Integrated Corridor Management

Phase 1 – Concept Development and Foundational Research

Task 2.5 – ICM Implementation Guidance

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FHWA Task Manager (COTR), John Harding

16. Abstract

This Implementation Guidance for Integrated Corridor Management (ICM) has been developed as part of Phase 1 (Foundational Research) for the Federal Highway Administration and the Federal Transit Administration Integrated Corridor Management Initiative. This Implementation Guidance document identifies and discusses the process steps needed to support the development, implementation, and operation of an ICM system. It is intended as a guide for transportation professionals who will be involved in some stage of the life-cycle for an Integrated Corridor Management System (ICMS).

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1. INTRODUCTION AND BACKGROUND

This *Implementation Guidance for Integrated Corridor Management (ICM)* has been developed as part of Phase 1 (Foundational Research) for the Federal Highway Administration and the Federal Transit Administration (FHWA / FTA) Integrated Corridor Management Initiative. The basic premise behind the ICM initiative is that independent, individual network-based transportation management systems and their cross-network linkages (Figure 1-1) can be operated in a more coordinated and integrated manner, thereby increasing overall corridor throughput and enhancing the mobility of the corridor users. This Implementation Guidance document identifies and discusses the process steps needed to support the development, implementation, and operation of an ICM system. It is intended as a guide for transportation professionals who will be involved in some stage of the life-cycle for an Integrated Corridor Management System (ICMS).

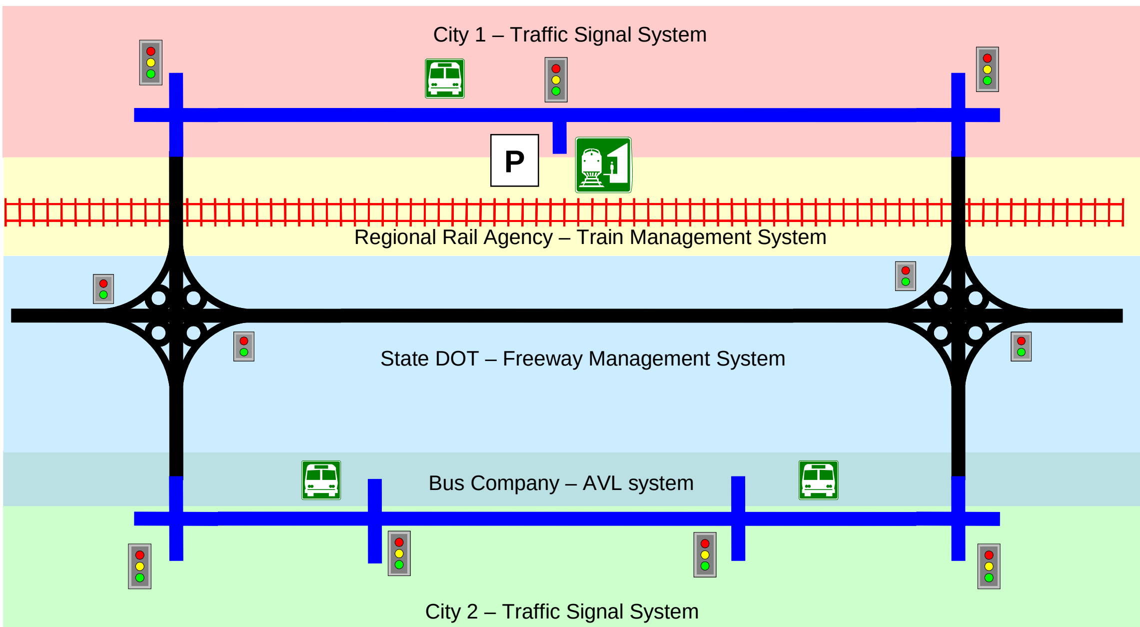

Figure 1-1. Schematic of Generic Corridor

This Implementation Guidance should be viewed as a "summary" document. Key issues, considerations and activities are identified herein, but with relatively brief discussions. More detailed information is provided in several supporting documents, including the following work products prepared during the Phase 1 Foundational Research:

- **Task 2.3 – Generic ICM Concept of Operations**: This is a high-level Concept of Operations (Con Ops) for a "generic" 15 mile-corridor, consisting of freeway, arterial, bus and rail networks, and serving a central business district. The document's primary purpose is to provide an example of an ICM Con Ops that can be used by agency and network owners as the basis for developing their own corridor-specific and real-world Concept of Operations.

- **Task 2.4 – Requirements:** This represents a high-level requirements document for the ICMS to be installed along the generic corridor identified in the aforementioned Con Ops.

- **Task 3.1 – Develop Alternative Definitions for Corridor and Integrated Corridor Management (ICM):** This Technical Memorandum discusses key attributes that were identified for possible inclusion in definitions used for the ICM initiative. It also presents final versions of these definitions, incorporating comments by FHWA and the stakeholders.
- **Task 3.2 – Develop Criteria for Delineating a Corridor:** This Technical Memorandum presents several guidelines and concepts that need to be considered when determining and delineating corridor boundaries. Its also discusses several approaches for utilizing these concepts and guidelines to identify the boundaries of a corridor.
- **Task 3.3 – Relationship between Corridor Management and Regional Management:** This Technical Memorandum compares and contrasts Integrated Corridor Management and Regional Management, identifying the similarities, differences, and relationships between Integrated Corridor Management and Regional Management.
- **Task 3.4 – Identify Integrated Corridor Management institutional Strategies and Administration:** This Technical Memorandum focuses on “institutional integration” and the associated issues and alternatives, such as organizational structures that support coordination and collaboration, participating institutions and the stakeholders, processes for funding and staffing ICM, and inter-agency agreements.
- **Task 3.5 – Integrated Corridor Management Program Planning and Funding:** This Technical Memorandum addresses potential funding alternatives for Integrated Corridor Management projects.
- **Tasks 5.1, 5.2, 5.3 – Corridor Types; and ICM Approaches and Strategies:** This Technical Memorandum discusses several corridor characteristics that may be used to classify corridors, and identifies those attributes that are most critical in terms of screening and selecting the appropriate ICM approaches. This is followed by a discussion of these operational approaches, including definitions of several ICM strategies for each overall approach. Matrices are also provided for matching a corridor with a specific corridor type and then identifying potential ICM operational approaches and strategies.
- **Task 5.4 – Identify ICM Approaches and Strategies Requirements and Issues:** The focus of this Tech Memo is to identify high – level requirements and potential operational, technical, and institutional implementation issues associated with the ICM approaches and strategies.
- **Task 5.5 – Identification of Analysis Needs:** This Technical Memorandum identifies existing capabilities to model ICM within corridors, and identifies gaps in current tools that must be addressed in order to allow for effective modeling of ICM.

Additional documents covering the systems engineering process and related activities are also referenced. These various documents, including links to web sites where they may be downloaded, are listed in the Appendix.

BACKGROUND AND DEFINITIONS

Definitions are important as they provide the basis for a common understanding, thereby facilitating communication and discussion among ICM stakeholders.

Integrated Corridor Management

Integrated corridor management consists of the operational coordination of multiple transportation networks and cross-network connections comprising a corridor, and the coordination of institutions responsible for corridor mobility. The goal of ICM is to improve mobility, safety, and other transportation objectives for travelers and goods. ICM may encompass several activities. For example:

- Cooperative and integrated policy among stakeholders.
- Concept of operations for corridor management.
- Communications among network operators and stakeholders.
- Improving the efficiency of cross-network junctions and interfaces.
- Mobility opportunities, including shifts to alternate routes and modes.
- Real-time traffic and transit monitoring.
- Real-time information distribution (including alternate networks).
- Congestion management (recurring and non-recurring).
- Incident management.
- Travel demand management.
- Public awareness programs.
- Transportation pricing and payment.

Integrated Corridor Management may result in the deployment of an actual transportation management system (ICMS) connecting the individual network-based transportation management systems (complete with ICMS central hardware and servers, data base, decision support software, joint sharing of command and control activities, etc.); or integrated corridor management may just be a set of operational procedures agreed to by the network owners with appropriate linkages between their respective systems. Regardless of the type of "system" deployed, the process steps and associated activities identified herein are directly applicable.

Corridor

From the perspective of the ICM initiative, a *corridor* has been defined as a largely linear geographic band defined by existing and forecasted travel patterns involving both people and goods. The corridor serves a particular travel market or markets that are affected by similar transportation needs and mobility issues. The corridor includes various networks (e.g., limited access facility, surface arterial(s), transit, bicycle, pedestrian pathway, waterway) that provide similar or complementary transportation functions. Additionally, the corridor includes cross-network connections that permit the individual networks to be readily accessible from each other. The term "network" is used in the corridor definition to denote a specific combination of facility type and mode.

Integration

The definition of ICM includes the term "coordination" multiple times. Such coordination, and the associated network interconnection and cross network management, requires "integration," a term defined in the dictionary as "making into a whole by bringing all parts together." In the context of ICM, integration is a bridging function between the various networks that make up a corridor, and involves processes and activities that facilitate a more seamless operation. In order to implement ICM, the transportation networks within a corridor (and their respective ITS systems) need to be “integrated” in several different ways, specifically:

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

It is emphasized that the various issues associated with operational, institutional, and technical integration are closely related and interdependent; for example, operational integration can be more effective when technical integration has been implemented; successful technical and operational integration typically require institutional integration (and the associated managerial support and funding) as a prerequisite; while ongoing operations and maintenance (considered an operational integration issue) is equally important to the long term technical success of an ICMS.

A SYSTEMS ENGINEERING APPROACH

The ICM Implementation Guidance is based on the principles of “systems engineering,” a formal process by which quality is continuously promoted. Systems engineering may be described as a “requirements-driven development process”; that is, the user (i.e., stakeholder) requirements are the overriding determinant of system concept and design, component selection and implementation.

The systems engineering process is often shown as a “V” (Figure 1-2) (see Reference 3) as a way of relating the different stages in the system life cycle to one another. A key feature of the V model is how it explicitly shows the relationship between work done on each side of the V; for example, the testing activities on the right side of the V are based on the results (e.g., needs, goals and objectives, performance measures, concept of operations, requirements) from the corresponding steps on the left side of the V. Moreover, at any specific stage where deliverables are produced (i.e., the right side of the V), those who are responsible for validating conformance to these documents are engaged to review the results and to begin development of their validation and verification plans.

