation system by serving as an alternate to traditional major infrastructure investments which may be more expensive or constrained by environmental issues"*
>
> Alex Estrella, ICM Manager,
> San Diego Association of Governments

ICM is about more than just incident management or incident response. The concept of ICM is further explored in the white

paper "Conceptualizing Integrated Corridor Management" in Appendix A. This white paper provides a detailed examination of the following four strategic areas of ICM:

- Demand Management
- Load Balancing
- Event Response
- Capital Improvement

In addition to understanding what ICM is, agencies interested in ICM also want to answer these related questions:

- Should I implement ICM?
- What are some ICM strategies?
- What benefits can I expect from ICM?

These three questions are examined below.

Should I implement ICM? In determining a viable candidate corridor for ICM, it is helpful to answer the following questions about the current operations in the corridor:

- Is congestion in the corridor increasing and are travel times becoming less reliable?
    - ICM strategies can provide a near-term solution to these issues.
- Does the corridor have existing infrastructure and systems for each modal network and can the existing infrastructures and systems be effectively integrated?
    - ICM can take advantage of these systems to meet the operational needs of the corridor.
- Do existing infrastructure devices and systems provide real-time or near real-time data on corridor conditions that can be used to compute corridor performance measures and to assess the effectiveness of potential control strategies?
    - ICM requires a solid foundation of real-time or near real-time data for coordination of effective responses to corridor conditions.
- Does the corridor contain alternative routes and modes for travelers?
    - ICM will facilitate informed travel decisions to maximize corridor efficiency.
- Are the existing transportation systems fully optimized?
    - ICM provides benefits through corridor-wide capacity optimization across all networks and modes.
- Do some of the agencies in the corridor already have agreements to coordinate operations and management?
    - Implementing ICM would involve expanding operations to involve all transportation networks in a corridor.
- Are all relevant agencies on board with supporting corridor operations? To be effective, ICM requires resource commitments (personnel and funding) from all affected agencies.

What are some ICM strategies? Determining the most effective ICM strategies is part of the process of implementing ICM. To better understand some of the strategies used as part of ICM, it is helpful to look at the example of the ICM Pioneer Demonstration Sites and their respective strategies listed below:

Dallas, Texas, US 75 ICM Proposed ICM Approach and Strategies by Goal:[8]

- Increase corridor throughput: HOV lanes, transit usage increase, increase/maximize supply (additional transit, additional parking, and diversion of vehicles), integrated approach to management (trade-offs between agencies to improve overall corridor operations), and modeling of corridor and strategies (for the decision support subsystem);
- Improve travel time reliability: advanced traveler information system (ATIS) and incident management (response time improvements – consistent goal among agencies within corridor);
- Improved incident management: inter-agency cooperation, inter-agency information sharing (center-to-center), agency training on common approach (current courses available), integrated policies for incident response (towing policies, response times), and decision support model (for historical, and near real-time scenario evaluation); and
- Enable intermodal travel decisions: model of multi-mode system, ATIS (availability of other modes, linked Web sites/portal, and third party integration), and marketing/advertising (public outreach/education).

San Diego, California, ICM Strategies Based on the I-15 Corridor Goals and Objectives:[9]

- Share/distribute information: manual information sharing, information clearinghouse/information exchange network between corridor networks and agencies; 511 (pre-trip traveler information); en-route traveler information (smart signage and smart parking); access to corridor information by ISPs and other value-added entities; automated information sharing (real-time data); and common incident reporting system and asset management system;
- Improve junctions/interfaces: signal pre-emption – identifying "best route" for emergency vehicles; multimodal electronic payment; signal priority for transit, bus priority on arterials; transit hub connection protection; multi-agency/multi-network incident response teams/service patrols; and training exercise;
- Accommodate/promote network shifts: modify ramp metering rates to accommodate traffic (including buses) shifting from arterials; promote route shifts between roadway and transit via en-route traveler information devices; promote shifts between transit facilities via en-route traveler information devices; congestion pricing for managed lanes; and modify arterial signal timing to accommodate traffic diverted from the freeway;
- Capacity/demand management (short-term): land use control; modify HOV restrictions; increase roadway capacity by opening HOV/HOT lanes/shoulders; scheduled closures for construction; coordinate schedule maintenance and construction activities among corridor networks; planned temporary addition of transit capacity; and modify parking fees (smart parking); and
- Capacity/demand management (long-term): peak spreading; ridesharing programs; expand transit capacity; and land use around BRT stations.

What benefits can I expect from ICM? The potential effects of ICM have been simulated at the three Pioneer AMS Sites. The results of these experiments have been documented and some example results are listed in Table 1 below. The differences in benefits among each of the Pioneer AMS Sites are the result of differences in corridor sizes, selection of control strategies, and other factors that varied from site to site. What is consistent, however, is that the overall benefit-cost ratios are all at least 10:1. (Note: the table lists net benefits; i.e., total benefits minus total costs, rather than overall benefits.)

Table 1. Expected Annual ICM Benefits of Pioneer Sites

Benefit (from Simulations)	Dallas	Minneapolis	San Diego
Annual Travel Time Savings (Person-Hours)	740,000	132,000	246,000
Improvement in Travel Time Reliability (Reduction in Travel Time Variance)	3%	4. 4%	10. 6%
Gallons of Fuel Saved Annually	981,000	17,600	323,000
Tons of Mobile Emissions Saved Annually	9,400	175	3,100
10-Year Net Benefit	$264M	$82M	$104M
10-Year Cost	$14M	$4M	$12M
Benefit-Cost Ratio	20:1	22:1	10:1

[Source: Integrated Corridor Management (ICM) ITS Benefits, Costs, and Lessons Learned: 2014 Update Report, USDOT FHWA. 2014]

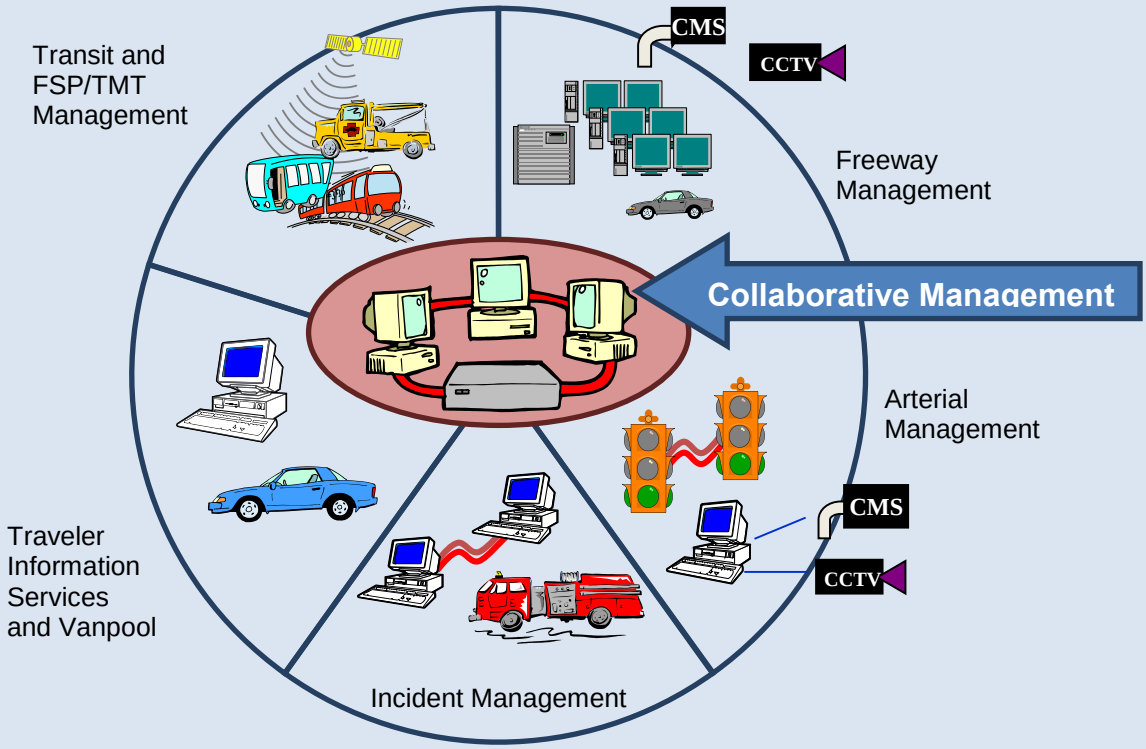
What Is an Integrated Corridor Management System?

While ICM is the concept and practice of managing a corridor in an integrated fashion, the ICMS is the underlying infrastructure that enables agencies to perform that management process in an efficient manner. An ICMS is a set of tools to help the corridor's transportation network managers and operators achieve the ultimate goal of keeping their networks operating at optimal levels. The ICMS can use existing network infrastructure to facilitate new functionality. Figure 3 shows examples of the types of independent systems, each used to manage some aspect of the transportation networks in a corridor that an ICMS might integrate. The infrastructure used to manage these transportation networks includes useful communication systems, archived and near real-time data systems, AMS systems, roadside control systems, and other corridor assets. Through integration of these systems, an ICMS can expedite communication and enhance the decision-making capability of operators through shared operations, management, and data as well as by performing analyses that may not be available without the ICMS. This helps corridor transportation network operators better understand the conditions of the systems that they manage both individually and collectively.

> *"The level of achieved success will be subject to the fact that ICM will change how we operate and manage transportation systems. Stakeholders should be prepared and positioned themselves to change how stakeholders will operate and manage their individual systems under an ICM environment."*
>
> Alex Estrella, ICM Manager, San Diego Association of Governments

In the example shown in Figure 3, the central integration element is the collaborative management of a set of networks and systems, accomplished by human interaction and possibly a set of both automated and non-automated tools. One major automated tool not shown in this figure is the Decision Support System (DSS).

Figure 3. San Diego ICM Example: Developing Systems for High Performance Corridors



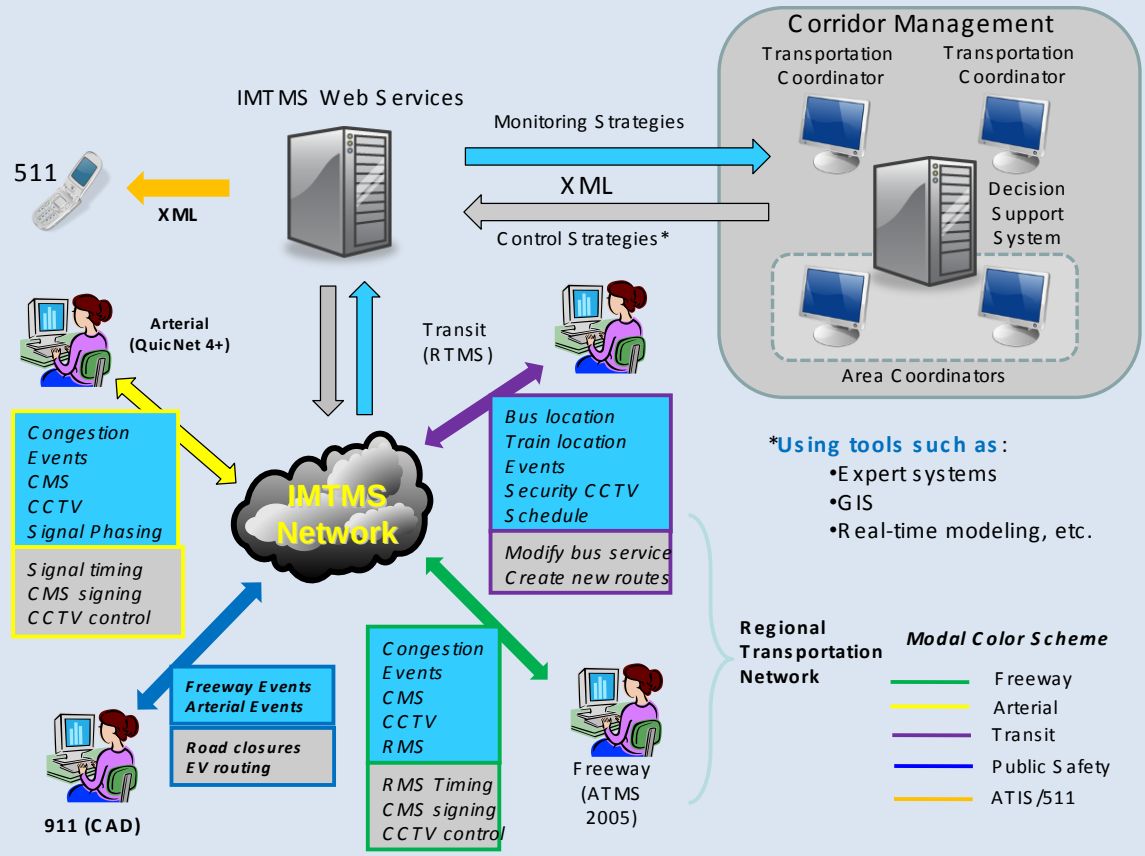
[Source: San Diego ICM Pioneer Site Kick Off Meeting presentation, October 24, 2006, unpublished.]

Another way to view an ICMS is as a group of independent systems joined (integrated) by a DSS. The ICMS would use the DSS component to analyze corridor data and provide recommended congestion mitigation strategies to corridor managers and operators. Figure 4 is a conceptual depiction of a DSS component for an ICMS. The U.S. DOT has captured information on DSS efforts across the United States in a report entitled "*Assessment of Emerging Opportunities for Real-Time Multimodal Decision Support Systems in Transportation Operations: Concept Definition and Current Practice Report.*"[10] Additional details on the information processed in a DSS and the potential improvements a DSS can make in an ICMS are included in APPENDIX B. Defining the ICMS Decision Support System

The data from the independent network systems can be collected, integrated, and analyzed to provide operators with the benefit of an automated DSS. The DSS might also employ AMS to offer improvements (predictive capabilities) to corridor operators, and this can help them make better-informed corridor decisions. An example of this may include the ability of corridor operators to promote mode shift during severe congestion involving long delays. Through the ICMS, operators could access DSS information that will tell them about the availability of capacity on other modes and the likelihood that travelers would be willing to switch modes. If the likelihood is high and capacity is available, announcements could be made to travelers that a mode switch may provide a better option for travel. Additionally, the DSS could allow real-time

monitoring and prediction of the impact of these decisions so operators can change their approach to be more responsive to real-time changes in the network.

Figure 4. San Diego ICM Example: Future Decision Support System (conceptual)[11]



[Source: *Concept of Operations for the I-15 Corridor in San Diego, California*, SANDAG, et al. for U.S. DOT, FHWA-JPO-08-009. 31 March 2008, p. 5-3.]

Analysis, Modeling, and Simulation for ICM

The uses of AMS for ICM, along with the recommended ICM AMS approach, can be found in the ICM AMS Guide.[12] Lessons learned from the three ICM Pioneer Sites selected for the AMS stage revealed that the AMS process was extremely beneficial as it was credited with improving the accuracy of the analyses and provided a more robust knowledge base for evaluating future strategies and investments.

The ICM AMS Guide offers a recommended ICM AMS approach, in a step-by-step format, to help the reader conduct ICM AMS successfully and effectively. Guidance is provided to assist corridor managers and analysis/modeling managers in successfully conducting AMS for their own ICM applications. AMS is not intended to be performed as a one-time, self-contained planning process. Instead, AMS is intended to be an ongoing, continual improvement process designed to assist practitioners in envisioning, designing, and refining ICM strategies.

One step detailed in the ICM AMS Guide is how to evaluate existing traffic conditions to better understand the factors that influence congestion and the frequency with which these factors occur. Evaluating influencing factors provides the opportunity to identify the best combinations of multiple scenarios that are most representative of actual conditions. This information can be used to define analysis scenarios that make the best use of analysis resources. This allows analysis resources to be targeted towards appropriate scenarios that do not under- or over-estimate the impacts of the ICM strategies.

The information on the impact of the ICM strategies can then be used, in turn, to help determine which combinations of ICM strategies are likely to be most effective under which conditions. The ICM AMS Guide also explains how AMS can be used to discern optimum combinations of strategies both to make the ICM implementation more successful as well as to identify conflicts or unintended consequences inherent in certain combinations of strategies that would otherwise be unknowable before implementation.

Appendix A of the ICM AMS Guide documents the algorithmic process developed under the ICM program that is used to calculate key national measures of corridor performance. The algorithms offer a practical and broadly applicable method of calculation while breaking new ground in the definition of mode-independent, trip-based measures of aggregate corridor performance with explicit consideration of probability-weighted operational conditions. Appendix A provides a detailed description of how measures of delay, travel-time reliability, and throughput are calculated from simulation outputs. A brief discussion of travel time variance is also provided given that travel time variance measures are used in ICM-related benefit-cost calculations.

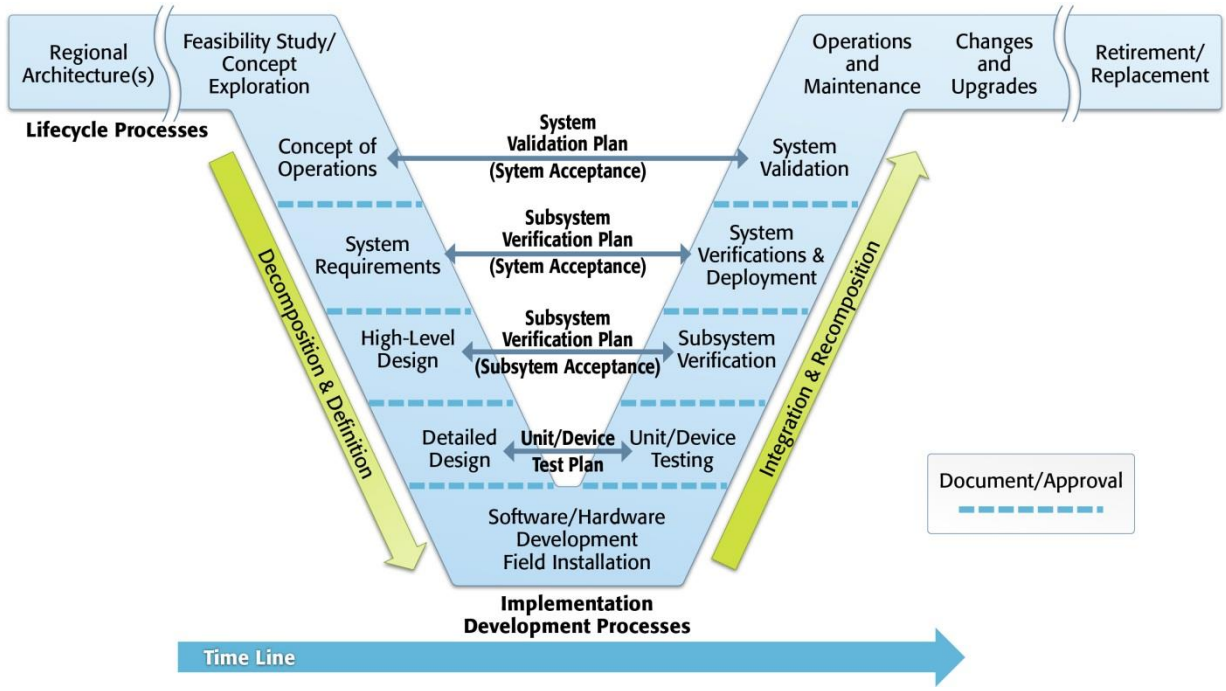
Managing the Complexity of an ICMS Implementation

Managing the complexity of an ICMS implementation will not be easy. In most cases, the project will involve bringing together multiple agencies that perform operations using diverse methods and include the integration of their heterogeneous systems. Increased communication, organization and documentation will be required to ensure that all project partners understand and agree upon project expectations and are kept informed of the status of the project. Systems engineering is the discipline developed to manage the complexity of large-scale systems. In particular, systems engineering is often used in the management of software intensive projects. It is highly recommended that a systems engineering approach be used to manage ICMS implementations. Having a defined process tailored to the ICMS project will be critical for successful implementation.

> *"The Systems Engineering process allowed us to maintain a structured implementation approach. This might seem a bit trivial and obvious, but the implementation of the ICMS is not like any other project as it touches on different modes, systems, technologies, and institutional elements. Following the SE process has provided the roadmap to not only assure that we deliver a successful project, but also the SE process has helped us decipher 'what-how-why' items will be achieved and presenting it in a way that is multi-agency/modal focused and integrated."*
>
> Alex Estrella, ICM Manager,
> San Diego Association of Governments

The Systems Engineering Guidebook for Intelligent Transportation Systems, Version 3.0 describes a systems engineering process for ITS projects. Figure 5 below shows an example of the systems engineering process using the VEE development model. Chapter 3 of this guide provides more details on the systems engineering process.

Figure 5. Systems Engineering VEE Diagram



[Source: *Systems Engineering Guidebook for Intelligent Transportation Systems, Version 3.0,* U.S. DOT. November 2009.]

Working with multiple agencies often means dealing with a mixture of project management processes. Some of the benefits of using systems engineering processes to manage the implementation of ICMS include improved control of the project and common terminology, expectations, and understanding of the work being performed. The Systems Engineering Management Plan (SEMP) is developed early in the project process and will be agreed upon by all project stakeholders, providing them with a harmonized systems engineering process for a successful project implementation. The SEMP provides a common understanding of how the work will be managed and provides traceability from one phase of the project to the next. The SEMP also helps to inform stakeholders about key project milestones and what role they will play in the success of those milestones. Additionally, the SEMP identifies decision gates for the project. These decision gates require agreement from all project stakeholders for the project to move forward. With project controls in place, project stakeholders should feel more confident that they know what work needs to be done and how it will be carried out. More details on the SEMP are provided in chapter 3, section 3.2 of this Guide.

> *"When working with so many corridor stakeholders it is critical to have a defined process to guide the work, foster communication, and manage expectations. Stakeholders found that the systems engineering process gave them the tools needed to manage project efforts and achieve ICM goals."*
>
> Koorosh Olyai
> Assistant Vice President
> Mobility Programs Development
> Dallas Area Rapid Transit

Chapter 3. ICM Implementation Guidance and Lessons Learned

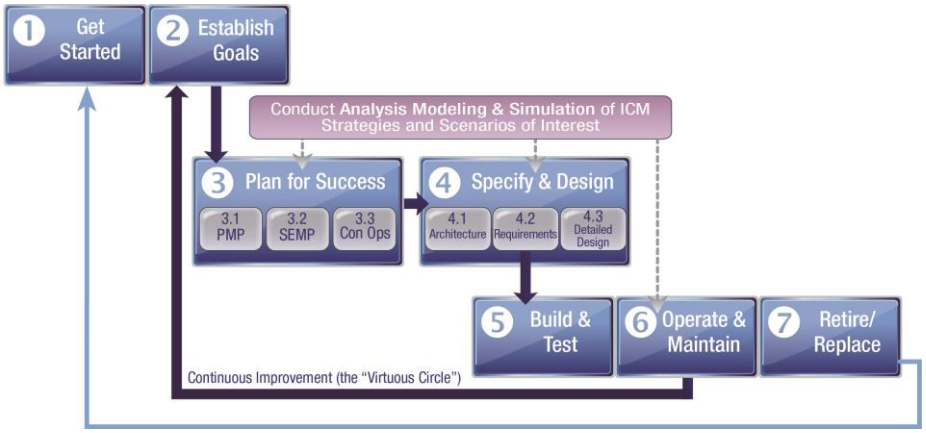
This chapter provides a detailed description of the ICM implementation process including organization of the effort and key activities. The implementation process is numbered as sections 1 through 7, which correspond to the following seven phases:

1. Get Started
2. Establish Goals
3. Plan for Success
4. Specify and Design
5. Build and Test
6. Operate and Maintain
7. Retire/Replace

This ICM implementation process is generally representative of the systems engineering process followed by the ICM Pioneer Sites. The systems engineering process thus provides the framework for the guide.

provides a mapping of ICM implementation phases to the systems engineering phases and tasks used in the Systems Engineering Guidebook for ITS.[13] Table 2 also provides a summary of the activities, products (outputs), staff roles, and resources and templates associated with each of the phases.

At the beginning of each section, the graphic below is used to identify the phase being described. There is a numbered block to represent each phase. Note that phases three and four are divided into three parts—each part corresponding to each major work item. Also, note that the blocks in the graphic below match the phases shown in the columns in Table 2.



[Source: Research and Innovative Technologies Administration, ITS JPO.]

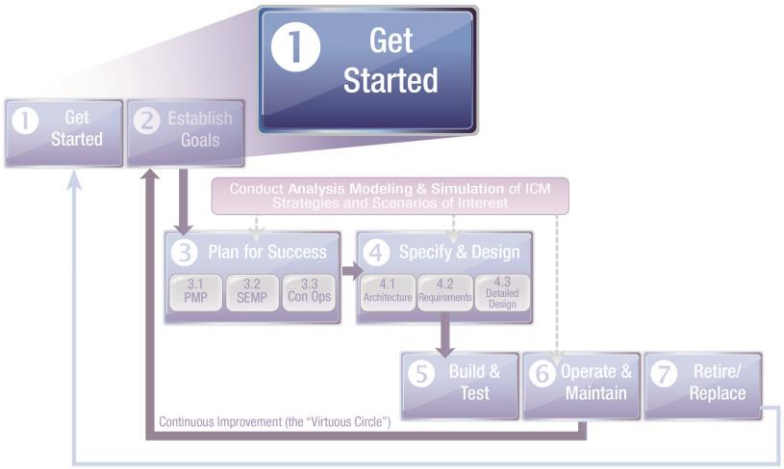
As explained in chapter 1 under *How to Use This Guide*, the sections in chapter 3 were designed to be read independently as each phase of the project progresses. Each section starts with a brief summary of the project phase and then each phase description contains the following information areas: manage for quality, resources, highlights, questions to answer, lessons learned, and example. Each section provides opportunities for improving the implementation process and lessons learned from previous implementations.

Table 2. ICM Implementation Process

ICM Phase	Get Started 1	Establish Goals 2	Plan for Success 3			Specify and Design 4			Build & Test 5	Operate & Maintain 6	Retire or Replace 7
			(3.1) PMP	*(3.2) SEMP*	*(3.3) ConOps*	*(4.1) Architecture*	*(4.2) Requirements*	*(4.3) Design*			
Activities	• Foster Champions and Organize Stakeholders • Coordinate with Planning Process • Interface with the Regional ITS Architecture • Develop and Approve Project Charter	• Explore the ICM Concept • Develop Goals, Measureable Objectives, and Data Collection Needs • Analyze System Problems and Identify System (User) Needs • Conduct Feasibility Assessment • Identify Development Support Resources	• Asses Project Management Activities • Determine Roles and Responsibilities • Initiate Procurement Discussions • Prepare Project Management Plan and supporting plans (as needed)	• Asses Project Management Activities and Technical Tasks • Transition Critical Technologies • Define Needed Systems Engineering Processes and Resources • Make Procurement Decisions and Specify Integration Activities • Prepare SEMP	• Define/Refine Project Vision, Goals and Objectives • Explore Project Concepts • Develop Operational Scenarios • Develop and Document Project Concept of Operations • Define System Boundaries	• Develop, Decompose, and Evaluate Project Architecture Alternatives • Identify and Evaluate Internal and External Interfaces • Evaluate Industry Standards and Identify Standards Gaps • Select and Document The High-Level Design • Perform Preliminary Design Review (PDR) • Conduct a Traceability Review	• Develop Requirements • Write and Document Requirements • Review for Completeness • Analyze, Refine, and Decompose Requirements • Manage Requirements • Technical Reviews • Perform Preliminary Design Review (PDR)	• Perform Detailed Design • Evaluate Commercial Off-The-Shelf Products (COTS) and Applications • Perform Technical Reviews • Perform Critical Design Review • Tradeoff Studies • Traceability	• Perform Component Development • Purchase COTS Products and Applications • Integrate System Components, Products and Applications • Conduct a Traceability Review • Develop Operations, Maintenance, and Training Manuals and Plans • Conduct Training	• Plan Operations and Maintenance • Collect Operations and Maintenance Information • Perform Operations and Maintenance • Monitor and Assess System Performance • Identify Changes to O&M Procedures • Update O&M Procedures • Validate System	• Assess System Retirement/ Replacement • Analyze System Performance • Assess Alternative ICM and/ or ICMS Options • Assess System Disposal Costs • Assess System Replacement Costs
Products	• Approved Project Charter • Capabilities and Availability of the Agencies • Inventory of Corridor Resources • Inventory of Available Corridor Data	• Corridor Boundaries • Project Needs Assessment • Project Goals and Objectives • Preliminary Project Constraints • Feasibility Assessment • Corridor Data Collection Needs • Regional ITS Architecture Assessment • Initial Stakeholder Agreements	• Project Management Plan • Assigned Roles and Responsibilities	• Systems Engineering Management Plan • Supporting Technical Plans • Request for Proposal	• Concept Selection • Concept of Operations	• High-Level Design (Project Architecture) • Internal and External Interface specifications • Selected Industry Standards	• Requirements Specifications: System and Subsystems • Requirements Traceability and Verification Matrix	• Detailed Design Document • Component Detailed Design • Selected COTS Products and Applications • Unit Verification Plan	• Verified System • Project Approval • Operations Manual • Maintenance Manual • Training Manuals and Plans • Trained Staff	• O&M Plan and Procedures • Updated O&M Procedures • System Performance Reports • System Validation Document	• System Retirement/ Replacement Report • System Retirement/ Replacement Decision
Staff Roles	• Organization Rep's • Project Managers • Contracting Officers • Procurement Specialists • System Operators • Technical Staff • Facilitators	• Organization Rep's • Project Managers • System Operators • Technical Staff • Project Planners • Policy Analysts • Public Spokespersons	• Organization Representatives • Procurement Specialists • Project Managers • System Operators • Technical Staff • Project Planners • Systems Engineers			• Organization Representatives • Project Managers • Procurement Specialists • Technical Staff • Requirements Engineers • System Designers • System Component Developers • Specialty Engineers			• Project Managers • Procurement Specialists • Requirements Engineer • System Designers • Sys. Component Dev's • Test Designers • Independent Analysts	• Organization Rep's • Procurement Specialists • System Operators • Technical Staff • O&M Managers • Program Managers • Public Spokespersons	• Organization Rep's • Procurement Specialists • System Operators • Technical Staff • O&M Managers • Program Managers
References & Templates	• ICM Knowledgebase • SEGB phase 1, section 3.2 • ITS Architecture • Turbo Architecture • U.S. DOT Planning for Operations • Advancing Metropolitan Planning for Operations Desk Reference • Guide to IEEE 1512	• ICM Knowledgebase • ICM AMS Plans • SEGB phase 0, section 3.3 and Needs Assessment • FHWA SE for ITS Intro. • ITS Architecture • Turbo Architecture • Advancing Metropolitan Planning for Operations Desk Reference • INCOSE Handbook • IEEE 15288 • App. A. Conceptualizing ICM	• ICM Knowledgebase • SEGB phase 1, section 3.4.1 and Project Plan • Advancing Metropolitan Planning for Operations Desk Reference • PMI PMBOK (IEEE 1490)	• ICM Knowledgebase • SEGB phase 1, section 3.4.2, SEMP and CM Plan • ITS Architecture • Turbo Architecture • IEEE 828 and 1220	• ICM Knowledgebase • Dallas ICM Pioneer Site • San Diego ICM Pioneer Site • SEGB phase 1, section 3.4.3 and ConOps • ITS Architecture • Turbo Architecture • Advancing Metropolitan Planning for Operations Desk Reference • IEEE 1362	• ICM Knowledgebase • Dallas ICM Pioneer Site • San Diego ICM Pioneer Site • SEGB phase 2, section 3.5, Requirements Specs and Design Specs • ITS Architecture • Turbo Architecture • IEEE 830, 1016, 1233 and 1471 • Appendix C. ICM Walkthroughs			• ICM Knowledgebase • SEGB phase 3, section 3.6, Integration Plan, Verification Documents, Deployment Plan and Validation Documents • ITS Architecture • Turbo Architecture • Example Verification Cross Reference Matrix • Sample Test Procedure • Sample Change Req. Form • IEEE 829, 1012, 1028, 1044	• ICM Knowledgebase • SEGB phase 4, section 3.7 and O&M Plan • ITS Architecture • Turbo Architecture • Guide for Implementing IEEE 1512 Using a Systems Engineering Process	• ICM Knowledgebase • SEGB phase 5, section 3.8.1 • ITS Architecture • Turbo Architecture • INCOSE Handbook • IEEE 15288
SEGB Phases & Tasks			Project Planning	Systems Engineering Management Planning	Concepts of Operations	Requirements Development and High Level Design		Component Level Detailed Design			
	Interfacing with Planning and Regional ITS Architecture	Needs Assessment, Concept Exploration and Benefits Analysis	Project Planning and Concept of Operations			System Definition and Design			System Development and Impementation	Operations and Maintenance/Changes and Upgrades	Retirement/ Replacement

Mapping of ICM Phases to Systems Engineering Guidebook (SEGB) for ITS Phases and Tasks

[Source: Research and Innovative Technologies Administration, ITS JPO.]



[Source: Research and Innovative Technologies Administration, ITS JPO.]

Get Started (Phase1)

This phase includes the activities conducted to identify and coordinate the participants and information necessary to plan an ICM project. These activities are described following the guide convention described previously: manage for quality, resources, highlights, questions to answer, lessons learned, and example.

Manage for Quality – Getting Started

One of the first things that needs to be accomplished when getting started with ICM is to choose a stakeholder that will manage and lead the work to be performed. The following checklist includes some of the more important activities for which the Project Lead will be responsible:

- Schedule meetings to discuss activities, status, action items, and risks;
- Ensure that guidance is made available to those stakeholders that are not familiar with ICM; and
- Ensure that all stakeholders understand and are comfortable with the project process.

Getting Started Resources

There are many resources available to assist with getting started with ICM. For information on ICM, stakeholders should visit the U.S. DOT ICM Web site: http://www.its.dot.gov/icms/. At the ICM Web site, stakeholders will find a great deal of information on the concept of ICM and its implementation. There is also an "ICM Knowledgebase" were people can search and find publications on ICM including presentations, newsletters, and fact sheets as well as AMS results and systems engineering documents from the ICM Pioneer Sites. Section 3.2.1 of The Systems Engineering Guidebook for ITS contains a good description on "Interfacing with Planning and the Regional ITS Architecture."[14] Section 3.9.1 also provides good details on stakeholder involvement.

Getting Started Highlights

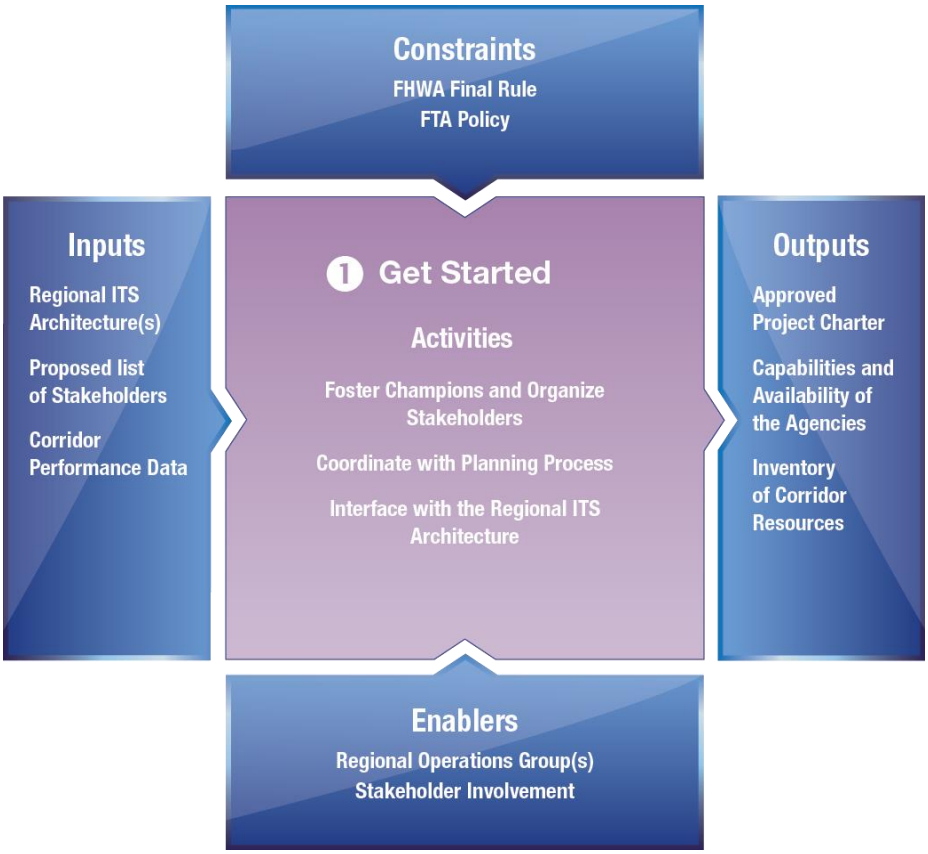
The following activities, also shown in Figure 6 below shows the planning process for getting started with ICM. The inputs and constraints should be completed and available prior to beginning the activities.