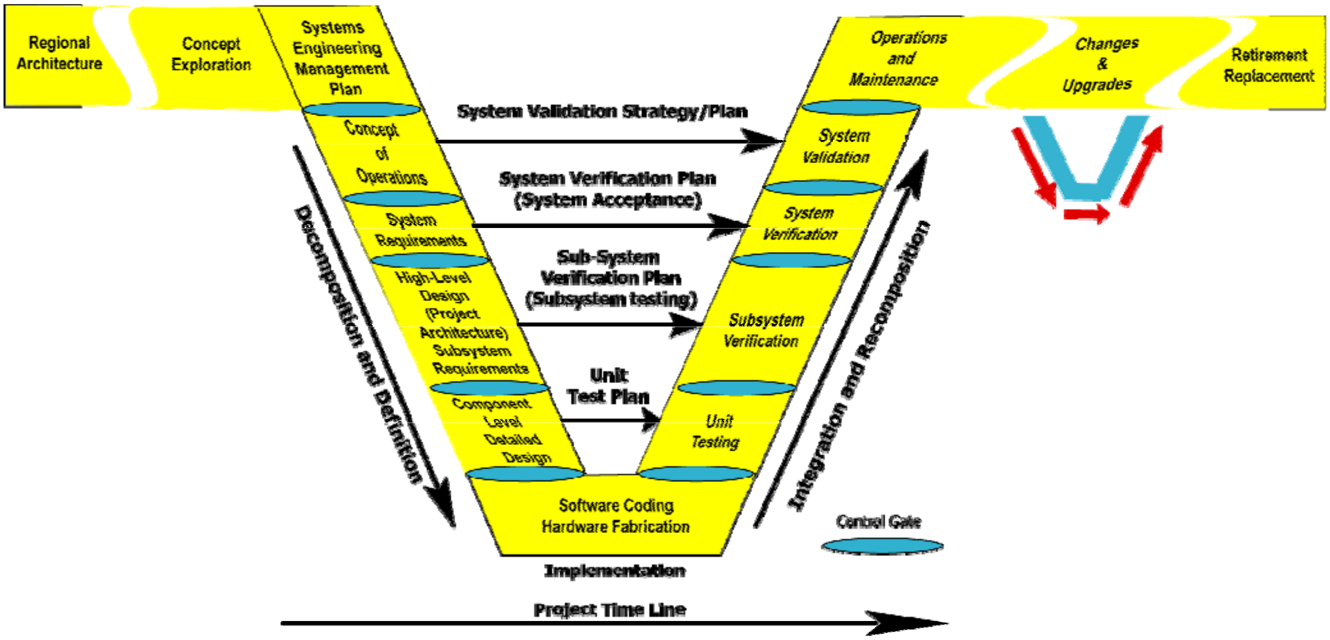

Figure 1-2. "V" Diagram

Following the systems engineering process can help ensure that the correct system is designed, and that the system is built correctly. The specific ICM-related functions and process steps associated with each stage are listed in Table 1-1 and described in subsequent chapters. While this may look like a sequential approach, wherein each activity is completed before beginning the next, the actual process is an iterative one, with multiple activities frequently performed in parallel (and possibly some steps accomplished “out of sequence”). Moreover, as the stakeholders move through the process, gathering and analyzing additional information, initial concepts developed during previous steps may be modified. For example, the initial corridor boundaries may be adjusted based on a quantitative analysis of spare capacity and the frequency of events necessitating ICM, with subsequent adjustments possible as a result of detailed modeling of the corridor. These modifications to the corridor boundaries may, in turn, result in the identification of new stakeholders (and related integration issues) or different ICM strategies. This “two steps forward and one step back” is a normal part of the overall process.

Many different processes can be used to plan, develop, design, and deploy an Integrated Corridor Management System. The objective of this ICM Implementation Guidance is **not** to prescribe a single process that should be universally adopted. If the corridor stakeholders already have a proven process, and it generates the necessary documentation and provides linkages between system testing and system concepts / requirements, then that process should be used. If such a process does not exist, then the process and functions described herein represents a good starting point, with adjustments being made to meet the specific needs of the corridor and its stakeholders.

Table 1-1. ICMS Development Process

STAGE / PROCESS STEPS	REFERENCES
CONCEPT EXPLORATION **Functions**: • Identify Need for Corridor Management • Establish Corridor Stakeholder Group • Identify Potential Corridors and Initial Boundaries **Result**: Stakeholders, Potential Corridor & Boundaries	ICM 3.1, 3.2, 3.4 References 1, 2, 3, 4, 5, 7, 8, 9
SYSTEMS ENGINEERING MANAGEMENT PLAN **Functions:** • Develop management plan for developing the ICM **Result:** ICM Program Management Plan	References 1, 2, 3

SYSTEM CONCEPTION
 	
Functions: Needs Analysis and ICM System Concept, including:
• Inventory Existing Systems / Data Collection
• Identify Current Corridor Conditions, Problems, and Needs
• Establish Corridor Vision and Goals
• Identify Potential ICM Approaches and Strategies
• Refine Corridor Boundaries
• Create Performance Measures and Metrics
• Define Proposed Changes
• Develop a System Concept
    o Align with the Regional ITS Architecture
    o Identify Operational Scenarios
    o Identify Implementation Issues (Operational, Technical, and Institutional)
 	
Result: Concept of Operations
	ICM 2.3, 3.1, 3.2, 3.3, 3.4, 5.1-3, 5.4
	
	References 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 16

REQUIREMENTS **Functions:** • High level ICMS Requirements • Detailed ICMS Requirements • Traceability between requirements and needs / concepts • Performance Analysis **Result**: Requirements Document, Revised Corridor Boundaries, Initial ICMS Traceability Matrix	ICM 2.4, 5.4, 5.5 References 1, 2, 3, 4, 5

<table>
<tr><th>STAGE / PROCESS STEPS</th><th>REFERENCES</th></tr>
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ICMS HIGH – LEVEL DESIGN

Functions:

- Decompose requirements into alternative architectures
- Identify and define system interfaces, interconnects, information flows, and overall topology
- Evaluate / select ICMS Standards
- Develop ICM System Architecture
  - Consistency with Regional ITS Architecture
- Continue resolving institutional – related issues (organizational structure, funding, stakeholder responsibilities)

Result: High – level Design Document (ICMS Architecture, interfaces, information flows, standards), Design Reviews

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ICM 5.4

References 1, 2, 3, 4, 5, 7, 8, 15

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ICM DETAILED DESIGN

Functions:

- Decompose each system and sub-system into individual hardware, software, database, etc. components
- Identify component technologies and design features
  - Evaluate COTS solutions
  - Enhancements / additions to existing ITS systems within the corridor.
- Design and specify system components
- System design traceability
  - Which components address which requirements?
  - Are these allocations appropriate and complete?
- Continue resolving institution-related issues (organizational structure, funding, stakeholder responsibilities)

Results: System, Sub-systems, and Component Designs (documented in an ICMS Design Report)

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ICM 5.4

References 1, 2, 3, 4, 5,

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PROCUREMENT

Functions:

- Define project sequencing and funding
- Determine the most appropriate procurement mechanism
- Develop necessary ICMS procurement documents
  - Address Intellectual Property Issues
- Develop overall program plan for building, operating, and maintaining the ICMS (Budget & Schedule)
  - Operations and Maintenance Plan
- Resolve remaining institutional – related issues

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ICM 3.4, 3.5, 5.4

References 1, 2, 3, 4, 5, 8, 12, 13, 14, 16

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STAGE / PROCESS STEPS	REFERENCES
(organizational structure, funding, stakeholder responsibilities) o Agreements **Results**: ICMS Procurement Documents, Project Plan, Operations and Maintenance Plan, Interagency Agreements, ICMS	
IMPLEMENTATION & DEPLOYMENT **Functions:** • Transform the ICMS design(s) into an operating system • Software engineering and coding; hardware fabrication • System integration and testing / Verification o Unit, sub-system, system • System deployment, verification and acceptance • System validation • Training and Documentation • Development of Response / Scenario Plans **Results**: Integration Plan, Verification Plan, Validation Plan, Ops Manual, Maintenance Manual, Response / Scenario Plans	ICM 5.4 References 1, 2, 3, 4, 5, 16
OPERATIONS AND MAINTENANCE / EVALUATION **Functions:** • On – going operations and maintenance of ICMS in accordance with the "Operations and Maintenance Plan" • Performance measurement and evaluation of corridor as a whole o Update and Refine ICM strategies and operational procedures / response plans as appropriate • Consider expanding ICMS (using systems engineering process) • Review and update Institutional Agreements o Ensuring that they are up to date as the system and its operation evolves. **Results:** Improved corridor performance	ICM 3.4, 5.4 References 1, 2, 3, 4, 5, 12, 16
CONFIGURATION MANAGEMENT - Cross-cutting Process	Reference 1, 2, 3, 4, 5, 6

2. CONCEPT EXPLORATION

This initial stage of the ICM development (and systems engineering) process is used to perform a high-level feasibility assessment of Integrated Corridor Management and the potential of its application. Once the determination has been made that ICM will likely provide benefits and is therefore worth pursuing, the effort focuses on the institutions and people involved. Concept exploration results in an ICM stakeholder group and a preliminary identification of key corridors and their boundaries.

IDENTIFY THE NEED FOR CORRIDOR MANAGEMENT

System engineering is often referred to as a “requirements-driven development process,” and these requirements must be based on *needs*. The most important reason to develop and implement ICM is that one or more corridors have operational problems, and ICM can meet some (and hopefully many) of these operational needs. In this step, the decision to pursue integrated corridor management either as an actual system or as a series of operational procedures is made.

In general, transportation management and operations, and the supporting ITS-based systems, have been applied in a “stovepipe” fashion; for example, State DOTs and toll/tunnel authorities implementing freeway management systems, local jurisdictions implementing arterial traffic signal control systems, and transit agencies implementing their own systems for tracking and managing bus and rail service Public safety entities (e.g., police, emergency service providers) have also implemented their own computer aided dispatching and related systems. These agency-specific systems have provided benefits in the context of their individual networks, but coordination is often lacking. What has too often been missing from this collection of independent transportation management systems is a corridor-wide focus involving the operational, technical, and institutional integration of the individual networks that compose the corridor.

A primary objective of ICM is to make significant improvements in the efficient movement of people and goods through the proactive management of both the corridor as a whole and the transportation assets that make up the corridor. The decision to implement an ICMS should be based on a clear understanding and commitment by stakeholders that integrated corridor management is needed; that the transportation networks and the cross-network connections comprising a corridor should operate as a unified and integrated transportation system. Stakeholders should recognize that ICM can provide benefits beyond the operations of a particular network or agency. Through the systems engineering process, the corridor stakeholders identify the need for integrated corridor management and establish ICM as a shared objective committing to the necessary coordination and collaboration.

Like many of the activities and analyses discussed within this ICM Implementation Guidance, the identification of corridor needs is a continuing and iterative process, starting at a high level and moving through subsequent levels of greater detail and refinement. This exploratory “needs analysis” represents an initial (and mostly qualitative) review of the corridors and their respective networks, current and projected operational problems within the corridor, deployed ITS systems and future ITS deployments, and integration opportunities within the corridor; followed by an initial assessment of whether ICM can improve travel within one or more corridors. The impetus for focusing on corridor-wide operations and potential ICM solutions may also come from needs identified during a special event or major incident. Regardless, subsequent (and more detailed) needs analyses will determine the required operational strategies and the amount of integration and coordination needed for corridor management.