Under the direction of the stakeholders, either in-house staff or a contractor will execute the activities and deliver the outputs shown.

Figure 6 below shows the planning process for getting started with ICM. The inputs and constraints should be completed and available prior to beginning the activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the activities successfully and are described in the following sections:

- Foster Champions and Organize Stakeholders
- Coordinate with Planning Process
- Interface with the Regional ITS Architecture
- Develop and Approve Project Charter

Figure 6. Getting Started With ICM



[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.2.1, November 2009]

Foster Champions and Organize Stakeholders

Building a team of stakeholders to assist with the planning and design of an ICMS is a critical first step in moving forward. Metropolitan areas that are considering ICM will likely have formal or informal operations planning groups from which to build an ICM Team. As a corridor is being considered for ICM, it is important that **all agencies** affecting the operation and maintenance of **all networks** are invited and participate in the planning of the ICM. The roles and level of involvement may differ, but to be most effective, the ICM Team should consider all transportation resources (those affecting supply and demand). Additionally, it is important to invite stakeholders that may simply benefit from the system, to participate. If stakeholders receive enough benefit, they may be willing to share in long term funding strategies for the system.

Cast a wide net early in the process, so as not to exclude possible stakeholders early on. The question of who should be involved should be left to the participants themselves, although it is important to keep all stakeholders informed throughout the process, even when they are not directly involved. Let the stakeholders determine their own involvement as the process moves forward. The initial invitees will likely come from various operations groups and technical committees and should cover the following groups:

- Inter-jurisdictional– DOT, Metropolitan Planning Organization (MPO), local
- Multimodal– rail, bus, freeway, arterial, freight
- Public Safety Services – police, fire and rescue, safety service patrol
- Support Services – parking, traveler information systems/511 providers, commuter/rideshare organizations, media, tolling

As the ICM stakeholder group is being formed, several items regarding how to coordinate efforts should be considered:

- Determine the Lead Agency and Points of Contact (POCs)
    - Which agency will take the lead on organizing and hosting meetings?
    - Which agency will provide administrative support, such as note taking and documenting action items?
    - Who are the points of contact for the stakeholder group?
    - Which agency will provide resources or initial funding for preliminary activities?
- Determine the mission, activities, and operating procedures
    - What are the initial activities to be conducted?
    - What are the interpersonal communication protocols? How do we make sure all participants are on the same page?
    - What are the decision protocols? How are decisions made among the participants?
- Determine the relationship with existing processes and groups
    - How will this ICM stakeholder group relate to the existing planning process?
    - How will it relate to other local/regional operations technical committees?

As the stakeholder group is organized, the champion or champions need to be identified (generally champions will “self-identify”) to lead the ICM team. In some cases, champions will need to be fostered or encouraged because of their strategic importance to the success of ICM in the region. This strategic importance could be related to their role, position, or influence in the corridor. In addition, it may be

beneficial to ensure that all of the key operating agencies in the corridor have a champion, since this will provide momentum for that agency's involvement in the project. Ideally, the champion(s) should:

- Understand ICM and the concept of corridor operations;
- Be able to lead a diverse team;
- Possess good communications skills;
- Be willing to commit the necessary time to the project; and
- Be able to marshal the necessary funding and personnel resources.

The Systems Engineering Guidebook for ITS makes the following points on the role of the champion:

> Good leadership includes imparting the vision of the project:
>
> - Why it is needed?
> - How it will help solve current problems?
> - How it will benefit each of the stakeholder groups?[15]

Coordinate with Planning Process

ICM planning should be effected within the framework of the transportation planning process and guided by regional priorities. Planning for ICM is an objectives-driven, performance-based approach that can be thought of as "planning for operations" at the corridor level. Planning for operations is a joint effort between planners and operators to support improved regional transportation system management and operations. It requires coordination and collaboration between a number of regional partners, including planning staff and operations staff from metropolitan planning organizations (MPOs), State departments of transportation, transit agencies, highway agencies, toll authorities, and local governments. It involves the consideration of management and operations (M&O) strategies in transportation planning – including the integration of M&O strategies in the metropolitan and statewide transportation plans. The FHWA Office of Operations maintains a Web site[16] that lists (and provides links to) a number of documents that relate to coordinating planning and operations at the State, regional, and local levels. The ICM planning group should consider these documents in its planning process.

ICM strategies can be simply thought of as M&O strategies with certain characteristics as discussed in chapter 2: they support the integrated operation of transportation networks within the corridor.

The following list gives the primary elements of the objectives-driven, performance-based approach to planning for operations.[17]

- Regional Goals. Establish goals that focus on efficiently managing and operating the transportation system.
- Operations Objectives. Develop operations objectives—specific, measurable statements of performance—to include in the Metropolitan Transportation Plan or Long-Range Statewide Transportation Plan (MTP/LRSTP) that will lead to accomplishing the goal or goals. The

Advancing Metropolitan Planning for Operations Desk Reference provides recommendations on how to phrase these operations objectives.[18]

- Performance Measures. Using a systematic approach, develop performance measures, analyze transportation performance issues, and recommend management and operations (M&O) strategies.
- M&O Strategies. Select M&O strategies within fiscal constraints to meet operations objectives for inclusion in the MTP/LRSTP and STIP/TIP.
- Investment and Implementation. Implement strategies, including program investments, collaborative activities, and projects.
- Monitoring and Evaluation. Monitor and evaluate the effectiveness of implemented strategies and track progress toward meeting operations objectives.

Before federal funds can be approved and used for implementation, the ICM project(s) must be programmed on the metropolitan transportation improvement program (TIP) or the statewide transportation improvement program (STIP). In the early planning phase for ICM, it is likely that planning funds will be used to support initial activities.

ICM Planning Questions to Consider in Get Started Phase:

1. What data is available in the region to monitor transportation system performance and track progress toward operations objectives?
2. What are the gaps, problems, and issues in providing transportation system management and operations across our region?
3. What are the transportation corridors that are best suited to be candidates for ICM deployment?
4. What ICM strategies may be available to help achieve our operations objectives?
5. How can we most effectively integrate ICM strategies with other existing or planned technology deployments to provide a greater level of service for the customer?
6. How can we define this ICM project or program in terms of functional requirements and operations concepts?

Key points to consider in planning for ICM:

- Conduct ICM planning within the context of the approved transportation planning process;
- Take advantage of the data available from the planning process;
- Specify goals and measurable objectives that advance operational performance outcomes for the regional transportation system;
- Consider the benefits of incremental deployment of ICM in a series of related projects to accomplish the ultimate vision of ICM within the corridor;
- Consider how ICM will relate to other corridors, services, and systems within the region;
- Identify performance measures that allow the region to track progress toward achieving its objectives; and
- Ensure that ICM (and any ICMS built to support it) are captured within the context of the regional ITS architecture (see section 1.3.3 below).

Interface with the Regional ITS Architecture

A regional ITS architecture is defined as "A specific, tailored framework for ensuring institutional agreement and technical integration for the implementation of ITS projects or groups of projects in a particular region. It functionally defines what pieces of the system are linked to others and what information is exchanged between them."[19]

The regional ITS architecture serves as an important guide for the development of ICM. The regional ITS architecture shows all of the existing and planned operational transportation systems in a region and how they will fit together. From a planning perspective, the regional ITS architecture supports the region's objectives and the specific needs of transportation planning agencies. It shows how data is collected, archived, and processed to support transportation planning and performance monitoring.

Components of the regional ITS architecture include:

Scope: Definition begins with a clear statement of the geographic and jurisdictional boundaries, the time horizon, and the scope of transportation services that are covered by the architecture. The Rule/Policy leaves a lot of latitude to the region in defining the scope, but suggests that the regional ITS architecture cover the entire metropolitan area at a minimum. The ICM project or program will likely be considering a subset of the region, but in some cases the physical corridor boundaries may necessitate the need to consider multiple regional ITS architectures.

Stakeholders: A list of the traffic agencies, transit operators, public safety agencies, traveler information providers and other organizations and groups that plan, develop, operate, maintain, and use the regional transportation system is included in every regional ITS architecture. This broad stakeholder list should include all of the agencies that are involved in transportation planning, operations, and management as well as groups that use the transportation system (e.g., fleet operators) or impact its operation (e.g., special event venue owner/operators). This list of stakeholders provides a good check to ensure that you have invited all relevant stakeholders to ICM planning meetings.

Roles and Responsibilities: The regional ITS architecture also defines the high-level roles and responsibilities of each of the stakeholders that operate and manage the transportation system as part of an "operational concept" for the region. The roles and responsibilities are short statements like "share CCTV video feeds with other agencies in the region."

Inventory: This is a list of the existing and planned components or "elements" of the regional transportation system. The inventory elements are frequently systems in their own right and include the operational centers (e.g., a State DOT Freeway Management Center), field equipment (e.g., the dynamic message signs, CCTV cameras, and signal systems), vehicles (e.g., transit vehicles and public safety vehicles), and traveler equipment (the devices the traveler uses). Importantly for ICM planning, the inventory should also include any monitoring and data collection systems that are used by transportation planners.

Interfaces: A definition of the interfaces between the inventory elements is a focal point of the regional ITS architecture. Each interface is represented as both an "Interconnect" (indicating whether there is a connection between the two elements) and as a set of information flows or "architecture flows" that describe the information that is shared. The architecture flows are also associated with relevant ITS standards.

Services: The ITS Services that are included in the regional ITS architecture represent a consensus of the architecture stakeholders. These ITS Services are implemented through projects.

Project Sequencing: The regional ITS architecture is implemented through many transportation programs and projects that occur over years or even decades. The regional ITS architecture includes a sequence that allocates projects to broad timeframes like near- (0-3 years), mid- (3-7 years), and long-term (8+ years). The project sequencing often provides finer granularity than the ITS services, particularly for near-term projects. Having the knowledge of what ITS projects are coming on line and being designed is very important to effective ICM planning. This information can be leveraged to consider opportunities to add ICM-specific objectives and requirements onto ITS projects that are being implemented. By piggybacking ICM functionality on approved projects, transportation agencies can reduce the cost of implementing ICM.

Agreements: The regional ITS architecture also includes a list of agreements because institutional coordination is required to support the technical integration that is shown in the architecture. The list of agreements should identify the existing and planned agreements in the region that are needed to support an integrated transportation system. Note that the agreements should extend beyond implementation into operational agreements that define agency roles and responsibilities for system operation.

All of the architecture components are defined in more detail in the regional ITS architecture Guidance Document.[20]

The regional ITS architecture provides a very good starting point for ICM planning activities. It is important to remember that planning and implementing the ICM project(s) may necessitate changes to the regional ITS architecture to take into account the planned ICMS. This is to be expected and is simply a normal part of the regional ITS architecture maintenance process.

Develop and Approve Project Charter

The development of a project charter is a recommended practice of the Project Management Institute. The purpose of the project charter is to formally authorize a project or a phase and to document the business case and the initial requirements that satisfy stakeholders' needs and expectations. The approved project charter identifies the project manager and deputy project manager and formally initiates the project, in this case the ICM project. The charter provides the project manager with the authority to apply resources to project activities.

This concept can easily be adapted to the ICM process. The development of the ICM project charter should be one of the first activities that the ICM stakeholder group embarks upon. The ICM project charter should be a brief document containing mission and vision statements that reflect the consensus view of the involved stakeholders and should briefly describe the need for ICM in the corridor. The development of the charter begins the process of getting the stakeholders to work together to reach agreement as a group and achieving buy-in from individual agencies on continued participation in the stakeholder group activities. The ICM charter could be considered a variation of a memorandum of understanding (MOU) or memorandum of agreement (MOA) and should be signed or approved by all stakeholder agencies. If necessary, the ICM charter should be revised over time as warranted by changes to the ICM management structure or stakeholders.

The funding that is authorized at this stage may be limited to what is needed to carry out the initial planning work, but reflects stakeholder commitment to the ICM project.

The ICM Project Charter should include:

- The project purpose and a brief ICM vision statement;
- Transportation needs to be addressed by ICM in the corridor;
- ICM corridor boundaries and high-level project scope;
- Project success criteria and milestone approval requirements;
- Roles and membership of the ICM corridor stakeholder group;
- Assigned project manager and deputy project manager and a clear description of their responsibilities and authority level;
- Approved funding and resource commitment; and
- Summary schedule.

Questions to Answer – Getting Started

In getting started with ICM, stakeholders need to make certain consensus decisions to initiate the project. It is important for the stakeholder group to answer the main questions about the proposed project before proceeding to subsequent phases of the project. The following is a list of ICM questions to start with:

- Has a list of stakeholders been agreed upon and have potential champions been identified?
- Have steps been taken to coordinate with the transportation planning process?
- Has the ICM Team addressed the interface with the regional ITS architecture?
- Was a Project Charter approved by the stakeholders?
- Have initial and lifecycle funding issues been discussed?

Lessons Learned – Getting Started

The following lessons apply to this phase of the ICM program:

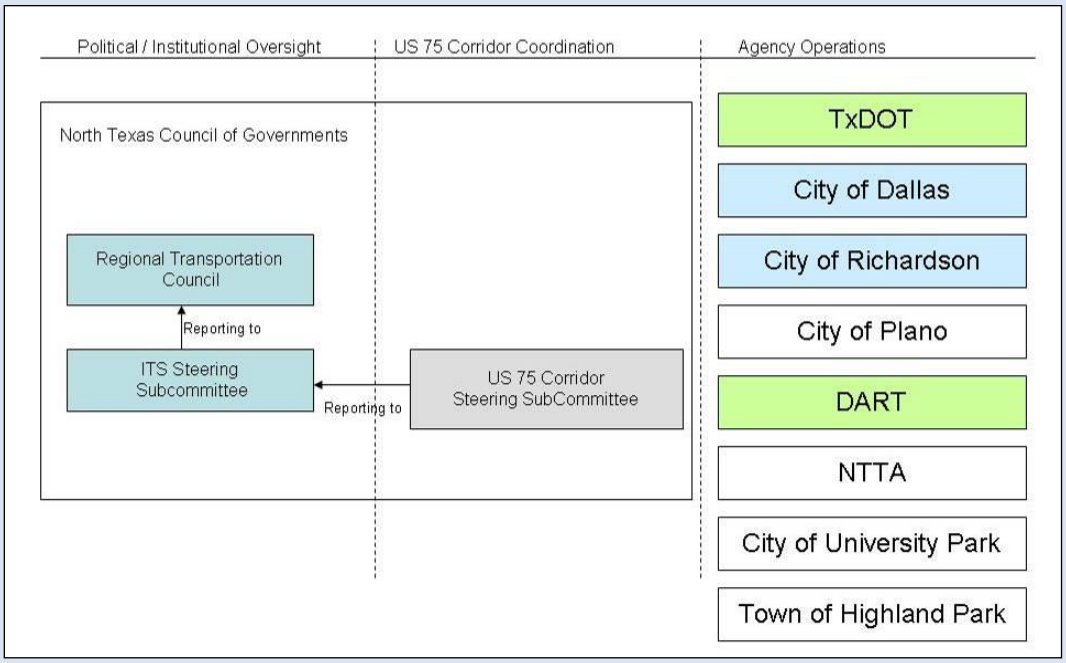
- Stakeholder selection – When initiating an effort to consider ICM for a regional corridor, look to include all potential stakeholders early in the process. Some agencies and organizations may choose not to participate, but all should be invited.
- Stakeholder involvement – Let potential stakeholders decide what their involvement will be as the process moves forward, but encourage as broad a participation as possible. Even if agencies or organizations choose not to participate at the start, keep them informed about the decisions being made. Initially reluctant partners can prove to be strong participants later on.
- Initiate stakeholder agreements – Initiate discussion of partner agreements early and try to identify the benefits to potential partners that help them justify committing to the project. There is a need to understand the business models of every partner and how to get them (e.g., tolling, and parking) involved. You need to find the incentive to get them to commit on day one. Why would a toll road want congestion eased if that is how they make money? Well, there is also the parking aspect and a lot of them make money on the parking too. Also, tolling agencies may see benefits due to reduced incident congestion on the toll roads and improved throughput allowing them to collect more revenue. You have to find out if they are willing to sign on to the project and do it early.

- Leadership commitment – Involve executive leaders in facilitating the multi-agency partnerships vital to the long-term success of ICM. Their support is essential and it is particularly valuable if one (or more) of those executive leaders becomes a champion for ICM. Leadership turnover plans should also be considered to get new leadership on board and in support of the project.
- Planner and modeler input – Involve transportation planners and modelers, along with the transportation operations personnel, early in the process. Transportation planners and modelers can provide input into the performance measures selected and can help the team understand how best to track system performance against the established goals. Ongoing funding will likely be tied to performance so this is an important consideration for the project.
- Systems engineering training – The ICMS will be a complex system, make sure that stakeholders receive early training on systems engineering to prepare them for defining the system and managing its complexity. Use a qualified SE trainer and have a SE 101 course to kick-off the process. Having a good basic understanding of SE is the most important thing before anything else starts.
- Project skills – These projects require a lot of different skill sets (e.g., traffic engineers, signal system experts, freeway management experts, software specialists, data specialists, good operators, good managers, and a strong champion or leader.)
- Network operational environments – Holding meetings in the offices of other stakeholders is helpful to understand the working environment of all stakeholders.
- Agency restrictions and limitations – Stakeholders need to be sensitive and try to understand the restrictions and limitations of other agency partners.
- Contracting for success – Consider roles, responsibilities and accountability when selecting prime and subcontractors. It may be easier for agencies to work with one prime contractor that holds subcontracts rather than having multiple contractors reporting to them. This may minimize the some “not in my scope” responses to project requests. Of course, each circumstance is unique, so this is just one consideration for setting up contracts. Pioneer Site Example –Getting Started

Pioneer Site Example – Getting Started

The Dallas ICM Pioneer Site built its coalition of stakeholders out of the pre-existing institutional arrangements within the North Texas Council of Governments. The agencies have a history of cooperation, including efforts on the North Texas Regional ITS Architecture, which facilitated development of the ICM coalition, and the US 75 Corridor Steering Subcommittee meets on a regular basis to discuss ICMS planning and deployment activities. Figure 7 below shows the institutional framework established by the eight stakeholder agencies for the US 75 ICM.

Figure 7. US-75 ICM Institutional Framework[21]

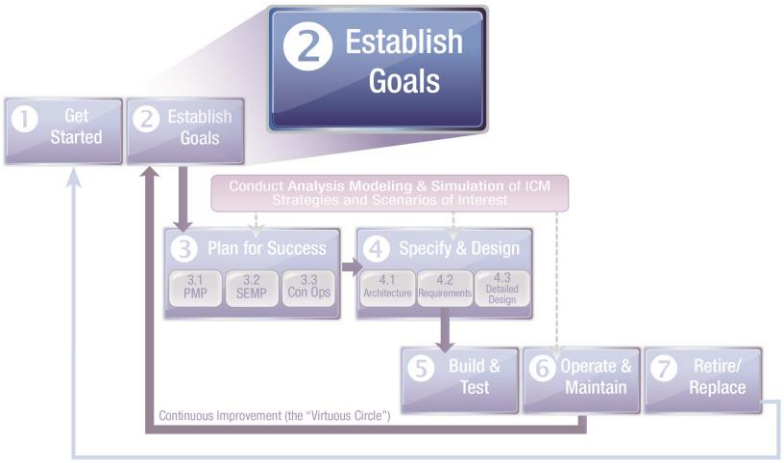


Source: *Concept of Operations for the US-75 Integrated Corridor in Dallas, Texas*, DART, et al. U.S. DOT, FHWA-JPO-08-004, 30 April 2008.]

The San Diego ICM Pioneer Site project development team was organized out of the existing members of the I-15 Managed Lanes project. The following paragraph provided by San Diego Association of Governments (SANDAG) explains the San Diego ICM Project Team within the context of the I-15 Managed Lanes project.

> Decision-making authority for matters of policy that affect the I-15 Managed Lanes Corridor lies with SANDAG's Board of Directors and is handled by delegation to the SANDAG Transportation Committee. The Transportation Committee is the body through which issues are vetted with public involvement and regional transportation issues are resolved. Detailed issues relative to the I-15 Corridor and the ICM project would be delegated by the Transportation Committee to SANDAG staff, with guidance provided by a Technical Working Group established by the SANDAG Board of Directors. The SANDAG Project Manager (Team Leader) would administer the ICM project with oversight from the ITS Chief Executive Officer's Working Group. The involvement of other stakeholders such as local agencies (cities) and transit operators would be established through the Technical Working Group. The Project Development Team would be established through a Project Charter and would meet on a regular basis to provide the team with guidance and direction, as well as receive and review and

comment on project deliverables. The Technical Working Group (TWG) serves as the primary forum to address project issues, and will be composed of SANDAG staff, consultants and key stakeholder representatives from the ICM team. When issues cannot be addressed within the context of the Technical Working Group, the Project Manager would elevate issues to the ITS CEO Working Group for resolution of issues or conflicts.



[Source: Research and Innovative Technologies Administration, ITS JPO.]

Establish Goals (Phase 2)

This phase includes the activities necessary for the stakeholders to gain an understanding of ICM and to initiate the planning for an ICM project. These activities are described following the guide convention described previously—manage for quality, resources, highlights, questions to answer, lessons learned, and example.

Managing for Quality – Establishing Goals

One of the first things that needs to be accomplished when establishing goals for ICM is to choose a stakeholder that will manage and lead the work to be performed. The following checklist includes some of the more important activities that the Project Lead will be responsible for:

- Schedule meetings to discuss activities, status, action items, and risks;
- Ensure that guidance and training is made available to those stakeholders that are not familiar with ICM; and
- Ensure that all stakeholders understand and are comfortable with the project process.

Establishing Goals Resources

There are many resources available to assist with establishing goals for ICM. One excellent resource is the Advancing Metropolitan Planning for Operations Desk Reference discussed in section 1.3.2. Another resource that stakeholders should visit for information on ICM is the U.S. DOT ICM Web site: http://www.its.dot.gov/icms/. At the ICM Web site, stakeholders can find a great deal of information on the concept of ICM and its implementation. There is also an "ICM Knowledgebase" where people can search and find publications on ICM, including presentations, newsletters, and fact sheets—plus AMS results and systems engineering documents from the ICM Pioneer Sites. The Systems Engineering Guidebook for ITS contains a good description on concept exploration in section 3.3.1, Needs Assessment, and section 3.3.2, Concept Exploration and Benefits Analysis. In addition, stakeholders can use their own standard processes for goal setting.

Establishing Goals Highlights

The activities shown in Figure 8 are described below in this section under the following sub-headings:

- Explore the ICM Concept
- Develop Goals, Measurable Objectives, and Data Collection Needs
- Analyze System Problems and Identify System (User) Needs
- Conduct Feasibility Assessment
- Identify Development Support Resources

Figure 8 below provides a framework for establishing the goals of ICM. This framework identifies some of the inputs and controls needed before beginning the process, activities that should be performed during the process, and some of the outputs or products that need to be completed before moving to the next phase of the project. Enablers for this process are identified as those human resources that will facilitate completion of the activities.

Figure 8. Establishing Goals for ICM

[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.3.1, November 2009]

Explore the ICM Concept

ICM involves coordinating transportation management activities and processes among those agencies within a corridor whose actions affect how effectively people and goods can move on the transportation networks within that corridor. One of the first things to accomplish during this phase is the establishment of an ICM concept exploration working group. This group works best if it includes a representative set of relevant agency decisionmakers and has the resources needed to conduct a reasonable exploration of ICM concepts for the corridor.

The concept exploration working group must select and define a candidate corridor within which agencies can implement ICM. A candidate corridor can be of any size or type, but the U.S. DOT's research to date has focused on urban corridors in large metropolitan areas. To select and define a candidate ICM corridor with specific geographic boundaries, the working group must select for the following factors:

- A major transportation network (roadway) with heavy traffic that is congested during peak travel periods must exist;
- Alternate transportation networks – at a minimum, one or more roadway networks and one or more transit networks, with periods of unused or underused capacity – must exist within the corridor (to handle diversion from the main, congested network or networks);
- Networks within the corridor must have (or must plan for implementing) real-time or near-real-time data collection; and
- Transportation network operators within the corridor must have a culture of interagency cooperation and collaboration (Note: while this is not mandatory, having this collaborative culture facilitates the establishment of the necessary inter-agency agreements that make ICM possible, if they do not already exist).

The working group should propose the geographic boundaries of a corridor that encompasses all of the above factors to the stakeholders considering ICM.

Once the working group has identified a candidate ICM corridor, it should identify the transportation problems or issues that exist and consider how concepts within the ICM strategic areas might address these problems and issues.

As Appendix A indicates, the four major strategic areas of ICM include:

- *Demand management* – which addresses usage patterns for the corridor's transportation networks. Generally, travelers driving in to work from suburban or ex-urban locations to work locations within the corridor and then making the return trip after work to their homes cause congestion in urban corridors. Building more roads or widening existing roads is a congestion-mitigation strategy that has rarely proven successful in the long term. While it may provide short-term relief, ultimately growth along the travel corridor leads to the same or greater congestion along those roads. While the overall approach to implementing ICM in a corridor might include road construction, the working group should consider other ways of addressing demand. These might include such ideas as high-occupancy vehicle (HOV) or high-occupancy toll (HOT) lanes, incentives to encourage ride-sharing, closing off sections of the urban area to vehicles, encouraging telework, or congestion pricing. Some of these approaches could become part of the overall ICM strategy for the corridor.
- *Load balancing* – which addresses how travelers use the networks in a corridor. The working group can examine such ideas as mode shift (e.g., having drivers become transit riders), use of

reversible lanes during peak travel times, use of roadway shoulders as travel lanes to increase capacity during peak travel times, ramp metering, and other similar ideas to balance the traffic loads on corridor transportation networks. The working group can also consider options that add short-term capacity to a network (e.g., adding additional train cars to a transit train during peak demand periods) or valet parking at some facilities to move people through the facility faster. (One can consider some of these possible approaches as being either demand management or load balancing; the category is not important, but the potential positive impact of the approach is. There are also longer term load-balancing options that can involve some capital projects, such as building roads that allow travelers a shorter route to some destinations or providing light-rail transit options for certain heavily congested corridors.)

- *Event response* – which deals with how the combined transportation network managers respond to both planned and unplanned events (incidents) that affect the capacity of or the demand on the corridor's transportation networks. The most successful approaches, as indicated by the actual experiences of the Pioneer Sites, deal with establishing pre-coordinated response plans that represent what the corridor's stakeholders consider the most effective manner of dealing with likely events (planned or unplanned). Usually, the likelihood of an event is determined from the historical record of events within the corridor and the experience of the corridor's transportation managers.
- *Capital improvement* – which deals with upgrades to corridor facilities. This could include roadway, transit, and parking construction projects, but more likely will focus on the increased use of technology within the corridor to facilitate the coordinated management of the corridor's transportation networks. One type of capital improvement the concept exploration working group should consider is the development of an ICMS, a system to support ICM decisions.

U.S. DOT research in ICM and other congestion management initiatives has identified a number of control strategies or tactics that agencies can apply in strategic areas covered by ICM. The Pioneer AMS Sites modeled a representative sample of these. The control strategies modeled included:

- Earlier dissemination and information sharing among agencies;
- Parking information at park and ride lots;
- Freeway traveler information (pre-trip and en-route);
- Arterial traveler information (pre-trip and en-route);
- Transit traveler information (pre-trip and en-route);
- Signal retiming on arterials or frontage roads during incidents;
- Ramp meter retiming during incidents;
- Coordinated signal and ramp meter operation;
- System wide coordinated ramp metering;
- HOT lane (congestion pricing);
- HOV lane (changing minimum number of occupants);
- Opening HOV/HOT lanes during incidents;
- Dynamic transit re-routing;
- Transit capacity expansion during special events; and

- Arterial signal priority for transit.

During concept exploration, it is premature for the working group to decide which control strategies agencies might use in the defined corridor. However, what the working group can determine at this point is what data is needed to assess the potential impact of potential control strategies within the corridor. The working group can also assess whether the data needed is actually available or can be obtained with a reasonable expenditure of resources. The ICM AMS Guide[22] provides some guidance on what data is required for different AMS activities. The working group may also choose to initiate discussion on how to characterize overall corridor performance rather than individual network performance and potential implications for data collection. Goals, objectives, and performance measures are discussed in more detail in Section 2.3.2, below.

If the region cannot afford to implement the type of AMS effort performed at the Pioneer AMS Sites, it should consider a more limited form of AMS. Some AMS work is needed to assess the potential impact of control strategies that the working group is considering for the corridor. Without any AMS, stakeholders could decide to implement control strategies that have limited value and benefit within the corridor.

In this phase, it is also helpful to review the regional ITS architecture to determine what ITS projects the region plans to initiate (and when) and which systems the region has scheduled for upgrades. Additionally, many regional ITS architectures include current operating agreements among agencies and identify ITS standards used in the region. These agreements and standards help identify constraints on a proposed ICMS.

The most common documents that come out of the concept exploration activity are the description of the proposed corridor and its boundary, a description of data needs for AMS, and a list of potential ICM control strategies that the working group will explore further while performing the corridor needs analysis. Note that one does not perform concept exploration and needs analysis in a sequential manner. There is considerable back and forth between the two activities as the working group considers how it can best resolve transportation problems and issues within the corridor.

Develop Goals, Measurable Objectives, and Data Collection Needs

Having explored the ICM concept, identified the transportation problems and issues within the corridor, and examined possible control strategies for addressing those problems and issues, the next step for the working group is to define an initial set of goals that it would like to achieve through the application of ICM. Goals are high-level statements of what the region wants to accomplish. As an example (cited later in this section), the Dallas Pioneer Site set “improve corridor throughput” as one of its goals. That particular goal can be achieved in one of three possible ways:

1. Move the same amount of people and goods as are moved today but at a faster rate;
2. Move a greater amount of people and goods than are moved today but at the same rate as today; or
3. Move a greater amount of people and goods than are moved today at a faster rate than today.

To assess whether it can achieve its goal, the site first had to decide how it was going to measure throughput. The ICM AMS Guide discusses[23] one method of calculating throughput.

For each goal identified, the working group should propose a set of measurable objectives; i.e., statements that set out the quantifiable means by which one determines that the region is meeting the goal. For example, to meet the goal stated above, the working group might define as a measurable

objective: “The percentage of reliable passenger miles delivered within a 2-hour threshold shall increase by an average of 5 percent per year over a 5-year period.” Then, the region has to collect the data necessary to determine whether it is achieving that objective during the 5-year period.

Appendix A of the ICM AMS Guide identifies how to calculate key corridor performance measures and indicates the type of data required to perform each of the calculations. While sites considering the implementation of an ICM approach for their corridor may not have the resources or the time to conduct the type of analysis performed by the Pioneer AMS Sites, any site that is considering ICM should perform some level of AMS before finalizing its decision.

The documentation produced by the working group in this activity should include the set of recommended goals and measurable objectives and the results of any AMS efforts conducted. The stakeholders within the corridor should review these results and recommendations and decide whether to proceed with an ICM approach. And, having decided to proceed to implementation of ICM, the stakeholders need to agree on the actual goals and objectives (which can be an endorsement of what the working group recommended) that will drive ICM implementation. This important activity will also have implications for the routine data collection required to estimate corridor performance over time.

Analyze System Problems and Identify System (User) Needs

One can view the transportation networks within a corridor as a *system*; i.e., a set of interacting or interdependent components forming an integrated whole. When there are problems or issues within that system that keep it from operating at its desired level, one can define *needs* that address those problems; a need is a major desired capability that is required to resolve one or more problems identified within a system.

In discussing ICM, however, one is really discussing two *types* of systems: the *transportation* system within a corridor and the *information* system that supports the execution of the control strategies that the corridor’s transportation stakeholders have decided are best suited to their transportation needs. Suppose that a region decided that it wanted to encourage mode-shift to reduce the number of single-passenger vehicles on roadways during peak travel periods. Also suppose that the region considers “mode-shift” to include both encouraging travelers to use transit options and encouraging travelers to join with other travelers in light vehicles through van pooling or ride-sharing. The desired capability in the *transportation* system is “Encourage travelers to shift from single-passenger-in-a-vehicle travel to travel-with-other-travelers-in-the-same-vehicle.” There are multiple possible approaches (solutions) that a region could take to implement that capability (e.g., financial incentives or disincentives, publicity campaigns that emphasize the better travel reliability of transit options, establishment of HOV and/or HOT lanes along with facilities where drivers can meet and combine their trips into a single vehicle, etc.) However, there are also needs for the *information* system that supports the implementation of those solutions.

Needs, whether they are for the transportation system or the information system, should relate back to the goals and objectives defined. Needs express the capabilities required to achieve objectives, which in turn lead to the accomplishment of goals. For the information system, the ICMS that supports ICM, those needs include data collection.

As part of the needs analysis activity, the working group should consider what information systems exist within the region that wholly or partially address the desired ICM capabilities. For example, the region may have existing traveler information systems that communicate road congestion information to travelers or enable travelers to plan a trip using either transit options only or a combination of transit and other modes. The region may have information systems that collect information about volumes and speeds of

traffic on its roadways and about the number of passengers on transit vehicles. The region may have systems that provide information about the availability of parking at key locations; e.g., transit stations, within the region. All of those types of systems support capabilities that enable ICM. In all likelihood, however, these systems are standalone systems operated by individual agencies and may not support the type of data sharing among agencies that ICM requires. Even if there are data sharing agreements among the agencies in a region, they may not be exhaustive enough to support the full inter-agency collaboration required to implement ICM.

It is the combination of gaps in the capabilities of the existing systems, new desired capabilities that none of the existing systems were designed to satisfy, data collection capabilities required to support the measurement of objective and goal attainment, and upgrades desired in existing facilities and systems that will yield the set of needs for the region's ICMS. The working group has to document those needs (in a solution-free manner) for the region's stakeholders to consider and either approve or reject. The final set of system needs approved by the stakeholders becomes the starting point for feasibility assessment and operational concept definition.

Conduct Feasibility Assessment

In the real world, available resources limit the ICMS that a region can build. Money is not the only constrained resource, but it is an important one. The working group has to decide, of the capabilities it would like to have in an ICMS, which ones can be obtained with available resources. Feasibility is assessed in three ways. First, the benefit that a capability will provide has to eclipse the cost of obtaining that capability. Most organizations have an investment threshold, i.e., a differential between the investment amount (cost) and the investment return (benefit). If a potential investment does not exceed that threshold, the investment is not made. Public sector agencies are no different than the private sector in this regard, with the major difference being that public sector agencies may choose to consider societal benefits (monetized or not) as part of the investment decision. Second, the investment required must be within the budgetary constraints of the investing agency (or agencies). If an agency does not have or cannot get the necessary investment capital, it does not matter how much benefit can be derived from the investment. Third, the investment has to be technically feasible. There must be sufficient technology available to the agency to implement the desired capability within the desired timeframe.

One way to improve the feasibility assessment related to a capability is to change the timeframe over which the feasibility is assessed. For example, a region may not have the resources to implement all of the ICMS capabilities that they would like if they try to implement them all at once. However, by staging the implementation of these capabilities over a longer period (called an *incremental deployment*) than initially envisioned, the region's stakeholders can change the benefit-cost equation. By implementing a lower cost, higher benefit option sooner, the region's stakeholders begin to accrue value from the initial deployments. Those accrued benefits can offset the cost of later investments required to expand capabilities or enable new ones.

The documentation that the working group should generate in this activity includes the description of the desired capabilities, a benefit-cost analysis of the overall set of capabilities desired, and a proposed implementation approach (staged or *incremental deployment* versus all-at-once deployment). The region's stakeholders must review and either accept or modify the working group's recommendations before proceeding to the next phase.

Caution: No matter how tempting it may appear to choose a solution at this point, doing so is premature. No matter how good a solution may seem, until the region defines the requirements for its ICMS,

stakeholders will not know how well this possible solution meets their needs. This is a painful lesson learned on other ITS projects.

Identify Development Support Resources

A robust ICMS may need to include or integrate a complex network of corridor information systems, such as: transit management systems, freeway management systems, traveler information systems, incident management systems, arterial management systems, parking management systems, and decision support systems. Compounding the complexity of these system interactions is the number of independent agencies and jurisdictions involved with corridor management activities.

If the ICMS development effort involves this level of complexity, corridor decisionmakers should consider having an in-house, certified systems engineer or a certified systems engineering consultant to provide system concept and development support for the project and to advocate for the stakeholders. It is important for decisionmakers to acquire the correct expertise for the systems engineering work.