IDENTIFY CORRIDOR STAKEHOLDERS

The basic institutional fabric of the surface transportation network is multi-agency, multi-functional, and multi-modal. Successful management and operation of a corridor (vis-à-vis ICM) requires that the perspectives and concerns of these different constituencies, or stakeholders, be considered. Stakeholders include any person or group with a direct interest (a “stake,” as it were) in the integrated operation of the corridor and the associated networks and cross-network linkages.

Stakeholders are sources of the corridor vision, goals and objectives, operational approaches and strategies, and requirements. It is the stakeholders who must ultimately agree on ICM concepts and policies; the development and approval of ICM operational response plans and procedures (including the agency-specific responsibilities for implementing and monitoring the plans); the ICMS architecture and system designs; and the on-going operation, maintenance, evaluation, and improvement of the ICMS. The various participants will also address and finalize the corridor boundaries (which, should the boundaries change during the process, may alter stakeholder participants).

The number of stakeholders in a corridor where ICMS is implemented will be based upon the transportation networks and operational area of the corridor. The Regional ITS Architecture Guidance Document (Reference 8) provides an extensive list of the range of stakeholders that have participated in regional ITS architecture development efforts around the country. Summarized in Table 2-1 is a checklist of *possible* stakeholders who may be involved in the Integrated Corridor Management.

All appropriate stakeholders need to be brought into the picture early on to make sure their needs are considered, and to determine how they will be involved in the process to plan and develop an ICMS. Bringing together all the stakeholders throughout this process can serve to heighten awareness of the importance and need for integrated corridor management, and to cultivate an interest in coordinated operations and corridor solutions. Moreover, it allows each entity (e.g., network owner / operator) to understand the specific functions and perspectives of their partner agencies, as well as their respective institutional constraints and barriers, thereby making the collaborations more productive.

For those corridors where a Regional ITS Architecture has been developed, the corridor stakeholders will have already worked together on several of the issues that need to be addressed during development of the ICMS. As such, any existing regional ITS committees and groups can serve as a natural forum to kick-off the ICMS development. In fact, it is doubtful if any additional stakeholders will be needed (i.e., required for corridor management, but not included in the regional ITS architecture), although the relative interest and level of involvement on the part of stakeholders, and the actual stakeholder representatives, may differ.

Table 2-1. Candidate ICM Stakeholders

Transportation Agencies (Roadway)
•State departments of transportation (DOT)
•Local agencies (City & County)
  ➢ Department of transportation
  ➢ Department of public works
•Federal highway administration (FHWA)
•State motor carrier agencies
•Toll/Turnpike & Bridge / Tunnel authorities
	Transit / Multi-Modal Agencies
	•Local transit (city/county/regional)
	  ➢ Bus (local, express, BRT)
	  ➢ Light Rail
	  ➢ Commuter Rail
	•Federal transit administration
	•Paratransit operations
	•Rail services (e.g., AMTRAK)
	•Federal rail administration
	•Port authorities
	•Seaport authorities/terminal operators
	•Department of airport or airport authority

Fleet Operators
•Commercial vehicle operators (CVO)
  ➢ Long-Haul trucking firms
  ➢ Local delivery services
•Courier fleets (e.g., US Postal Services, Federal Express, UPS, etc.)
•Taxi companies
	Public Safety Agencies
	•Law enforcement
	  ➢ State police and/or highway patrol
	  ➢ County sheriff department
	  ➢ City/Local police departments
	  ➢ Transit / Port police
	•Fire Departments / first responders
	  ➢ County/city/local
	•Emergency medical services
	•Hazardous materials (HazMat) teams
	•911 Services
	•Department of Homeland Security / FEMA

Travelers •Commuters, residents •Tourists/Visitors •Motorists (SOV) and their passengers (HOV) •Transit riders •Commercial vehicle operators •Bicyclists/pedestrians	**Private Sector** •Traffic reporting services / Information Service Providers •Local TV & radio stations •Travel demand management industry •Telecommunications industry •Automotive industry •Private towing/recovery business
Planning Organizations •Metropolitan planning organizations (MPOs) •Council of governments (COGs) •Regional transportation planning agency (RTPA)	**Activity Centers** •Event centers (e.g. sports, concerts, festivals, ski resorts, casinos, etc.) •National Park and US Forest Services •Major employers •Airport operators
Other Agencies •Tourism boards/visitors associations •School districts •Local business leagues/associations •Local Chambers of Commerce •National Weather Services (NWS) •Air and Water Quality Coalitions •Bureau of Land Management (BLM) •Academia interests, local Universities •Military (including Coast Guard) •US Army Corps of Engineers	**Other Agency Departments** •Information technology (IT) •Planning •Telecommunications •Legal/Contracts

As with any multi-jurisdictional initiative, “champions” are essential to take the lead in the ICM endeavor, to arrange and organize inter-agency meetings, to continuously promote the need for ICM, and to show the individual network stakeholders the benefits that can accrue from integrated corridor management on both a corridor and individual network basis. The champions must also have the authority, ability, and credibility to influence decisions within all agencies and groups. Outreach to policy makers is a key part of building support at the political level.

Identifying a *lead agency* may also be useful. It may be the MPO, a “regional” transportation agency, or a State DOT. Obviously, the ICM champion or lead agency must function as an advocate and help guide the ICM development process. At the same time, however, any lead agency must be careful that it is not viewed by the other entities as using the ICM concept as a means to expand its own influence and control.

IDENTIFY CORRIDORS AND INITIAL BOUNDARIES

The range and variability of potential corridor characteristics (e.g., operational, institutional, technical, and the physical layout of corridor networks) is so vast that there can be very few hard and fast rules concerning the identification and delineation of corridor boundaries. Rather, there are several guidelines and concepts, mostly operational and physical in nature (Table 2-2), that need to be considered by the stakeholders when determining corridor boundaries. Moreover, corridor boundaries may not even be fixed; the size of a corridor may expand and contract depending on the operational situation necessitating the implementation of ICM strategies.

This initial corridor identification and boundary delineation is primarily conceptual and qualitative in nature, relying on local knowledge (and possibly a high-level review of any available data on travel patterns and markets) combined with engineering judgment (considering the various guidelines listed in Table 2-2) to develop a “first draft” of corridor boundaries. The intent of this initial activity is to ferret out the rough impact area of the corridor (e.g., drawing elongated ovals or rectangles on a map of the metropolitan area or region), identifying the corridor networks, cross-network linkages and junctions, the major trip ends, and the primary and alternate routes and modes that serve them.

More detailed analyses of corridor boundaries are addressed in subsequent steps. Moreover, it is emphasized that a corridor’s boundaries are never truly “final.” During the “Evaluation, Operation, and Maintenance” stage of the ICMS life-cycle, the operation of the corridor as a whole is evaluated using ICM performance measures, and adjustments to the ICMS are made as appropriate. Such refinements may be operational, technical, or institutional in nature, and they may include changes to the corridor boundaries as well, which may require additional conceptual and detailed analyses.

Table 2-2. Summary of Corridor Boundary Delineation Concepts and Guidelines

- A key attribute of a corridor is that it has no predefined size or scale
- Encompass multiple networks. This involves some combination of freeways, arterials (with or without managed lanes), transit utilizing roadway right-of-way (e.g. bus and/or light rail), and/or transit in separate or exclusive ROW (e.g. subway, elevated rail).
- The individual networks within the corridor are approaching optimization in terms of their respective operations, including the presence of ITS technologies and management strategies.
- Appropriate cross-network linkages and junctions exist throughout the length of the corridor thereby permitting route and mode shifts without severe mileage and/or travel time penalty to the travelers.
- Forms a largely linear geographic band (i.e., the length of the corridor is much greater than its width).
- Define a pathway for the movement of people and goods, with this pathway connecting major sources of trips (e.g., population and employment centers, commercial establishments, intermodal facilities, special event venues). These trips need to be network benign meaning that the trip can be serviced in a similar manner by the different alternative travel choices facilitating total corridor capacity and demand management.
- No “maximum corridor length.” A corridor’s length is determined by the major origins and destinations served by the corridor. The distance between these trip sources is irrelevant provided that they result in a travel market(s) with similar transportation needs and mobility issues.
- A practical minimum length for a corridor exists (5 miles as a rule-of-thumb).
- Provides mobility opportunities including shifts to alternate routes and modes. This assumes that available spare capacity exists on the adjacent networks and network linkages within the corridor under some operational scenarios.
- Outer (extended) boundaries should be considered for extraordinary (atypical and infrequent) circumstances, such as a major incident or construction activity that completely closes a network for several hours or longer, a special event that significantly increases demand, or a disaster requiring evacuations.
- Always keep in mind that the overall goal of ICM is for the corridor to operate as an integrated system such that all the existing capacity can be more effectively used.

3. SYSTEMS ENGINEERING (ICM) MANAGEMENT PLAN

Good systems engineering starts with planning. Handling the various management issues that will undoubtedly arise during the development of an ICMS is easier to do if there is a good program plan to start with. This stage focuses on the development of a Systems Engineering Management Plan (SEMP) / ICM Program Plan.

A good program plan is one that is complete, comprehensive, and communicated. Completeness and comprehensiveness of the plan is ensured by:

- Including all tasks that must be performed.
- Accurately estimating the resources required to accomplish each task.
- Assigning the appropriate resources to each task.
- Defining all dependencies among tasks.
- Identifying all products or other criteria whose completion signifies that a task is done.
- Determining how to measure progress against plan when managing a project.

The ICM program plan must then be communicated to everyone that it affects. Those agencies and individuals assigned to work on ICMS tasks need to be informed as to what work they are responsible for, when they should begin and complete a task and how they will know when a task is done, who else will be working on that task, what tasks are dependent on the one they are working on and which other tasks their task depends on, and what non-people resources they will need to do their job.

A recurring theme in this ICM Implementation Guidance (and the overall ICM initiative) is the concept of distributing specific operational responsibilities and sharing control functions in a manner that transcends institutional boundaries. The distribution of responsibilities begins with the ICM Program Plan. This is a major institutional issue, and it is very doubtful that all of the responsibilities can be defined in the initial ICM Program Plan. Nevertheless, the program plan should, as a minimum, identify which of the stakeholders are responsible for each the various process steps and activities leading up to the actual deployment and start-up of the ICMS; for example, who is responsible for the collection and analyses of what information, who is responsible for developing the Concept of Operations and Requirements Documents, who is responsible for the system designs, who is responsible for developing verification plans and the subsequent testing, who is responsible for monitoring overall progress on the plan, what are the other stakeholders' responsibilities with respect to reviewing and providing input to these documents, and will this work be done in-house, by consultants, or some combination of the two. Moreover, the ICM Program Plan should also address the schedule and key milestone dates.

Program management is a continuous activity. Once the initial ICM Program Plan is complete and approved by all the stakeholders, it is essential to track each task, measure its progress, revise the overall plan if needed, and identify and address any obstacles that impede plan progress. The program plan will also be updated and expanded over time as the process continues, as additional information is gathered and analyzed, and as the various integration issues are resolved. In some cases separate plans, focusing on a particular activity (e.g., integration, verification, configuration management, operations and maintenance), will be developed as an adjunct (and compatible) to the ICM Program Plan.

4. SYSTEM CONCEPTION

The system conception stage consists of two major activities:

- **Needs Analysis.** This focuses on determining how the corridor should operate relative to how it operates today. As noted in Chapter 2, the identification and analysis of corridor needs is a continuing and iterative process, starting at a high level (mostly qualitative) and moving through subsequent levels of greater detail, quantitative analyses, and refinement. The corridor needs are identified from discussions with stakeholders coupled with the results of analytical evaluations. This is a multi-layered process that can include identification of current performance deficiencies, identification of the operational performance envisioned by stakeholders, conducting an inventory of current and near-term corridor capabilities and assets. and the identification and the identification of any missing assets needed to implement the proposed ICMS. This needs assessment should include operational, institutional, and technical integration considerations along with potential constraints (funding, staffing availability, schedule, facilities).
- **Operational Concept.** The ICMS concept explains how things are expected to work once the ICM program and system is in operation and identifies the responsibilities of the various stakeholders for making this happen. The ICM approaches and strategies are identified. These consist of those services that can be applied to the corridor to improve the efficiency, throughput, safety, and convenience of the corridor networks through better information, coordination of network junctions, pro-active management of capacity and demand, advanced technologies and systems, and improved institutional frameworks. These services are defined at a very high level and then prioritized based on the corridor needs. Other considerations include corridor vision and goals, alignment with any regional ITS architecture, and corridor-wide performance measures.

Some of the key questions that must be addressed during this stage are identified in Table 4-1 (modified from Systems Engineering Reference 1).The results are then documented in a *Concept of Operations*, a formal document that provides a user-oriented view of the Integrated Corridor Management concept and any associated ICM Systems. It is developed to help communicate this view to the corridor stakeholders and to solicit their feedback.

Table 4-1. Key Operational Concept Questions

Needs Analysis	• What is wrong with the current situation? • What needs does the ICMS fill? • Have we clearly articulated the need? • Do all corridor stakeholders have a common understanding of the Corridor goals and objectives?
Concept of Operations	• Is our concept consistent with any Architecture(s) with which it must interact? • Have we identified all intended users of the ICMS? • How will each intended user interact with the ICMS? • How is this different from the current situation, if at all? • Do the intended users understand their role in the ICMS? • Have we coordinated with all other agencies affected by the ICM program and system?

INVENTORY EXISITNG SYSTEMS / DATA COLLECTION

This process step includes several activities, including:

- Developing an inventory of the existing network-specific transportation management and ITS-based assets, along with any transportation management or ITS improvements that are likely to be implemented on networks within the corridor in the next few years.
- Gathering data that describes the corridor and its operation, including all the networks and cross-network connections within the corridor.
- Reviewing the regional ITS architecture in which the Integrated Corridor Management System will function.

Inventory

The process of developing a corridor inventory begins with collecting existing information from a variety of sources, including the Transportation Improvement Program (TIP), the Long Range Transportation Plan, the Regional ITS Architecture, any network-specific ITS plan outreach materials, and operational procedures. The inventory should identify each asset — including transportation management centers, roadside and transit systems (e.g., field devices and communications networks), traveler information systems, and other ITS attributes — and provide a brief description that explains the attributes of each asset (e.g., associated organization or network, existing or planned, functionality, standards used). The inclusion of future improvements in the corridor inventory is important because they may factor into the development of an ICMS.

In addition to the technical assets, the inventory should also address the current operational procedures and institutional framework within the corridor. Examples of this information include the following:

- Inter-agency relationships and organizational approaches, including agency-specific responsibilities, during various scenarios (e.g., recurring congestion, incident / outage, special event, emergency), plus any additional mechanisms that have been established to enhance inter-agency coordination.
- Information shared between agencies, and in what manner.
- Operational procedures and response plans.
- Network-specific performance measures.
- Policies and procedures for the dissemination of traveler information, including linkages to the media and other Information Service Providers.
- Hours of operation and associated staffing.
- Marketing and outreach programs.
- Existing inter-agency agreements.

The initial inventory should be reviewed with appropriate stakeholders to verify its accuracy and to collect additional inventory information.

Physical and Operational Data

Information on the physical attributes and operations of the corridor are necessary to identify needs, refine the boundaries, and select the most appropriate ICM strategies. Information and data in this regard may include the following:

- Operating capacity of each network within the corridor (e.g., number / width of roadway lanes, headways/capacity of transit vehicles including local and express service).
- Location and capacity of cross-network connections.
- Location and capacity of network junctions and interfaces (e.g., ramps, transit stations, parking lots, toll facilities).
- Major traffic generators (i.e., origins and destinations) serviced by the corridor.
- New infrastructure and generators planned for the future.
- Primary travel markets served by the corridor (e.g., commuters, goods and freight movement, shopping, tourism, recurring events, combination), and how that may vary by time of day, day of week, or period of year.
- Current and future projections of demand and usage for the individual corridor networks and cross-network linkages or junctions (e.g., roadway volumes by vehicle type, transit passenger boardings, variations by time of day, day of week, period of year).[1]
- Type and frequency of events that can impact corridor operations (e.g., roadway incidents and crashes, transit incidents and outages, evacuations, weather, major special events).

Regional ITS Architecture

As noted above, one of the sources for inventory information is the Regional ITS Architecture. It is generally assumed that the corridor(s) in question will be part of a larger region for which a Regional ITS Architecture has been developed in accordance with FHWA Rule 940[2] (Reference 7) and the associated FTA Ruling (FTA National ITS Architecture Policy Section 5.d.6).

Integrated corridor management builds upon regional management; in this context, an ICMS may be considered a "sub-regional architecture." As such, the development of an Integrated Corridor Management System (and the ICMS architecture) should be compatible and consistent with the regional ITS architecture, which requires an understanding of the various attributes that comprise the regional architecture and the associated management functions. Moreover, the regional ITS architecture may be very useful in developing the corridor management concept and resolving various operational, institutional, and technical issues. For example:

[1] In the context of ICMS being a system of already deployed network transportation management systems, it is assumed that much of these data will already be available from these network systems and that minimal, if any, new data collection will be required.

[2] This rule, which became effective in April 2001, requires the development of a "regional ITS architecture," which is defined in the rule as "a regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects or groups of projects. The regional ITS architecture is based on the National ITS Architecture and consists of several parts including the system functional requirements and information exchanges with planned and existing systems and subsystems and identification of applicable standards, and would be tailored to address the local situation and ITS investment needs."

- The regional ITS architecture development process may serve as a key enabler in identifying the appropriate stakeholders, establishing champions, and initiating the institutional relationships that will sustain integrated corridor management.
- The system inventory and operational concepts developed during the regional ITS architecture development process may serve as a template and information source for the ICMS inventory of systems and concept of operations.
- In the event that attributes of the regional ITS architecture have already been (or will soon be implemented), the ICMS should incorporate and build upon these regional elements to the greatest extent possible. In other words, an ICMS should not "re-invent the wheel."

While any integrated corridor management system must be compatible and consistent with the regional ITS architecture, it must be emphasized that corridor management and regional management are **not** the same thing. The major differences lie in their size and how their respective boundaries are defined, the extent to which individual network operations (and the cross network linkages and junctions) within a corridor are integrated together, and how this integrated corridor is managed and evaluated on a day-to-day basis. Similarities and parallels exist between regional and corridor management with respect to institutional integration (i.e., the coordination and collaboration between network owners and operators) and technical integration (i.e., communications links, interfaces, standards, etc. to support information sharing), but due to the enhanced and expanded operational features of corridor management, additional institutional and technical integration may be required within a corridor as compared to regional management. The differences and similarities between regional and corridor management in terms of their respective integration needs are summarized in Table 4-2.

Table 4-2. Comparison of Regional and Corridor Management

Attribute	Region	Corridor
Facility Types	Includes all surface transportation facilities such as streets, bridges, tunnels, transit routes, airports, ports, etc.	Several if not all of the facility types in a region. The corridor-specific facilities are distinguished by the fact that they serve the same or similar travel markets, are adjacent, and are readily accessible from each other.
Boundaries	Geographically defined (e.g., jurisdictional and agency boundaries, MPO)	No predefined size or scale. Operationally defined (travel markets and mobility needs, travel patterns, adjacent networks and cross-network linkages). In the context of the ICM Initiative, a region is comprised of several corridors (i.e., a corridor is a sub-set of the region)
Stakeholders	Agencies that manage and operate the transportation facilities. Also includes other agencies that are involved with these facilities or have an interest in regional transportation issues (e.g., law enforcement, emergency service providers, MPO).	Many if not all of the same regional stakeholders. No additional stakeholders (required by corridor management; but not for regional management); although the relative interest and involvement by stakeholders, and the actual stakeholder representatives, may differ.
Institutional	Crosses geographic, political and institutional boundaries.	Crosses geographic, political and institutional boundaries; though likely less than within the region.

Attribute	Region	Corridor
Operational Focus	In general, information sharing and coordination of agencies that operate the various networks within the region, supporting regional management of individual network activities.	Builds upon regional information sharing and coordination to provide integrated operations along the various corridors within the region. This includes operational integration of adjacent networks and cross-network linkages on a daily basis (e.g., accommodating or promoting cross-network shifts, balancing the capacity-demand relationship).
Performance Focus	Network-based measurements (freeway, arterial, bus, rail). Indirect relationship to customer/user performance.	Common measurements across corridor networks. Direct relationship to customer/user performance.
Technical Focus	Regional ITS Architecture to support information sharing and regional coordination.	ICMS builds upon the regional ITS architecture, but may have additional information sharing requirements (e.g., command and control, response plan details)

CURRENT CORRIDOR CONDITIONS, PROBLEMS, AND NEEDS

Before corridor goals and objectives can be established and the associated ICM approaches and strategies prioritized, the problems within the corridor and the needs of the stakeholders must be understood. Using the inventory information and data gathered from the previous activity, coupled with stakeholder discussions, the corridor needs are identified and documented. This effort should include operational, technical, and, institutional deficiencies and constraints, thereby providing insight as to the types of problems being faced in the corridor, and leading to a conclusion as to the overall potential of applying ICM to the corridor.

Stakeholders represent a major and important source for identifying and defining corridor issues, needs, and constraints. Their input should be elicited via interviews and/or workshops. The results should then be consolidated and edited, combining similar issues (i.e., repetitions of the same need and/or issue) and eliminating any issues and needs that are not relevant to the management and operation of the corridor. It may also be worthwhile to categorize and summarize the resulting list by the different types of corridor integration. For example, **operational,** including specific scenarios (e.g., incident management, traveler information, emergencies) and related concerns; **technical** (e.g., standards, field devices); **institutional** (e.g., coordination, procedures, organization, decision making); and any cross-cutting issues and needs.