There is a distinction between system integration skills and systems engineering skills. System integrators specialize in building systems, similar to a construction contractor specializing in building roadways. Typically, one would not hire a roadway contractor to perform the planning and engineering work for a new roadway project because that is not their specialty. Just as planners and design engineers develop roadway plans and specifications, systems engineers perform the planning and system design/definition work for systems. A systems integrator is then hired to build the system. This is not to say that a particular systems integrator may not also know systems engineering or a particular roadway contractor may not also know how to design a roadway. It just means that decisionmakers need to establish good criteria when deciding on system concept and development support for an ICMS project and make sure that the correct skills are made available. The International Council of Systems Engineers (INCOSE) offers a certification program for Certified Systems Engineering Professionals (CSEP). Decisionmakers may want to require that the systems engineering staff they elect to use have a CSEP designation.

If procuring systems engineering expertise, decisionmakers should consider asking bidders to submit examples of their systems engineering work and processes. They should also consider asking bidders to provide an introductory overview of their processes. Their processes should be easy to understand and logical to follow as each project phase progresses. Independent systems engineering evaluators should also be considered to assess systems engineering products delivered and to attend reviews and walkthroughs. Some Indefinite Delivery/Indefinite Quantity (IDIQ) contracts may already have staff with INCOSE CSEP designations.

Finally, decisionmakers should consider providing early systems engineering training for the stakeholders that will play a role in the system development. These stakeholders should also be provided with systems engineering guides and other resources that will be helpful for the development of the system. Later sections of this document identify some recommended resources. The project will be much easier to manage and develop if stakeholders have a common frame of reference and understanding of systems engineering processes.

Questions to Answer – Establishing Goals

In the initial stages of establishing goals for ICM, stakeholders will need to make certain consensus decisions to initiate the project. This process is typically a difficult thing to do, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed project and then developing answers to those questions (with the consensus of the stakeholder group). The following is a list of ICM questions to start with:

- Were the corridor problems identified and the corridor needs agreed upon?
- Have meaningful performance measures and goals been identified to evaluate benefits and lifecycle costs?
- Were the functions of the proposed ICM System assessed and found to be feasible?
- Were all necessary ICMS concept and development support resources identified along with the means to obtain these resources if not already available?
- Have stakeholder agreements been considered and initiated?

Lessons Learned – Establishing Goals

The following lessons learned apply to this phase of the ICM program.

- Team involvement – Managing an ICM project requires a project team of knowledgeable and committed staff that can provide oversight, direction, and necessary reviews.
- Project responsibility and commitment – ICM project teams need to be committed to the process, take ownership of the work products, and see the work products through to successful completion. It is imperative that all stakeholders take responsibility for their part in the project and play an active role in providing successful outcomes. Key activities that can seem time-consuming but provide significant benefit later in the project include: the definition of the current corridor and system assets (both physical and data), identification of corridor needs, and the development of a common vocabulary among partners to describe existing systems and proposed capabilities.
- Stakeholder input – Before proceeding with the development of an ICMS, it is essential that the stakeholders be able to describe why the proposed system is needed and what the goals of the ICMS are.
- Procurement, cost and schedule – Multiple procurements from multiple agencies are a challenging endeavor. If, as a part of the ICM project, one of the stakeholder agencies slips schedule or misses requirements in selection and procurement, this can affect the project as a whole. Procuring systems prematurely (prior to defining the requirements) could significantly impact the cost and schedule of the project. Having some flexible contracting and procurement mechanisms for the project can be helpful when unforeseen issues arise.
- Normalization of acronyms and terminology – When working with multiple agencies, it was found that terminology and acronyms can differ in definition. It is advisable to develop an acronym and terminology list that includes common definitions.
- Realization of benefits – Stakeholders should understand that ICMS development takes time and benefits might not be fully realized until well past the end of the project. This message should be thoroughly considered and conveyed to decisionmakers to help manage expectations for the project.
- Project performance measures – Select some performance measures that can be elevated from mid-level to upper-level management to help decision makers understand the overall vision of the project.

Pioneer Site Example – Establishing Goals

The Dallas ICM Pioneer Site Concept of Operations describes the Dallas ICM Demonstration Project Vision and Goals agreed upon by all corridor stakeholders:

The US-75 ICM Project Team defined the Vision for the Corridor as:

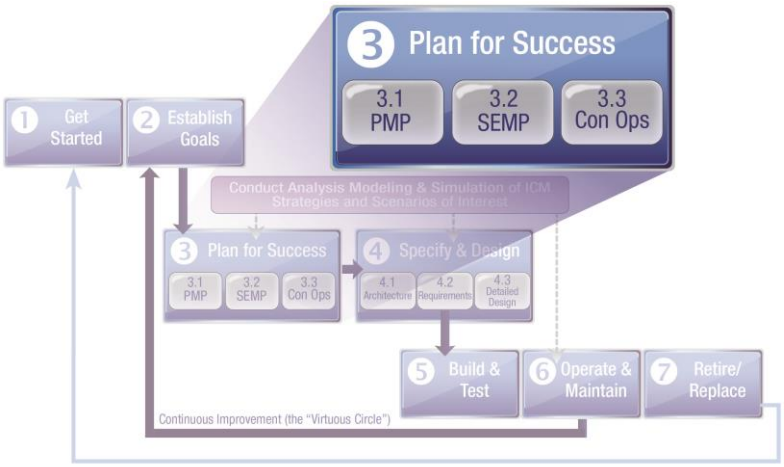
> "Operate the US-75 Corridor in a true multimodal, integrated, efficient, and safe fashion where the focus is on the transportation customer."

Using the Vision Statement as a starting point, the US-75 Steering Committee developed four primary Goals for the ICM…

- Increase Corridor Throughput
- Improve Travel Time Reliability
- Improve Incident Management
- Enable Intermodal Travel Decisions[24]

The Dallas ICM Concept of Operations provides a more detailed description of each of these goals along with the Objectives and Strategies for each of the Goals.

The Dallas transportation operations stakeholders, through the North Central Texas Council of Governments, have a history of formal coordination dating back to 1996.[25] The ICM coordination is built upon the foundation agreement that started regional ITS cooperation in the Dallas/Fort Worth area—the Regional Comprehensive Intelligent Transportation Systems Agreement—a copy of this agreement is included in the Dallas ICM ConOps.[26]



[Source: Research and Innovative Technologies Administration, ITS JPO.]

Plan for Success (Phase 3)

This phase includes the activities for organizing the management and the technical programming approach to ICM in a region and implementing an ICMS. This discussion of this phase is divided into the three main documents produced during this phase of the project:

- Project Management Plan
- Systems Engineering Management Plan
- Concept of Operations

The information on each of these documents follows the guide convention described previously: manage for quality, resources, highlights, questions to answer, lessons learned, and example.

Project Management Plan

The Project Management Plan (PMP) establishes the management approach used for the ICM project. The PMP provides an opportunity for stakeholders to develop consensus on the overall project structure, deliverables and procedures. The PMP also documents stakeholder decisions about project scope, tasks, schedule, and costs. Once stakeholders have approved the PMP, the project can move forward. The PMP is also a living document and should be updated to reflect agreed-upon changes and lessons learned.

Managing for Quality – PMP

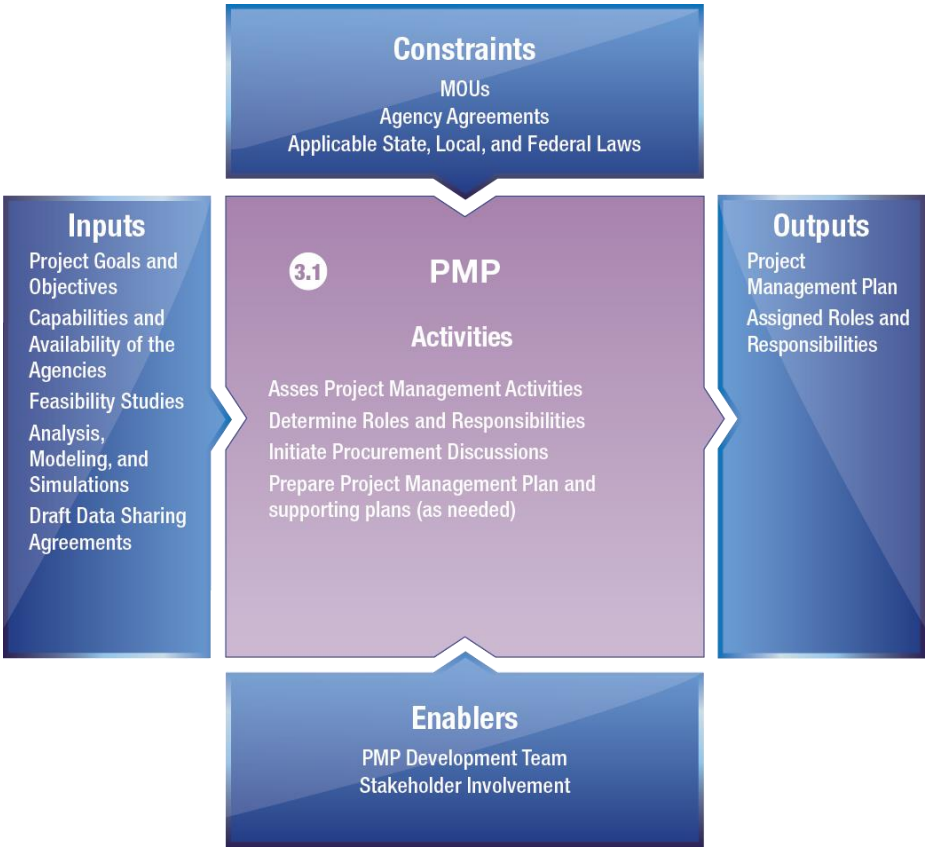
One of the first things that needs to be accomplished when organizing the PMP activity is to choose which stakeholder will lead the activity and manage the PMP development work performed by either in-house staff or a contractor. The following checklist includes some of the more important activities that the PMP Lead will be responsible for:

- Schedule periodic PMP Team meetings to discuss the PMP development, status, action items, and risks;
- Coordinate among stakeholders to make sure that the correct and necessary information is provided for the PMP development;

- Ensure that information is made available to stakeholders that are not familiar with the scope of the PMP;
- Coordinate reviews, walkthroughs and approvals of the PMP, and make sure the work remains on schedule; and
- Ensure that all stakeholders are comfortable with the PMP and support it before moving forward.

Figure 9 shows the ICMS PMP planning process. The inputs and constraints should be completed and available prior to beginning the PMP activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the PMP activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the PMP activities successfully.

Figure 9. ICMS PMP Planning Process



[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.4.1, November 2009]

PMP Resources

There are many resources available to assist with the development and understanding of the PMP. The Systems Engineering Guidebook for ITS, Version 3.0[27] provides information and a brief template for the development of a PMP. The IEEE 1490-2003 Guide: Adoption of PMI Standard, A Guide to the Project Management Body of Knowledge (PMBOK)[28] is another good resource for defining the management of projects. Finally, the Florida Statewide Systems Engineering Management Plan for ITS, version 2.0[29] provides information and a detailed template for the development of a PMP.

PMP Highlights

While most agencies already have defined PMP practices in place, the challenge in implementing ICM is organizing all stakeholders and developing agreements on how the project will be managed, procured, and scheduled as well as how the system will be developed, implemented, operated, and maintained.

Some items that the PMP should address includes the following:

- Communication management;
- Change management;
- Quality management;
- Resource management;
- Cost and schedule management;
- Monitoring and control;
- Roles and responsibilities;
- Project organization chart; and
- Expertise/qualifications needed to complete the project.

The PMP should be tailored to each project. If other plans or processes make sense for the control of an ICMS project, then those processes and plans should be included in the PMP. The project stakeholders should make the determination about additional plans or processes that they feel are necessary for the ICMS project management.

Questions to Answer – PMP

For the PMP development, stakeholders will need to make certain consensus decisions about how they expect the ICMS project to be managed. Getting started with this process is typically a difficult thing to do, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed ICMS management process and then (with the consensus of the stakeholder group), developing answers to those questions. The following is a list of questions to start with:

- Have roles and responsibilities been established?
- Has leadership been identified for project tasks?
- Do task team members have the appropriate expertise?
- Has needed expertise been identified plus a plan to obtain it?
- Have sufficient control gates and control mechanisms been implemented?
- Have all project tasks been identified?
- Have all project tasks been defined sufficiently to be understood by the stakeholders?
- Do the stakeholder's agree that the project budget is sufficient?
- Have stakeholders truly 'bought into the program' and do they know and fully understand to what they are committing?
- Is there a plan to keep stakeholders involved and fully contributing? Does this include a plan of action if stakeholders begin to lose interest?
- Is there a plan to manage project expectations?

- Has a project schedule been developed, reviewed, and agreed to by all stakeholders?

Lessons Learned – PMP

The following lessons apply to this phase of the ICM program.

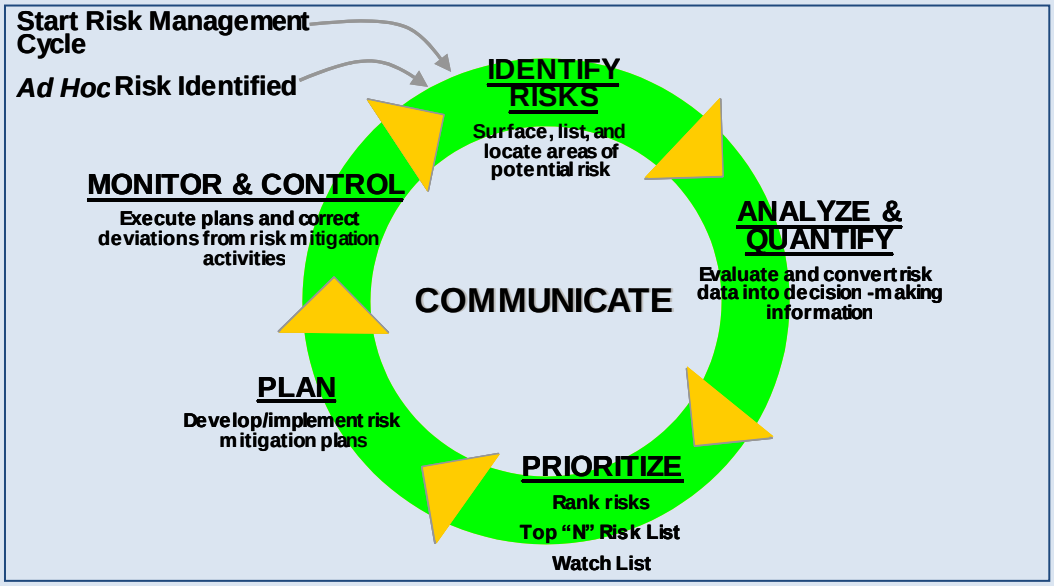
- Roles and responsibilities – ICM stakeholders' roles and responsibilities should be documented to eliminate confusion among stakeholders.
- Project expertise – make every effort to acquire the correct project expertise (e.g., systems engineering, software and hardware design and integration, communications, etc.).
- Leverage corridor expertise – Consider forming subcommittees of subject matter experts to lead and conduct specific sub activities for the project.
- Concrete project guidance – make sure project guidance is concrete so the contractor is not confused or getting mixed messages. There should be a unified message when providing guidance.
- Build consensus – Lots of communication among stakeholders is key for project success. Stakeholders need to listen to each other and come to consensus on what system is possible within the corridor.
- Clear direction – It is helpful to decide early about the roles and responsibilities of each agency. Capture action items – Make sure there is good documentation of action items in the stakeholder meetings. It is important not to lose sight of stakeholder responsibilities.
- Allow for the unknown – Allow more time for the unknown. Stakeholders should understand that there can be lots of unexpected issues to deal with when you are working with so many partners.
- Promote system benefits – The ICM program manager should make sure that stakeholders understand the benefits to them and do not lose sight of the benefits. Sometimes stakeholders need reminders of the eventual benefits to stay committed to the process.
- Engage management – A regional MPO can play a key a role in keeping senior management engaged and supporting the project. Ongoing communication with high-level decision makers will be important for promoting the project and securing needed funding.
- Marketing plan – Marketing is important because the value of ICM is not readily visible on the surface. When developing a business case for ICM think about the ICMS from both the users' perspective and the ICM partners' perspective. Do not underestimate the benefits of marketing that targets the traveler. Present the system as a complete solution that makes it easier to commute and get around. Initiate a marketing campaign that highlights outcomes people can relate to. Working with agency partners to get the word out about the system and providing Q&A features on the agency websites and using media and press articles are all very helpful.

Pioneer Site Example –PMP

The Dallas Pioneer Site incorporated risk management into their PMP. They planned, at an early stage of the project (prior to 20 percent design completion), to have the contractor's project manager—in consultation with the contractor's deputy project manager –technical, ICM program manager, stakeholder leads, and key project staff—review the initial list of potential risks, identify additional potential risks, and modify or remove items in the initial list as needed. The contractor's Project Manager, ICM program manager, stakeholder leads, and key project staff assessed the probability of occurrence of each identified risk and its potential impact on the outcome of the project. If it was determined that the probability of a risk occurrence combined with its impact on the project was high, a mitigation action plan

would be developed and implemented for that risk. Figure 10 depicts the steps of a standard risk management process. The Dallas Pioneer Site adopted these steps for their risk management process.

Figure 10. Dallas ICM Example: Risk Management Process



[Source: Dallas ICM PMP, version 2.5, December 15, 2010, unpublished.]

Systems Engineering Management Plan

Development of the SEMP is key to achieving quality in project development and ultimately producing a successful ICMS. The purpose of the SEMP is to give the project owners/stakeholders a tool to manage the complexity of the project. The SEMP will help to lead the technical management effort for the ICMS and will be the vehicle by which all project stakeholders stay informed about the project activities and how they will be managed. Stakeholders should be able to reference the SEMP to help them understand what tasks will be performed during the project and what roles and responsibilities they have in performing and/or reviewing those tasks.

FHWA Rule 940 (and similarly FTA Policy) on System Architecture and Standards requires that "all ITS projects funded with highway trust funds shall be based on a systems engineering analysis" (23 CFR 940. 11).[30] The items required in the systems engineering analysis would logically be described in the SEMP and addressed at the appropriate point in the project implementation process. This is further discussed below.

Managing for Quality – SEMP

One of the first things that needs to be accomplished when organizing the SEMP activity is to choose which stakeholder will lead the activity and manage the SEMP development work performed by either in-house staff or a contractor. The following checklist includes some of the more important activities that the SEMP Lead will be responsible for:

- Schedule periodic SEMP Team meetings to discuss the SEMP development, status, action items, and risks;
- Ensure that guidance is made available to those stakeholders that are not familiar with the scope and purpose of the SEMP;
- Coordinate among stakeholders to make sure that the correct and necessary information is provided for the SEMP development;
- Coordinate reviews, walkthroughs and approvals of the SEMP, and make sure the work remains on schedule; and
- Ensure that all stakeholders are comfortable with the SEMP and support it before moving forward.

In addition to resources specifically devoted to development of the SEMP, prospective deployers of ICM should consider resources relevant to procurement decisions. Developing and deploying an ICMS is not a trivial exercise. At the moment, there are no commercial off-the-shelf (COTS) ICMSs available on the market and the ICMSs being built by the two Pioneer Demonstration Sites are specifically tailored to their environments and their specific goals and objectives.

There are a number of resources available that address the special characteristics of ITS projects and the options that an agency should consider when deciding how it will procure either an ITS capability or the resources to build an ITS capability. Among these are the following:

- Systems Engineering Guidebook for ITS—particularly sections 4. 9 and 8. 3;
- Systems Engineering for Intelligent Transportation Systems—this document also references the next and a tool developed through the National Cooperative Highway Research Program (NCHRP) to support ITS procurements;
- Considerations for a Guide to Contracting ITS;
- Guide to Contracting ITS Projects (this document was the end result of the research that produced the above listed document);
- The Road to Successful ITS Software Acquisition;
- FHWA's Federal Aid ITS Procurement Regulations and Options; and
- Innovative Contracting Practices for ITS (consists of two parts, an Executive Summary and a Final Report).

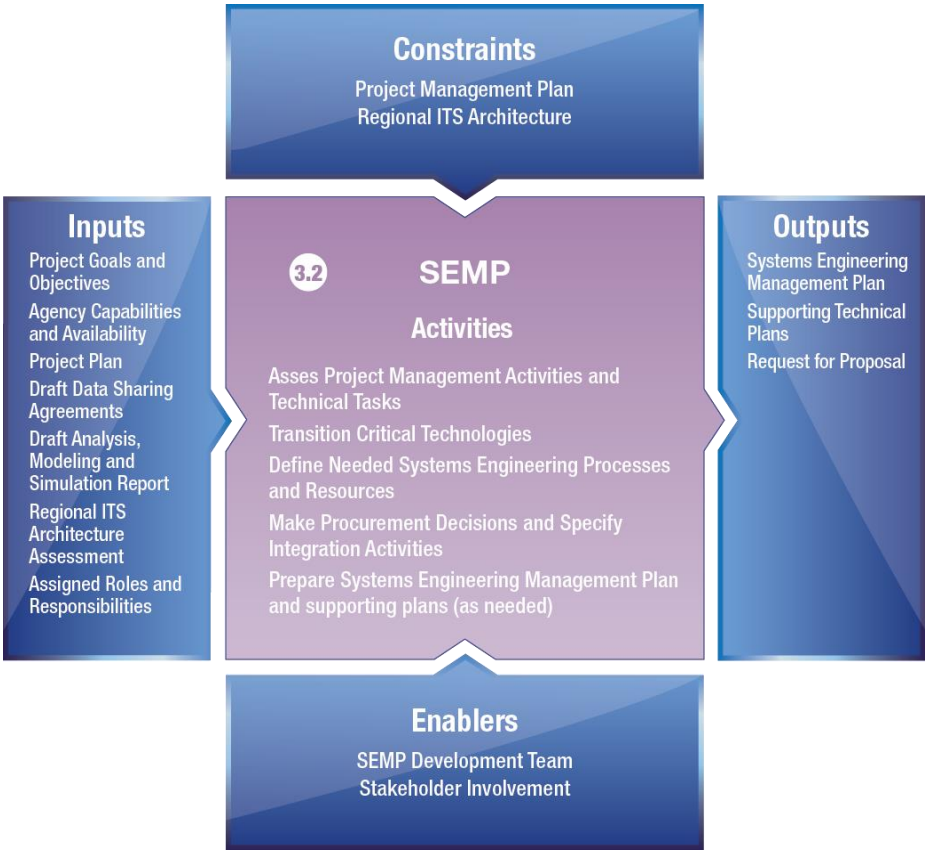
Some other points to consider in the procurement decision-making process:

1. If the agency leading the procurement effort does not have standard templates for systems engineering documentation, it should consider specifying the IEEE standard that relates to the relevant document (e.g., IEEE Std. 1362 for a Concept of Operations document; IEEE 1471 for System Architecture Descriptions) and asking that the delivered document conform to that standard.
2. If the agency is going to acquire hardware as part of the ICM procurement process, consider whether to include a technology refresh option – to ensure that the acquired hardware technology does not quickly become obsolete.
3. When acquiring services, such as systems engineering support and project management support, look for individuals proposed who have both experience and certifications. Certifications alone

are not sufficient. Experience can overcome the lack of certification, but a combination of the two is best.

Figure 11 below shows the ICMS SEMP planning process. The inputs and constraints should be completed and available prior to beginning the SEMP activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the SEMP activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the SEMP activities successfully.

Figure 11. ICMS SEMP Planning Process



[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.4.2, November 2009]

SEMP Resources

There are many resources available to assist with the development and understanding of the SEMP. The Systems Engineering Guidebook for ITS, Version 3.0[31] provides information and a brief template for a SEMP. The IEEE 1220-2005 Standard for Application and Management of the Systems Engineering Process[32] is another good resource for defining the management of systems engineering. Finally, the Florida Statewide Systems Engineering Management Plan for ITS, version 2.0[33] provides very detailed information and detailed templates for the development of a SEMP.

SEMP Highlights

The SEMP is the document that sets the expectations for how the technical elements of the project will be managed and how the ICMS will be developed. The SEMP often includes plans that describe the

management efforts for the entire system lifecycle. The SEMP is a living document and should be updated as additional information is learned about the system and its environment.

Some of items that should be in the SEMP include:

- Task Identification – identify tasks that must be performed and the task completion criteria (Note: tasks may be included as a work breakdown structure (WBS) which organizes tasks into a hierarchical structure and manages tasks and subtasks by name, budget, team roles and responsibilities, etc.);
- Technical Planning and Control Processes – establish the technical program planning and control processes including technical reviews, walkthroughs, and decision gates;
- Risk Management – introduce the risk management plan to initiate a formal process for stakeholders to manage project risks;[34]
- Engineering Program Integration – provide guidance on how the various engineering teams (communications, design, information technology, multimodal, etc.) will work together to support the project development;
- Systems Engineering Process – provide details of the Systems Engineering process that will be used to define the ICMS including the specific methodologies to be used for the ConOps, architecture, requirements, design, and testing;
- Specialty Engineering Plans and Procedures – determine what specialty plans (human factors, system safety, system security, etc.) and procedures will be needed for the project;
- Configuration Management – provide the configuration management plan that will facilitate control of changes to the ICMS and its artifacts including the ConOps, architecture, requirements, and design iterations; and
- Performance monitoring – Initiate system performance monitoring processes to determine what improvements may be needed for ICMS and external systems. Schedule periodic performance reviews to assess future system needs and operational improvements.

The SEMP should be tailored to each ICMS project. If other technical plans or processes make sense for the control of a particular system then those technical processes and plans should be included in the SEMP. The project stakeholders should make the determination about additional technical plans or processes that they feel are necessary for ICMS management and control.

The SEMP should also be tailored so that the project will meet the FHWA issued 23 CFR 940. 11 and the FTA issued policy that requires all ITS projects funded with highway trust funds to be based on a systems engineering analysis.[35] The systems engineering analysis promotes increased up-front planning and system definition prior to technology identification and implementation. Goals of the systems engineering analysis include ensuring project quality and making sure that stakeholder needs are being met.

Questions to Answer – SEMP

For the SEMP development, stakeholders will need to make certain consensus decisions about how they expect the system life cycle to be managed. Getting started with this process is typically a difficult thing to do, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed system management process and then developing answers to those questions (with the consensus of the stakeholder group). The following is a list of questions to start with:

- Does the SEMP reflect practices necessary to satisfy all stakeholder agency project management needs?
- Do all stakeholders understand the SEMP and agree with the processes outlined in it?
- Does the SEMP make provisions for the system lifecycle and are the stakeholders in agreement with those provisions?
- Have all stakeholders reviewed and approved the SEMP?

Lessons Learned – SEMP

The following lessons apply to this phase of the ICM program:

- Defining the systems engineering process – The systems engineering process that the system development team will use needs to be documented in detail. This includes identifying the system analysis methodology that will be used, the requirements documentation and management methodology that will be used, the traceability mechanisms that will be used, how needs elicitation will be conducted, how walkthroughs will be conducted, and how testing will be conducted.
- Defining the semantics behind terminology – Often it is found that terminologies differ in meaning (e.g., high-level and detailed design; or system, subsystem, element, function), so it is critical to the success of the project that terms be well defined and understood and agreed upon among stakeholders.
- Educating stakeholders – It has been found that if the stakeholders have little understanding of the project control processes then the project will suffer. It is critical that stakeholders understand the process and are prepared for their roles in defining the system and managing system development.
- Maintaining stakeholder engagement – The project and task leads need to make sure that stakeholders stay engaged in the process and are not “burned out” by the work. Activities need to be well organized and stakeholder roles need to be well communicated so expectations will be clear and time will not be wasted, especially when it comes to user needs workshops and system walkthroughs.
- Organizing technical staff – It is good to have a strong prime contractor that can keep the stakeholders working together and the system development moving forward. It is also good to have a strong core team that are experienced and can make decisions and keep the project moving forward. It is not recommended to have a core group of stakeholders/developers that is too large or too small.
- System training plan – Recognize that there are different levels and jobs performed throughout the ICM process, so nobody needs to have all the training. Operators and field personnel need training on how to use the system and an online help tool to answer questions during the operation of the system. A three day training class will not help when there are questions that need to be answered later during system operations.
- Training scenarios – Explore many training scenarios for the system training plan. Include class room training, hands on training, attrition training, situational training (e.g., what would you do if you had an F5 hurricane come through your area), operational training, maintenance training, and practice, practice, practice.
- Gaining consensus – The SE process is important because stakeholders need documentation that they can give to contractors to develop from. It is important that all stakeholders develop a shared vision through the SE documentation.

- Leverage stakeholder expertise – Assigning specific tasks to subcommittees of subject matter experts can help to accomplish tasks sooner.
- Configuration management – Have a good configuration management plan that communicates all system changes to all stakeholders in a timely manner. Consider using online document repositories to make sure that stakeholders have the most up to date project information. Key activities for configuration management include identifying what needs to be controlled, how to keep track of configuration updates, keeping track of the status of updates to the configuration items (e.g., proposed, approved, or implemented), communicating the updates, and then verifying that configuration management procedures are being followed and the updates are being incorporated.
- Communication and coordination – Communicating and coordinating early and often can help to shorten the project schedule.
- Agency technical manager – It may be helpful to have an agency technical manager to help guide the system developer.
- Technical reviews – Plan well for documentation reviews. Make sure all stakeholders are aware of the schedule and plan for adequate time to review documents in a timely manner. These reviews are important and can slow down the project if they are not completed on time.
- Operations and Maintenance plan – Consider long term operations and maintenance including issues like funding, warranties, vendor/technical support or a software support agreement (e.g., application support, network support, security support, and operation systems support), staffing resources (short and long term), etc.

Pioneer Site Example –SEMP

Coordinating with the regional ITS architecture early in the ICMS development process helps ensure conformance with the ITS Architecture and Standards FHWA rule 23 CFR 940.11 and the FTA policy.[36] As part of their SEMP development, the San Diego Pioneer Site consulted their regional ITS architecture before beginning their ICMS development work and found the following market packages to be relevant to their ICM deployment. These market packages were subsequently represented in their ICMS architecture.

- ATMS 01 – Network Surveillance
- ATMS 03 – Surface Street Control
- ATMS 04 – Freeway Control 18
- ATMS 07 – Regional Traffic Management
- ATMS 06 – Traffic Information Dissemination
- APTS 08 – Transit Traveler Information
- ATIS 02 – Interactive Traveler Information
- ATIS 05 – ISP Based Trip Planning and Route Guidance
- AD01 – ITS Data Mart

[Source: San Diego ICM Pioneer Demonstration Site, I-15 ICM Systems Engineering Management Plan, Version 4, 9/26/11, p. 28, unpublished.]

Additional market packages are being implemented with their ICMS that will need to be updated in their regional ITS architecture:

- AD03 – ITS Virtual Data Warehouse
- APTS 07 – Multi-modal Coordination
- APTS 09 – Transit Signal Priority
- ATMS 05 – HOV Lane Management
- ATMS 10 – Electronic Toll Collection
- ATMS 18 – Reversible Lane Management

[Source: San Diego ICM Pioneer Demonstration Site, I-15 ICM Systems Engineering Management Plan, Version 4, 9/26/11, p. 28, unpublished.]

All updates or changes to the architecture will be submitted to and vetted by the Regional ITS Architecture Committee, which will work closely with the I-15 ICMS Stage III project Development Team. Expected changes include updates to operational concepts, market packages, and data flows.

Concept of Operations

Development of the ConOps is key to defining the system that will be built. The ConOps will document what the ICMS must do and at what level it is expected to perform. The ConOps provides the vehicle for all project stakeholders to have input to and stay informed about the system definition. The ConOps also provides guidance to the system development team. The Stakeholders and system developers should be able to reference the ConOps to help them understand the system, including what the system must do, what constraints the system will have placed on it, what system performance must be achieved, what operational modes the system will include, and how users will interact with the system.

Managing for Quality – ConOps

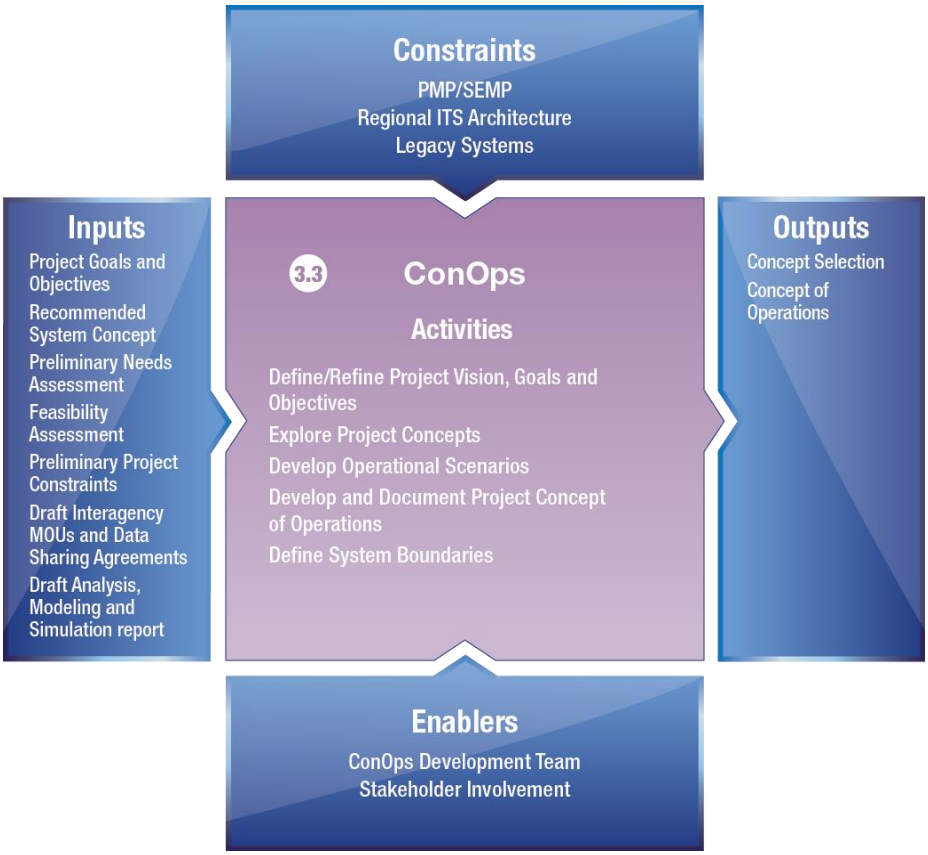
One of the first things that needs to be accomplished when organizing the ConOps effort is to choose a stakeholder that will manage and lead the ConOps work performed by either in-house staff or a contractor. The following checklist includes some of the more important activities that the ConOps Lead will be responsible for:

- Schedule periodic ConOps Team meetings to discuss the ConOps development, status, action items, and risks;
- Ensure that guidance is made available to those stakeholders that are not familiar with the scope and purpose of the ConOps;
- Schedule workshops to facilitate the elicitation of stakeholder needs and vision for the system, these workshops should include exercises that help stakeholders to better envision, discuss and define what they need the system to do;
- Coordinate among stakeholders to make sure that the correct and necessary information is provided for the ConOps development;
- Coordinate reviews, walkthroughs and approvals of the ConOps, and make sure the work remains on schedule; and
- Ensure that all stakeholders are comfortable with the ConOps and support it before moving forward.

> *"The ConOps is an essential tool for capturing corridor needs and translating them into system needs. This phase of the project should not be underestimated. A well-developed ConOps is key to successfully guiding system development and ensuring that project and stakeholder goals are met."*
>
> Koorosh Olyai
> Assistant Vice President
> Mobility Programs Development
> Dallas Area Rapid Transit

Figure 12 shows the ICMS ConOps planning process. The inputs and constraints should be completed and available prior to beginning the ConOps activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the ConOps activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the ConOps activities successfully.

Figure 12. ICMS ConOps Planning Process



[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.4.3, November 2009]

ConOps Resources

There are many resources available to assist with the development and understanding of the ConOps. The Systems Engineering Guidebook for ITS, Version 3.0[37] provides details about and a brief template for the development of a ConOps. Stakeholders should review these sections in the guide to gain a better understanding of the ConOps development process. The IEEE 1362-1998 Guide for Information Technology –System Definition – Concept of Operations (ConOps) Document[38] is another good resource for developing a ConOps. For those that do not have access to the IEEE standard, they may want to use the ConOps template provided with Florida's Statewide Systems Engineering Management Plan for ITS, version 2.0.[39] This template provides very detailed information about what should be included in a ConOps and it is based on the IEEE standard.

ConOps Highlights

The ConOps is the document that describes the stakeholders' vision and expectations for what the new system will do for them. Stakeholders need to take the time to really think about how the new system will improve their current operations and improve the service that they provide to their customers. Stakeholders need to try to be as specific as they can in describing desired improvements, and they should not allow their vision to be inhibited by costs. This is important because some improvements may turn out to be cost prohibitive, while some improvements may end up being more feasible than stakeholders had originally thought.