An analysis of the gathered data should provide quantitative measures of the operational issues and needs within the corridor, such as:

- Peak-period travel times and level of service relative to “free flow” conditions.
- Frequency of incidents and outages that cause congestion and delays.
- Impact of trucks and other commercial traffic.
- Schedule adherence for transit.
- Spare capacity within the corridor (by network and by time of day).
- Operational problems and/or gaps in existing ITS-based systems.
- Other constraints (e.g., lack of parking, bottlenecks).

The results of this process (stakeholder elicitation, quantitative analyses) should be presented to the stakeholders for review and comment. A workshop setting may be very beneficial in that it can encourage continuing discussion and feedback until all agree that their and the corridor's needs have been captured. Since generally the needs cannot all be met, and sometimes may even be conflicting, they should be further analyzed (perhaps during the workshop) to identify the highest priority issues and needs on which to focus the ICM program and system.

Corridor Type

A related activity is to identify the corridor "type." ICM Technical Memorandum 5.1-3 discusses several corridor characteristics that may be used to classify corridors and includes a matrix for identifying corridor types and their aspects. In summary, a corridor may be defined by the following characteristics:

- Network Combinations:
  - Roadway only (e.g. freeways and / or arterials).
  - Roadway with managed lanes (e.g. HOV, reversible) and / or some form of toll facility within the corridor.
  - Roadway and transit utilizing roadway right-of-way (e.g. bus and / or light rail).
  - Roadway with managed lanes or tolling and transit utilizing roadway ROW.
  - Roadway, transit utilizing roadway ROW and transit in separate or exclusive ROW (e.g. subway, elevated rail).
  - Roadway with Managed Lanes / Tolling and Transit (In Both Roadway ROW and Separate ROW).
  - Other combinations (including waterways).
- Operational Characteristics:
  - Type of event or scenario (e.g., roadway incident, transit incident, planned event, evacuation, recurring congestion).
  - Duration and severity (e.g., a fender-bender blocking one lane of a freeway will have significantly different operational ICM needs as compared to a multi-vehicle crash (with injuries) blocking several lanes as well as lanes in the opposite direction for emergency response vehicles; similarly, weekend maintenance of track will require significantly different approaches as compared to a transit strike).
  - Available spare capacity within the corridor, including adjacent networks and the cross-network linkages or junctions (e.g., if spare capacity is available on other adjacent networks, route and mode shifts may be easier to implement; even if sufficient spare capacity does not exist, such shifts may still be implemented to "share the pain," along with implementing ICM strategies that focus on reducing demand and/or increasing capacity).

CORRIDOR VISION AND GOALS

The purpose of a vision statement is to portray the future ICM system and its operation for a specific time horizon, providing a platform for establishing goals and objectives.

The vision statement must also be simple, easy to read and accessible to a wide audience.

The ICM vision should be developed through an iterative process involving all the corridor stakeholders. Such a consensus building approach is very important for a corridor-based approach to transportation management and operations involving multiple agencies and stakeholders, both public and private. NCHRP Synthesis 337: "Cooperative Agreements for Corridor Management" (Reference 12), stresses the "importance of establishing a shared vision of the corridor and for each party to look at the corridor as a whole—not just from within or outside of the right-of-way (or, more specifically, their individual facilities). The willingness of each party to work toward a common vision and to compromise for mutual benefit can form the basis of a lasting and effective agreement on corridor management."

The corridor goals and objectives are formulated with a view to address the current corridor conditions, deficiencies, and needs, and to help achieve the long-term vision. They also provide the framework for defining ICM approaches and strategies. The differences between goals and objectives may be summarized as follows:

- Goals are broad; objectives are narrow.
- Goals are general intentions; objectives are precise.
- Goals are intangible; objectives are tangible.
- Goals are abstract; objectives are concrete.
- Goals can't be validated as is; objectives can be validated.

The last bullet is very important. Objectives, being more precisely defined than goals and therefore permitting validation, provide a means by which the effectiveness of alternative strategies can be evaluated against a benchmark or each other. They also provide the basis for developing corridor-wide performance measures. In essence, the ICM objectives should be observable (i.e., accomplishment of the objective can be observed, with no doubt as to whether the objective has been met or not) and measurable (i.e., one can state that it was 100 percent accomplished, 50 percent accomplished, etc). At the same time, the objectives should not be to confining; that is, there should be some flexibility to allow for changes in the overall situation. If the objective can only be achieved under optimum conditions, then it is too confining.

IDENTIFY POTENTIAL ICM APPROACHES AND STRATEGIES

This process step involves an assessment of whether or not Integrated Corridor Management can address the operational deficiencies and needs within the corridor, followed by an identification of the specific ICM approaches and strategies to be implemented, including how they satisfy the corridor's goal and objectives.

An *approach* can be defined as "the means or method used in dealing with or accomplishing something." Accordingly, an ICM approach may be viewed as the overall method of achieving operational coordination on a corridor-wide basis, as defined and agreed to by the corridor stakeholders. A *strategy* is a specific plan of action within the broader context of the overall approach, with multiple strategies associated with each approach.

The level of integration (i.e., operational, institutional, technical) required within the corridor will depend greatly on the particular approach and the associated strategies selected by the corridor stakeholders. The affiliated level of network and stakeholder coordination may be viewed as moving along a continuous spectrum, from basic information sharing, to ad hoc relationships built around specific issues or special events, to more formal collaborative relationships with mutually agreed-upon objectives and strategies, and finally joint ownership and control of transportation facilities and services. The following ICM approaches have been defined to identify segments of that integration and coordination spectrum:

- Information sharing and distribution.
- Improve operational efficiency of network junctions and interfaces.
- Accommodate and promote cross-network route and modal shifts.
- Manage capacity, or the demand relationship within corridor, in “real-time” for the short term.
- Manage capacity, or the demand relationship within corridor, for the long term.

Multiple strategies are associated with each approach, as listed in Table 4-3 (with further descriptions provided in Technical Memorandum 5.1-3.). It is emphasized that these strategies focus on the operation of the corridor (comprised of multiple adjacent networks) as a whole, and the cross-network linkages and junctions. Moreover, these ICM approaches and the associated strategies are not mutually exclusive; in fact, they tend to build upon one another and, in some cases, are pre-requisites. For example, information sharing is essential to the success of the other approaches, and promoting cross-network shifts may require capacity (operational) modifications to handle the additional users on alternative networks. Moreover, these ICM approaches may also represent a staged sequence (temporal) to ICM deployment (e.g., starting with information sharing, and then moving on to integrated corridor operations over time).

It is noted that Technical Memorandum 5.1-3 includes several matrices that can be used to match a specific corridor type with the appropriate ICM operational approaches and strategies. This represents only an “initial screening,” however; the “final” selection of ICM strategies can only come from a consensus by the stakeholders after cooperative identification and analysis of the specific needs for improving travel in the corridor. Moreover, it is very important to map (i.e., make “traceable”) each selected ICM strategy to the corridor goal(s) and objective(s) and to the corresponding need(s) it addresses.

Table 4-3. ICM Operational Approaches and Strategies

Information Sharing/Distribution

- Manual information sharing.
- Automated information sharing (real-time data).
- Automated information sharing (real-time video).
- Information clearing-house/Information Exchange Network between corridor networks or agencies (e.g., information is displayed on a single graphical representation of the corridor, showing real-time status of all the corridor networks and connections).
- A corridor-based advanced traveler information system (ATIS) database that provides information to travelers pre-trip.
- En-route traveler information devices owned and operated by network agencies (e.g., DMS, 511, transit public announcement systems) being used to describe current operational conditions on another network(s) within the corridor.
- A common incident reporting system and asset management (GIS) system.
- Shared control of “passive” ITS devices, such as CCTV.
- Access to corridor information (e.g., ATIS Database) by Information Service Providers (ISPs) and other value-added entities.

Improve Operational Efficiency of Network Junctions and Physical Interfaces

- Signal priority for transit (e.g. extended green times to buses that are operating behind schedule).
- Signal pre-emption or “best route” for emergency vehicles.
- Multi-modal electronic payment.
- Transit hub connection protection (holding one service while waiting for another service to arrive).
- Multi-agency or multi-network incident response teams and service patrols and training exercises.
- Coordinated operation between ramp meters and arterial traffic signals.
- Coordinated operation between arterial traffic signals and rail transit at-grade crossings.

Accommodate and Promote Cross-Network Route and Modal Shifts

- Modify arterial signal timing to accommodate traffic shifting from freeway.
- Modify ramp metering rates to accommodate traffic shifting from arterial.
- Modify transit priority parameters to accommodate more timely bus / light rail service on arterial.
- Promote route shifts between roadways via en-route traveler information devices (e.g. DMS, HAR, “511”) advising motorists of congestion ahead, directing them to adjacent freeways or arterials.
- Promote modal shifts from roadways to transit via en-route traveler information devices (e.g. DMS, HAR, “511”) advising motorists of congestion ahead, directing them to high-capacity transit networks and providing real-time information on the number of parking spaces available in the park and ride facility.
- Promote shifts between transit facilities via en-route traveler information devices (e.g. station message signs and public announcements) advising riders of outages and directing them to adjacent rail or bus services.
- Re-route buses around major incidents.

Manage Capacity – Demand Relationship Within Corridor (Real-time/Short-term)

- Lane use control (reversible lanes or contra-flow).
- Convert regular lanes to transit-only or emergency-only.
- Add transit capacity by adjusting headways and number of vehicles.
- Add transit capacity by adding temporary new service (e.g., express bus service, "bus bridge" around rail outage or incident).
- Add capacity at parking lots (temporary lots).
- Increase roadway capacity by opening HOV/HOT lanes and shoulders.
- Modify HOV restrictions (increase minimum number, make bus only).
- Restrict ramp access (metering rates, closures).
- Convert regular lanes to truck-only.
- Coordinate scheduled maintenance and construction activities among corridor networks
- Variable speed limits (based on TOD, construction, weather conditions).
- Modify toll and HOT pricing.
- Modify transit fares to encourage ridership.
- Modify parking fees.
- Variable truck restrictions (lane, speed, network, time of day).
- Restrict or reroute commercial traffic.

Manage Capacity – Demand Relationship Within Corridor (Long-Term)

- Low cost infrastructure improvements to cross-network linkages and junctions.
- Re-routing rail transit to alternative rail networks.
- Guidelines for work hours during emergencies or special events.
- Peak spreading.
- Ride-sharing programs.

REFINE CORRIDOR BOUNDARIES

This step represents a more quantitative analysis for delineating the corridor boundaries. It builds upon the initial boundaries identified as part of the concept exploration stage, taking into account the information gathered during the system conception stage (e.g., inventory of existing systems and network characteristics, identification of current operational conditions and deficiencies, needs analysis, corridor goals and objectives, selected ICM approaches and strategies, institutional framework). Potential activities in this regard (some of which may have already been done) include the following:

- Identify operational characteristics and scenarios within the corridor (e.g., frequency of incidents or events and their general location and impact, potential weather impacts, whether the corridor is part of an evacuation route, time-of-day/day-of-week/time-of-year considerations) and identify appropriate ICM scenarios and strategies for these operational scenarios.
- Identify individual major trip ends and their specific alternative routes and modes (including the associated cross network linkages and junctions) for the operational scenarios.

- Determine the spare capacity of the individual networks and cross-network linkages (vis-à-vis trip volumes, transit loadings, parking demand) and the total spare capacity within the corridor for the various ICM scenarios.
- Estimate the additional travel time for likely network shifts.

Based on these operational analyses (which can likely be done via simple calculations in a spreadsheet format), the corridor boundaries may be further refined and adjusted; for example, expanding the corridor boundaries for selected operational scenarios (e.g., major incidents) to increase the amount of spare capacity, reducing the corridor width due to excessive travel time penalties, or identifying scenarios which may require a regional (corridor-to-corridor shifts) approach.

Another option is to model and simulate the corridor (and any alternative boundaries) under a variety of operational scenarios and combinations of ICM approaches and strategies. This level of detail and analysis is not required for the Concept of Operations, although it is addressed as part of the requirements stage of the overall process.

PERFORMANCE MEASURES AND METRICS

Performance measurement is important for the several reasons: it provides the basis for identifying the location and severity of problems such as congestion, service delays, and high accident rates within the corridor; it permits the evaluation of the effectiveness of the implemented corridor management strategies in meeting the operational goals and objectives for the corridor; it allows a comparison of operations from year to year as well as a comparison of performance relative to other areas or corridors; and it provides information to decision makers, stakeholders, and to the public (e.g., justification for the continued operation or expansion of the ICMS project). Performance measurement must be viewed as a continuous process focused on assessing the progress made towards achieving the operational goals identified for the corridor. In essence, if you don’t measure results, you can’t tell success from failure; if you can’t see success, you can’t reward it; and if you can’t see failure, you can’t correct it.

Several references provide guidelines for selecting performance measures and the attributes of good performance measures as summarized below:

- **Goals and objectives.** Performance measures should be identified to reflect the goals and objectives for corridor management, including validation of the objectives.
- **Limited number of measures.** All other things being equal, fewer rather than more measures is better. Too much information, too many kinds of information, or information presented at too fine a level can overwhelm decision makers and the public.
- **Ease of collection.** The data required for performance measures should be easy to collect and analyze, preferably directly and automatically from the various transportation management systems that comprise the ICM.
- **Data needs.** At the same time, performance measures should not be solely defined by what data are readily available. Data needs and the methods for analyzing the data should be determined by what it will take to create or ‘‘populate’’ the desired measures. Data collection specific to performance measurements should be identified and collected.

- **Sensitivity.** Performance measurement must be designed in such a way that change is measured at the same order-of-magnitude as will likely result from the implemented actions.
- **Facilitate improvement.** The ultimate purpose of performance measures must clearly be to improve the operation of an integrated corridor. Performance measures must therefore provide the ability to diagnose problems and to assess outcomes that reveal actual operational results. There must be a means to incorporate the findings of performance measures as a means to enhance the operations of the corridor.
- **Simple and understandable.** Within the constraints of required precision, accuracy, and facilitating improvement, performance measures should prove simple in application with consistent definitions and interpretations.

By definition, a corridor is comprised of several different networks, including roadway and transit modes. Each of these separate modes and facilities can be expected to have their own set of performance measures. The selected measures may be the same for each mode, and presentation of the data may be made on a parallel basis, as shown in Table 4-4.

Table 4-4. Modal Performance Measures

	Highway Measures	Transit Measures
Measures of Quantity	Person Throughput (# of passengers)	Person Throughput (# of passengers)
	Vehicle Miles of Travel	Vehicles Miles of Travel (train miles)
	Average Vehicle Occupancy (persons/vehicle)	Average Vehicle Occupancy (passengers/train)
Measures of Quality	Average Travel Time	Average Travel Time
	Average Travel Speed	Average Travel Speed
	Density (Vehicles/lane mile)	Density (Passengers/seat, percent)
	Time Heavily Congested (percent)	Time Heavily Congested (percent)

In other instances, the mode-specific performance measures may not have any relationship to one another or to corridor operations as a whole. For example, a roadway network may utilize the volume/capacity ratio or level of service; while transit modes may use measures such as boardings per revenue hour or revenue mile, total operating cost per revenue hour or revenue mile, net deficit per boarding (difference between operating cost per boarding and revenue per boarding), and crowding (passengers per seat for peak and off peak).

Integrated corridor management requires performance measures that are "mode-neutral," reflecting overall corridor mobility and reliability (e.g., person-based or trip-based utilizing travel times and delays). Moreover, three dimensions of corridor operations should be tracked with performance measures: source of congestion or problem, temporal aspects, and spatial detail. Customer satisfaction measures should also be considered. It is emphasized that these "corridor-wide" performance measures are in addition to any network-specific performance measures. As such, the relationship between the corridor performance measures and network-specific measures need to be addressed.

In addition to the performance measures for the corridor, consideration should also be given to the development of “success thresholds” for these measures. These thresholds provide an indication that the corridor goals have been achieved. As such, they should be viewed as long-term targets that reflect the future vision of how the corridor will operate. Upon deployment of the ICMS, any movement toward the target performance values will indicate that ICMS is having the desired effect.

In all likelihood, one or more of the corridor goals will not readily lend themselves to quantitative measurements, such as goals that address institutional integration and all stakeholders sharing a “corridor view.” For such goals, a more qualitative approach is necessary. This will involve conducting a periodic assessment that provides the means by which the corridor transportation agencies can measure the effectiveness of their coordination and integrated operations from a high-level, institutional view.[3] Examples of questions to be addressed may include:

- Do the corridor agencies meet regularly with one another and with other agencies and organizations?
- Have inter-agency agreements defining responsibilities for ICMS operation, maintenance, and funding been developed and executed?
- Are the results of coordinated operations reviewed, discussed, and acted upon, particularly following major events or activities?

To be effective, such assessments should be conducted as a group exercise, including as many stakeholder representatives as possible.

PROPOSED CHANGES

This process step focuses on what is needed to implement the selected ICM strategies. This effort results in a high-level list of asset-based “requirements” [4] for the ICMS, providing a sense of the overall scope for the ICMS concept. These needed assets are then compared to the existing or planned assets within the corridor to identify the proposed changes and additions to the current technical, operational, and institutional situation within the corridor. Moreover, the proposed changes will aid in the development of ICMS requirements and the definition and scoping of specific projects required to deploy and implement the ICMS.

Table 4-4 presents a list of potential asset needs for a corridor. This list is not intended to be complete, nor will every corridor and ICM concept require all the assets identified therein. These potential ICMS “requirements” are classified as follows:

- **Network Systems.** These are the required network-based systems. They are identified by the National ITS Architecture nomenclature of “Market Package” for ease of reference to functionality (Reference 15).

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[3] Several self-assessment tools have been developed by FHWA for this purpose. In particular, the “Roadway Operations and System Management” self-assessment tool can be adapted to reflect ICM concepts, thereby providing the means by which the corridor transportation agencies can measure the effectiveness of their coordination and integrated operations.
[4] The ICMS requirements, as used in the parlance of systems engineering, are developed in the next stage of the process.

- **Network Subsystems & Technologies.** This column provides additional information on the minimum network ITS-based requirements (e.g., specific field devices, hardware, system functionality).
- **Information.** This column lists the data and other information to be gathered by the network systems, and subsequently shared among the stakeholders and corridor travelers.
- **Communication Subsystems.** These assets are communications – related, including the types of communications (e.g., center – to – center) as identified in the National ITS Architecture, interfaces to systems, and associated ITS standards.
- **Other/Performance.** This column is used for other ICM-required assets that don't "fit" into the other categories, such as the few regional or multi-system market packages, institutional assets (responsibilities and policies), and support tools.

These various assets are not necessarily independent or separate from one another. There are several relationships across columns; for example, the Market Package "Network/Probe Surveillance" requires one or more of the items included in the "Network Subsystems & Technologies" column (e.g., traffic detectors, CCTV, road weather sensors), which in turn provide several of the elements listed in the "Information" column (e.g., link volumes and travel times, video images, air quality). The items included in the "Communications Subsystems" column are then necessary to technically integrate all of these systems and devices into a corridor-based system, while the "Other" items support corridor integration from an operational and institutional basis. There are also dependencies within columns, particularly for the various Market Packages (as described in the National ITS Architecture documentation – Reference 15).

The next step is to compare these needed ICMS assets to the existing and near-term assets within the corridor (as obtained from the inventory/data collection step). There are many ways of performing this analysis and then presenting the results. One example is to modify Table 4-5 (or similar list) to show only those assets necessary for the proposed ICM strategies, and highlight those assets that are already operating within the corridor or are future assets based on current improvement plans. Consideration should also be given to those assets that are only partially deployed within the corridor as compared to fully deployed. Those assets and issues that are not highlighted represent the proposed changes and additions.