When envisioning a new system it may be helpful to start by isolating corridor problems and then detailing how those problems are currently being addressed, or not being addressed. This process begins earlier in the concept exploration as discussed in Phase 2. Once there is a good understanding of the project problems, then stakeholders can begin the process of envisioning how those problems could be solved. Stakeholders should consider what resources are currently available to assist with proposed system concepts and what needs are not being met by the current system. If existing corridor systems will be able to facilitate new ICMS concepts, then the stakeholders need to identify and collect information that can be shared about those existing systems. This information will likely be needed for the system definition, design, implementation, operation, maintenance, and refinement phases of the system life cycle.

Operational scenarios are the heart of the ConOps. Stakeholders need to be able to articulate potential operational scenarios to the authors of the ConOps. The authors will then document the scenarios in terms of the proposed system. "A scenario is a step-by-step description of how the proposed system should operate and interact with its users and its external interfaces under a given set of circumstances. Scenarios should be described in a manner that will allow readers to walk through them and gain an understanding of how all the various parts of the proposed system function and interact. The scenarios tie together all parts of the system, the users, and other entities by describing how they interact. Scenarios may also be used to describe what the system should not do."[40] With both the system vision and operational scenarios defined by the stakeholders, the ConOps authors should be able to identify the user needs for the system.

One method of identifying system needs is to read through the operational scenarios line by line and identify each potential system need or the functionality envisioned for the system. The identified potential need or functionality can then be analyzed for formal user needs. For example, if a scenario states that the system will require user identification (ID) for access to the system, then there will be certain needs associated with the processing of a user ID. Users IDs will likely need to be stored by the system in order to facilitate user authorization. This may bring about a need for the system to archive data. Note that each user need should trace to one or more operational scenarios. When needs are written the following criteria can be used to determine if a need is well written:

1. Is the need uniquely identifiable? Each need must be uniquely identified; that is, each need shall be assigned a unique number and title.
2. Does the need express a major desired capability? Each need must express a major desired capability (corridor level) in the system, regardless of whether the capability exists in the current system or situation or is a gap.
3. Is the need solution free? Each need must be solution free, thus giving designers flexibility and latitude to produce the best feasible solution.
4. Does the need capture the rationale? Each need must capture the rationale or intent as to why the capability is needed in the system.

The following is an example of a user need for data storage that does not meet the above criteria:

> The "access/store historical data" user need provides the capability to create and populate a historical database instance. This database contains real-time information on corridor performance as derived from data collected in the "collect and process data" user need. Accessing existing historical databases in freeway management system, transit management system, and arterial management system is an important function of this user need. Having consistent export formats for data from these historical databases would simplify corridor-wide analysis. Ad hoc reporting based on this historical data allows the system users to create a variety of reports that characterize corridor operations and performance. These reports can then be stored in the ICMS historical database.

This need is not solution free. The description partially focuses on the need and partially on the allocation of the need to a software system (database). The allocation of data storage to a database should not be decided until the project advances to detailed design.

The following is an improved example of a need addressing data storage:

> Need to archive data – Data collected by an ICMS needs to be archived so that it can be used in processes that occur after the immediate collection period. These types of processes are analytical and/or predictive in nature and help transportation system managers assess the impact of prospective actions that they may take. Impact assessment tools, such as decision support systems, use archived data.

This need is solution free.

Stakeholders should definitely hold a ConOps walkthrough to make sure that the ConOps authors have captured what the stakeholders envisioned for the proposed ICMS, to make sure that the needs have been identified and defined properly, and to determine whether the initial system boundaries and high-level functions have been documented. The stakeholders should be able to leave the ConOps walkthrough with a good understanding of what the system will do. If they do not have a good understanding of the system, then additional work needs to be done to make sure that the vision and needs are documented sufficiently.

The operational needs for an ICMS are further explored in the white paper "Conceptualizing Integrated Corridor Management" in Appendix A. This white paper 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.

Refer to the white paper for a detailed description of each of these needs. Also, refer to the example at the end of this section, which provides a list of the problems/needs and associated goals from the Dallas ICM Concept of Operations.

It is important to note that the ConOps, along with other systems engineering documents, is a living document. The ConOps will be revisited, updated, and modified as the system is developed and while it is maturing. The first version is to be considered a baseline and should be updated as additional discoveries are made during the development of the ICMS.

Questions to Answer – ConOps

In the initial stages of the ConOps development, stakeholders will need to make certain consensus decisions about the system they are envisioning. Getting started with this process is typically a difficult thing to do, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed system and then developing answers to those questions (with the consensus of the stakeholder group). The following is a list of ICM questions to start with:

- What problems are not being satisfied by the current system?
- What are the current operational deficiencies?
- Why do these current operational deficiencies exist?
- What are the corridor boundaries?
- What external systems will the ICMS interface with?
- Who will provide access to Interface Control Documents?
- What limitations, if any, will corridor operations impose on the system?
- What corridor restrictions will need to be dealt with?
- What decisions will the system be expected to facilitate?
- How will good performance be described or characterized?
- What are the current constraints on the system?
- What are the existing inventories of current external systems?
- What operational policies exist for the system? What are the data quality expectations for the project?
- What strategies could be employed to aid the corridor? Examples:
    - Integrating HOV/HOT lanes with arterial/transit operation; and
    - Integrating real-time parking guidance with on demand mode shift control.
- What performance metrics can be used to verify improvement in the corridor? Examples:
    - Mode choice changes;
    - Total person throughput; and
    - Person trip-time/trip reliability.

Lessons Learned – ConOps

The following lessons apply to this phase of the ICM program.

- Normalization of acronyms and terminology – When working with multiple agencies, it was found that terminology and acronyms can differ in definition. It is advisable to develop an acronym and terminology list that includes common definitions.
- Consistency in naming conventions – When working with multiple agencies, it was found that naming conventions can differ (e.g., operator names, data element names, agency names, etc.). It is advisable to keep a list of naming conventions and how the inconsistencies will be managed.
- Identification of external systems – Make sure all appropriate external systems are included. Poll a large group to make sure they have the opportunity to have input into what external systems should be included in the ICMS.

- Operations and management changes –ICM will likely change the operations and management of transportation systems. Stakeholders should be prepared and position themselves to change how they will operate and manage their individual systems in an ICM environment.
- Data sharing – Determine what data is available and the quality of the data in the external systems and initiate agreements on how to share the data.
- Data types and formats – Stakeholders need to assess the data types and formats that are stored in the various external systems and look at how to make that data work for the intended ICMS purposes.
- Updating needs – Refine needs as needed. Sometimes requirements will drive changes in the needs. These updates should be a priority as they may have serious impacts on the system definition.
- Compound Needs – Needs may have to be broken up if too many capabilities are described in the need. A need should express only one major desired capability. Make sure that the systems engineering process defines a common need format or grammar.
- System constraints – Be careful about the use of constraints (e.g., when defining inter-jurisdictional agreements be cautious of specifying what has not currently been agreed to, and do not forget to identify rules, regulations and laws that the system must follow.)
- System security access – Keep a list/table that identifies operators and permission levels, update that list as the project proceeds and changes are identified.
- Use caution and confirm terminology/metrics – Use of sensitive metrics such as fatality rates may be restricted by some agencies, make sure that terms and metrics are approved for use.
- Transition planning – Consider what may happen if the ICM Coordinator function needs to transition from one agency to another and have a tentative plan for that transition. This may be an operations lesson or a planning lesson.
- Concept development – For initial concept development use a financially unconstrained transportation planning process. This helps to not place limits on the process and system. An incremental implementation approach can always be used if the system concept exceeds available funding.
- Defining system boundaries – Make sure that stakeholders understand the difference between jurisdictional/geographic boundaries and functional boundaries. The system boundaries are functional boundaries.
- Corridor boundaries – The geographic boundaries of the ICMS may change slightly after implementation due to secondary impacts. It is hard to conceive of all impacts in the initial concept phase, however ICM deployers should consider that geographic boundary changes may be needed later.
- Early modeling and simulation – More effort needs to be spent on identifying what needs to be tracked and reported on. Sources and sinks need to be well modeled to adequately capture operational needs.
- Jurisdictional boundaries – Stakeholders should think through operations at jurisdictional boundaries. For example, in some regions some road links are operated by the state DOT, so for example if incidents occur on a frontage road the cities may not be able to put that incident information into the system. Meanwhile, the state DOT is focused on what happens on the mainline. This means the cities have to contact the state DOT and ask them to enter frontage road incidents. These operational issues at jurisdictional boundaries somehow need to be addressed early on in the process.

- Concept definition and verification – Spend a good amount of time in the earlier stages of the Vee development process in order to make the testing phase more useful. Consider how the system should be verified and what will help stakeholders feel satisfied during system acceptance.
- Operations and Maintenance – Plan for operations in the early stages of the SE process. Identify operations and maintenance operational scenarios, needs and requirements. Include maintenance functions and flows in the architecture.
- System expansion – Do not be surprised when system implementation is complete and additional organizations want to be integrated into the ICMS. Plan for this flexibility in the initial concept definition stage.
- Environmental benefits – Do not forget to consider how to capture environmental benefits of the system. Environmental benefits may be very useful in justifying ongoing operational funding.
- Project flexibility – Stakeholders should remain flexible to accommodate new needs and functionality to be added to the system as the project advances. As the project advances it is likely that new and better ideas will be presented to the stakeholders to consider for implementation into the system. Sometimes what you really need for the system to work becomes clearer as the work progresses and it is possible that changes to the system may be needed. The SE process is an iterative process so take advantage of that flexibility to make updates during the system development process.
- System control strategies – The ICMS stakeholders may not want to share control and that does significantly impact system design and development. Stakeholder's desires need to be captured in the ConOps phase for proper system development. Whether centralized control, centralized coordination or another system management strategy is used, that system management concept needs to be well documented to obtain the system desired. The details that are captured in the ConOps and requirements help to convey the desired system to the system developer and this helps to avoid confusion moving forward.
- Shared control – As shared systems are considered understand that changes to agency operations will take time, and agency staff will need a lot of time to get comfortable with transferring control of their systems to other agencies and systems, especially when signal systems are involved.
- Justify the envisioned system – Use the operational scenarios to tell the story of the envisioned system and describe a justification of the envisioned system that helps the various stakeholders understand the benefits them.
- Arterial surveillance – Arterial surveillance is critical and must be addressed for effective corridor management. One of the key techniques for integrated corridor management is the potential balancing of traffic demands between freeway and arterial facilities. However, to successfully manage such diversion is critical to develop and maintain situational awareness of arterial traffic conditions.
- Intellectual property rights – All stakeholders seeking to participate and provide services for the ICMS need to be aware of the intellectual property rights, policies, and standards for the corridor. These discussions need to occur early in the process so that these issues can be resolved and systems definition can move forward.
- Developing a vision – Involve management across multiple levels including intuitional, operational, and technical, and use transportation planners, modelers, and facilitators to help agencies understand each other's needs, capabilities, and priorities. Build a mantra of respect. It can be a challenging for smaller local agencies to buy into the overall vision of an ICMS, especially when under pressure to budget contracts. Overcome these challenges by continuing to

sell the vision to individual city officials and council members. Focus on the technical and conceptual aspects of specific applications and to clarify how the benefits will be perceived by their constituents.

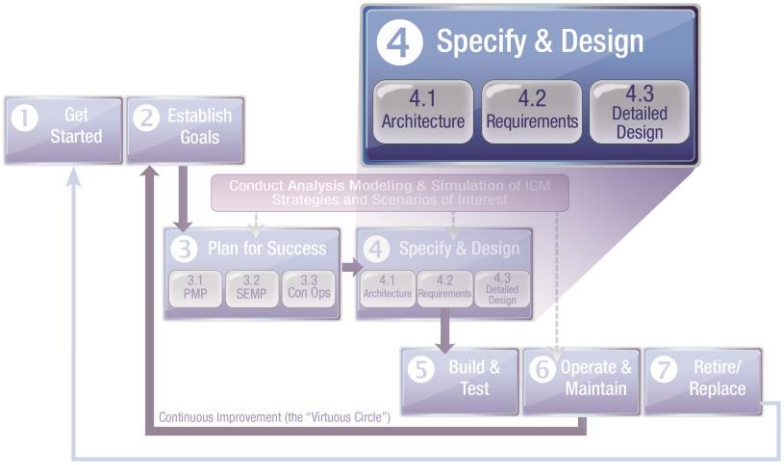
Pioneer Site Example –ConOps

The Dallas Pioneer Site identified needs for their ICMS and documented them in their ConOps. Table 3 provides a summary listing of the needs they identified mapped against the project goals they identified. The full list of the Dallas ICMS operational needs along with descriptions can be found in their Concept of Operations.

Table 3. Dallas Example: Mapping of Goals Against Corridor Needs

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

[Source: *Concept of Operations for the US-75 Integrated Corridor in Dallas, Texas*, DART, et al. for U.S. DOT, FHWA-JPO-08-004. 30 April 2008, Table 4. 1-2 Mapping of Goals against Corridor Needs, p. 69. http://ntl.bts.gov/lib/30000/30400/30409/14390.htm.]



[Source: Research and Innovative Technologies Administration, ITS JPO.]

Specify and Design (Phase 4)

This phase includes the activities for specifying and designing an ICMS. This discussion of this phase is divided into the three main documents produced during this phase of the project:

- System Architecture
- System Requirements
- System Design

The information on each of these documents follows the guide convention described previously: manage for quality, resources, highlights, questions to answer, lessons learned, and example.

Architecture

System architectures can be described from many perspectives using various methods and modeling techniques. Some are described as logical or functional views, physical views, operational views, communications views, and security views. Details of these views can be captured in data, process, and behavior models to aid in the definition of the system.

In this section, we will focus on the logical view, because it captures the functions, flows, controls, and decomposition of a system. This information helps to define what the system must do and helps to understand some of the behavior of the system. Additionally, the logical view leads to development of the physical view. The physical view is simply a logical view that has been allocated to physical components or mechanisms. This allocation to physical components helps to clarify what needs to be built.

Development of the logical architecture is one key resource for describing what the ICMS will do. The logical architecture is a diagrammatic representation of the system. The logical architecture captures the functionality of the system and shows what data or process flows the system will include. The logical architecture also provides a visual representation of the functional requirements, so it can be used as a convenient way to communicate the system to stakeholders rather than having them read through pages of text. The logical architecture can also help to determine when the system functional description is

finished. If all the conceivable scenarios for the system can be traced through the logical architecture, then there is a good possibility that the system functional description is complete.

The logical architecture and requirements should be developed iteratively. The decomposition of functions can often be performed easily through logical architecture diagrams. Once the functions and flows have been decomposed, the requirements can be extracted directly from the flows and functions shown in the diagrams. An example of this will be shown later in section 4.1.3.

Iterative development of the architecture and requirements is helpful. It can be difficult to define a system by simply writing pages of text. Architecture diagrams provide a nice visual check on the way inputs flow through functions and are transformed into outputs.

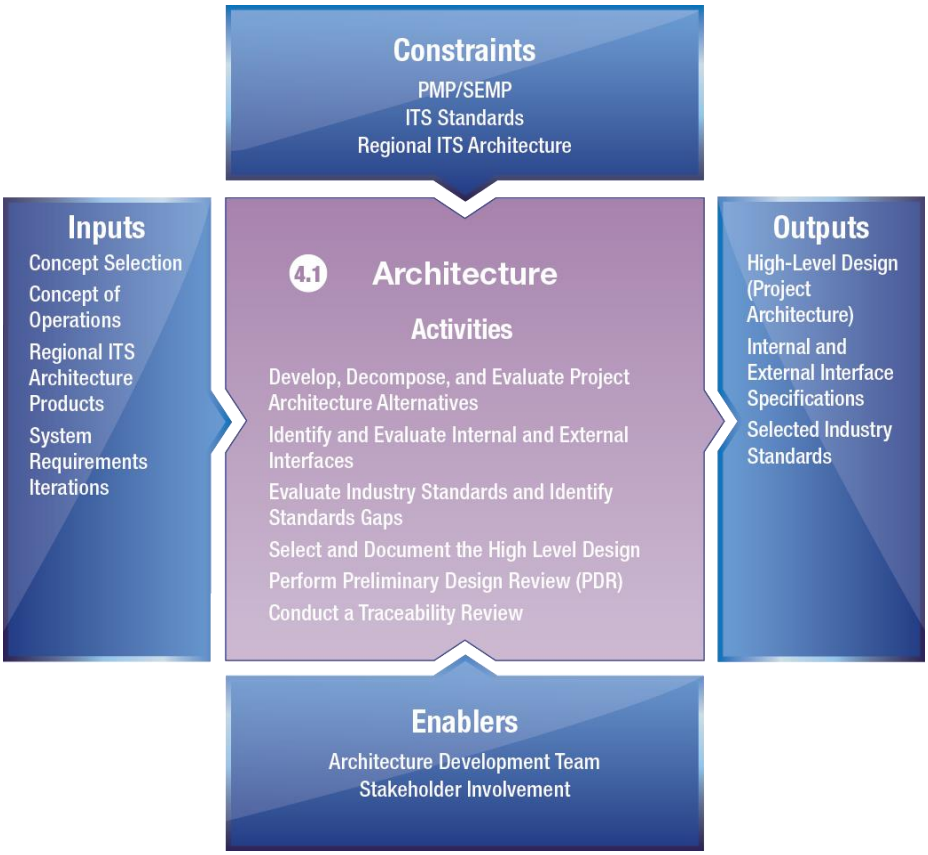
Managing for Quality – Architecture

One of the first things that needs to be accomplished when organizing the logical architecture effort is to choose a stakeholder that will manage and lead the logical architecture work performed by either in-house staff or a contractor. The following checklist includes some of the more important activities that the logical architecture lead will be responsible for:

- Schedule periodic logical architecture team meetings to discuss the logical architecture development, status, action items, and risks;
- Ensure that guidance is made available to those stakeholders that are not familiar with the architecture analysis methodology details provided in the Systems Engineering Process (SEP) section of the SEMP;
- Coordinate among stakeholders to make sure that the correct and necessary information is provided for the logical architecture development;
- Coordinate reviews, walkthroughs, and approvals of the logical architecture, and make sure the work remains on schedule;
- Make sure that the logical architecture is consistent with the user needs, ConOps, and requirements; and
- Ensure that all stakeholders are comfortable with the logical architecture and support it before moving forward.

Figure 13 shows the ICMS architecture planning process. The inputs and constraints should be completed and available prior to beginning the architecture activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the architecture activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the architecture activities successfully.

Figure 13. ICMS Architecture Planning Process



[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.5.2, November 2009]

Logical Architecture Resources

There are many resources available to assist with the development and understanding of system architectures. The Systems Engineering Guidebook for ITS, Version 3.0[41] provides an overview of architecture development. Stakeholders should review this information in the Guide to gain a better understanding of the architecture development process. The National ITS Architecture (logical architecture diagrams) help to identify functions and flows for ICM related services. IEEE Std.1471-2000, *Recommended Practice for Architectural Description of Software-Intensive Systems*[42] is an available standard for system architectures; however, it was not used for developing ICM project architectures at any of the Pioneer Sites, so no good example of its use for ICM is available. Another resource for understanding and using System Architectures in ITS is Florida's Statewide Systems Engineering Management Plan for ITS, Version 2.0.[43] This document explains system architectures and how to apply them at the project level.

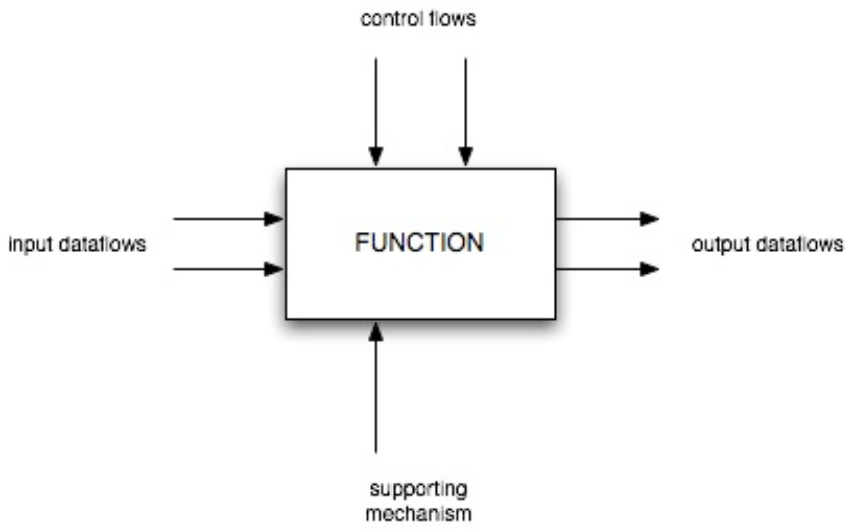
Architecture Highlights

There are various ways to analyze and represent architectures. Two of the more popular ways are through structured analysis and object-oriented analysis. Structured analysis is often used to represent the system architecture and object-oriented analysis is often used for software architectures. Object oriented analysis is a method of analysis specifically designed to efficiently develop software. Structured

analysis was designed to provide logical representations that are easier for humans to interpret intuitively. Because structured analysis methods are relatively intuitive, it makes it easier for systems engineers to communicate the architecture features to stakeholders.

Figure 14 below shows a representation of the Structured Analysis and Design Technique (SADT). The left arrows represent inputs or data flows. The inputs are defined by nouns (e.g., user ID, user name, user account number, etc.). The top arrows represent controls on the system (e.g., rules, regulations, laws, etc.). The right arrows represent outputs and are also defined by nouns (e.g., travel time, speed, heading, etc.). The center box represents a function which is defined by a verb noun phrase (e.g., store data, calculate travel time, provide user response, etc.). The left top and right arrows plus the center box represent pieces of the logical architecture. The bottom arrow describes the system mechanisms (e.g., elevator car, database, printer, etc.). The mechanisms describe physical components to which the logical architecture will be allocated. All of the arrows and the center box represent the pieces of the physical architecture.

Figure 14. Structured Analysis and Design Technique (SADT)



[Source: Structured Analysis Website (Figure 15.11), Open Source Wiki, Last accessed March 23, 2007.]

The systems engineer can begin the logical architecture by reviewing the ConOps. The major functionality of the system should be captured in the ConOps and many of the flows can also be found in the ConOps. The ConOps will not provide all the pieces of the architecture, but it should provide the high-level functionality of the system and enough information to get the architecture started. This baseline architecture will provide stakeholders with a visual representation of the system at a high-level and it will aid in the elicitation of requirements. It is helpful to iterate the logical architecture and requirements elicitation activities. Additionally, logical architecture diagrams are much easier to present to stakeholders to gain their concurrence with the system definition than presenting pages of requirements text. An experienced systems engineer should be able to mine functional requirements from architecture diagrams. For example, Figure 15 is a data flow diagram from the National ITS Architecture, and the requirements below have been generated directly from the diagram.

Focusing on the function (circle) labeled “P1.2.5.4 Determine Dynamic Parking Lot State” shown in Figure 15, one can identify that this function will become a requirement that may be written as follows:

> P1.2.5.4 The system shall determine dynamic parking lot state.

Likewise, “P1.2.5.1 Provide Parking Lot Static Data” from the same diagram may be written as follows:

> P1.2.5.1 The system shall provide parking lot static data.

Note that the verb noun phrase rule used to label the functions makes it easy to also write the requirement and translates easily to the rules for writing requirements discussed in chapter 3, section 4.2 of this document.

The data flows (arrows) going in and out of the functions should simply be thought of in terms of accepting or sending data. Other action words could also be used (e.g., receive, collect, obtain or distribute, disseminate, publish, etc.) In the upper left corner of the function P1.2.5.4 there are two Information Service Provider (ISP) flows that are written as requirements below:

Flow 1: “parking lot dynamic information request by ISPs” could be written as follows:

> The system shall accept parking lot dynamic information requests from ISPs.

Flow 2: “dynamic parking lot information for ISPs” could be written as follows:

> The system shall send dynamic parking lot information to ISPs.

Note that the National ITS Architecture authors took some liberties with the external flows and added some terminator information to the flow name. In this case, “ISP.”

Taking a look at the flow that goes between P1.2 5.1 and P1.2.5.4 ”parking lot static data,” a requirement could be written as follows:

> The Determine Dynamic Parking Lot State subsystem shall accept parking lot static data from the Provide Parking Lot Static Data subsystem.

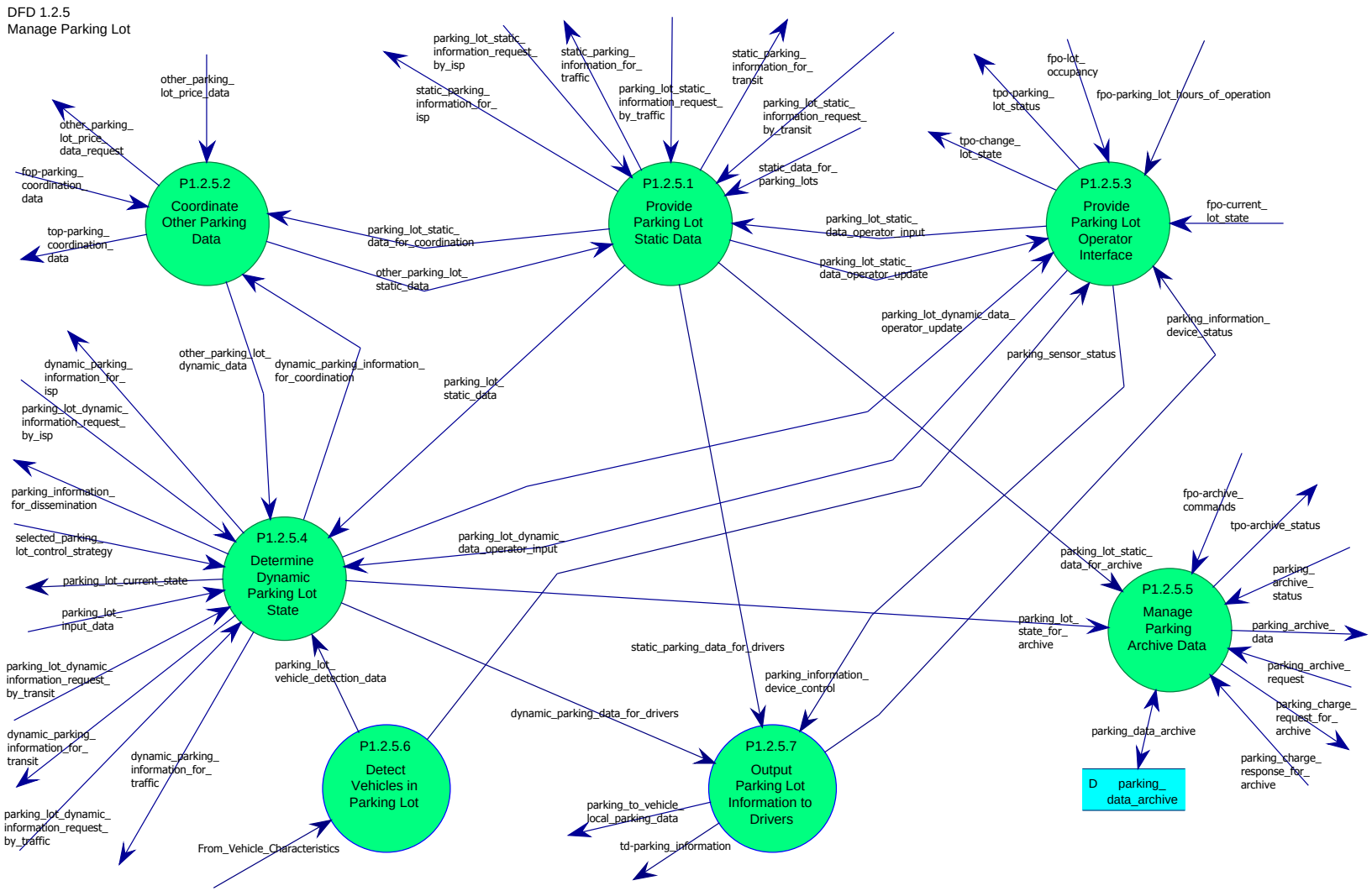
Sub-requirements or "child requirements" would be written for each of the requirements above to clarify precisely what data and information will be accepted or sent. The National ITS Architecture also provides some of the primitive data elements that could be selected for potential sub-requirements. Table 4 below provides examples of the types of flows and associated data elements that can be found in the National ITS Architecture. Note that the ITS standards should also be consulted to confirm data elements that should be used for requirements containing primitive data elements.

Table 4. Example: National ITS Architecture Data Flows and Primitive Data Elements[44]

Architecture Flow (Information Type): *parking information*

- **Data Flow**: *dynamic_parking_information_for_isp*
  - **Primitive Data Elements**: parking_lot_state, parking_lot_identity, parking_lot_occupancy, parking_lot_entrances_closed
  - **Function:** *1. 2. 5. 4-Determine Dynamic Parking Lot State--Out (pms)*
- **Data Flow**: *static_parking_information_for_isp*
  - **Primitive Data Elements**: *parking_lot_hours_of_operation, parking_lot_identity,parking_lot_price,parking_lot_spaces,parking_lot_entrance_location,parking_lot_type,parking_lot_features,parking_lot_fill_time,handicap_access_information*
  - **Function**: *1. 2. 5. 1-Provide Parking Lot Static Data--Out (pms)*
- **Data Flow**: *parking_lot_price_data*
  - **Primitive Data Elements**: *parking_lot_identity,parking_lot_price, parking_lot_charge_application_time, vehicle_type_for_charges*
  - **Function:** 7. 2. 1. 7-Update Parking Lot Data--Out (pms)
- **Data Flow:** *parking_lot_availability*
  - **Primitive Data Elements**: parking_lot_identity, parking_lot_spaces, traveler_identity
  - **Function:** *7. 2. 1. 9-Manage Parking Lot Reservations--Out (pms)*
- **Data Flow:** *parking_lot_reservation_confirm*
  - **Primitive Data Elements:** *parking_lot_identity, reservation_status, traveler_identity*
  - **Function:** *7. 2. 1. 9-Manage Parking Lot Reservations--Out (pms)*

Figure 15. Example: National ITS Architecture Parking Management Data Flow [45]

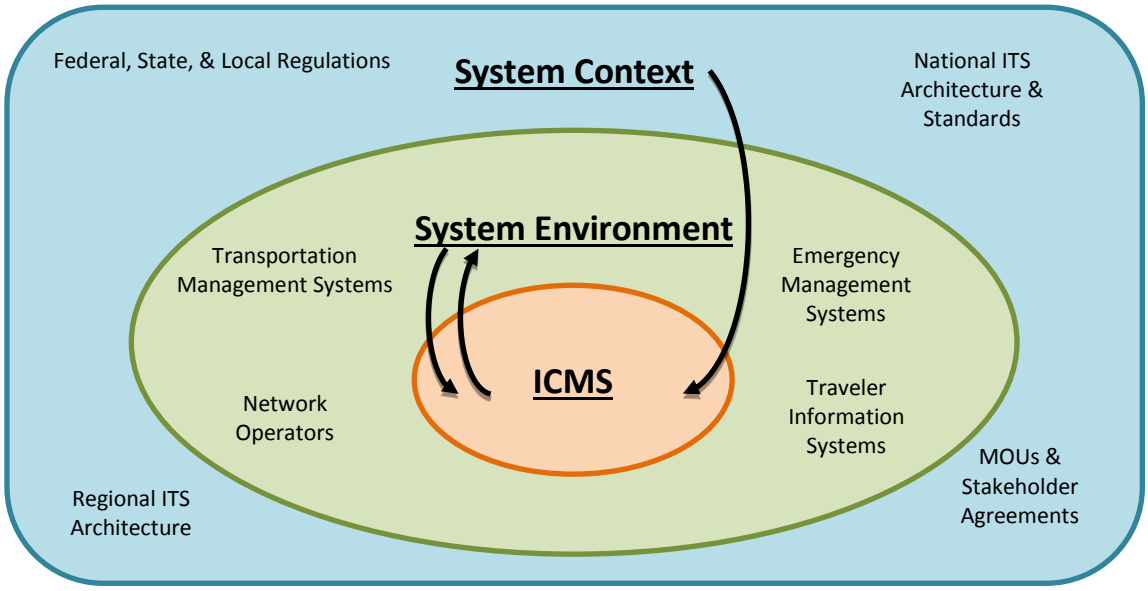


[Source: *National ITS Architecture*, U.S. DOT, http://www.its.dot.gov/arch/, Last accessed 2011.]

As shown above, the National ITS Architecture and regional ITS architectures are good references when beginning the ICMS architecture. The National ITS Architecture has many functions, data flows and user requirements that can be useful when beginning the ICMS definition process including functions and flows related to integrated corridor management (e.g., transit, parking, arterial, freeway, and emergency management). Some regional ITS architectures may not have some of the architecture views included in the National ITS Architecture, but they may have other region specific information that the ICM project will need to conform to. The National ITS Architecture also identifies many of the ITS standards that are required for specific ICMS related interfaces.

When reviewing the architecture work, the reviewers should make sure that the system boundaries have been finalized and that the functions and flows in the logical architecture diagrams are directly traceable to the functional requirements. When finalizing the ICMS boundaries, reviewers should consider the ICM context (see Figure 16). First, consider if items that affect the system, but that the system does not affect, have been determined (e.g., regulations, policies, laws, standards, agreements, etc.). These would be represented as system controls or constraints. Second, consider whether items in the system environment, or items that affect the system and the system has an effect on, have been identified (e.g., transportation management systems, network operators, traveler information systems, emergency management systems, etc.) Third, consider whether items that affect the system environment could eventually impact the system. (e.g., regulations, policies, laws, standards, agreements, etc.). These would be represented as controls or constraints on the system environment. Finally, make sure that the system boundaries are correct. Do not include systems that also serve other purposes within the boundaries of the ICMS. If current corridor systems need to be upgraded as a result of an ICMS implementation, they likely do not fit within the boundaries of the ICMS because those systems were already serving other purposes and were only upgraded to perhaps provide a more robust data set to the ICMS. External system upgrades can be managed with the implementation of the ICMS, but be sure to separate what is part of the ICMS and what is part of an external system upgrade.

Figure 16. ICMS Context Diagram



[Source: Noblis, Inc., for U.S. DOT, 2011.]

Finally, it should also be mentioned that with so many stakeholders involved with an ICMS implementation, it may be advisable to consider several alternative architectures. Evaluating and assessing the feasibility and costs of architecture alternatives helps to promote consensus and ultimately buy-in from stakeholders. Stakeholders should also keep in mind that systems can be defined for incremental implementation. So it may perhaps be beneficial to agree on a system definition with functions that in the short-term do not have to be implemented, but can be implemented incrementally over time as budgets allow. For example, some corridors may start with the integration of data from cross jurisdictional freeways and arterials and include a basic DSS utilizing preapproved response plans. Corridor stakeholders could then gradually include transit, light rail, parking and traveler information systems into their management strategies. The DSS could also evolve over time to include pre-approved multimodal response plans and automated evaluation and prediction capabilities.

Questions to Answer – Architecture

In the initial stages of the architecture development, stakeholders will need to make certain consensus decisions to initiate and finalize the architecture work. This process is typically a difficult thing to do, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed ICMS architecture work and then developing answers to those questions (with the consensus of the stakeholder group). The following is a list of ICM questions to start with:

- Have all constraints on the system been identified?
- Does the architecture consider requirements of the regional ITS architecture?
- Have the system boundaries been identified?
- Does the logical architecture include the functionality and flows discussed in the ConOps?
- Is the logical architecture traceable to the requirements?
- Have all system inputs been traced through to a system output, and have all system outputs been traced back to a system input?

Lessons Learned – Architecture

The following lessons learned apply to this phase of the ICM program.

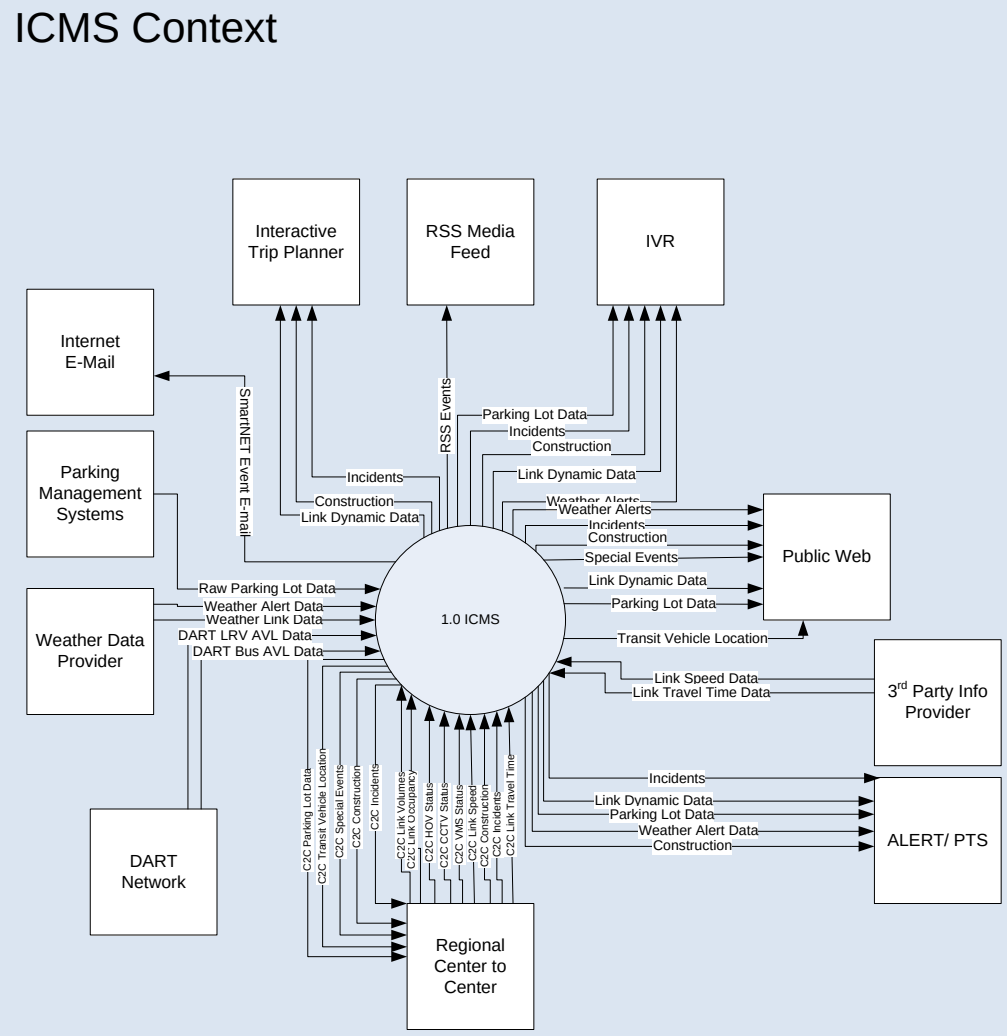
- Defining system boundaries – Gaining agreement on the system boundaries is one of the first steps in initiating the architecture.
- Functional decomposition and requirements hierarchy – Sound methods for functional decomposition and requirements hierarchy should be defined in the SEP section of the SEMP. These methods will serve as the basis for developing the architecture and will be an important guide for reviewers and stakeholders that attend the walkthroughs.
- Architecture and requirements walkthrough – A final draft logical architecture is needed before conducting the requirements walkthrough. The final draft architecture will help walkthrough participants to visualize the system and help to verify the functional requirements.
- Defining the system and external systems – Do not get overwhelmed by the organization, documentation, and definition of external systems and then run out of gas on the definition of the system itself.
- Functional decomposition – Make sure all subsystems are defined and decomposed logically, and make sure internal interfaces are defined for the system.

- Reverse engineering – If put in the position where a portion of the system is being reverse engineered, maintain logical abstraction when developing the logical architecture. Do not label the functions in the logical architecture with names that were designated for a completed physical system.

Pioneer Site Example –Architecture

As part of their work to identify their system boundaries, the Dallas Pioneer Site included an ICMS Context diagram in their system documentation—see Figure 17. This diagram helps to show the ICMS interfaces with existing transportation-related systems. System developers can use the context diagram to help explain the system environment and constraints to project stakeholders.

Figure 17. Dallas ICM Example: High-Level Integrated Corridor Management System Concept



[Source: Dallas ICM SyRS, version 7. 8, January 1, 2011, unpublished.]

Requirements

Having a good requirements development process is vital to defining the details of the system and communicating those details such that a physical system can then be implemented. The System Requirements Specification (SyRS) document organizes and communicates the details of the system including information about the system functionality, internal and external interfaces, constraints, performance, reliability, maintainability, availability, safety, and security. The SyRS provides stakeholders with an opportunity to verify that details of the system have been captured adequately and the project is ready to move forward to software/hardware development and implementation (i.e., build and test). The software/hardware development and implementation teams will closely follow the SyRS to verify that the work they perform meets the stakeholder's expectations.

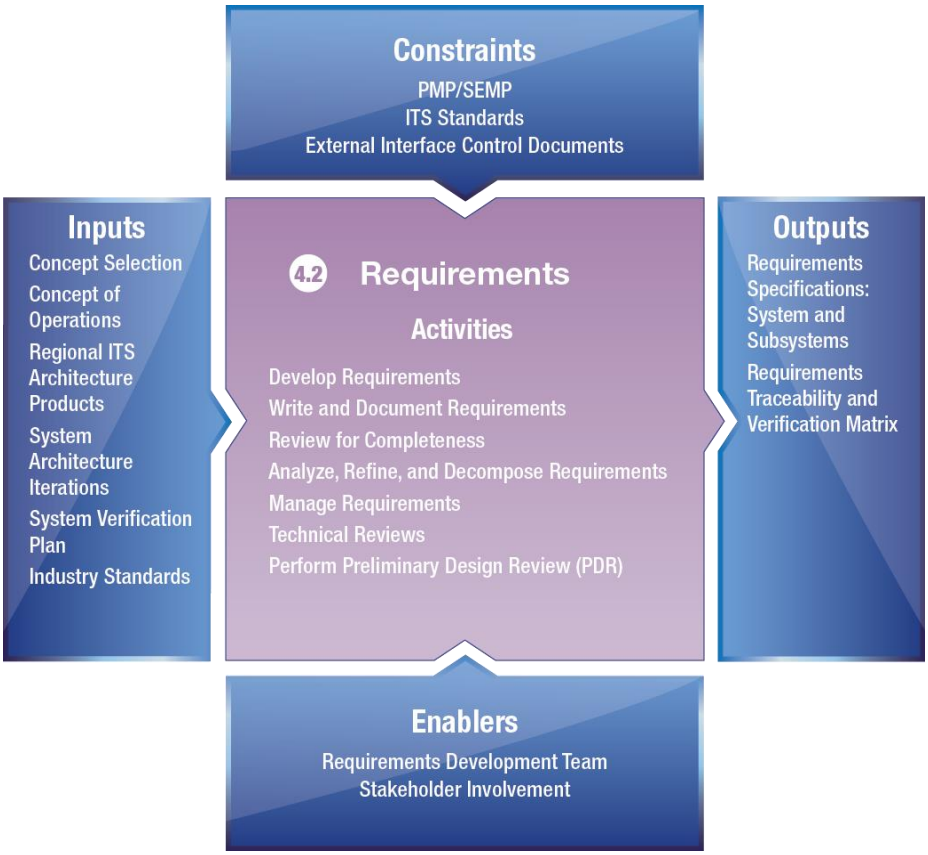
Managing for Quality – Requirements

One of the first things that needs to be accomplished when organizing the requirements effort is to choose a stakeholder that will manage and lead the requirements work performed by either in-house staff or a contractor. The following checklist includes some of the more important activities that the requirements lead will be responsible for:

- Schedule periodic requirements team meetings to discuss the requirements development, status, action items, and risks;
- Ensure that guidance is made available to those stakeholders that are not familiar with the requirements methodology and process details provided in the SEP section of the SEMP;
- Schedule workshops to facilitate the elicitation of stakeholder requirements;
- Coordinate among stakeholders to make sure that the correct and necessary information is provided for the requirements development;
- Coordinate reviews, walkthroughs and approvals of the SyRS, and make sure the work remains on schedule; and
- Ensure that all stakeholders are comfortable with the SyRS and support it before moving forward.

Figure 18 shows the ICMS requirements planning process. The inputs and constraints should be completed and available prior to beginning the requirements activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the requirements activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the requirements activities successfully.

Figure 18. ICMS Requirements Planning Process



[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.5.1, November 2009]

Requirements Resources

There are many resources available to assist with the development and understanding of system requirements. The Systems Engineering Guidebook for ITS, Version 3.0[46] provides an overview of system requirements development and provides a brief template for documenting requirements. Stakeholders should review this information in the Guide to gain a better understanding of the system requirements development process. The IEEE 1233-1998 Guide for Developing System Requirements Specifications[47] is an available standard for development of the SyRS. Another good resource for understanding and developing system requirements is Florida's Statewide Systems Engineering Management Plan for ITS, Version 2.0.[48] This document does a good job of explaining requirements development and provides a template for documenting system and subsystem requirements.

Requirements Highlights

The SEP section of the SEMP contains the requirements process that will be used for the project. That process should include methodologies for eliciting, organizing, and documenting the requirements. In the SEP, the requirements elicitation process, a requirements hierarchy process, and information about constructing well-formed requirements should be provided. The SEP should also explain how the requirements will be traced to both the user needs and the logical architecture.

The SEP section of the SEMP should provide an overview of the requirements elicitation process that will be used. Requirements elicitation techniques can range from informal brainstorming sessions to formal workshops lead by professional facilitators that are skilled at extracting information from stakeholders. Any method that helps stakeholders to successfully communicate what they want the proposed system to do is a good method for requirements elicitation. When holding elicitation sessions consider the following:

- Try to hold sessions with all participants in the same room viewing the same material;
- Distribute information about the process and any other supporting information prior to the meeting, so participants have time to prepare;
- Provide a clearly defined agenda;
- Invite senior level management to show support for the process;
- Invite relevant subject matter experts;
- Keep the number of invitees to a manageable level; and
- Expedite reviews of elicitation sessions and try to conduct and document the reviews of elicitation sessions the same day, but not more than one or two days after the session.

The requirements hierarchy section of the SEP should describe how the requirements will be organized in the SyRS. System requirements will be much more manageable, searchable and traceable with a well-documented requirements hierarchy process. Typically, a requirements hierarchy description will be included in the SEP and SyRS to explain the parent, child, and sibling relationships used for documenting the requirements. The hierarchy description should also include a key that explains how requirements types are defined. An example of the requirements hierarchy process is provided below.

<u>Requirements Type Key</u>

- F = Functional
- I = Interface (interface between ICMS and external systems)
- D = Data (send and receive data within the ICMS)
- C = Constraint
- P = Performance

<u>Parent, Sibling, and Child Relationships</u>

F1. 2 {Parent Requirement}
F1.2.1 {F1.2.1 thru F1.2.3 are child requirements of F1.2 and also siblings}
F1.2.2
F1.2.3 {Parent Requirement for Sub-functions F1.2.3.1 and F1.2.3.2}
F1.2.3.1 {F1.2.3.1 and F1.2.3.2 are child requirement of F1.2.3}
F1.2.3.2 {F1.2.3.1 and F1.2.3.2 are also siblings}

An example of the above can be drawn from the National ITS Architecture example used in chapter 3, section 4.1. Looking back at Figure 15 and developing requirements from the data flow diagram, the flows may be something similar to the following:

F1. 2. 5 The system shall manage parking lot information.
F1.2.5.1 The system shall provide parking lot static data.
F1.2.5.2 The system shall coordinate other parking data
(the term other will need to be defined).
F1.2.5.3 The system shall provide a parking lot operator interface.
F1.2.5.4 The system shall determine the dynamic parking lot state.
F1.2.5.5 The system shall manage archived parking data.
F1.2.5.6 The system shall detect vehicles in the parking lot.
F1.2.5.7 The system shall output parking lot information to drivers.

Requirement F1.2.5 is the parent requirement. Requirements F1.2.5.1 through F1.2.5.7 are children of requirement F1.2.5, and amongst themselves they are siblings. Note that several of the terms used in the requirements will need to be defined including the action words (e.g., coordinate, provide, manage, output, dynamic state, static state). Also, these requirements will need sub-requirements to define the exact information and data that are being referred to.

The SEP section of the SEMP should also define a grammar for writing well-formed requirements. The requirements should then be documented consistently to follow that grammar. “A well-formed requirement is a statement of system functionality (a capability) that can be validated, that must be met or possessed by a system to solve a customer problem or to achieve a customer objective, and that is qualified by measurable conditions and bounded by constraints.”[49]

The following are some questions that are often used when reviewing requirements and determining if they are well-formed:

- Is the requirement uniquely identifiable?
- Does it have a title and does the title reflect the meaning of the requirement?
- Is the requirement well-formed?
    - Does the requirement contain an actor [who]?
    - Does the requirement contain an action [shall do/not do something to]?
    - Does the requirement contain a target [the object of the action]?
    - Does the requirement contain any constraints [how, how often, how many, how fast]?
    - Does the requirement contain any conditions or localizations [if, when, where]?
- Is the requirement unambiguous?
- Is the requirement feasible?
- Is the requirement verifiable?
- Is the requirement logically consistent with the Parent(s) need?

The following requirement provides some examples of common errors when writing system requirements.

> 1.4.2.2 The system operator shall have the capability to distribute parking entrance location, parking availability, and parking price to traveler information service providers.

Three errors associated with the above requirement are described below.

- Error 1: The requirement is written from the perspective of the system operator and not the system. The system operator already has the capability to distribute parking information, if she/he so desires. It is important to remember that, in the SyRS, the capabilities of the operator are not being documented, but the capabilities of the proposed system do need to be documented.
- Error 2: The requirement includes superfluous words "have the capability to." These words can be removed and the requirement conveys the same intent.
- Error 3: The data elements in the requirement are not uniquely identifiable. This can cause problems during testing, because if the distribution of one of the data elements fails the entire requirement fails.

A suggested rewrite for the requirement is as follows:

> 1.4.2.2 The system shall distribute the following parking information to traveler information service providers:
>
> a. Parking entrance location
> b. Parking availability
> c. Parking price

The requirement is now written from the system perspective, it is concise and the data elements are uniquely identifiable.

Another important part of analyzing and documenting requirements is the need to make sure that the requirements trace to and satisfy the user needs. The needs to requirements traceability is typically captured in a Requirements Traceability and Verification Matrix (RTVM). Table 5 is an example of one method used to document requirements, identify traceability to needs, and identify verification methods.

Table 5. Sample Requirements to Needs Traceability (Hypothetical Example)

Requirement ID	Requirement Description	User Needs	Source	Verification Method
F1.1	The ICMS System shall store corridor transportation network data.	1	ConOps §4.2	Test
F1.2	The ICMS System shall support corridor event response decisions.	1	ConOps §4.2	Simulation and Test
I1.2.2	The ICMS System shall receive current status information for the corridor transportation network.	2	ConOps §4.2	Test
I1.3.1	The ICMS System shall send the current status of corridor ITS devices to the corridor agencies	3	ConOps §4.2	Test
C7.1	The ICMS shall comply with operating agreements regarding use of information received from external agencies	7	ICMS Agency External Agreement 10	Demonstration

Questions to Answer – Requirements

In the initial stages of the requirements development, stakeholders will need to make certain consensus decisions to initiate and finalize the requirements work. This process is typically a difficult thing to do, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed ICMS requirements work and then developing answers to those questions (with the consensus of the stakeholder group. The following is a list of ICM questions to start with:

- Can requirements be identified, without gaps, which define an operational scenario from initial system input through to a system output?
- Do all reviewers have easy access to the requirements development and organization methodology?
- Is the requirements organization and hierarchy easy to understand and follow?
- Have all needs been addressed and are they satisfied by the requirements?
- Is there traceability between the needs, requirements and architecture?
- Are action words defined properly in the requirements?

Lessons Learned – Requirements

The following lessons learned apply to this phase of the ICM program.

- Define requirements ID organization – Defining the requirements ID organization and hierarchy is important for managing the requirements documentation and traceability to other needs or requirements. The relationships between parent, children, and sibling requirements should be well defined and understood to avoid confusion during document reviews. Make sure child requirements are related to the parent and make sure that parent requirements have at least two child requirements.
- Keep requirements concise – Writing and reading requirements can be time consuming, so it is best to avoid using superfluous words and keep requirements concise.
- Action word definitions – Each requirement includes an action word that helps to define what the requirement accomplishes (e.g., provide, publish, store, manage, etc.). Make sure that all action words are defined and that there are no conflicting meanings among action words.
- Compound requirements – Each requirement should accomplish one action. If a requirement is compound or references more than one action, consider creating two or more requirements, as needed to capture all actions.
- Compound data flows – When dealing with a requirement that has one action with multiple primitive data flows (e.g., the system shall send user ID, user name, user address, etc.) consider using a lettered list (e.g., a) user ID, b) user name, c) user address, etc.). This allows each of the flows to be uniquely identifiable, which is important when the requirement and flows are tested.
- Understanding requirements terminology – Requirements terminology must be well understood by the requirements authors, especially the use of will, shall, should, and must (e.g., shall requires that an action be performed where should means the action is optional).
- Avoid confusing terms – Confusing terms should be avoided or defined in the requirements document (e.g., productivity, real-time, peak period, continuously, bottleneck, support, etc.)
- Requirements perspective – System requirements should be written from the perspective of the system focusing on what functions the system shall perform. Do not write system requirements from the user perspective as it is not the user that needs to be designed and built.
- Partition requirements – User requirements, system requirements and design requirements should be organized in separate documents or sections of a document.
- External system upgrades – Requirements related to external system upgrades should not be included with the system requirements. External system upgrade requirements should be included in a separate document or added to an appendix of the SyRS.
- System requirements focus – Make sure the system requirements focus on what the system does and not on the external systems and what they do.
- Accessing Interface Control Documents (ICDs) – if ICDs are referenced in the SyRS, provide access to the documents.
- Review user needs – It is a good idea to review needs prior to a requirements walkthrough or set aside a designated time to review them during the walkthrough.
- Preliminary Design Review – When the ConOps, architecture and requirements are at the draft or final draft stage, it is a good time to conduct a preliminary design review to determine whether the preliminary design can be approved and the project can move on to the detailed design stage.

- Solution neutral requirements – Make sure that system requirements are solution neutral to maximize the flexibility of choosing a solution that can satisfy the requirements. Technology is changing so rapidly that it does not make sense to specify a solution when developing system level requirements. It is very likely that lower cost and improved technologies will be available when the system gets to the design and implementation phases.
- Requirements iteration – Plan for the possibility of requirements iteration. Throughout the SE development process it is very likely that the development team will realize that some requirements were missed or were not written properly during initial requirements development. Plan for the flexibility to go back to the system requirements document and make appropriate revisions.
- Requirements elicitation – Start the requirements analysis early, be flexible, and communicate about everything. Conduct some good working sessions to really draw out needs from all partners and translate those needs into robust system requirements.
- Requirements development – The requirements development process was important. If you are new to a system concept the requirements development process helps to identify what is needed and helps to communicate system expectations among partners. For a new system you may not initially know all of your requirements, so it is important to plan for iteration into the process.
- ITS standards expertise – It is importatnt to have ITS standards expertise for system interoperability (e.g., TMDD). Additionally, TMDD may need to be updated to include some data sets for ICMS (e.g., response plan messaging).

Pioneer Site Example –Requirements

In the Dallas ICM system requirements document an action verb list was provided as an appendix. Table 6 shows the Dallas action verb terms and definitions used in the requirements. This action verb list helped to facilitate consistent usage of action verbs in the system requirements document.

Table 6. Dallas ICM Pioneer Site Example: Action Verbs and Definitions

Verb	Definition
Accept	to receive (e.g., data feed from another system)
Activate	to make active; cause to function or act (e.g., to make a planned event an active incident)
Add	to add (e.g., add a timestamp to a record)
Aggregate	to bring together; collect into one
Allow	to give permission to or for
Authorize	to give authority or official power to (associated with security authentication requirement)
Collect	to get from source; assemble
Compare	to examine (two or more objects, ideas, people, etc.) in order to note similarities and differences
Compute	to determine or ascertain by mathematical or logical means
Confirm	to make valid or binding by some formal or legal act; sanction; ratify
Determine	to settle or decide (a dispute, question, etc.) by an authoritative or conclusive decision
Display	to output (data) on a monitor or other screen
Evaluate	to judge or determine the significance, worth, or quality of; assess
Execute	to run (a program or routine) or to carry out (an instruction in a program)
Filter	to remove by the action of a filter

Generate	to bring into existence; cause to be; produce (e.g., generate a log file)
Import	to bring (documents, data, etc.) into one software program from another, implies translate
Manage	to handle, direct, govern, or control in action or use (e.g., manage the add, change, delete of an object)
Merge	to combine or blend
Monitor	to watch closely for purposes of control, surveillance, etc. ; keep track of; check continually
Notify	to inform (someone) or give notice to
Parse	to analyze (a string of characters) in order to associate groups of characters with the syntactic units of the underlying grammar
Predict	to declare or tell in advance; prophesy; foretell
Provide	to make available (e.g., provide a function to a user)
Publish	to make generally known (e.g., publish to C2C)
Receive	to get or be informed of
Recommend	to advise, as an alternative; suggest (a choice, course of action, etc.)
Refresh	to read and write (the contents of dynamic storage) at intervals in order to avoid loss of data
Remove	to get rid of; do away with (e.g., remove from User Interface display)
Reside	- Hardware constraint - e.g., reside in a controller cabinet
Restore	to bring back to a former, original, or normal condition
Restrict	to confine or keep within limits, as of space, action, choice, intensity, or quantity
Retrieve	to locate and read (data) from storage, as for display on a monitor
Save	to copy (a file) from RAM onto a disk or other storage medium
Search	to examine (one or more files, as databases or texts) electronically, to locate specified items
Select	to make a choice; pick
Send	to cause to be transmitted to a destination
Simulate	to create a simulation, likeness, or model of (a situation, system, or the like)
Sort	to arrange according to sort, kind, or class; separate into sorts; classify
Start	to set in operation
Store	to put or retain (data) in a memory unit
Translate	to convert (a program, data, code, etc.) from one form to another
Update	to incorporate new or more accurate information in (a database, program, procedure, etc.)
Use	- Constraint Only - to use a specific technology
Validate	to substantiate

[Source: Dallas ICM, Requirements for the US-75 Integrated Corridor Demonstration Project, version 7. 8, January 1, 2011, Appendix A “Action Verbs”, unpublished.]

Detailed Design

After the preliminary design review has been completed and the high-level design and system requirements have been approved, the component level detailed design can begin. At this point system requirements can be allocated to physical components (hardware, software, mechanical devices, or even manual processes). After the allocation process is complete, detailed design can commence. For example, software systems engineers will develop software architectures and requirements for coders to develop project software, hardware engineers will specify the hardware design to run the software, mechanical devices will be designed to perform system functions, or manual processes will be outlined and designed to perform system functions. Additionally, it may be determined that existing commercial off-the-shelf software could be used to perform system functions. Stakeholders should analyze these individual design possibilities to determine which are feasible, which provide the best performance, and which would be the most cost effective methods of system implementation. These types of analyses are typically referred to as trade-off analyses.

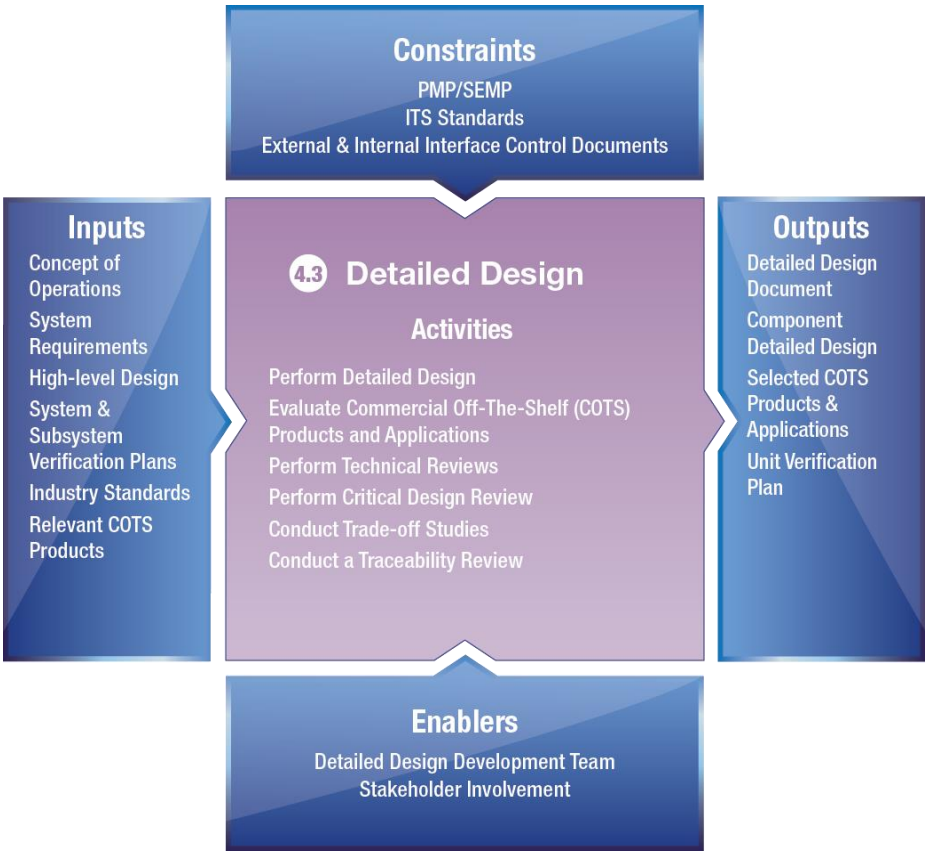
Managing for Quality – Detailed Design

One of the first things that needs to be accomplished when organizing the detailed design effort is to choose a stakeholder that will manage and lead the detailed design work performed by either in-house staff or a contractor. The following checklist includes some of the more important activities that the detailed design lead will be responsible for:

- Schedule periodic detailed design team meetings to discuss the detailed design development, status, action items, and risks;
- Ensure that guidance is made available to those stakeholders that are not familiar with the detailed design methodology and process details provided in the SEP section of the SEMP;
- Schedule workshops to facilitate stakeholder consensus for the detailed design;
- Coordinate among stakeholders to make sure that the correct and necessary information is provided for the detailed design development;
- Coordinate reviews, walkthroughs and approvals of the detailed design, and make sure the work remains on schedule;
- Schedule the critical design review to obtain stakeholder approval of the detailed design; and
- Ensure that all stakeholders are comfortable with the detailed design and support it before moving forward.

Figure 19 shows the ICMS detailed design planning process. The inputs and constraints should be completed and available prior to beginning the design activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the detailed design activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the detailed design activities successfully.

Figure 19. ICMS Detailed Design Planning Process



[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.5.3, November 2009]

Detailed Design Resources

There are many resources available to assist with the development and understanding of system detailed design. The Systems Engineering Guidebook for ITS, Version 3.0[50] provides an overview of system detailed design and provides brief templates for documenting detailed design specifications and interface design documents. Stakeholders should review this information in the Guide to gain a better understanding of the system design process. There are also IEEE guides and standards for activities conducted during detailed design. Stakeholders are encouraged to explore these resources and seek the expertise necessary to guide them to detailed design resources appropriate for control of the design methods chosen for their project. Another good resource for understanding detailed design is Florida's Statewide Systems Engineering Management Plan for ITS, Version 2.0.[51] This document does a good job of explaining detailed design and provides templates for documenting software and hardware development plans.

Detailed Design Highlights

The SEP section of the SEMP should describe the methodology for translating the system requirements to a detailed design (hardware, software, etc.). Numerous methodologies exist for doing this. If the stakeholders are comfortable with specific detailed design methodologies, standards or tools, then they may want to prescribe those methodologies and tools in their contracts. Otherwise, the detailed design team must work with developers to make sure that the methodologies proposed are well understood and

there is consensus on how the work will proceed and what products will be delivered. The detailed design team must make sure that a design review process is established and followed to ensure the quality of the work.

After system requirements have been allocated to a set of physical components/configuration items (CI), a design document should be generated that includes the definition of the design requirements, component specifications, interfaces, data models, testing and acquisition plans for each CI. Technical reviews should also be held to determine the adequacy of the design for each CI.

A system analysis should also be performed including technical trade-off studies, cost/benefit analyses, and risk mitigation alternatives analyses. Stakeholders will need this information to make informed decisions about technical, cost, risk and schedule impacts for all design alternatives.

All of the detailed design work should be captured in an overall detailed design document (DDD). Items that should be addressed in the DDD include:

- System design overview;
- Detailed design overview;
- Configuration item descriptions;
- Data models;
- Interface descriptions;
- User interface descriptions;
- Testing objectives, strategy and plans;
- Technical review plans (entrance and exit criteria);
- Configuration management plans;
- Risk management plans;
- Trade-off analyses; and
- Cost/benefit analyses.

The detailed design team should consider tailoring the DDD as needed and adding any additional plans or processes that are unique to their project management practices.

Near the conclusion of detailed design activities the detailed design team should be preparing for the critical design review (CDR). The CDR process should be defined in the SEMP and the process needs to ensure that the detailed design is ready for implementation. The detailed design team will need to review all detailed design deliverables to determine if they are complete and correct.

Questions to Answer – Detailed Design

In the initial stages of the detailed design development, stakeholders will need to make certain consensus decisions to initiate and finalize the detailed design work. This process can be very complex, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed ICMS detailed design work and then developing answers to those questions (with the consensus of the stakeholder group). The following is a list of ICM questions to start with:

- Do all reviewers have easy access to the detailed design development and organization methodology?
- Does the detailed design trace to the system requirements?
- Have verification plans been developed for each CI?
- Have alternatives analyses been conducted for each CI?
- Is the DDD complete?
- Have technical reviews been completed for each CI?
- Has the critical design review been conducted?
- Have all system and sub-system requirements been updated based on updates determined during the detailed design process?

Lessons Learned –Detailed Design

The following lessons learned apply to this phase of the ICM program.

- Design document updates – Should occur when design is altered or more detail is added due to prototype, variances, and additional work orders . A new release is not expected, however the working copy of the design document should be modified and available online.
- Design review – Milestones should be taken seriously and successful completion should be a prerequisite for proceeding to the next review phase.
- Standards – Use of the NTCIP communications standard was key to enabling integration of central software and field equipment from different manufacturers, and in giving the City the option to purchase future field equipment from different manufacturers.
- Documentation – Well documented software allows other system integrators to upgrade the system. It may be better to go with open source data and code. Accessibility of data needs to be built in to the system.
- Legacy system compatibilities – Stakeholders need to know your legacy systems and versions and capabilities from the start. It is important to know exactly what versions of C2C that each jurisdiction is running. If there are incompatibilities, then system upgrades will be required.
- Data feed plan B – It is good to have multiple data sources for the same data, because sometimes a particular data source is not available. It is good to have a plan B for all the data sources.
- Environment and seasonal impacts – Consider environmental and seasonal impacts to deployed subsystems. Consider whether environmental condition (e.g., heat, sunlight, snow removal chemicals) may impact some of the data collection subsystems that are installed in the field.
- Signal system operating potential – It is desireable to have signal systems with the same or similar operating potential. If partner jusrisdictions have older systems with limited potential those limitations will impact the effectiveness of the overall ICMS.
- Choosing system solutions to meet requirements – Having demonstrations of a prototype system early on helps to make sure the system meets operator needs and requirements. It is good to also have an early look at screen shots for the human machine interfaces to make sure that they meet operator needs.
- Harnessing data feeds – Make sure you are in touch with the people that have the data feeds and the technical knowledge about those feeds. The more you can automate your data feeds into the

ICMS the better, so you do not have to open multiple systems to get all the information that you need.

- Harmonizing base maps – Base maps will likely be different from various data sources and the links on the maps will likely be defined differently, so there will need to be a way to translate the different data schemes and harmonize all the map and link data.
- Response plan adjustments – Expect that the number of response plans will need to be adjusted once live operations begin. It may be better to start with a broader set of response plans and then narrow that down to a key set of the most useful response plans.
- Response plan development – Response plan development will take time, will have many dependencies and will require close coordination with signal timing plans. Leverage subject matter experts and provide the time and resources necessary for them to develop successful plans.
- Multiple Event Logs – If multiple users initiate a log for the same an event in the ICMS, then the system must be able to associate the multiple entries and close them when the event has cleared
- Harmonizing data element identifiers – If you are accepting various data elements from multiple networks/agencies, data elements (e.g., link identifiers) will likely be different across agencies for the same link. The system will likely need to use translation tables to manage the differences. These translations should also be verified for accuracy during testing.
- Harmonization of maps – If maps are used for the ICMS, requirements should be considered to address map updates. Operational procedures should also be considered to address map updates. For example, if roadways or transit lines are added to the system, then these updates need to be communicated well in advance so the ICMS can be updated. Likewise, if transit schedules or HOV lane schedules change, these operational changes need to be communicated so the ICMS or response plans can be updated.
- Harmonize system controls – Controls on the system (e.g., IT policies for the number of system login failures) should be harmonized across agencies. Some agencies may allow three login failures before a user is locked out and some agencies may allow an unlimited number of attempts. These issues should be addressed and agreed upon by all participating agencies well before the system is implemented.
- Graphical user interfaces (GUI) – Access your agency's IT policy for GUIs to help develop GUI system requirements and design details. If your agency has no policy on GUIs, access online resources for GUI development, GUI standards, or other GUI resources to help in the definition of needs, requirements, and design features desired for the GUI/system under development.

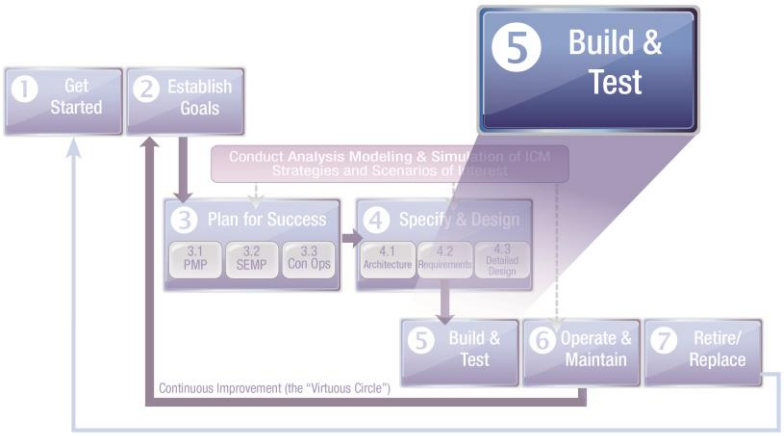
Pioneer Site Example –Detailed Design

As part of the Dallas Pioneer Site detailed design activities and documentation, the ICM Team included a process for making the "build, buy, and reuse" decisions. This activity involves investigating and documenting options and the related rationale for developing or acquiring the required capability through the following steps:

- Make Build/Buy/Reuse Analysis
- Verify Reuse Options
- Develop and Analyze Design Alternatives
- Make Build/Buy/Reuse Decisions
- Communicate Build/Buy/Reuse Recommendation
- Create Bill of Materials

[Source: Dallas ICM Architecture and Design Process document, June 2011, unpublished.]

Having a process in place provides a methodology to ensure that the best decisions are made and the stakeholders have the confidence to move forward with the project.



[Source: Research and Innovative Technologies Administration, ITS JPO.]

Build and Test (Phase 5)

After the CDR has been completed and the detailed design has been approved, system development and implementation can begin. This is also referred to as "build and test" in this guide. At this point system components (hardware, software, mechanical devices, or even manual processes) can be built or developed per the approved DDD. Additionally, if COTS products are going to be used, they can now be purchased. After components are built, developed, or purchased they can then be tested, integrated, and implemented.

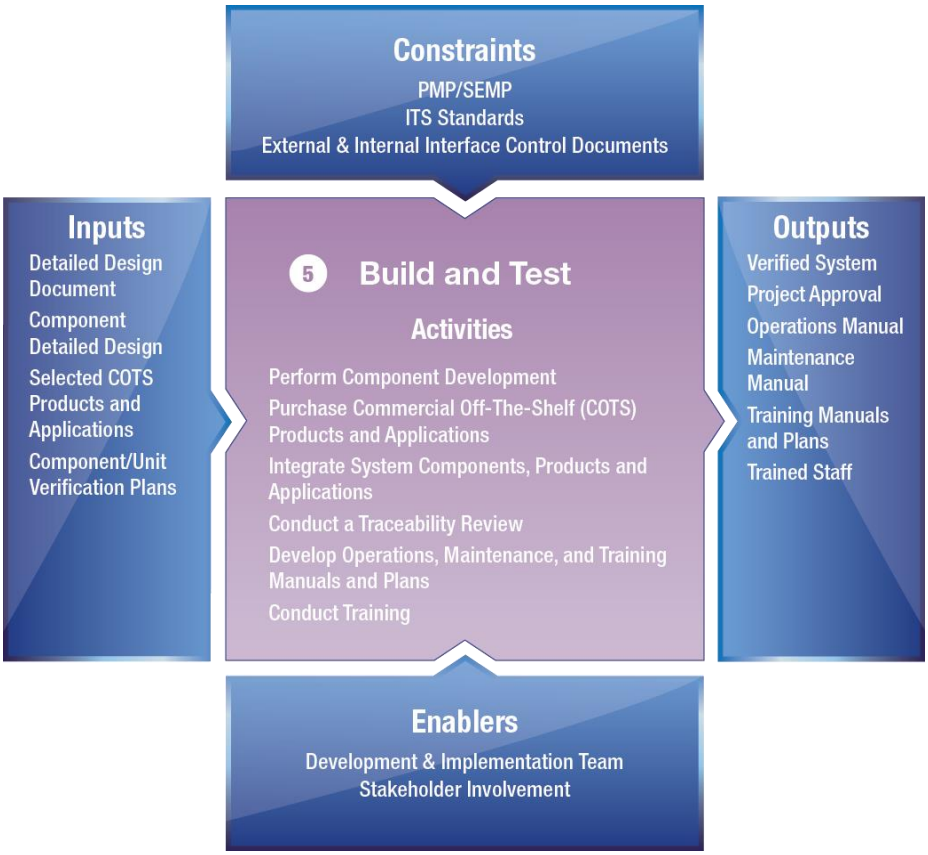
Managing for Quality – Build and Test

One of the first things that needs to be accomplished when organizing the development and implementation (build and test) effort is to choose a stakeholder that will manage and lead the development and implementation work performed by either in-house staff or a contractor. The following checklist includes some of the more important activities that the development and implementation lead will be responsible for:

- Schedule periodic development and implementation team meetings to discuss the development and implementation activities, status, action items, and risks;
- Ensure that guidance is made available to those stakeholders who are not familiar with the development and implementation methodology and process details provided in the SEP section of the SEMP;
- Schedule workshops to facilitate stakeholder consensus for development and implementation;
- Coordinate among stakeholders to make sure that the correct and necessary information is provided for the development and implementation activities;
- Coordinate reviews, walkthroughs, testing and approvals of the development and implementation activities, and make sure the work remains on schedule; and
- Ensure that all stakeholders are comfortable with the development and implementation work and support it before project acceptance.