Table 4-5. Potential ICMS Asset Requirements

Network Systems (Market Packages)	Network Subsystems & Technologies	Information	Communication Subsystems	Other (Regional) / Performance
• Network / Probe Surveillance • Surface Street control • Freeway Control • HOV Lane Management • Traffic Information Dissemination • Traffic incident Management • Traffic Forecast & Demand Management • Electronic Toll Collection • Emissions Monitoring / Management • Railroad Grade Crossing • Parking Facility Management • Reversible Lane Management • Speed Monitoring • Roadway Closure Management • Transit Vehicle Tracking • Transit Fixed Route Operations • Demand Response Transit Operations • Transit Passenger and Fare Management • Transit Traveler Information • ISP Traveler Information (broadcast, interactive, route guidance) • Intersection Safety Warning • Electronic Clearance • International Border Electronic Clearance • Weigh-In-Motion • HAZMAT Management • Emergency Call Taking and Dispatch • Emergency Routing • Roadway Service Patrols • Transportation Infrastructure Protection • Early Warning • Wide Area Alert • Disaster Response & Recovery • Evacuation & Re-entry Management • Disaster Traveler Information • ITS Data Mart / Warehouse • Maintenance / Construction Vehicle & Equipment Tracking • Road Weather Data Collection • Weather Information Processing and Distribution • Work Zone Management • Maintenance & Construction Activity Coordination • Other (e.g., Asset Management System)	• Traffic detectors / roadway surveillance • Vehicle probes • CCTV (video surveillance) • Traffic signal control / monitoring (TOD schedule) • Traffic signal control / monitoring (traffic adaptive) • Ramp Meters (local control) • Ramp Meters (central control) • HOV by-pass • DMS – roadway • HAR • Internet Traveler Information • Automated Incident Detection • Incident Detection (call – in, other) • Incident Response Plans / Guidelines / Teams • Incident Reporting System (GIS, common display) • Air quality sensors • Road Weather Information Sensors • RR Crossing Surveillance & Control Devices • Parking Surveillance/occupancy • Lane control signals • Variable Speed Limit Signs • Gates / Control • Electronic toll collection equipment • Transit Vehicle Location / GPS • Transit Schedule Performance Monitoring • Passenger Counting Equipment • Electronic Fare / Parking Payment Equipment • DMS – transit • Transit Public Address System • Transit Trip Planning System • Spare transit vehicles / operators • Telephone – Based ATIS (511) • Transit priority equipment (Intersection &Transit Vehicles) • Intersection Collision Monitoring Equipment • Public Safety CAD • Emergency vehicle priority / pre-emption (Intersection / Vehicles) • Service Patrol Vehicles • Moveable Lanes Barriers • Real-time conditions data base / common displays • Maintenance Vehicle Location AVL / GPS • Other	Roadways (Freeway, Arterial, Managed Lanes) • Link congestion levels • Link volumes • Link occupancies • Link / spot speeds • Link travel times • Intersection approach volumes • Ramp queues • Average Vehicle Occupancy • Tolls / Pricing • HOT fares Transit • Transit schedules • Transit vehicle location • Schedule or headway status/deviation • Transit vehicle headways • Link Travel Times • Priority requests • Next Vehicle Arrival • Average Waiting Time • Transit Fares • Average Vehicle Occupancy Equipment / Device Status • Locations • Surveillance / detectors • DMS • Other Traveler information Devices • Ramp meter • Traffic Signals • CCTV • Electronic toll / fare / parking equipment • Available transit vehicles / location Other • Video images / snapshots • Video control • Parking space availability • Incident location • Incident status / details • Maintenance/ construction events • HAZMAT tracking • Special events • Electronic payment account status • Emergency vehicle location • Maintenance vehicle location • Parking fees • Contact lists • Air quality • Road surface condition	• Center-to-Center • Center to field • Roadside to vehicle • Center to vehicle • Vehicle to vehicle • ITS standards for data formats and data transfer functions • Video transport standards (digital, analog) • Voice communications • Subsystem capacity for data distribution • Subsystem capacity for video distribution • Subsystem capacity / frequencies for voice communications (including interoperability) • Interfaces to network systems • Interfaces to emergency service systems (CAD) • Interfaces to proprietary / legacy systems • Interfaces to ISP's (data and video export) • Interfaces to financial transaction network • Interfaces to Internet • Security firewalls • Other	• Regional Traffic Control (MP) • Regional Parking Management (MP) • Multi-Modal Coordination (MP) • Regional / Sub-regional ITS Architecture • Information Exchange Network / Common displays for data entry/display • Data aggregation / storage of processed data for subsequent analysis • Availability of spare network capacity • Corridor Models (simulation) • Accuracy of data/information • Vehicle location accuracy • Surveillance coverage • Response plans • On – line decision support (for selecting response plans) • Definitions of responsibilities of agencies • Common policies for incident reporting and response • Special Event Plans • Common fare collection technology • Integrated back office systems • Dynamic fare pricing capability • Priority logic at intersections • System back up / disaster recovery

SYSTEM CONCEPT

The focus of this process step is to combine the information from the previous activities to provide a general description of the corridor under ICMS operations. This description should provide all stakeholders with both a consistent picture of what is envisioned for the corridor and a basis on which to identify their respective roles and responsibilities. The system concept must also address alignment with the Regional ITS Architecture, and the key system implementation issues (operational, institutional, technical), including how they may be resolved.

Regional Architecture

The ICMS concept should be compared to the Regional ITS Architecture to identify any possible issues and needs that may arise between the ITS Regional Architecture and the implementation of the ICMS concept. Specific considerations include the following:

- The regional ITS architecture development process results in specific standards and protocols for communications and information exchange between systems. These standards and protocols may serve as the foundation for defining the ICMS center-to-center (C2C) linkages, interfaces, and standards.
- In the event attributes of the regional ITS architecture, be they technical (e.g., C2C linkages, regional information exchange network/clearinghouse), institutional (agreements, administrative frameworks and processes), or operational (response plans for major special events or emergency operations), have already been (or soon will be) implemented, the ICMS concept should incorporate and build upon these regional elements to the greatest extent possible.
- The list of agency agreements for the regional architecture can be the starting point for developing the agreements and procedures to be implemented at the corridor level.

At the same time, the ICMS concept may identify issues and needs that require revisions to and/or expansion of the Regional ITS Architecture.

Operational Scenarios

Operational scenarios should be developed describing how the ICMS will function under various conditions. These scenarios also describe the responsibilities and activities from the viewpoint of the primary stakeholders (e.g., network owners and operators, public safety). Potential operational scenarios include daily operational scenario (e.g., recurring congestion), scheduled event scenario (planned special events or work zone operations), incident scenarios (roadway and transit incident), and major event scenarios (e.g., evacuation).

These examples need not be all inclusive, but they should address the underlying assumptions, identify the sequence of events, and describe the expected responses and actions for each stakeholder, including which stakeholder(s) assume a lead role for these activities. Developing and describing ICM operational scenarios provides an opportunity to lay out the ICMS and explain how it will work once it is in operation. It can be very helpful in promoting an understanding of ICMS processes and operations, given certain corridor events, and showing the stakeholders how the new ICMS will affect them. Operational scenarios also represent a useful tool for setting or managing user expectations for the ICM program.

Implementation Issues

The “proposed changes” identified in the previous process step will undoubtedly include several implementation issues. It is critical that the system concept identifies all such corridor and ICM concept issues, including those related to the selected strategies. Many of these issues involve choices that need to be addressed and subsequently resolved during later stages of the systems engineering process (e.g., design, procurement, and implementation). In all likelihood, it will not be feasible to resolve all the system issues and questions at the concept level. Nevertheless, these implementation issues and their possible solutions need to be identified so all stakeholders have a joint understanding of the issues and their possible impact on the successful development and implementation of the ICM concept. Potential implementation issues, which parallel integration, as previously defined, are summarized in Table 4-5. Additional information is provided in Technical Memoranda 3.4 and 5.4.

In all likelihood, the institutional framework by which the corridor’s ICM concept will be implemented, operated, managed, and maintained will represent a significant implementation issue. The Concept of Operations therefore needs to explain how the institutional framework will be established, the responsibilities of the unit(s) that compose the framework, the composition of leadership and staff, the distribution of decision-making authority, and how the framework will facilitate necessary external corridor interactions. The proposed institutional framework must be an approach that can be implemented and backed by all the corridor stakeholders.

Table 4-6. Potential ICMS Implementation Issues

Operational Issues

- Development of operational response plans (or scenario plans) for numerous scenarios and events that can be expected to occur within the corridor. Considerations in this regard include type / severity of event or incident; location(s); criteria for identifying the event / scenario; process for confirmation; specific strategies to be implemented and in what sequence; changes to network - based systems (timing plans, transit headways, pricing), etc.. These specific response plans need to be documented (e.g., “Operations Manual) and agreed to by all the involved and affected agencies / network owners, and continuously updated.
- Up-to-date database of contact personnel, resources, and their locations.
- Updates to network operational parameters (signal timing, transit schedules).
- Identifying available data and other information that should and should not be shared between agencies (e.g., personal information on drivers involved in an incident as input to police CAD).
- Policy towards route/modal shifts. Should the approach be relatively passive (i.e., provide traveler information to the corridor users as to conditions within the corridor and the ICMS accommodates any user-determined network shifts); or should a more proactive strategy be adopted (i.e., shifts to alternative routes and modes are promoted via the traveler information disseminated to the users). Also determination should be made about when and under what circumstances each policy should be utilized.
- Procedures and protocols[1] for identifying route/modal shifts when spare capacity exists on multiple networks.
- Policies for implementing route/modal shifts (as well as demand/capacity management strategies) when sufficient spare capacity is <u>not</u> available within the corridor (or cannot be provided in a time frame comparable to the situation).

- Common policies for incident response & reporting (including coordination with the formal "Incident Command Structure."
- Pricing (fares, parking, tolls, HOT) strategies and policies.
- Procedures and protocols for the shared use of resources and/or shared control of ITS devices, including resolution of multiple (and conflicting) requests for the same device (e.g., signal priority, DMS message, camera control).
- Resolution of multiple (and conflicting) requests for the same device.
- Priority strategy protocols between transit and emergency vehicles and control devices (traffic, transit, and emergency operations staff).
- Polices for disseminating traveler information in a consistent manner across networks such that the users can make informed decisions regarding the travel decisions (i.e., route, mode, time of day).
- Video distribution/censoring policy.
- Safety concerns with ICM strategies.
- Corridor modeling (e.g., evaluate impact of strategies and operating parameters).
- Corridor-wide performance measures and metrics.
- Marketing and outreach.
- Ongoing operations and maintenance of the ICMS (e.g., responsibilities for funding and support, hours of operation of ICMS, updating response plans, configuration management.[2]

Technical Issues

- Overall ICMS logical and physical architecture (e.g., centralized with ICMS-based center and direct control of network systems and devices; decentralized (peer-to-peer) with information sharing between individual network centers and systems, and network managers control devices in accordance with response plans; hybrid with an ICMS that requests actions by the individual network centers and systems; co-located TMCs, virtual ICMS center.)
- Required enhancements to the individual network-based systems in support of integrated corridor management (i.e., a high-level definition of additional field equipment necessary for the ICMS, and their placement).
- Expanded surveillance coverage and / or additional detection technologies (e.g., along the cross-network connections, network junctions such as park and ride lots, and /or the individual networks themselves) to optimize the ICM strategies and to support ICM performance monitoring. Related issues in this regard include the detector technologies, the specific information they provide, accuracy, distribution / placement within the corridor.
- Capabilities and upgrades to legacy systems.
- Avoidance of proprietary interfaces to limit the different types of interfaces.
- Data processing, aggregation, and display for system operators and for travelers.
- Data processing, aggregation, and archiving for subsequent analyses.
- Real-time calculation of available capacity, and location within the corridor.
- Expanded video coverage, including the distribution/placement of video collection points.
- Expanded coverage of ATIS devices, including the distribution or placement of devices.
- Communication links/technologies between network-based systems and ICMS (C2C).
- Communication subsystem capacity for data and video distribution.
- Other communication links or technologies (C2F, roadside to vehicle).

- Communication subsystem for voice communications (including interoperability among all agencies).
- Communications subsystem configuration (including possible shared use of agency communication resources.
- Data compatibilities and center-to-center standards (e.g., NTCIP, TCIP, IEEE for incident management, ATIS), including data dictionaries, message sets, protocols, and interfaces.
- Network system interfaces (e.g., "translators" for legacy systems).
- Video sharing and video switching standards.
- Communications to ISPs.
- Secure back up/disaster recovery.
- Firewall barriers for Internet-based systems.
- Common fare collection technology.
- Real-time decision support (i.e., software-based response plan selection/management tools are available that continuously look at the various, changeable network performance parameters; analyze and compare these data to response plan metrics; and then implements the most appropriate pre-planned response plan either automatically or with operator confirmation).
- Configuration management.