Figure 20 shows the ICMS development and implementation (build and test) planning process. The inputs and constraints should be completed and available prior to beginning development and implementation activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the development and implementation activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the development and implementation activities successfully.

Figure 20. ICMS Build and Test Planning Process



[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.6, November 2009]

Build and Test Resources

There are many resources available to assist with the development and understanding of system development and implementation (build and test). The Systems Engineering Guidebook for ITS, Version 3.0[52] provides an overview of the hardware and software development and subsystem and system integration processes. It also provides templates for integration and deployment plans and system verification. The IEEE also provides guides and standards for activities conducted during system development and implementation. Stakeholders are encouraged to explore these resources and seek the expertise necessary to guide them to development and implementation resources appropriate for control of the system development and implementation methods chosen for their project. Another good resource for understanding system development and implementation is Florida's Statewide Systems Engineering Management Plan for ITS, Version 2.0.[53] This document does a good job of explaining system

development and implementation and provides templates for documenting system verification plans, procedure, and reports and system integration support plans.

Another reference related to testing is the FHWA "Testing Programs for Transportation Management Systems Technical Handbook."[54] This handbook contains an in-depth discussion of testing methods, approaches, and types, as well as appendices with real-world examples. Three of the appendices have information very useful to those implementing an ICMS:

- Appendix A. Example Verification Cross Reference Matrix
- Appendix B. Sample Test Procedure
- Appendix C. Sample System Problem / Change Request (SPCR) Form

Build and Test Highlights

The SEP section of the SEMP should include a tailored set of technical planning documents needed for a particular project. Some of these planning documents may need to be identified and added to the SEMP as the project progresses and the need for additional project controls becomes apparent. The following list is a set of technical planning documents provided in the Systems Engineering Guidebook for ITS, Version 3.0.[55] these types of planning documents may be of use for the organization and execution of ICMS deployment:

- Technology Plan – describes the technical and management process to apply new or untried technology to an ITS or ICMS use. Generally, it addresses performance criteria, assessment of multiple technology solutions, and fallback options to existing technology.
- Interface Control Plan – identifies the physical, functional, and content characteristics of external interfaces to a system and identifies the responsibilities of the organizations on both sides of the interface.
- Technical Review Plan – identifies the purpose, timing, place, presenters & attendees, subject, entrance criteria, [a draft specification completed] and the exit criteria [resolution of all action items] for each technical review to be held for the project.
- System Integration Plan – defines the sequence of activities that will integrate software components into sub-systems and sub-system into entire systems. This plan is especially important if there are many sub-systems produced by a different development team.
- Verification Plan – almost always required, this plan is written along with the requirements specifications. However, the parts on conducting testing can be written earlier.
- Verification Procedures – define the step-by-step procedure to conduct verification. and must be traceable to the verification plan.
- Installation Plan or Deployment Plan – describes the sequence in which the parts of the system are installed/deployed. This plan is especially important if there

are multiple installations at multiple sites. A critical part of the deployment strategy is to create and maintain a viable operational capability at each site as the deployment progresses.

Identifying and developing the various development and implementation (build and test) plans helps to establish the overall implementation approach for the project. These plans need to address every aspect of deployment, including the roles and responsibilities of all stakeholders involved with the deployment and how sequencing and managing the deployment will occur.

It is important to know who will be performing unit and system verification, when it will occur, and how it will be performed. Likewise, it is important to know how unit integration will be managed, who is responsible for managing it, and the sequence of the integration. Similarly, the technical reviews need to be defined, scheduled, and managed to ensure adequate project control and quality.

Also during this stage of the project, the plans for operations, maintenance, and training need to be established. Operations, maintenance, and training guides need to be developed prior to moving into the actual operations and maintenance stage of the project. An ICMS will likely have many stakeholders that need to be trained prior to system acceptance, which is the point where actual O&M can begin.

When the development and implementation stage is completed, then the system acceptance testing (SAT) can begin. Often it is helpful to have an independent verification and validation (IV&V) team perform the final verification to determine whether the system meets the requirements. If the system passes system verification then the ownership of the system can be transferred to the ICM stakeholders.

Questions to Answer – Build and Test

In the initial stages of development and implementation (build and test), stakeholders will need to make certain consensus decisions to initiate and finalize the development and implementation work. This process can be very complex, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed ICMS development and implementation work and then developing answers to those questions (with the consensus of the stakeholder group). The following is a list of ICM questions to start with:

- Do all reviewers have easy access to the development and implementation organization methodology?
- Have the development and implementation goals and objectives been established?
- What development and implementation approach will be followed?
- Have all resources been secured for the project including funding?
- Have all stakeholders agreed to the deployment schedule?
- Are all stakeholders prepared to accept O&M of the system upon final acceptance?
- Has the system, subsystems and components been verified?
- Have all verification reports been received?
- Have relevant stakeholders been trained for the O&M of the system?

- Have the O&M manuals been verified?

Lessons Learned – Build and Test

The following lessons learned apply to this phase of the ICM program.

- Prototyping – The system should be demonstrated on an actual workstation mock-up.
- Independent Contractor Test Team – Confirm adequate coverage in specification to assure this standard development process protocol.
- Operator training –Conduct training early enough in the project to provide available and qualified resources to support testing activities.
- Testing – Thorough and realistic testing at every stage of system implementation, involving the owning agency in testing, and testing every change no matter how small and seemingly inconsequential, helps with progress monitoring and avoids expensive and time-consuming field retrofits. Take the verification process seriously and check things thoroughly. Plan to spend a lot of time on testing to make sure the system works as expected.
- Data feed testing – Plan to do a lot of testing to see if information coming into the system matches what the operators are perceiving.
- IV&V – Using a qualified independent verification consultant was a contractual requirement of the agency and is felt to have been critical to the success CHART has achieved to date.
- Qualifications – The contract required that the software contractor have a solid history of using systems engineering and also required that the winning contractor bring its documented internal systems engineering processes to the project and train the agency in its use.
- System trouble shooting – Monthly meetings to trouble shoot issues and review the system and data output to make sure it is accurate are very helpful. Showing the results of response plans in analyses is helpful to review the system performance. Reviewing traffic counts and other data sources you can use for analyses and confirmation is helpful. Lots of meetings to verify requirements and system performance are beneficial for achieving the desired project results.
- Iterative build process – Consider using an iterative build process for new components of a system. For example, a decision support system can be developed in multiple ways using multiple strategies. It may be that several options need to be explored to fulfil stakeholder expectations. Iteration can help to take development in a piece by piece process when there is uncertaintity in using new tools.
- Going live – Have a preproduction system and production system maintained for all development and upgrades. With the preproduction system, you can test upgrades before they go live and troubleshoot some problems with a live system.
- Soft launch – Be sure to have a shakeout period prior to the operations and evaluation periods to work out any bugs in the system. Do a soft launch prior to advertising the system to the public. There will likely need to be some adjustments based on findings from a live operational test period.
- Testing takes time – It would be nice if the testing process could be shortened, but that's probably not realistic. All partners should be prepared for a time commitment. Do not allow the test periods to suffer due to delays. Deployers should expect that resources dedicated to testing will be vulnerable to schedule delays. Test planning is complex and the development team should conduct multiple dry runs well in advance of acceptance testing. Also, keep in mind that ad-hoc additions to the test plan during testing can be problematic.

- Consider some early verification and validation – Some early testing with a prototype may be useful, especially when it comes to the user interfaces with the system. This could be done earlier at stakeholder meetings to help facilitate collection of stakeholder feedback and buy-in on the design.
- Test procedures – Testing procedures, including criteria for acceptance of each component, sub-system, and system, should address who is responsible for developing / approving the test procedures, who is responsible for conducting and monitoring the test, and procedures in the event a test is not passed.
- Test readiness – The SAT plan should be finalized and approved well in advance of the TRR and SAT. If a SAT plan is still undergoing changes throughout the week prior to the TRR or the SAT, the system is likely not ready for testing. The SAT plan should be finalized and vetted with all stakeholders prior to the TRR.
- Test environment preparation – Those responsible for conducting system testing need to perform a dry run of system testing in the actual test environment to make sure that the system is accessible and that there are no barriers or limitations to performing the system testing.
- Hardware testing – System Acceptance Testing is not just performed for software testing. Hardware should also be tested or certified for, among other things, operation in the intended operational environment and for expected reliability. Hardware with a short lifecycle or high failure rate would not be recommended for an ICMS.
- Failure testing – Failure testing should be included in all system testing. Testers should intentionally enter data that they know to be incorrect or unexpected by the system to see how the system handles erroneous input.
- Operational test environment vs. simulated test environment – Testing in a simulated test environment should be kept to a minimum and should not add confusion to the operational system testing process.
- Incremental testing – If it is clear that system testing will need to occur in phases, the test team needs to have a plan in place to conduct the incremental testing and communicate to stakeholders their plan for conducting all phases of the testing. This plan should be reviewed at each test phase so stakeholders know what to expect going forward. The plan should identify which items will be tested in each phase and the timeframe for that testing. If the plan changes, the changes need to be communicated to the stakeholders as soon as possible.
- Additional Testing – If items tested do not meet expectations, the test team needs to explain to stakeholders how and when additional testing will be conducted to resolve testing concerns.

Pioneer Site Example –Build and Test

The Dallas Pioneer Site SEMP successfully conducted the reviews outlined below in the Build and Test phase of their project. These reviews are important to ensure quality of the system build.

System Readiness Reviews (SRR)

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

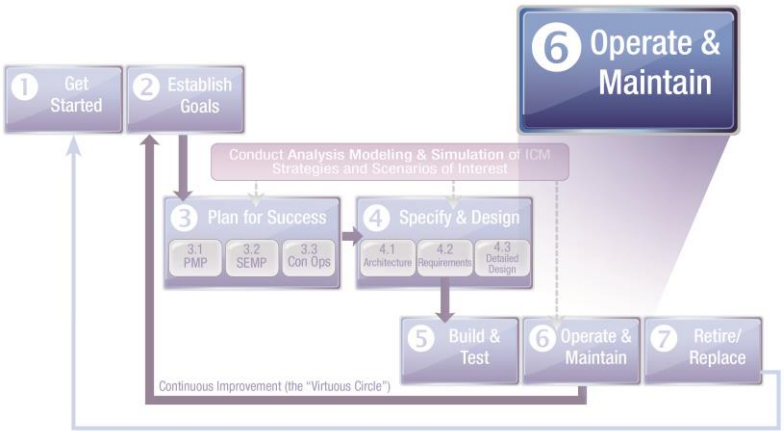
There are three (3) levels of Test Readiness Reviews at the sub-system level as defined below:

- Development Test Readiness Review – informal test readiness review conducted following successful completion of unit / module testing of a given sub-system
- Functional Test Readiness Review – formal test readiness review conducted following successful completion of the functional Test of a given sub-system.
- Integration Test Readiness Review – formal test readiness review conducted following successful completion of integration test of a given sub-system.

There is one level of Test Readiness Review conducted at the Enterprise level, and an Implementation Readiness Review following Enterprise testing as defined below:

- Acceptance Test Readiness Review – formal test readiness review conducted following successful completion of the Integration Test and Performance Test of each release.
- Go-Live Readiness Review – formal review conducted following successful completion of the System Acceptance Test and assessment of the system to go operational.

[Source: Dallas ICM Demonstration Project, Systems Engineering Management Plan, pages 38 and 39, January 1, 2011, unpublished.]



[Source: Research and Innovative Technologies Administration, ITS JPO.]

Operate and Maintain (Phase 6)

Operations and maintenance activities include operating the system, monitoring system performance, performing system diagnostics, making repairs, and making updates and changes to the system. Once the ICMS has been accepted, stakeholders will take over the responsibility of operating and maintaining the system. Because the system will serve so many corridor operators for many different purposes, decisions need to be made about the roles and responsibilities for system operations and maintenance. As identified in the previous phase, prior to system acceptance, corridor operators will have established leadership structures and agreements that outline how operations and maintenance will be managed among the stakeholders. In this phase the stakeholders will refine and finalize the specific plans and procedures for operating and maintaining the system.

Managing for Quality – Operations and Maintenance, System Validation

One of the first things that needs to be accomplished when organizing the operations, maintenance, and system validation efforts is to choose a stakeholder that will manage and lead the work performed by either in-house staff or a contractor. The following checklist includes some of the more important activities that the operations, maintenance and system validation lead will be responsible for:

- Schedule periodic O&M team meetings to discuss concerns about O&M activities, status, action items, and risks;
- Assess system validation with stakeholders and the O&M team to determine whether the correct system was built;
- Facilitate needed O&M updates and changes;
- Ensure that guidance is made available to those stakeholders that are not familiar with the O&M processes provided in the O&M plans initiated in the SEMP and finalized after system acceptance;
- Coordinate among stakeholders to make sure that the correct and necessary information is provided for O&M activities;
- Ensure that all stakeholders are comfortable with the O&M process; and

- Coordinate with public spokespersons to plan and conduct a public relations campaign to disseminate information on transportation policy and planned actions.

Figure 21 shows the ICMS O&M planning process. The inputs and constraints should be completed and available prior to beginning the O&M activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the O&M activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the O&M activities successfully.

Figure 21. ICMS Operations and Maintenance Planning Process

[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3. 7, November 2009]

Operations and Maintenance Resources

There are many resources available to assist with the development and understanding of system operations and maintenance. The Systems Engineering Guidebook for ITS, Version 3.0[56] provides an overview of the operations and maintenance processes. It also provides templates for operations and maintenance plans and system validation documentation. The IEEE also provides guides and standards for conducting system operations and maintenance. Stakeholders are encouraged to explore these resources and seek the expertise necessary to guide them to operations and maintenance resources appropriate for control of the system operations and maintenance for their project.

Operations and Maintenance and System Validation Highlights

Prior to the acceptance of the ICMS, each participating stakeholder should have a plan in place to operate its portion of the ICMS. Operators need to be trained and ready to manage the day-to-day responsibilities of the system. It may be a good idea for operators to perform initial and periodic simulations for randomly selected events if the ICMS allows for simulations without interrupting normal operations of the corridor. Through simulations and real corridor events, operators will be able to assess the performance of the ICMS, identify where the ICMS may be vulnerable, and propose upgrades or changes. These changes will of course need to follow the change management process defined in the PMP, which would include a complete vetting with all corridor stakeholders to achieve a consensus decision and approval. Stakeholders should have a documented process to address issues or problems that arise with ICMS operations, vet those issues or problems, develop solutions to any problems encountered, and agree on remedial actions.

Additionally, the ICMS will require regular maintenance, so all the mechanisms need to be in place to enable maintenance activities once the system is accepted. A maintenance plan should be implemented and include preventive maintenance measures to make sure the ICMS is running at optimal levels. The system should include diagnostic capabilities to determine if it is running at peak performance. Over time, maintainers may need to recommend system upgrades or modifications to facilitate peak performance of the system. Stakeholders should conduct periodic technical reviews to monitor and assess system performance, especially system failures and repair times.

After the system has been accepted and the system is in operation, stakeholders should be able to determine whether the deployed ICMS met the intended needs. In other words, “Was the right system built?” The system validation planning process should be included in the SEMP and can be executed during this stage of the project process. The ICMS stakeholders are responsible for this activity, which helps them to determine if they asked for the right tools to address their corridor problems. This process will also help stakeholders to identify and document lessons learned for future system acquisitions.

Questions to Answer – Operations and Maintenance and System Validation

In the initial stages of O&M and system validation, stakeholders will need to make certain consensus decisions to initiate and finalize the O&M and system validation work. This process can be very complex, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed ICMS O&M and system validation work and then developing answers to those questions (with the consensus of the stakeholder group). The following is a list of ICM questions to start with:

- Has the O&M plan been developed and approved by all stakeholders?
- Do all stakeholders understand their roles and responsibilities for O&M?
- Have O&M personnel been trained for system start-up?
- Have procedures been developed for system monitoring and issue resolution?
- Were valid system needs identified and documented?
- Were needs, objectives and goals measureable?
- Are all stakeholders participating in the system validation?
- Do stakeholders understand the validation plan and purpose?

Lessons Learned – Operations and Maintenance, System Validation

The following lessons learned apply to this phase of the ICM program.

- Training – Adequate training of all involved personnel is important, especially when new technology is being used or existing technology is being used in a new way.
- Transition – A carefully planned, methodical cut-over plan can add to the efficiency of changing over from old to new equipment.
- System staffing agreements – It is important to have all partner networks staffed because response plans need to be implemented within minutes to make sure they are effective. Consider having an agreement that says each partner will have their system staffed.
- Operations and Maintenance funding – Funding should be proportional to the population who will be using the system. This becomes very important when it comes time to be responsible for funding O&M. Participating agencies need to take charge and pay their part of O&M. Ongoing operations need ongoing funding. New regions that want to join the ICM should pay proportionately to gain ownership. Ongoing benefactors should pay to support the system.
- Communicate corridor changes – Stakeholders may want to formalize agreements to communicate corridor changes (e.g., construction, system upgrades, and maintenance) to the ICM Coordinator to help manage distruptions to the ICMS. Staff turnover plan – Staffing turnover can be distruptive to system operations. It is important to have a good staffing turnover plan to help get new staff up to speed as soon as possible.
- Operating hours – For full ICMS operation it best to have more personnel to cover all hours of the morning and evening rush hours.
- Dedicated ICM Coordinatior – Ideally having a dedicated ICM coordinator helps to achieve the full potential of the system. The coordinator does a great job of keeping the system working smoothly. The system does require some human interaction to make sure plans are being fully implemented to meet the needs of the corridor. The system supplies the implementation recommendation and the coordinator provides the follow up to make sure the recommendations are implemented to the benefit of the corridor.
- ICM Coordinator transitioning – Consider the potential for the ICM Coordinator responsibility to be transitioned to another agency and plan for it early and thouroughly. Consider potential impacts due to the project transition. Make sure all stakeholders have new contact information and are aware of new roles and responsibilities. Consider practicing the transition to make sure everyone is comfortable with then new leadership and the process is working smoothly.
- Lifecycle funding – ICM deployers need to make sure that they consider lifecycle costs. You need to look ahead into the future for the funding of the system operations and maintenance and updates to the system. You need to consider periodic timing updates, response plan updates, and other analyses to make the system work efficiently. Also, the benefits of the system need to be proven with accurate data and information to make the case for additional funding.
- Maintenance planning – Need maintenance plans for detection to make sure the system remains operational. Re-evaluating signal plans is something that needs to be planned for in design and maintenance. You have to have ongoing system update plans. Also, the communication plans for conveying system updates to partners needs to be well considered and managed (e.g., street names change, construction plans, etc.). You also need a document that shows the plans for how the system continues to operate, the roles and responsibilities among agencies, and the agreements among agencies.

- Roles and resposiblities – Make sure that there are clear roles and responsibilities for operations and maintenance (e.g., who do you contact when a server crashes at 3 am?)
- Response plan contacts – Operators need to know the numbers to call and have response teams available to implement response plans quickly. Make sure all contact information (e.g., numbers, rolls and responsibilities) are available to all stakeholders.
- Backup point of contact plans – Backup plans should be considered for agency points of contact. What happens if an agency representative is contacted about an event and no response is received? Who is the backup contact? Would a jurisdiction be ignored if no response is received?
- Response plan implementation – The DSS makes decisions based on traffic flow and sometimes the flow picks up before incidents are confirmed a response plan can be initiated. In many cases incident durations are not long enough to implement a plan. Camera feeds may not be available to visually confirm the type of incident and whether it may take a long time to clear. These types of issues need to be considered when initially defining the system and how it will operate. All stakeholders need to consider and understand the system limitations in order to manage incidents effectively and in order to find ways to manage the system limitations.
- Training – As a refresher, it is good to make sure that there is a training session just before the system goes live.
- Ongoing collaboration – Subcommittees need to continue to meet to help optimize the system and address ongoing issues. ICM stakeholders have to remember that any changes to their systems can impact the operations of other ICM stakeholders, so continued collaboration is necessary for the process to work.
- Troubleshooting – Monitor how often response plans are recommended, if changes are seen in data and response plan recommendations, it could be due to interruptions in data feeds.
- Response frequency – Agencies should not expect to see response plans recommended or implemented on a daily basis. Transportation networks are generally resilient enough to handle small or even moderate impact incidents without much intervention. However, having a system in place to handle the larger incidents and facility closures can be a real benefit.

Pioneer Site Examples –Operations and Maintenance and System Validation

One activity included in the draft operations and maintenance plan at the ICM San Diego Pioneer Site is to monitor, assess, and improve institutional/organizational coordination using the performance measures shown in Table 7 below.

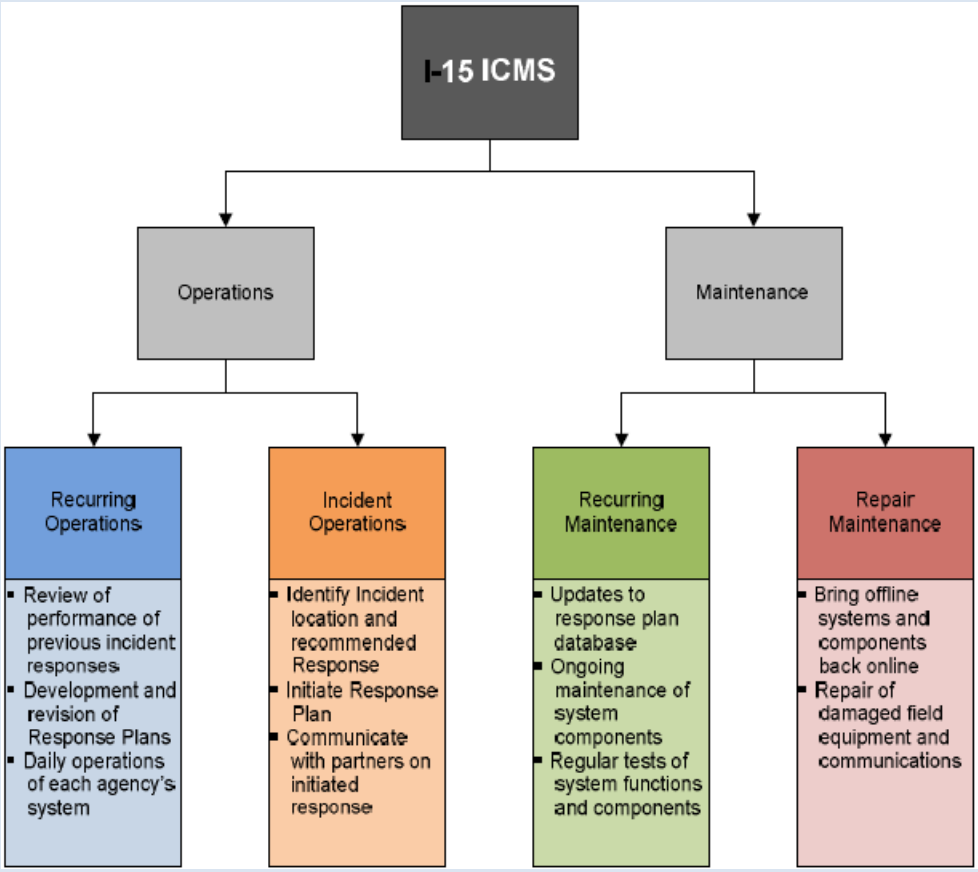
Table 7. San Diego Example: Performance Measures for Institutional/ Organizational Coordination

Performance Measure	Units	Measurement Approach
Number of communications between transportation partners	no.	automatic tracking through I-15 ICMS III
Number of predefined strategies for coordinated action	no.	running count kept during quarterly review meetings
Number of new coordination agreements	no.	count taken in the course of operations plan development
Coordination satisfaction levels for each partner agency	%	survey conducted as part of the quarterly review process

[Source: San Diego ICM Pioneer Demonstration Site, *I-15 ICM Stage III Demonstration Project, Draft Operations and Maintenance Plan*, Version 1200, 1/19/11, p. 44, unpublished.]

Also at the ICM San Diego Pioneer Site, stakeholders met and agreed on their high-level ICM-related operations and maintenance activities. Figure 22 below is taken from the SANDAG draft operations and maintenance plan and summarizes the activities that SANDAG is addressing during the ICM operations and maintenance phase.

Figure 22. San Diego ICM Example: I-15 ICMS Summary of Operations and Maintenance Activities



[Source: San Diego ICM Pioneer Demonstration Site, *I-15 ICM Stage III Demonstration Project, Draft Operations and Maintenance Plan*, Version 1200, 1/19/11, p. 46, unpublished.]

As seen in Figure 23, the Dallas ICMS can provide operational data for the corridor for selected periods of time. Figure 23 shows the number of incident events in the corridor during a period in August through September of 2014.

Figure 23. Incident Events with "Recommended" Response Plans from 8/16-9/29, 2014

[Source: Texas Transportation Institute briefing at the Dallas ICM Stakeholder Meeting October 22, 2014]

Additionally, the Dallas ICMS stakeholders collect data identifying the system performance within the corridor. Table 8, identifies the number of incidents, the number of plans recommended, and the number of signal system Targeted Event Excellerated Response System (TEARS) plans recommended, and the duration of the implemented plans.

Table 8. DSS Recommended Response Plans from 8/16-9/29

Tot. Incident Events: 26
Tot. Plans Recommended: 26
Tot. TEARS Plans Recom.: 8 (in red)

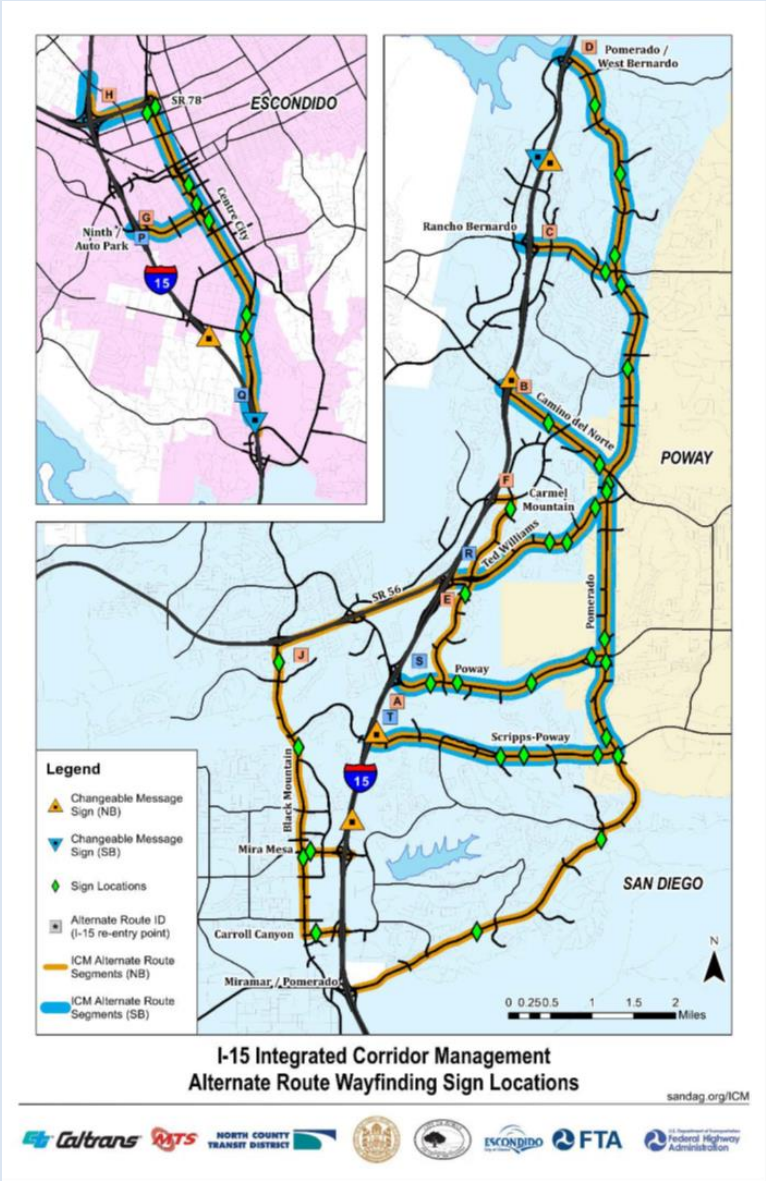
Notes:
* Duration from Implemented to Terminated/Superseded

Date	IncidentId	Cross Street	RuleId	Duration *
18-Aug	2014081816400705074	Arapaho Rd	J75S254 PM	not impl, closed in 5 min
19-Aug	2014081911191805074	Meadow Rd	J75S162 MD	3:30:20
	2014081914445505074	Midpark Rd	J75S260 MD	0:18:30
20-Aug	2014082012251805074	Midpark Rd	J75S260 MD	1:15:22
	2014082014090605074	Royal Ln	J75N163 MD	0:32:47
21-Aug	2014082115102305074	Legacy Dr	N75S300 PM	0:20:00
22-Aug	2014082207251705074	Galatyn Pkwy	J75N260 AM	0:29:05
28-Aug	2014082815093805074	Meadow Rd	J75S154 MD	1:10:08
	2014082816261505074	Belt Line Rd	J75S256 PM	0:44:56
2-Sep	2014090212032405074	Belt Line Rd	N75S203 MD	0:30:37
3-Sep	2014090307135405074	Arapaho Rd	J75N256 AM	1:02:31
	2014090317343105074	Renner Rd	J75N262 PM	**0:04:02**
4-Sep	2014090416500505074	Spring Valley Rd	J75N252 PM	0:24:41
10-Sep	2014091007552705074	Midpark Rd	J75S260 AM	**0:09:00**
11-Sep	2014091114064405074	Park Blvd	J75N354 MD	0:13:51
19-Sep	2014091916093805074	Meadow Rd	J75S162 PM	**0:03:20**
	2014091917390905074	Midpark Rd	J75N250 PM	0:12:00
23-Sep	2014092306243205074	Spring Valley Rd	J75N253 AM	0:30:00
	2014092308142505074	Spring Valley Rd	J75N252 AM	Not impl, closed in 3 min
24-Sep	2014092406500505074	Legacy Dr	J75S350 AM	0:37:06
	2014092408165605074	Belt Line Rd	J75N254 AM	0:29:31
	2014092416010205074	Galatyn Pkwy	J75N260 PM	0:37:54
25-Sep	2014092508443105074	Midpark Rd	J75S260 MD	Not impl, closed in 40 min
	2014092516463905074	Renner Rd	J75N262 PM	Not impl, closed in 5 min
	2014092517444805074	Spring Valley Rd	J75S258 PM	0:25:22
26-Sep	2014092616112705074	Renner Rd	J75N262 PM	0:20:05

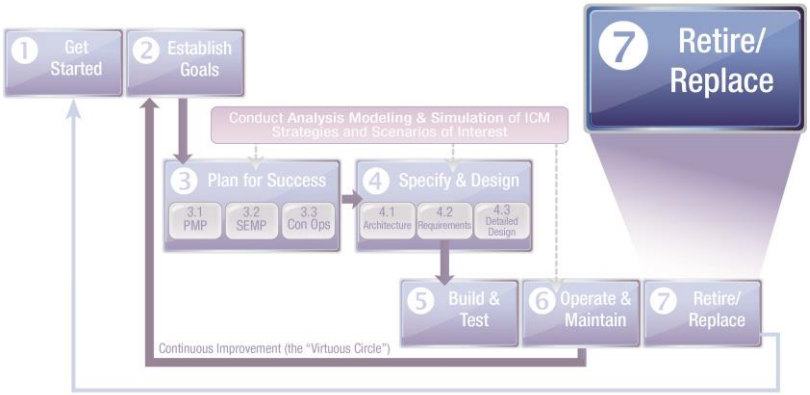
[Source: Texas Transportation Institute briefing at the Dallas ICM Stakeholder Meeting October 22, 2014]

As seen in Figure 24, San Diego is implementing active arterial routing to assist drivers with a combination of physical and electronic signs in order to clarify alternate routes recommended by the ICMS. The effort includes extensive coordination between Caltrans, SANDAG, and the various cities as well as outreach to the communities with a series of public meetings to communicate the purpose and benefits of the new signage.

Figure 24. I-15 Integrated Corridor Management Alternate Route Wayfinding Sign Locations.



[Source: San Diego I-15 Integrated Corridor Management Project Development Team Meeting # 60, August 19, 2015]



[Source: Research and Innovative Technologies Administration, ITS JPO.]

System Retirement/Replacement (Phase 7)

Eventually the ICMS may become obsolete or require a major overhaul replacing some or all of the original system. Stakeholders will need to have a plan in place to accommodate these types of changes when they occur. A system retirement or replacement plan should be included in the ICMS SEMP. A draft plan should be included with the delivery of the SEMP and refined prior to system acceptance.

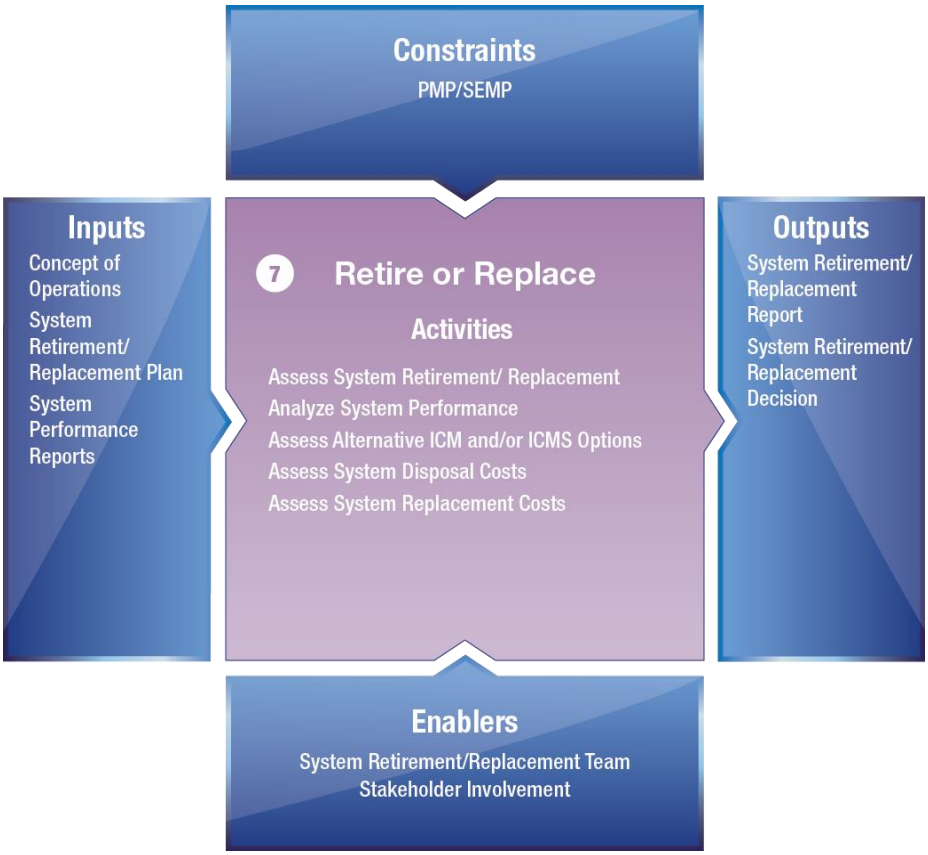
Managing for Quality – System Retirement/Replacement

One of the first things that needs to be accomplished when organizing the system retirement/replacement effort is to choose a stakeholder that will manage and lead the work performed by either in-house staff or a contractor. The following checklist includes some of the more important activities that the System retirement/replacement lead will be responsible for:

- Schedule periodic system retirement/replacement team meetings to discuss concerns about system retirement/replacement activities, status, action items, and risks;
- Facilitate needed system retirement/replacement;
- Ensure that guidance is made available to those stakeholders that are not familiar with the system retirement/replacement processes provided in the system retirement/replacement plans initiated in the SEMP and finalized prior to system acceptance;
- Coordinate among stakeholders to make sure that the correct and necessary information is provided for system retirement/replacement activities; and
- Ensure that all stakeholders are comfortable with the system retirement/replacement process.

Figure 25, shows the ICMS system retirement/replacement planning process. The inputs and constraints should be completed and available prior to beginning system retirement/replacement activities. Under the direction of the stakeholders, either in-house staff or a contractor will execute the system retirement/replacement activities and deliver the outputs shown. The enablers are the mechanisms used to manage and complete the system retirement/replacement activities successfully.

Figure 25. ICMS System Retirement/Replacement Planning Process



[Source: Noblis for ITS JPO, Modeled after: Systems Engineering Guidebook for ITS, Section 3.8.1, November 2009]

System Retirement/Replacement Resources

There are many resources available to assist with the development and understanding of system retirement/replacement. The Systems Engineering Guidebook for ITS, Version 3.0[57] provides an overview of the system retirement/replacement processes. The IEEE also provides guides and standards for conducting system retirement/replacement processes. Stakeholders are encouraged to explore these resources and seek the expertise necessary to guide them to retirement/replacement resources appropriate for control of the system retirement/replacement processes for their project. Another resource for understanding system retirement/replacement processes is Florida's Statewide Systems Engineering Management Plan for ITS, Version 2.0.[58] This document does a good job of explaining system retirement/replacement processes.

System Retirement/Replacement Highlights

At some point the ICMS will no longer fully meet stakeholder needs or it may become too costly to operate and maintain. At this point stakeholders need to consider either retiring the system or investing in a major overhaul. To assess the approach to system retirement/replacement, stakeholders need to consider such factors as:

- Corridor needs;
- System performance;
- Operational costs;
- Maintenance costs;
- Disposal costs;
- Cost of new systems;
- Performance of new systems;
- Availability of new systems;
- Corridor impacts; and
- System transition.

Questions to Answer – System Retirement/Replacement

In the initial stages of system retirement/replacement, stakeholders will need to reach consensus on the decision to initiate and finalize the system retirement/replacement work. This process can be very complex, especially when many stakeholders are involved. One way to get started is by developing a set of questions about the proposed ICMS system retirement/replacement work and then developing answers to those questions (with the consensus of the stakeholder group). The following is a list of ICM questions to start with:

- Were analyses performed to assess the performance of the system?
- Has a determination been made to see if the current system still addresses corridor needs?
- Were current system lifecycle costs assessed against the lifecycle costs of possible new systems?
- Were stakeholders given the opportunity to come to a consensus decision on system retirement/replacement?

Lessons Learned – System Retirement/Replacement

The following lessons learned apply to this phase of the ICM program.

- Timeframe – In the SEMP, establish a target system life-cycle timeframe; that is, the number of years the system is expected to be in service. This is important information for performing life-cycle cost analysis associated with retirement/replacement.
- Evolution – If a system needs to be replaced, consider replacing it in an incremental manner (i.e., sub-system by sub-system).[59]
- Realizing full benefit potential – After the system has been in operation and data can be analyzed, it will likely become apparent that some system updates and revsions are needed before the system can achieve full benefit potential.
- Making the case for upgrades – Operational data and analyses are important and need to be collected to support potential planning and upgrades to the system. The benefits identified will help to make the case to decision makers for additional upgrade funding.

Pioneer Site Example –System Retirement/Replacement

The Dallas and San Diego ICM pioneer sites created new opportunities to identify functionality suitable for original ICMS purposes and developed software to accommodate that functionality. However, software developers are taking the lessons learned from these original projects and are refining and upgrading their software to provide even greater services for ICM deployers. The following is a list of new software capabilities that are being built into newly updated ICM software products:

- Options for expanded geographic coverage
- Analyses for environmental benefits
- Streamlined data harmonization
- Centralized and coordinated control strategies
- Improved signal system analyses for the corridor
- Ability to communicate with multiple signal systems/vendor products
- Improved decision support tools
- Improved multimodal and multi-agency operations
- Improved analytics and performance measures

These new software products and features may be used for upgrades to current ICMS and help other regions to better justify ICM in their corridors.

APPENDIX A. Conceptualizing Integrated Corridor Management[1]

Introduction

This section covers the purpose of this paper and background information necessary to understanding the concepts and systems being discussed.

Purpose of the White Paper

This white paper provides a basis for a definition and understanding of integrated corridor management (ICM) and an integrated corridor management system (ICMS). It promotes discussion and agreement on definitions and concepts among the ICM initiative support team.

Background

Operations in today's urban transportation corridors are largely handled independently by each transportation network operator within the corridor. While the transportation network operators may collaborate or interact to some extent to deal with incidents or pre-planned events occurring within the corridor, each transportation network operator handles most day-to-day operations independently, without communication with other transportation network operators. As congestion becomes heavier and incidents increase within the corridor, this independent operation of transportation networks has become less effective in meeting the transportation needs of the corridor and the businesses and people within it and using it.

The U.S. Department of Transportation (U.S. DOT) believes that one solution to addressing the growing congestion and resulting reduced mobility within urban transportation corridors is the integration of the operation of all transportation networks within a corridor, to maximize the effectiveness of their use and to mitigate the effect of incidents that affect the movement of people, goods, and services within the corridor. This integrated operation of corridor transportation networks is the subject of a major U.S. DOT initiative known as *Integrated Corridor Management*.

To illustrate what is meant by ICM, let us consider a scenario involving the Interstate 5 (I-5) corridor in Seattle, WA. This corridor is illustrated in Figure 26 and consists of the following major transportation networks:

- 30 miles of Interstate 5 (I-5), which has reversible high occupancy vehicle (HOV) lanes in its median
- 20 miles of Interstate 405 (I-405), also with HOV lanes, which parallels I-5
- 24 miles of State Road 99 (SR 99), which parallels I-5
- A commuter rail line (Sounder Commuter Rail), which provides four trips daily between Everett, WA and Seattle

[1]Integrated Corridor Management White Paper, Noblis, June 2008.

There are also major cross roads that intersect this corridor. Interstate 90 (I-90) crosses all three of the major roads in the corridor, as do State Roads 520 and 522 (SR 520 and SR 522).

At present, without an ICM approach for the corridor, and without an ICMS that would allow the transportation network operators within the corridor to accomplish ICM, it may not be possible for those operators to respond effectively to a major incident that closes a portion of I-5 for an extended period of time. In general, the transportation network operators within this corridor want to accomplish the following:

- Ensure traveler safety
- Prevent catastrophic incidents that strand road users
- Provide viable alternatives to road users
- Keep travelers informed

The emphasis on road users is because the current ridership on the commuter rail system is only about 1,000 people per day. There is currently no plan to attempt to move more roadway users to commuter rail. This might become an object of an ICM approach, should the corridor's transportation network operators adopt one.

Let's consider what happens if a major incident, one that closes I-5 for an extended period of time occurs. To illustrate such an incident, let us assume that a truck fire occurs on northbound I-5, between Exits 170 and 172, which closes all of the northbound lanes on I-5. This fire is expected to keep those lanes closed for at least 12 hours. At the time of the incident, around 1 pm, the HOV facility on I-5 is closed. This situation is illustrated by the red jagged block in Figure 27.

Figure 26. I-5 Corridor, Seattle

[Source: Noblis, Inc., for U.S. DOT, 2008.]

Without ICM and an ICMS, each transportation network operator reacts to the incident in the manner permitted by the operator's network management system. The freeway operator, for example, might post messages on dynamic messaging signs (DMSs) located sufficiently before the incident to divert travelers from I-5 to either I-405 (if possible) or to the arterials that allow travelers to bypass the incident. However, if the arterial network operators are not expecting this additional volume on their roads, they may not be able to handle the unexpected demand and their networks may become congested and delays build. Similarly, transit bus operators cannot prepare for or encourage travelers to shift to their mode of transportation, since they are not expecting any reason for increased demand.

With an effective ICM approach in place, however, the transportation system operators in the corridor would be able to take a series of actions that could mitigate the effects of this incident on the entire corridor. The steps they could take include:

- Implementing signal timing plans that favor northbound SR 99
- Coordinating I-5 ramp meters north of exit 172 and adjacent arterial traffic signals, including northbound SR 99
- Placing detour signage on SR 99 and adjacent arterials
- Using law enforcement personnel to facilitate traffic at intersections not under centralized control
- Advising commuters of the incident and its effects, via broadcast media (TV, radio), email alerts, and other mechanisms. The advice could include:
    - Suggesting that road users re-route to SR 99 or I-405, using I-90 or SR 520
    - Suggesting staggered trip departure times based on license plate numbers or some other scheme
- Lifting HOV lane restrictions
- Eliminating parking restrictions until 8 am the following day
- Changing bus schedules and routes
- Providing free shuttle service
- Adding commuter rail service

These actions illustrate how ICM might work in a specific corridor for a specific incident. However, they do not cover all that ICM might entail. To provide a better understanding of ICM and ICMS, we need to establish a basic framework and concepts for this initiative.

Figure 27. Truck Fire Incident on I-5

Source: Noblis, Inc., for U.S. DOT, 2008.]

Basic ICM Concepts

There are four basic concepts that one needs to understand before one can explain ICM. These concepts are:

- Corridor modes of operation

- Strategic areas for ICM
- Conceptual Levels within the corridor
- ICM environment

The following discusses each of these basic concepts.

Corridor Modes of Operation

There is a distinction between the corridor modes of operation and the transportation modes within a corridor. A corridor mode of operation refers to a particular manner in which the corridor ICM manager and/or the transportation network operators are operating the transportation networks that comprise a corridor. A transportation mode is a particular manner, variety, or form of transportation. For example, one could walk (pedestrian mode) along a roadway that is also being used by cars and buses (two different transportation modes).

All corridors operate in two major modes: Normal mode and Event mode. Normal mode is the mode that constitutes all the actions one takes to ensure that day-to-day transportation needs are addressed. Event mode has two sub-modes: Planned event mode and unplanned event mode. Planned Event mode is the mode where, prior to its occurrence, it is known that either an event that reduces existing corridor capacity will occur, e.g., construction along a network that temporarily reduces its capacity, or an event that increases demand on corridor network capacity will occur, e.g., a sporting event that increases demand on one or more networks during a specific period of time. Unplanned Event mode is the mode where either an event that reduces existing corridor capacity, e.g., an incident on a network, or an event that increases demand on one or more corridor networks, e.g., an emergency evacuation, occurs without foreknowledge.

A corridor can shift between Normal mode and Event several times during a single day or it can operate in a single mode (whether Event mode or Normal mode) for the entire day. In addition, if an event continues for an extended period, the Event mode can transition into a “Normal” mode of operation. A case in which this might occur is when a planned event, such as major road construction, will take place over several months. For the period of the planned road construction, operation of the affected roadways in the corridor to deal with the continuing disruptions of the previous traffic patterns becomes the “Normal” mode of operation.

A corridor does not change operating mode automatically if an event occurs. The corridor manager has to assess the severity, impact on the entire corridor, and expected duration of an event before deciding to switch from Normal mode to Event mode. If the event severity is low, there may be no need to switch into Event mode. The corridor operator could decide to ignore the event and continue Normal mode operations. For example, a minor crash (“fender bender”) during a rush hour period may not be severe enough to justify changing to Event mode. The impact of the event also needs to be considered. The example given earlier in the paper of the truck fire on I-5 is a case where the corridor operator might shift to Event mode operation for the northbound traffic on I-5, but continue Normal mode operation on the southbound lanes. Event duration is also important and refers primarily to how long an event affects corridor operations. If the event only disrupts operations for a short time, there may be no need to shift into Event mode operation. For example, if an accident without injuries occurs on a major freeway at the end of the rush hour period and does not extend the rush hour period, its effect on Normal mode operations may be very short, even if the incident is not cleared for several hours.

Another factor that can affect the decision to shift from one operational mode to another is the ability of the existing systems to support the shift. This will be discussed further in section 2. 3. 4.

Strategic Areas for Integrated Corridor Management

To manage a corridor in an integrated fashion requires the corridor manager to develop strategies in four areas and implement those strategies in one or more areas. The four areas are:

- Demand Management
- Load Balancing
- Event Response
- Capital Improvement

Figure 28depicts these four strategic areas as the foundations (pillars) of ICM and the following text describes each strategic area in more detail. Within the first three strategic areas (demand management, load balancing, event response), one can develop *control strategies* (tactics or actions) that establish *what* one actually does to implement the strategy. For the capital improvement area, one doesn't develop *control strategies*; instead, what the transportation system operator normally develops are recommendations for capital expenditures for facility improvements. The transportation system operator may be able to implement some recommendations (e.g., the installation of ITS) more easily than others.

Figure 28. ICM Strategic Areas

[Source: Noblis, Inc., for U.S. DOT, 2011.]

The following sections describe the strategic areas in more detail.

Demand Management

Demand management addresses patterns of usage of transportation networks. The demand for transportation networks changes by time of day (morning rush hours and evening rush hours), day of week (weekends versus week days), and time of year (demand during school vacations is lower than during school sessions; demand during major shopping holidays is different than during non-holiday periods). Actions that a corridor manager will take to manage demand involve either changing the pattern of demand or addressing changes in demand patterns that have occurred without corridor

manager action. The type of demand management actions that a corridor manager might apply depend on the mode of operation of the corridor. The demand management actions that address Normal mode operation are generally actions that have long-term effects or that require long lead times to implement. For example, a corridor manager might choose to implement congestion pricing on roadways within the corridor. This could have the long-term effect of shifting demand to other roadways or changing the time when travelers begin their trips. Demand management actions that address Event mode operation are either ones that can be planned in advance (for planned events) or ones that require rapid decision-making based on real-time or near real-time information on the conditions existing in the corridor (unplanned events). For example, the corridor manager could decide to open HOV lanes to regular traffic during a weather emergency (either "planned", i.e., one where the weather event is expected or "unplanned", where the weather event is a surprise). If the decision to open HOV lanes is made overnight to deal with road conditions the following morning, the Event mode of operation can be planned in advance. If the decision is made because an unexpected storm (or a storm whose severity is greater than expected) has adversely affected road conditions, this is more along the lines of an unplanned event. The example given at the start of this paper, of a truck fire on I-5 that closed down the northbound lanes is a clear example of an unplanned event.

Load Balancing

Load balancing addresses how travelers use the transportation networks in a corridor. Ideally, each transportation network would carry as many travelers as it is capable of carrying, without delay, during its usage periods, thus operating each network at its maximum effectiveness. However, that ideal is difficult if not impossible to achieve, since all transportation networks do not address all travelers' origin and destination objectives in the same manner. Load balancing during Normal mode operation involves actions that encourage the shifting of trips from one transportation mode to another mode, if the second mode has excess capacity and the first is at or near maximum effective capacity. For example, a corridor manager whose freeway and arterial roadways are congested during peak usage periods who also has underused transit network capacity could inform travelers of the availability of parking at transit stations and the availability of transit options that would allow the travelers to reach their destinations with more regularity. These actions could encourage travelers to shift from roadway usage with private vehicles to transit usage. Load balancing to address Event mode operation involves actions that encourage the shifting of trips from one transportation mode to another, to achieve the most efficient use of existing transportation network capacity, actions that temporarily increase the throughput of a transportation network, and actions that temporarily increase the capacity of a transportation network over its normal operational capacity in the corridor. These actions are either ones that can be planned in advance (for planned events) or ones that require rapid decision-making based on real-time or near real-time information on the current corridor conditions (unplanned events). For example, transit operators can increase the number of buses and/or trains that run on holidays along certain routes, to encourage travelers attempting to reach a specific destination to use transit rather than driving.

It should be recognized that some actions can be considered either load balancing or demand management. For example, if a corridor manager implements transit subsidies and increases available transit station parking to encourage travelers to shift from roadway modes to transit modes, this could be considered either demand management or long-term load balancing.

Event Response

Events, in this context, are occurrences that affect either the capacity of one or more transportation networks or the usage of those transportation networks. Events can be categorized either by their duration, i.e., short-term versus long-term, or by their effect. Effects include:

- Reduction of capacity
- Increase in demand
- Change in demand pattern

Examples of short-term events that reduce capacity include crashes that reduce roadway capacity by blocking lanes, disabling of buses or transit rail cars by accidents, and weather that blocks lanes (e.g., floods, heavy snow). Examples of short-term events that increase demand are evacuations due to weather (e.g., hurricanes, flooding) or games and concerts that increase the demand for the use of transportation modes leading to the event venue. Examples of short-term events that change the demand pattern are weather that causes business or schools to release employees and students earlier (or later) than usual and sporting events that increase travel along certain roadways, causing the travelers who customarily use those roadways to have to find different routes to their destinations. Short-term events can be either planned (for which actions can be pre-planned and executed on demand) or unplanned (for which pre-planned actions can be executed, if relevant, but which may require decision-making in real-time to address the circumstances of the event).

A long-term event, however, may cause a shift in the perception of what “normal” operation is during the event. The duration of a “long-term” event is something that cannot be defined in the abstract. What “long-term” means will depend on what the transportation network operators in a corridor decide constitutes “long-term” and may vary from corridor to corridor. However, when an event extends over more than the temporal period agreed upon as defining “long-term”, it leads the transportation network operators to take the same or similar actions to manage the corridor during the entire event. For example, a long-term capacity-reducing event such as road construction or repair that closes existing lanes for an extended period means that the capacity in that portion of the corridor has to be managed at its reduced level for the duration of the construction or repair. An example of a “long-term” event may be a golf tournament in a region that increases demand in the corridor over a three or four day period. During the tournament, transportation system operators have to recognize the increased demand and manage the corridor accordingly. This tournament can also serve as an example of an event that changes the pattern of demand. Travelers who usually travel on the roads in the vicinity of the golf tournament may need to use other roads to reach their usual destinations at their usual times – or may need to use different modes of transportation during the tournament. In these examples, transportation network operators should have sufficient advanced notice of the event to establish a plan for handling corridor operations for the duration of the event.

Should there be an unplanned, long-term event, e.g., a flood that washes out a major bridge or road in a corridor, the initial response of the transportation system operators is likely to involve actions where decisions are made in real-time, based on real-time or near real-time information on the conditions of transportation networks within the corridor. However, once the initial response actions are in place, the transportation system operators shift to actions that will repeat for the length of time that it takes to restore the corridor’s capacity.

One key aspect of long-term events is that they could cause a permanent shift in what constitutes Normal mode of operation for the corridor. For example, the long-term construction event that initially reduced

the capacity of the network could have the longer-term effect of increasing corridor capacity, with accompanying mode shifts and changes in travel patterns. Another long-term event that would cause a permanent shift in Normal mode operations is the construction of a new residential development. During the initial construction period, the effect on Normal mode operations could be a reduction of capacity. However, the longer-term effect is likely to be a combination of increased demand and changes in travel patterns.

Capital Improvement

Corridor managers may determine that capital improvements to corridor facilities are needed to mitigate transportation problems within the corridor. These capital improvements might be either construction of additional capacity on existing networks, addition of networks, or use of technology (such as intelligent transportation systems [ITS]) on new or existing facilities. The decision to undertake capital improvements may not fall under the purview of the corridor managers, but they could recognize and recommend needed capital improvements. Capital improvement is a long-term approach, as most capital improvements take months or years to implement. While the capital improvement is taking place, the actual transportation system usage can change, making the capital improvement obsolete before it is completed. To improve the chances that capital improvements will lead to enhanced performance of corridor facilities, transportation system operators should evaluate the prospective changes, using analytical tools, to assess the probable impact of those improvements on overall corridor performance, given expected demand changes.

Conceptual Levels within the Corridor

In developing the overall approach to integrated corridor management, one must consider three distinct conceptual levels within the corridor. These are:

- Physical
- Information processing
- Execution or decision-making

Figure 29 depicts these three conceptual levels and the following text describes them in more detail.

Physical Level

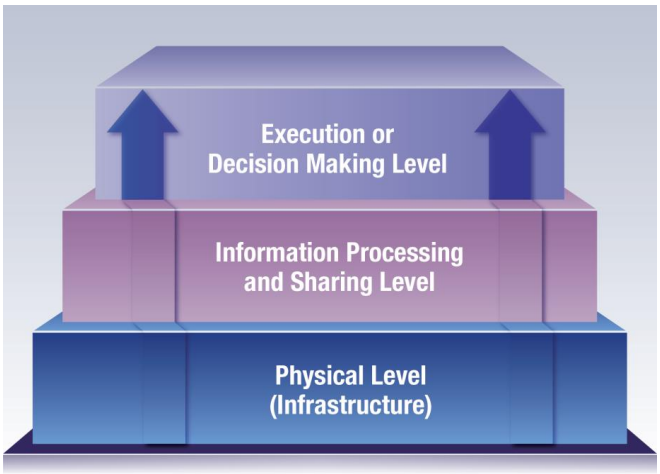
The physical level is the transportation infrastructure for the corridor. The physical level consists of:

- Facilities
- Transportation networks (which use the facilities)
- Transportation modes (which use the transportation networks, and which are distinct from the operating modes for integrated corridor management)
- Devices (which are in facilities, in networks, and in modes)
- Data (which comes from the devices in facilities, in networks, and in modes)

- Communications networks (which transmit data from the devices into the information processing level)

The physical level is the most tangible level of the corridor. It consists of components that are actually in, on, or under the ground.

Figure 29. ICM Levels



[Source: Noblis, Inc., for U.S. DOT, 2011.]

Information Processing and Sharing Level

The information processing and sharing level provides the tools and information systems that take data from devices and transform them into information that transportation system operators can use to make operational decisions about the transportation networks. The information processing and sharing level is a combination of tangible components and less tangible ones. These include:

- Computers to process and store data
- Communications networks to move data and information around within the level
- Display devices to present information, in both graphic and textual format, to operators, managers, and other decision makers
- Databases that physically store the data (and information) for retrieval as needed
- Devices for the manual entry of data and commands by operators, managers, and other users of the information processing level
- Communication devices to allow the exchange of information and decisions among the transportation system operators

Although there are physical components in this level, the most important components at this level are the information that it provides for operational decision making and for planning purposes and the information sharing and communications among peers that it permits.

Execution or Decision Making Level

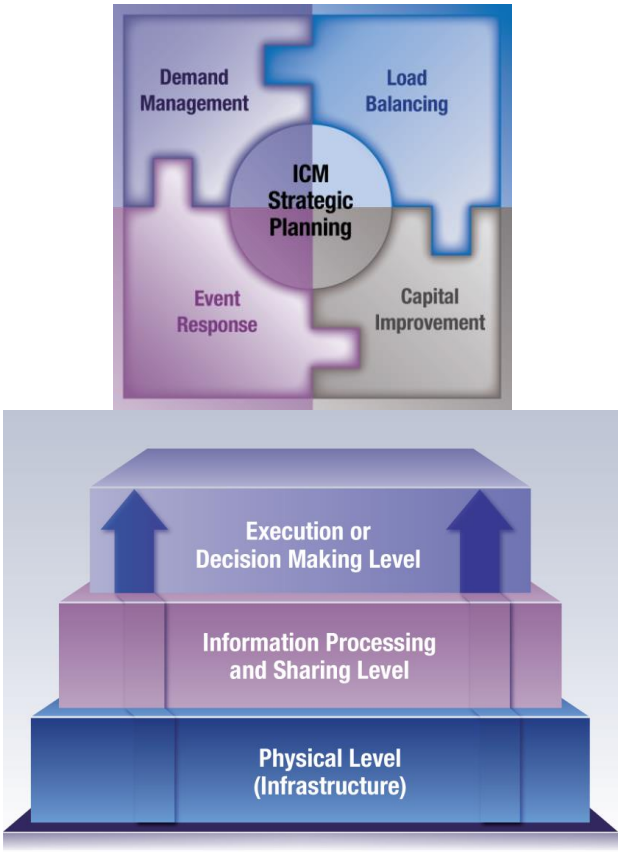
This level is the most intangible of the three. The tangible components are the people who make the decisions and execute the actions needed to operate the transportation systems in the corridor. The intangible components are the plans, actions, and on-the-spot decisions that they make in response to the operating conditions within the corridor. The controls that one uses to operate corridor networks are part of this level as well.

ICM deals principally with the execution or decision making and the information processing and sharing levels, since ICM is basically an abstract concept. The ICMS that supports ICM, however, encompasses all three levels: Physical, Information Processing and Sharing, and Execution or Decision Making. The Physical level is the foundation level. Without it, an ICMS has nothing to do, since this level provides the data about the operation of the corridor's networks that an ICMS uses to enable operational decisions. But the Information Processing and Sharing level and the Execution or Decision Making level are the crux of an ICMS.

The ICM Environment

Figure 30 illustrates the ICM environment, in which an ICMS must operate. The environment deals with the four strategic areas and includes the three levels already discussed. The pillars used to illustrate the strategic areas rest on the steps representing the three levels.

Figure 30. ICM Environment



[Source: Noblis, Inc., for U.S. DOT, 2011.]

Stakeholders

Stakeholders are entities that interact with a system. For an integrated corridor management system, the major stakeholders include:

- Travelers and other transportation network users – these include the individuals who use the transportation networks within a corridor to go from one location (origin) to another (destination), whether for personal use or for business use. Business transportation system users include commercial vehicle operators and owners, which are the individuals and organizations that are interested in moving freight along the transportation networks in a corridor. Their trips within the corridor may involve either traversing the entire corridor or going to one or more locations within the corridor.
- Commercial and government entities – these include individuals and organizations that are employers, service providers, and vendors of goods within a corridor. While they may not travel themselves within the corridor, they are interested in the ability of their employees and customers to travel within the corridor. They will have major concerns if employees and customers are either delayed in or prevented from traveling within the corridor.
- Transportation network operators and their staff – these are the individuals who are responsible for managing the specific modal networks within the corridor (and who may include the individual or organization entrusted with overall management of the corridor through an integrated corridor management system). [2]
- Public safety personnel – these are the police, fire, and emergency services operators and staff that use the corridor and provide safety-related services within the corridor.
- Other service providers – this includes both organizations that remove damaged vehicles from roadways (e.g., AAA, tow truck operators) and hazardous materials (HAZMAT) cleanup organizations[3] that remove or mitigate toxic spills when they occur.

Interactions among Stakeholders

The following discussion takes the point of view of the transportation network operators for the integrated corridor and ignores interactions that do not involve actions or communications related to integrated corridor management.

Transportation network operators provide travelers and commercial vehicle operators information about traffic conditions within the corridor through several means:

- Media feeds – these include information feeds to local media, such as radio and television stations that allow those stations to give their listeners information about current traffic conditions. These stations generally provide periodic spot updates on traffic conditions. An emerging media feed is the supplemental navigation data that is being piped into in-vehicle navigation devices, not really intended for a human listener, but intended to provide the driver with travel directions and information about businesses at the driver's destination.

[2] Transportation organization personnel who provide safety services (e.g., roadside assistance personnel) fall into this category.
[3] Some fire and rescue organizations may perform HAZMAT cleanup operations. There are, however, other organizations that specialize in HAZMAT cleanup that either is more extensive that what fire and rescue organizations can do or is done by them in lieu of using fire and rescue organizations.

- Dynamic message signs (DMS) – these convey en-route information about conditions ahead of the traveler. Many jurisdictions are posting travel times between two destination points along the driver's expected route (e.g., from the sign's location to an exit point ahead). Many are also posting information about incidents causing congestion or hazardous conditions (where the information posted usually includes the distance ahead where congestion begins). Other travel-related information might include the presence of work zones ahead (and any speed reductions associated with a work zone). In transit systems, these signs may provide information about arrival and/or departure times of transit vehicles and about real-time parking availability at transit park-and-ride facilities.

- Highway advisory radio (HAR) – these allow a driver to tune the vehicle's radio to a station that provides information about current traffic conditions along the driver's expected route. HAR stations provide the same type of information as DMS, but generally in more detail.

- 5-1-1 systems – these are voice-response systems that an individual can call, using some telephone device, to get information about traffic conditions along a specific (requested by the caller) route or highway segment. These systems can also provide general messages (called "floodgate" messages) that provide information that the transportation system operator believes to be of interest to all callers. With cellular phones, an individual can call the 5-1-1 system from within a vehicle in-transit, although many jurisdictions are placing legal restrictions on drivers' use of cell phones while operating a vehicle. Some 5-1-1 systems also provide transit information or forward a caller to a transit agency customer service center. Transit information provided may include transit service area, hours of operation, routes and schedules, fares, real-time vehicle arrival times, and conditions within the transit network.

- Traffic and transit web sites – these are Internet-based web sites that have real-time or near real-time information about traffic conditions along the roadways and transit systems in a region. These are primarily expected to be pre-trip planning sites, although cellular phones that allow Internet web browsing can also be used to access these sites from within an in-motion vehicle.

All of those options are means by which transportation system operators can provide information to drivers about current traffic conditions within the corridor. Operators can also use outreach campaigns and publicity releases to print, radio, and television media to get information to the public on transportation policy and planned actions. These media interactions can promote campaigns intended to encourage changes in the public's use of transportation systems (*demand management*) or encourage shifts in the mode of transportation that the public uses (*load balancing*). In some cases, they can be used to inform the public about temporary changes in expected capacity of or demand for transportation services (*event response*), so that the public can plan its use of the transportation system accordingly.

The above interactions are ones in which the transportation system operators are "pushing" information to travelers and commercial vehicle operators and drivers. There are also information "pulls" from these sources, when operators use mechanisms such as surveys, questionnaires, and focus groups to solicit information about the public's and industry's current and potential future use of transportation facilities. In addition, travelers and commercial vehicle operators (and drivers) voluntarily provide information to transportation system operators. This information might be in the form of a complaint about ongoing congestion or poor traffic movement at an intersection or along a route; information about an incident that just occurred; or a request for a traffic control device at a specific point.

Transportation system operators also interact with public safety personnel when dealing with events that occur on transportation networks within the corridor. When events are planned or known in advance, the

interaction usually involves deliberation between the parties on the best response, given available resources, for the known or planned event. This can lead to a set of pre-planned actions that become codified as part of the standard or customary set of actions that operators and public safety personnel will take in response to known conditions. Preplanning for unplanned events can also take place in a deliberate fashion, to ensure that all parties consider the types of events that can occur, the likelihood that the event will occur, and the resources expected to be available for response. Then, when an unplanned event occurs (e.g., a flood or a serious crash), the transportation and public safety agencies involved can consult their set of preplanned responses and determine which best fit the circumstances. It then becomes a matter of executing the preplanned actions.

Ad hoc responses to unplanned events may also be required. Should these circumstances occur, all agencies involved must rely on their communications and information gathering systems to determine what range of responses best suit the circumstances and then coordinate a set of responses to those circumstances. Experience and judgment will influence the responses considered, but communication and coordination are needed to achieve an effective response.

Having discussed the basic concepts and framework for ICM, we now need to consider what the ICMS that supports ICM looks like. The next section discusses the ICMS.

The Integrated Corridor Management System

An integrated corridor management system is a tool to help the corridor's transportation network operators keep their networks operating at optimal levels. While it will not be possible to keep the networks operating optimally all of the time, that is the overall goal to which those operators aspire. In discussing the ICM, we will cover two major aspects:

- Operational needs of an ICMS
- System architecture for an ICMS

The operational needs covered in the next section may not all apply to every ICMS. However, the intent is to convey the broadest set of operational needs, from which one can decide which not to ascribe to a particular ICMS.

Operational Needs for an Integrated Corridor Management System

Operational needs are the highest level "requirements" or needs for a system. The following operational needs are an attempt to abstract, at the highest level, the overall needs for an ICMS. This does not mean that these are all of the needs for an ICMS. Each of these needs should generate one or more requirements that need to be satisfied by the specific system(s) that comprise the ICMS.

1. Need for communication with transportation network users– To deal with conditions in all operational modes, transportation system operators need to communicate with the users of the transportation networks in the corridor, to let them know what conditions are and what alternative travel modes are available. The communication can occur in either (or both) of two ways:
    - Active communication – used to send information directly to or receive information directly from users of the corridor. Examples of information flow to corridor users are: dynamic message signs (DMS) on roadways and transit locations, email to users that have signed up for email notification and alerts, and broadcasts over public or private news channels. Examples of information flow from corridor users are: complaints about

corridor conditions and specific timing plans implemented in the corridor, notifications of incidents that have occurred within the corridor, and requests from users for specific services.

- Passive communication – used to place information on a resource available to the users of the corridor. It lets them seek the information. Examples are: 511 systems, web sites that convey information on congestion and travel times on roadways and transit, travel planning sites that allow travelers to select trip options using one or more modes.

2. Need for interactive communication with colleagues– To ensure that actions taken by one transportation system operator do not have unintended consequences on overall corridor operation, transportation system operators need to communicate interactively with their colleagues when planning and executing actions that are not customary actions. The communication does not have to be continuous, but does need to occur immediately when actions are about to change normal operational decisions. With an ICMS, it should not be necessary to communicate interactively with colleagues to confirm operational status or existing conditions, as the first has been agreed upon (and any change to it requires the communication) and the second should be evident from the real-time or near real-time information that the physical level systems are providing.

3. Need for standard definition of customary actions– As a corollary to the above need, customary actions need to be defined in a standard manner that is communicated to all transportation system operators within a corridor. This allows each operator to know what actions other operators may take during customary actions and the circumstances that will trigger those actions. As an addendum to the set of actions defined for customary actions, there should be a set of defined pre-planned actions that are triggered by specific events. While the specifics of each action plan may depend on actual circumstances (e.g., a crash will trigger certain responses, but the actual response may depend on the location or severity of the crash), the steps and event triggers should be clearly delineated so that each operator knows what actions he or she is expected to take if an event occurs.

4. Need for transportation system operators and public safety organizations to coordinate – Transportation system operators and public safety organizations (e.g., police, fire, emergency services) need to coordinate on a real-time basis when incidents arise that require response by both types of organizations. The coordination is two-way. If the situation is one where the transportation system operator requires assistance, the communication goes from the transportation system operator to the public safety agency(ies), requesting assistance. If, on the other hand, the public safety agency wants to dispatch a vehicle to a particular location and wants to know the status of traffic on the available networks, the public safety agency initiates the communication, to determine the best routing for the responding vehicles. Under these circumstances, the public safety agency may require the assistance of an operator to facilitate the response, e.g., traffic signal preemption for public safety vehicles.

5. Need to manage the supply of services to match demand– Transportation network operators need to manage the supply of services to match demand. Assessing the availability of service during periods of varying demand involves knowing about either permanent or non-permanent changes to service availability. For example, the transportation network operators need to know when their physical resources are available for use, whether these physical resources involve fixed facilities, e.g., roadways, parking lots, transit stations, or vehicles that are used to transport people and goods, e.g., buses, train cars, and ferry boats. Examples of services also include maintenance vehicles and public assistance vehicles, such as those whose drivers assist

motorists who have broken down on or along a roadway network. Information about the location of such vehicles needs to be available in real-time or near real-time, so that transportation network operators can dispatch vehicles to locations where they are needed, based upon which vehicles are both capable of dealing with the situation and are closest to the location where they are needed.

6. Need to have competent and well-trained staff –The transportation system operators need to have competent and well-trained staff, to ensure that their physical and information processing infrastructures are properly operated and maintained. In addition, all individuals in decision-making positions need to have ongoing training in interpreting the information provided and determining the most effective actions to take when circumstances require non-customary action.

7. Need to monitor the location and status of vehicles within corridor management agency fleet(s) – Agencies involved in corridor management need to be able to track the location of vehicles in their fleet(s) for numerous reasons. For example, knowing the location of service vehicles allows an agency manager to dispatch the closest vehicle capable of dealing with an incident or problem on the transportation network. This can be such items as a crash, a failed device (e.g., traffic signal), debris on a road, a stalled bus, or icy conditions that are imperiling travelers. Transit managers need to know the location of trains and/or buses, to determine whether those vehicles are on schedule, so that they can decide whether to initiate an action to assist an off-schedule vehicle to get back on schedule.

8. Need to visualize information –Transportation system operators need to be able to see, in a visual format, the information representing the performance of the networks they are attempting to manage. Information presented as numbers or charts is useful, but the best means of quickly grasping the status of a network is to see its performance depicted visually – using some graphical representation of the network as a network, with color used to illustrate different performance states.

9. Need to share control of devices within a corridor – Transportation system operators need to share the control of devices[4] within the corridor, to permit real-time confirmation of or responses to situations that may occur within the corridor. Device control sharing rules should be established through institutional agreements among the different operators within the corridor, to have a clear well-defined policy that describes the roles and responsibilities of each operator for controlling shared devices.

10. Need to monitor the effectiveness of control tactics implemented in the corridor – After a corridor manager implements a control tactic, the corridor manager needs to determine how effective the control tactic has been. This is either verifying what conditions exist after implementation of the control tactic or detecting the results of executing the control tactic. This monitoring is part of a feedback mechanism within an ICMS. If the tactic used is effective in dealing with the problem, the corridor manager then only needs to monitor the corridor status to determine if the control tactic being used should be canceled (if necessary). If the tactic is not effective, the corridor manager needs to consider and implement other tactics.

11. Need to understand demand for transportation services– Transportation system operators also need to understand the demand for their services. Understanding the demand for services includes the evaluation of alternatives for responding to changes in demand whether temporary or long-term. Understanding demand requires operators to collect information about the volume of people who are demanding their services and the origin and destination of their trips. Operators must also collect information about the willingness of those travelers to shift from one

[4] The control of the devices within the corridor does not have to be part of the ICMS, as long as the ability to share this control exists. Device control is usually performed by a specific central system associated with the devices. ICMS involves more of the center-to-center (C2C) interaction that is supported by national ITS standards.

network or mode to another during a specific trip. Operators must also collect information about the price sensitivity of those travelers to changes in the pricing for service units.

12. Need to monitor threats to the corridor – Threats to the corridor are occurrences that may involve a real or potential disruption to corridor operation. Threats can come from natural sources (e.g., hurricanes, flooding, tornados, severe thunderstorms, icing) or from manmade sources (e.g., terrorist activity, hazardous materials spills). In monitoring threats, the corridor manager gathers information to help determine whether those threats may affect corridor operations and help assess their potential (or actual) impact. Frequently, monitoring threats requires that the corridor manager collect data or information from sources outside the agencies involved in corridor management. For example, the National Weather Service and private and/or local weather services may provide information on natural threats. Local, state, and federal police agencies and departments of homeland security may provide information on suspected or actual manmade threats. Private citizens may provide information about threats as well. Threat monitoring involves not just collecting the information, but also disseminating it to agencies that may be affected by the threat, whether real or potential.

13. Need for corridor performance measures – Transportation network operators need to develop corridor level performance measures that can be used to determine how well a corridor is operating. All operators need to agree that these are the performance measures that they will use and against which their performance will be judged. The performance measures should consist of both long- and short-term performance measures.

14. Need for impact assessment tools– Transportation system managers also need tools that allow them to assess the potential impact of actions under consideration on the operation of the corridor. The actions under consideration can be either long-term (e.g., new construction within the corridor) or short-term (e.g., adding buses temporarily to a route to handle increased demand at a planned event). The tools need to consider both intra-network effects and cross-network effects to deliver the net effect on corridor operations.

15. Need to archive data– Data collected by an ICMS need to be archived so that it can be used in processes that occur after the immediate collection period. These types of processes are analytical and/or predictive in nature and help transportation system managers assess the impact of prospective actions that they may take. Impact assessment tools, such as decision support systems, use archived data.

16. Need to have descriptive data about corridor infrastructure– Transportation operators need to have geometric data and geographic data about the physical facilities within the corridor. The geometric data will include such things as the shape of the facility (e.g., is the roadway curved or straight, how many lanes (and what types of lanes) does an intersection have); the number of levels in a facility (e.g., are there stacked roadway levels, how many levels do parking facilities have), and usage of facilities (e.g., is there a bus rapid transit lane along a roadway). The geographic data will include the terrain mapping of roadways, the subterranean usage within a facility (e.g., subway levels, subterranean parking levels), and the placement of infrastructure devices on, above, or below ground. Other types of infrastructure descriptive data include, for transit agencies, data about route configurations, transit vehicle stop locations and characteristics (e.g., whether the stop has a parking facility and, if so, the number of parking spaces that the parking facility has), and train lengths (in number of cars), for rail transit.

17. Need to have a quality information processing infrastructure– The components that form the information processing infrastructure within a corridor need to be, at a minimum:

- Reliable
- Available
- Maintainable (and well maintained)

- Extensible
- Interoperable

18. Need to monitor corridor status – The status of the corridor refers to both the condition of the transportation networks within the corridor and the condition of the devices, facilities, and other equipment that form the physical infrastructure of the corridor's transportation network. One uses both surveillance and detection as means of satisfying this need. One uses surveillance both to verify conditions and to detect conditions. One uses detection to discover or determine conditions, which one may verify through either surveillance or other means.

19. Need for real-time or near real-time information– To deal with unplanned events, transportation system operators need to have real-time or near real-time information on the conditions within the corridor. The real-time or near real-time information needed includes:

- Travel volumes on networks within the corridor
- Travel times on networks within the corridor
- Location and effect of unplanned event(s) (e.g., number of lanes out of service, number of buses removed from active service)
- Unused capacity on existing networks (a calculation based on available capacity and actual use)

20. Need for non-real-time data– Some data may be either too expensive to collect in real-time or near real-time or it may be infeasible to collect it in that fashion because of the lack of infrastructure. This type of data is also needed for planning and controlling facilities within the corridor. For example, it may be necessary to collect information on pedestrian usage of an intersection, by time of day, day of week, and day of month. Knowing this information would enable the transportation system operator to plan the amount of time to allow for pedestrians to cross an intersection safely.

21. Need to collect and process data in real-time or near real-time– Collecting real-time or near real-time data is not enough. The data collected needs to be processed to turn it into the type of information that transportation system operators can use to make operational decisions about their networks and about the corridor as a whole. Speed and volume information on roadways needs to be compared against historical data to indicate when throughput on a roadway is dropping below expected levels. This alerts a roadway network operator that unexpected congestion is occurring and the operator can look for its causes. Transit system operators need to know when their transit vehicles or trains are not running on schedule so that they can coordinate service (e.g., transfers at major connections) and look for the causes of the schedule delays. They also need to know where the transit vehicles or trains are located and whether they are moving, to pinpoint the nature of the problem and its location.

22. Need to monitor the status of the physical transportation infrastructure– Transportation system operators need to monitor the status of all data collection equipment, communications networks, and other devices within the corridor on a real-time or near real-time basis. Knowing which devices are fully operational enables them to determine which ones can be used to effect changes in the corridor's networks, which ones can communicate effectively and provide information, and which ones are usable for various purposes. As a corollary to this need, the operators need to know the location of all devices and other facilities within the corridor, to understand which can be used to address different circumstances and situations that arise within the corridor. As a second corollary to this need, the operators need to effect repairs, as quickly as possible, on all devices and other facilities (including communications networks) when they fail, to return them to service.

23. Need to have quality physical infrastructure– The components that form the physical infrastructure within a corridor (e.g., devices such as DMS, telecommunications networks,) need to be, at a minimum:
- Reliable
- Available
- Maintainable (and well maintained)
- Extensible
- Interoperable

Table 9 shows the relationship between the operational needs and the levels in the ICM environment.

Table 9. ICM Operational Needs and ICM Environment Levels

Need Id.	Needs	Levels: Execution or Decision Making	Levels: Information Processing	Levels: Physical
N. 01	Need for communication with transportation network users	X		
N. 02	Need for interactive communication with colleagues	X		
N. 03	Need for standard definition of customary operations	X		
N. 04	Need for transportation system operators and public safety organizations to coordinate	X		
N. 05	Need to manage the supply of services to match demand	X		
N. 06	Need to have competent and well-trained staff	X		
N. 07	Need to monitor the location and status of vehicles within corridor management agency fleet(s)	X		
N. 08	Need to visualize information	X		
N. 09	Need to share control of devices within a corridor	X	X	
N. 10	Need to monitor the effectiveness of control tactics implemented in the corridor			
N. 11	Need to understand demand for transportation services	X	X	
N. 12	Need to monitor threats to the corridor			
N. 13	Need for corridor performance measures	X	X	
N. 14	Need for impact assessment tools	X	X	
N. 15	Need to archive data	X	X	
N. 16	Need for descriptive data about corridor infrastructure	X	X	X
N. 17	Need to have a quality information processing infrastructure		X	
N. 18	Need to monitor corridor status			
N. 19	Need for real-time or near real-time information		X	X
N. 20	Need for non-real-time data (e.g., sample data)		X	X
N. 21	Need to collect and process data in real-time or near real-time		X	X
N. 22	Need to monitor the status of the physical transportation infrastructure		X	X
N. 23	Need to have quality physical infrastructure			X

ICMS Architecture

Having described what ICM is and the environment in which it operates, and having identified the needs of an ICMS, one now needs to consider what components comprise the architecture of an ICMS. The

basic question is: what does one need to have to provide the capabilities to support integrated corridor management, i.e., what does the integrated corridor management system look like?

A corridor can have several types of networks. The networks in a corridor that an ICMS must address include:

- Freeway roadway networks
- Arterial roadway networks
- Bus transit networks
- Rail transit networks (heavy rail and light rail)
- Commuter rail networks
- Freight rail networks
- Ferry networks

All corridors will have at least the first three networks. Corridors may have one or more of the remaining four networks. Each network in a corridor must be optimized before one can consider an ICM approach; if congestion problems would go away just by optimizing the corridor networks, it is unlikely that an ICM approach would be needed.

To optimize corridor networks, one needs to have in place data collection and data processing capabilities on each of those networks. Without these capabilities, one cannot perform the analysis necessary to optimize the individual networks. Optimizing the corridor, however, requires the ability to collect, process, and evaluate the information from each of the individual networks in a consolidated fashion.

One way to consider the architecture of an ICMS is to look at the three basic functions of any information system. These are:

- Input – the data required for the system to provide useful results
- Processing – the manner in which the system manipulates its input data to provide useful results
- Output – the useful results that the system provides

Let us consider each of these in turn.

Inputs

There are six major types of inputs that an ICMS will use:

- Continuous input data – These are real-time or near real-time data that provides information on the conditions within the corridor, the location of vehicles, and the performance of corridor networks. Some of the types of data that fall into this category include:
    - Data from traffic loops and detectors
    - Passenger counts from transit vehicles and stations
    - Vehicle location information, using automated vehicle locator (AVL) technology

- Sample data – These are data that are collected on an occasional basis and used for analytical studies. The data are not collected continuously because the cost of collecting them is high or the technology to collect them continuously is not yet available. Some of the types of data that fall into this category include:
    - Origin-Destination (OD) data for trips within the corridor
    - Pedestrian counts at intersections by time of day
    - Usage data on resources provided, e.g., 511 usage, web site usage
- Continuous sample data – These are sample data that are collected in real-time or near real-time, as they become available. The data are not continuously available, but are available continuously when they are available. Some of the types of data include:
    - Cell phone data used to calculate travel times
    - Downloads of data from transit buses
    - Data from probe vehicles
- Analytical data – These data are the output of an ICMS (or other system) process that get fed back into a new process within an ICMS. The data may be used to modify or govern other data.
- Geometric data– These are data about the physical shape of facilities within the corridor and are critical for the evaluation of the ability of those facilities to handle different types of control tactics.
- Geographic data– These data, generally stored in geographic information systems (GISs), describe the terrain in the corridor, the location of devices within the corridor (and the spatial relationship of the devices to ground level), and the uses of different types of facilities and terrain.

Process

Process lies at the heart of the ICMS, since this is what takes the input and transforms it into the information used to manage the corridor. The types of processes that an ICMS contains include:

- Demand volume processing – this is the collection of data on the usage of transportation modes on the networks within the corridor and the transformation of that data collection into information on the patterns of demand, by time period (time of day, day of week, month of year) and operational mode (Normal, Event).
- Travel time processing – this is the collection of data on (or calculation of) the speed at which the users of transportation modes are traveling and the calculation of the average time it will take those users to traverse a specific distance. This can be done for any mode of travel within the corridor. Some calculations involve real-time or near real-time data (e.g., vehicles traveling on roadways, rail cars traveling on rail networks); others can involve sample data (e.g., pedestrian walk time between two points, to provide estimates of travel times for travelers using walking as one of their travel modes).
- Facility capacity usage – this is the collection and processing of information on the total usage of facilities within the network. Knowing how much of a facility is in use allows one to inform prospective users of the remaining available capacity, so that they know whether their trip can include the use of that facility. For longer term planning purposes, this information, along with the calculation of the trend in facility capacity usage, can indicate when a facility will become unable to handle any more users. At this point, the prospective users must either be diverted or the facility's capacity increased (or prospective users can wait for others to cease their usage, thus making the facility available for prospective users).

- Predictive and/or forecasting – this is the use of historical (archived) data to predict future conditions on a transportation network. The predictions can either be short-term, e.g., what will travel speeds be on a roadway link given time of day, day of week, month of year, and historical usage of the link at similar time periods, or longer-term, e.g., what capacity will be needed on a specific transportation facility, given forecasted population growth, forecasted origin-destination usage of the facility, and forecasted land usage in the area.
- Decision support systems – this is the use of real-time analytical tools, feedback from existing data collection systems, analytical data from off-line analytical processes, and human (manual) inputs to assess potential decisions and their impacts on operational conditions.
- Control – this is the use of automated systems to monitor and manage different capabilities within the corridor. For example, timing plans for traffic signal systems control the flow of vehicles along an arterial roadway network. Transit signal priority changes the timing of signals along the route of a behind-schedule transit bus to allow the bus time to get back on schedule. Transit connection protection holds a feeder bus for a late transit vehicle along a connecting trunk line.
- Archive – this is the storage of data for future use, i.e., use by other processes in time periods after its collection.

Outputs

The outputs of an ICMS are all designed to be used to manage corridor networks. There are five major types of outputs:

- Continuous output – This is information that is continuously generated to enable real-time decision making. The output may be used either directly by transportation system managers and operators or provided to customers for their use in decision making (or both). Examples of this type of output are:
    - Congestion maps, such as those used in Transportation Management Centers (TMCs) or on traffic web sites, to provide information on the travel conditions on corridor roadways
    - Travel times across modes, frequently provided through all traveler information conduits, including 5-1-1 systems and dynamic message signs. Travel times are continuously computed from real-time or near real-time data and are posted on a predetermined basis
    - Traffic volumes along roadways
    - Transit vehicle location (broadcast global positioning system [GPS] coordinates)
    - Transit vehicle arrival times
- Analytical output – This output is derived from analytical processes either performed automatically or through a combination of automated and manual processes. Frequently, analytical output is further processed by humans, who interpret the information and decide how to use it. Types of analytical output include:
    - Operational plans, based on information about travel demand by time of day or on the estimated impact of potential or planned events on traffic conditions and transit capacity/service
    - Long-range plans, such as road construction or traffic control modifications and new or revised transit service, based on projected growth in specific areas of the corridor
- Event-driven response output – This is information that combines both analytical and continuous data to recommend changes to operational tactics. This can be either short-term, such as

recommended changes to a ramp metering plan based on unexpected demand at a specific ramp or re-routing buses around a traffic accident, or longer-term, such as recommended changes to a timing plan in effect on an arterial roadway network, based on an incident on an adjacent freeway network.

- Automated feedback – This is information that goes from one process to another, to provide control information to the second process. It is similar to event-driven response output, except that there is no manual intervention involved.
- Archived data– This is the storage of both the raw data collected by data collection processes and processed data (information) generated by processes within the ICMS. The archived data is generally used by predictive or forecasting processes within the ICMS.

Once the ICMS implementer has developed the architecture of the ICMS and defined its major operational needs, the ICMS implementer would then derive the requirements for the ICMS. A discussion of the ICMS requirements is beyond the scope of this white paper.

Definitions

Integrated Corridor Management (ICM)is the set of coordinated actions taken to ensure that the networks within a defined corridor operate at their optimal performance, given the capacity available for each network.

An **Integrated Corridor Management System (ICMS)**is the set of procedures, processes, data, information systems, and people that support transportation system managers in making coordinated decisions involving the optimal performance of all transportation networks within a corridor and in executing those decisions in an effective manner.

Surveillance is close watch kept over someone or something and can either be direct, i.e., human observation without an intervening device, or remote, i.e., human observation using an intervening device. In the context of an ICMS, it is the use of humans and intelligent transportation systems devices to keep close watch over the conditions on one or more transportation networks or transportation facilities.

Detection is the act of discovering or determining the existence, presence, or fact of something or someone. In the context of an ICMS, it is the use of humans and intelligent transportation system devices to discover or determine the existence, presence, or fact of conditions, vehicles, and status of devices in or on transportation networks and/or transportation facilities.

APPENDIX B. Defining the ICMS Decision Support System

A decision support system (DSS) is a system that supports business or organizational decisionmaking activities. A DSS can serve management, operations, and planning levels of an organization to facilitate decisionmaking. The DSS is particularly useful when applied to situations where conditions are rapidly changing and there are many variables involved that may affect the decisions that need to be made. A properly designed DSS is an interactive system intended to help decision makers compile useful information from a combination of raw data, documents, personal knowledge, or operational models to identify and solve problems.

Typical information that a decision support application might gather and present include:

- Inventories of information assets, including legacy and relational data sources;
- Comparative analyses of operations between one period and the next; and
- Projected analyses based on assumptions, modeling, and simulation.

The ICMS DSS could employ a variety of DSS methodologies including table-based, expert systems, event scenario matrix, custom rules-based, model driven, or data driven. These DSS methodologies are being explored and deployed in many regions across the country for various types of ITS projects. The U.S. DOT has captured information on these efforts in a report entitled Assessment of Emerging Opportunities for Real-Time Multimodal Decision Support Systems in Transportation Operations: Concept Definition and Current Practice Report.[60] Readers of this ICM Implementation Guide are encouraged to read this report, explore the DSS methodologies used, and talk to deployers to gain a better understanding of which methodologies work best under certain conditions. Each region has its own unique conditions, so ICMS deployers will need to explore which methodologies will work best in their regions based on their own conditions.

An ICMS that includes a DSS can benefit ICM in multiple ways, including:

- Improving corridor efficiency and safety;
- Speeding up the process of decision making;
- Increasing operational control;
- Encouraging exploration and discovery of corridor problems and solutions;
- Speeding up operational problem solving;
- Facilitating corridor communication;
- Promoting corridor learning or training;
- Generating new evidence in support of decisions;
- Revealing new approaches to thinking about the problem space; and
- Helping to automate managerial and operational processes.

Decisions about the development and implementation of the DSS deployments at the ICM Pioneer Sites will be aided by the AMS work at each site. This work is ongoing and is planned to be discussed in a future update to this guide.

PIONEER SITE LESSONS LEARNED: DSS

The following DSS lessons learned were identified during the Dallas and San Diego ICM pioneer site project implementations.

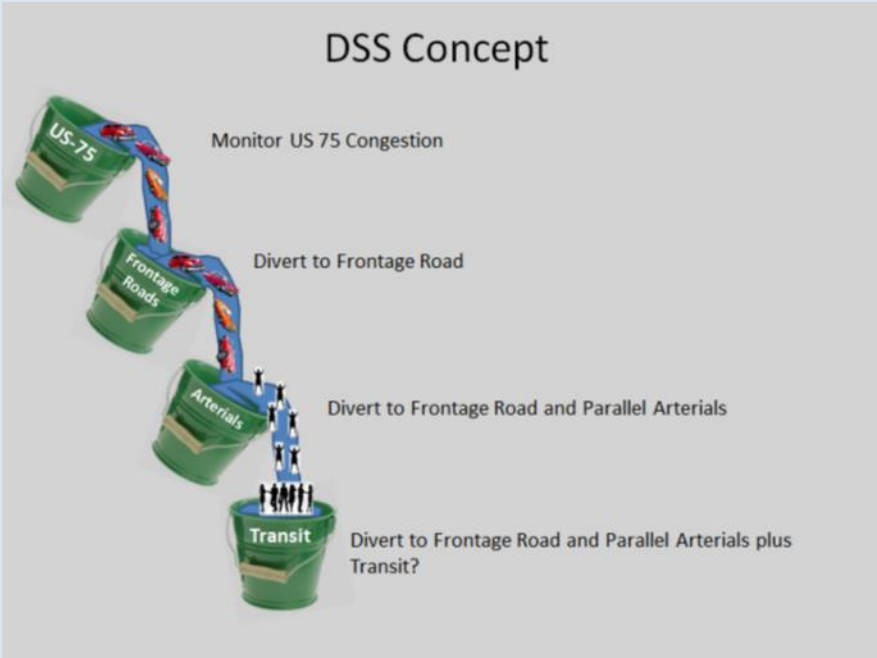
- DSS modeling and forecasting – including modeling and forecasting into the DSS requires significant computing power and storage capabilities. Be sure to specify an acceptable time window for a DSS-generated response plan to be issued after the request is generated. Anything greater than five minutes could be too long in a dynamic network with lots of changes.
- DSS Development – Use a focused iterative approach when defining, designing, and building the DSS. Fine tune the decision tools until acceptable output is achieved. The DSS will need to be assessed and scaled for the corridor.
- Response plan adjustments – Expect that the number of response plans use by the DSS will need to be adjusted once live operations begin. It may be better to start with a broader set of response plans and then narrow that down to a key set of the most useful response plans.
- Response plan development – Response plan development will take time, will have many dependencies and will require close coordination with signal timing plans. Leverage subject matter experts and provide the time and resources necessary for them to develop successful plans
- DSS trouble shooting – Periodic meetings to trouble shoot DSS issues and review the system and data output to make sure it is accurate are very helpful. Showing the results of response plans in analyses is helpful to review the system performance. Reviewing traffic counts and other data sources you can use for analyses and confirmation is helpful.
- Troubleshooting – Monitor how often the DSS recommends response plans, if changes are seen in data and response plan recommendations, it could be due to interruptions in data feeds or detection systems.
- Gain stakeholder trust – Opportunities for advancement are in coordinated management. Regions will need alternatives for travelers -- especially transit, common and reliable data platforms for decision making, and consensus on the expansion of existing institutional arrangements.
- Obtain hands-on experience – A shake-out period is Important and you can expect improvements and enhancements will occur during this period, the shake-out period also provides for training on an active system.
- Traffic signal considerations – Response plans need to consider existing timing plan coordination, time of day timing plans, and direction of travel. Keep in mind that traffic signal controllers will likely have limitations and ICMS developers will need to adjust for these limitations.
- Stay flexible – DSS adjustments will have to be considered on an ongoing basis because a corridor is always evolving, crash patterns are always changing, and eventually new data or functionality will be added to the ICMS.

PIONEER SITE EXAMPLE: DSS

The San Diego and Dallas ICM Pioneer Sites are deploying a combination of DSS methodologies.

The Dallas Pioneer Site is deploying expert system, event scenario matrix, and custom rules-based DSS methodologies. Figure 31 shows the general DSS concept for the Dallas ICM.

Figure 31. Dallas ICMS DSS Concept



[Source: Development Process of the DSS Response Plans and Traffic Signal Timing Plans for the Dallas ICM Project – White Paper (Unpublished), Texas Transportation Institute, April 25, 2014]

The San Diego Pioneer Site is deploying an expert system and combines a *rules-based methodology* using incident response parameters with *knowledge-based* information on roadway geometry and field device locations to generate response plans consisting of changeable message signing strategies and incident checklists automatically. The *rules-based* expert system is created with operator inputs on the impact of certain types of incidents on the freeway system.

APPENDIX C. ICM Walkthroughs

What is a Walkthrough?

An ICM or ICMS walkthrough is a step-by-step demonstration of all deliverables or artifacts created during the project lifecycle process. Any of the artifacts produced during the project should be subject to a walkthrough. The walkthrough provides an in-depth review of the work performed and allows stakeholders the opportunity to confirm that their needs are being met.

How to Prepare for a Walkthrough

A basic walkthrough plan and template should be provided in the PMP or SEMP and then tailored for each project-specified walkthrough. A good guide to follow for walkthroughs is the IEEE Std. 1028, IEEE Standard for Software Reviews, Section 7 – Walkthroughs. This guide provides some generic guidance that can be tailored for many types of project artifacts. The following template provides the basic outline for a walkthrough.

Walkthrough Template

Note: This template is based on IEEE Std. 1028, IEEE Standard for Software Reviews, Section 7 – Walkthroughs.

The Contractor shall maintain a revision history of this walkthrough template (or any other walkthrough template provided by the Contractor), in a manner such as the table below.

Revision History			
Date	**Rev.**	**Section(s)**	**Description**

1 INTRODUCTION – STATEMENT OF OBJECTIVES

This section shall state the general purposes or objectives for the walkthrough that is to be conducted. Major objectives for walkthroughs of systems engineering document include:

- Educating the audience on the purpose of the document, its concepts, and contents (Note that, in the case of the walkthroughs proposed for this contract, the audience will have read the documents and prepared comments or questions on the content of the document.) ;
- Finding anomalies within the document;
- Improving the quality of the document;
- Identifying and considering alternative concepts that the document's authors may not have considered (or determining why the authors rejected those concepts);
- Evaluating the documents conformance to standards and/or specifications recommended as guidance (and determining if deviation from that guidance is acceptable);
- Evaluating the usability of the document for its intended systems engineering purpose;
- Ensuring that each document in the systems engineering process is consistent with its predecessors; and
- Identifying elements missing from the document that are considered critical by the audience.

1.1 RESPONSIBILITIES

This section shall identify the roles that individuals participating in the walkthrough will have and will assign specific tasks to the individuals who are in those roles. The roles that shall be established for each walkthrough are the following:

- Walkthrough leader;
- Recorder;
- Author; and
- Team member.

1.2 WALKTHROUGH LEADER

For walkthroughs conducted as part of this contract, the role of walkthrough leader shall be shared by an author of the document being reviewed and by a U.S. DOT representative, generally (although not necessarily) the COTR for the contract. Each individual shall be assigned specific responsibilities. The table below lists suggested responsibilities that walkthrough leaders may be assigned.

Responsibilities that walkthrough leaders may be assigned. Task	Team Member
Conducts the walkthrough	U.S. DOT representative
Handles administrative tasks (i.e., distributing documents and arranging the meeting)	Shared by U.S. DOT and Contractor
Ensures the meeting is conducted in an orderly manner	U.S. DOT representative
Prepares the statement of objectives to guide the team through the walkthrough (see Section 1 Introduction – Statement of Objectives)	Contractor
Ensures that the team arrives at a decision or identified action for each discussed item and manages Rework/Follow-up efforts	Contractor
Issues the walkthrough output	Contractor

Individuals holding management positions over any member of the walkthrough team shall not participate in the walkthrough. Teams shall consist of at least two representatives from the contractor, one as the co-leader of the walkthrough and another as the recorder. Management representatives from the contractor may observe the walkthrough, but may not participate.

1.3 RECORDER

This section shall identify the individual who will perform the duties of the recorder of the walkthrough. The recorder shall note all decisions made during the walkthrough, identify issues that remain to be resolved (if any), and identify actions arising during the walkthrough. In addition, the recorder shall note all comments made during the walkthrough that pertain to anomalies found, questions of style, omissions, contradictions, suggestions for improvement, or alternative approaches. The recorder may also be the individual who produces the “Walkthrough Comment Resolution report,” an expected deliverable.

1.4 AUTHOR

The individual who is assigned the author role shall be one of the authors of the document under review, if the document has multiple authors. The preference is to have the principal author of the report assigned to this role.

1.5 TEAM MEMBERS

The U.S. DOT shall inform the contractor of the names of individuals who will participate, as U.S. DOT representatives, on the team conducting the walkthrough. The Contractor shall include those individuals, along with its own representatives assigned as team members in a table that identifies all team member participants for the specific walkthrough being conducted. Walkthrough team members are responsible for having reviewed the document and having prepared comments and/or questions related to the document. Team members shall identify and describe any anomalies or other concerns (e.g., missing information, inconsistencies, etc.) that they have found in the document.

2 INPUT

This section shall identify all inputs needed for the walkthrough. At a minimum, the inputs shall consist of the following:

- Statement of objectives for the walkthrough (see Section 1 Introduction – Statement of Objectives);
- Comment forms (see Appendix for a sample form);
- Document being reviewed; and
- Applicable standards.

Other inputs that may be provided for the walkthrough include:

- Anomaly categories (these shall be defined and provided to the team members at the same time as the walkthrough comment forms and walkthrough checklists); and
- Walkthrough checklists.

3 ENTRY CRITERIA

This section describes the criteria to be met before the walkthrough can begin.

3.1 AUTHORIZATION

Walkthroughs with U.S. DOT representatives are called for as part of the work of this contract. This is sufficient authorization.

3.2 PRECONDITIONS

This section shall list the preconditions that must be met before the walkthrough can begin. At a minimum, the following preconditions must be met:

- A statement of objectives for the walkthrough has been established and received U.S. DOT approval;
- The required review inputs are ready and have been in the hands of U.S. DOT reviewers for the minimum time specified in the contract; and
- Any standards that are required to evaluate the product are available. (Note: the U.S. DOT will not require the contractor to provide standards to the U.S. DOT reviewers. However, the

contractor team members shall have copies of the applicable standards provided by the contractor.)

4 PROCEDURES

The following sections detail the procedures to be followed during the walkthrough.

4.1 PREPARATION FOR THE WALKTHROUGH

The contractor shall work with the COTR to ensure that the walkthrough is conducted in an appropriate manner. To this end, they shall perform the following activities:

- Plan for the time and resources required to conduct an adequate walkthrough of the systems engineering document(s) under review;
- Provide for the facilities needed to conduct the walkthrough;
- Identify all walkthrough team members and inform them of the date and time of the walkthrough;
- Provide walkthrough team members with copies of the document(s) to be reviewed;
- Ensure that walkthrough team members possess appropriate levels of expertise and knowledge to comprehend the systems engineering document(s) under review;
- Distribute, in a timely manner, any other materials needed by the walkthrough team members;
- Ensure that planned walkthroughs are conducted as scheduled; and
- Act on walkthrough team recommendations in a timely manner.

4.2 OVERVIEW PRESENTATION

The author (as identified in Section 2. 3) or other Contractor representative may choose to make an overview presentation to start the walkthrough. If so, this section shall say so. A hard copy of the presentation materials shall be made available to the walkthrough participants.

4.3 EXAMINATION

This section shall describe the process for examining each document subject to review. It shall state how reviewers will provide their comments, both in writing and orally to the author. At a minimum, it shall discuss the following:

- What overview presentation, if any, will be made and by whom;
- How the discussion of general anomalies of concern will be conducted;
- How specific anomalies will be presented by reviewers (e.g., reviewers shall present anomalies that are not general anomalies when the author reaches that section of the document where the anomalies exist);
- How the walkthrough leader will coordinate discussion of specific anomalies;
- How action items will be determined;
- How decisions will be reached; and

- What immediate documentation, if any, will be provided at the end of the walkthrough (e.g., recorder raw notes as opposed to the walkthrough comment resolution report).

This section shall also discuss what the output of the walkthrough will be. At a minimum, the output shall contain:

- Document on which the walkthrough was conducted;
- Walkthrough team members;
- Statement of the walkthrough's objectives;
- An anomaly list identifying each anomaly location and description;
- A list of the recommendations made to address each anomaly;
- A list of actions, due dates, and responsible individuals;
- Any recommendations made by the walkthrough team on how to dispose of deficiencies and unresolved anomalies; and
- A list of decisions made during the walkthrough that affect the document.

4.4 REWORK/FOLLOW-UP

This section shall identify what the walkthrough leader(s) will do to ensure that action items assigned in the meeting are closed.

5 EXIT CRITERIA

This section shall list the exit criteria for the walkthrough. At a minimum, exit criteria shall include:

- The objectives stated in Section 1 have been met;
- Recommendations and required actions have been recorded; and
- The walkthrough output has been completed (see Section 4. 3).

6 DATA COLLECTION RECOMMENDATIONS

An anomaly, as defined by IEEE Std. 1044, is "any condition that deviates from expectations based on requirements specifications, design documents, standards, etc. or from someone's perceptions or experiences."[61] Walkthroughs during this contract are expected to find anomalies in the systems engineering documentation produced by the contractor. The finding of anomalies, followed by their correction, is part of the process of ensuring the quality of the final systems engineering products. This section shall define the types of anomalies (i.e., classification) and severity of the anomaly (i.e., ranking) to be recorded during walkthroughs. At a minimum, anomalies should fall into the following classifications:

- Editorial or style issues;
- Missing information;
- Inconsistencies in document content (internal);
- Inconsistencies between document under review and documents previously accepted in "final" form;

- Deficiencies with the statements of user needs, which may involve:
    - Need is not well-written;
    - Need is ambiguous;
    - Need is not uniquely identifiable;
    - Need does not express a major desired capability;
    - Need is not solution free;
    - Need does not capture the intent and rationale as to why it is needed;
    - Need is not satisfied by the requirement;
    - Need does not trace to a requirement;
    - Need is missing;
    - Need has editorial deficiencies (e.g., misspellings, grammatical errors); or
    - Other.
- Deficiencies with requirements, which may involve:
    - Requirement is not well-formed;
    - Requirement is ambiguous;
    - Requirement is not logically consistent with Parent(s), and sibling requirements;
    - Requirement is not traceable to at least one user need;
    - Requirement is not feasible;
    - Editorial; or
    - Other.
- Other.

In addition, anomalies shall be ranked according to their importance or impact on the document under review and on the overall project. The contractor shall propose an anomaly ranking scheme for U.S. DOT approval.

The above walkthrough template provides good highlights of the preparation for a walkthrough and documenting outcomes. The following lessons on the walkthrough process also provide some tips on conducting the ICMS walkthroughs.

Exhibit B–1: ICM Walkthrough Lessons Learned

- Walkthrough workbook – Consider preparing a walkthrough workbook that addresses each item to be reviewed, what the review criteria is for the item, and include space for reviewer comments related to each item.
- Requirements walkthroughs – Perform a requirements trace from an initial system input through to a final system output. This will help to identify any gaps in the requirements and architecture.
- Walkthrough “parking lot” – Create a parking lot for issues that need to be resolved offline – schedule a meeting for parking lot issues and follow through with the issues until resolution.
- Requirements walkthrough resources – During the walkthrough provide access to reference materials (system architecture, list of action verbs, problem statements, needs, etc.) so participants can access details of the work.

- Document feedback – At the conclusion of the walkthrough solicit participant feedback on the process to include in the lessons learned for the project and to make improvements for future walkthroughs.
- Repeat walkthroughs – Be prepared to repeat walkthroughs if needed.
- Next steps – While wrapping up the walkthrough, document next steps for improvements to the work.
- Stakeholder participation – Invite pertinent stakeholders to walkthroughs, make sure that the appropriate requirements are discussed with the appropriate stakeholder groups, don't waste stakeholder time by reviewing requirements that do not relate to them.
- Stakeholder engagement – Make sure all stakeholders remain engaged.
- Face-to-face process – Holding face-to-face walkthroughs has proven to be more productive that just providing comment on artifacts. A reviewer's intent can often be lost in translation on paper.
- Stakeholder preparation – Make sure stakeholders know what to expect coming into the meetings/walkthroughs and they have bought into the process.

APPENDIX D. List of Acronyms and Abbreviations

Term	Description
AMS	Analysis, Modeling, and Simulation
ATIS	Advanced Traveler Information System
C2C	Center-to-Center
Caltrans	California Department of Transportation
CDR	Critical Design Review
CFR	Code of Federal Regulations
CI	Configuration Item
ConOps	Concept of Operations
COTS	Commercial Off-The-Shelf
CSEP	Certified Systems Engineering Professionals
DART	Dallas Area Rapid Transit
DDD	Detailed Design Document
DMS	Dynamic Message Sign
DSS	Decision Support System
FHWA	Federal Highway Administration
GUI	Graphical User Interface
FTA	Federal Transit Administration
HOT	High-Occupancy Toll
HOV	High-Occupancy Vehicle
ICDs	Interface Control Documents
ICM	Integrated Corridor Management
ICMS	Integrated Corridor Management System
ID	Identification
IDIQ	Indefinite Delivery/Indefinite Quantity
IEEE	Institute of Electrical and Electronic Engineers
INCOSE	International Council of Systems Engineers
ISP	Information Service Provider
ITS	Intelligent Transportation Systems
IV&V	Independent Verification and Validation
M&O	Management and Operations
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MPO	Metropolitan Planning Organization
MTP/LRSTP	Metropolitan Transportation Plan or Long-Range Statewide Transportation Plan
NCTCOG	North Central Texas Council of Governments
NTTA	North Texas Tollway Authority
O&M	Operations and Maintenance

Term	Description
PDR	Preliminary Design Review
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PMP	Project Management Plan
RITA	Research and Innovative Technology Administration
RTVM	Requirements Traceability and Verification Matrix
SADT	Structured Analysis and Design Technique
SANDAG	San Diego Association of Governments
SAT	System Acceptance Test
SEGB	Systems Engineering Guidebook for Intelligent Transportation Systems
SEMP	Systems Engineering Management Plan
SEP	Systems Engineering Plan
SPCR	System Problem / Change Request
SRR	System Readiness Review
STIP	Statewide Transportation Improvement Program
SyRS	System Requirements Specification
TEARS	Targeted Event Accelerated Response System
TIP	Transportation Improvement Program
TRR	Test Readiness Review
TSS	Transport Simulation Systems, Inc.
TxDOT	Texas Department of Transportation
U.S. DOT	United States Department of Transportation
WBS	Work Breakdown Structure

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