Institutional Issues

- Identification and distribution of responsibilities (e.g., lead, support roles) between the corridor stakeholders for all activities associated with the planning, design, procurement, implementation, testing and acceptance, and operations and maintenance of an ICMS.
- Organizational and administrative framework/structure that supports ICMS operations and coordination within the corridor; that is, the set of relationships, institutions, and policy arrangements that shape ICMS activities and funding (e.g., ad hoc relationships, informal working groups that meet regularly, formally established joint working groups with assigned responsibilities, funded entity (i.e., a "corridor manager") with full-time staff and well-defined responsibilities).
- Compatibility of ICMS technologies and standards with agency IT requirements.
- ICMS funding mechanisms (e.g., in-kind contribution of resources, pooled funding, funded legal entity).
- Policies and procedures for data sharing, access rights, filtering, etc.
- System procurement/implementation approach, including individual agency responsibilities in this regard.
- Inter-agency liability.
- Policies and arrangements with private entities (parking, ISP).
- Federal involvement.
- Inter-agency agreements between the different stakeholders that document the resolution of the various operational, technical, and institutional issues, and explain the associated details.
- Updating the inter-agency agreements.

[1] In this context, the term "protocols" refers to operating procedures, plans, and organizational arrangements. As discussed later, it also can refer to technical ITS standards for transmitting information between network systems within the corridor.
[2] Configuration management is a cross-cutting activity that is discussed in a subsequent section herein.

CONCEPT OF OPERATIONS

The Concept of Operations (ConOps) is a formal document that provides a user-oriented view of integrated corridor management, the ICM approaches and strategies, and the associated operations. It is developed to help communicate this view to the stakeholders and to solicit their feedback. In essence, the ConOps documents the results and findings from the "system conception" stage, laying out the ICM concept, explaining how things are expected to work once it is in operation, and identifying the responsibilities of the various stakeholders for making this happen. The ConOps answers the following questions:

- What – the known elements and the high-level capabilities of the system.
- Where – the geographical and physical extents of the system.
- When – the time-sequence of activities that will be performed.
- How – resources needed to design, build, and operate the system.
- Who – the stakeholders involved with the system and their respective responsibilities.
- Why – justification for the system, identifying what the corridor currently lacks and what the system will provide.

The ConOps does not delve into technology or detailed requirements of the ICMS, but it does address the operational scenarios and objectives, information needs, and overall functionality. The ConOps must also address the institutional environment in which integrated corridor management must be deployed, operated, and maintained. Paraphrasing the "IEEE Guide for Concept of Operations Documents" and the FHWA document "Developing and Using a Concept of Operations in Transportation Management Systems," a ConOps offers several benefits, including:

- Providing a means for engaging ICM stakeholders and soliciting their input as to their respective desires, visions, and expectations (without requiring them to provide quantified, testable specifications), as well as their thoughts and concerns on possible solution strategies.
- Providing a means of describing stakeholders and users' operational needs for ICM, without bogging down in detailed technical issues.
- Identifying the institutional, technical and operational environment in which ICM will function.
- Formulating and documenting a high-level definitions and descriptions of integrated corridor management and any associated ICM system.
- Providing a foundation for all lower-level "sub-system" descriptions and requirements.

An ICMS Concept of Operations for a "generic corridor" has been developed (Technical Memorandum 2.3) as an example of an ICM ConOps that can be used by agency and network owners as the basis for developing their own corridor-specific and real-world ConOps. It is emphasized that this generic document is intended as guidance, not as a "template." Moreover, the generic corridor itself should not be construed as the optimum configuration for implementing ICM. It is only a tool to facilitate the development of this ConOps example.

Other references[5] for developing a concept of Operations are identified in the Appendix. Finally, it should be emphasized that just as the example generic ConOps does not follow verbatim the ConOps layout identified in these references; it is not necessary for the user to perfectly match the structure of the generic ConOps document.

[5] In particular, Reference 10: “Developing and Using a Concept of Operations in Transportation Management Systems.”

5. REQUIREMENTS

Requirements are the foundation for building an Integrated Corridor Management System. In this stage, a determination is made, in a more detailed manner than in the c*oncept of operations*, of what the ICMS should do. Requirements drive system development and are also used to determine (i.e., verify) if the ICMS has been built and installed correctly.

Requirements are statements of the capabilities that the ICMS must have (i.e., “functions”), geared to addressing the needs and objectives as defined by the corridor stakeholders and their respective organizations. For requirements to be most useful, they should be statements of *what* is desired, not descriptions of *how* the need should be satisfied; that is, good functional requirements are written without specifying technical design or implementation details.

The ICMS functional requirements should be based on the information obtained during the System Concept Stage (as documented in the Concept of Operations). In developing the requirements, several questions should be continuously asked, such as: What’s the reason for this requirement? What critical purpose does it meet? What happens if we don’t provide this capability? How can this requirement be quantified and verified?

Written requirements are important. A written requirements document captures what you are trying to achieve with this system in a tangible form, that others can read, review, and interpret. In addition to being technology-independent, good system requirements posses the following attributes:

- **Necessary**. Something that must be included, or an important element of the system that, if absent, other system components would be unable to compensate for.
- **Concise** (*minimal*, *understandable)*. Stated in language that is easy to read, yet conveys the essence of what is needed.
- **Attainable** (*achievable or feasible*). A realistic capability that can be implemented for the available money, with the available resources, in the available time.
- **Complete** (*standalone)*. Described in a manner that does not force the reader to look at additional text to know what the requirement means.
- **Consistent**. Does not contradict other stated requirements nor is it contradicted by other requirements. In addition, uses terms and language that mean the same thing from one requirements statement to the next.
- **Unambiguous**. Open to only one interpretation.
- **Verifiable**. Must be able to determine that the requirement has been met through one of four possible methods: inspection, analysis, demonstration, or test.

As is the case with most activities in the ICMS Implementation/Systems Engineering process, the development of ICM requirements can run through several iterative cycles of defining, reviewing, and refining. A key point related to this stage is that the end product must be a set of requirements on whose meaning all the ICM stakeholders agree. To achieve this buy-in and to eliminate ambiguity, it is often useful to conduct one or more ICM System Requirements review or “walk-through.” It is important to make sure that all stakeholders interpret the requirements the same way. This is a critical step in the overall process; if everyone does not have the same interpretation, some will have expectations that will not be met, and unnecessary or inadequate capabilities may end up being implemented. It is also useful to have the system testers (i.e., the “verifiers”) engaged during this process not only to review the requirements that they will have to test against, but also to begin developing the tests.

There will likely be two levels of requirements developed for an ICMS:

- High-level requirements: These focus on ICMS functions as a whole (i.e., system level). A few examples of such ICMS requirements are provided in Table 5-1.
- Detailed requirements: Each system level requirement is decomposed into a more refined set of requirements allocated to individual network systems and sub-systems.

Table 5-1. Sample ICM System-level Requirements

Requirement Types: • UR: User Requirement • FR: Functional Requirement • PR: Performance Requirement • SR: System Requirement **Examples:** UR1: The following systems shall be integrated under the umbrella of the ICMS (e.g., State DOT ATMS, Rail Agency Transit Management System, City Signal System). FR1: The ICM shall operate in the following modes (e.g., off-line, on-line monitoring, on-line control, training and simulation). PR1: The ICMS shall make available corridor operations measures to provide information about the real-time performance of travel alternatives on a network link basis. PR2: Corridor performance measures shall consist of: (e.g., travel times on selected comparable network links, travel times on corridor trips).

In addition to the requirements document, a traceability matrix should also be prepared that “traces” each ICMS requirement back to the specific ICM concepts, objective(s), and needs as defined during the System Concept Stage; and vice-versa. As the ICMS development process moves forward, this Traceability Matrix will be expanded to document the compliance of the system designs with these requirements.

Once the requirements have been accepted, changes and updates to the ICMS requirements (and the traceability matrix) should be controlled using a change management process as discussed in chapter 11.

PERFORMANCE ANALYSIS

This recommended activity entails simulating the corridor under a variety of operational scenarios and combinations of ICM approaches and strategies as defined in the Concept of Operations. Simulation techniques that vary demand and capacity, and that provide for network shifts, should be used (see Technical Memorandum 5.5.). Such a performance analysis will permit a detailed evaluation of corridor and individual network performance when operated as an ICMS under a variety of scenarios and demand situations, and with different boundaries (e.g., networks and their limits).

This will permit a check on the operational implications of the proposed ICMS. Trade-offs may be required between the characteristics of the corridor to support the chosen strategies; the different scenarios (e.g., incident, regular, evacuation) that need to be addressed; the ability to manage spare capacity or to temporarily create spare capacity; and the boundaries that identify the operational impact of the corridor. The results from this performance analysis may be utilized to modify the ICM approaches and strategies (and, as a result, the associated requirements), further refine the corridor networks and boundaries, and provide quantitative estimates of benefits (e.g., travel times and delays with and without ICM) that can be used in promoting the ICM program to stakeholders and decision makers.

6. DESIGN

The design phase of the ICMS development effort defines the details of **how** the system requirements will be satisfied. The FHWA course on systems engineering defines system design as the "appropriate selection of system components and their interconnection so as to meet the system requirements." As shown in the "V" diagram (Figure 1-2) and in Table 1-1, the design phase consists of two phases:

- High-level Design (System Architecture).
- Component-level Detailed Design.

It is important that the results of these design efforts be documented (i.e., design reports) and provided to corridor stakeholders for review and comment. This should include extensive design reviews, such as presentations and walk-throughs, between the design team and stakeholders to ensure that the design approach, system architecture, information flows and interface standards, component designs, etc. are consistent with the ICMS needs and stakeholder expectations. The ICMS integrators and integration testers should also be engaged to review the design and interface specifications and to begin developing plans and test-cases for ICMS integration and integration-testing.

The ICMS ttraceability matrix, as noted in chapter 5, should also be expanded to map the system and component designs back to the ICMS requirements, thereby documenting their compliance with the ICMS needs and objectives.

HIGH-LEVEL DESIGN

The high-level design stage defines the ICMS architecture. This process includes the development of alternative architectures and their evaluation in terms of functionality (i.e., the ability to provide the selected ICM operational strategies and satisfy the ICMS requirements), performance, cost, and other issues (technical and institutional). Both internal and external interfaces, including the existing network-based ITS systems that will be integrated into the ICMS (i.e., a "system of systems"), and needed industry standards are identified during this step.

Defining Interfaces

The Regional ITS Architecture Guidance Document (Reference 8) describes a process for "Define Interfaces" that is directly applicable to a corridor and an ICMS. This process focuses on identifying the interconnects between the systems and subsystems within the corridor and defining the information that flows between the systems. Specific activities (tailored for an ICMS) are summarized in Table 6-1.

Part of this process is to define the information exchanged between the network-based ITS systems, the ICMS, and appropriate subsystems. In the context of an ICMS, this information will include data (e.g., traffic flow and transit status, incident information, device status, command and control functions), video, and voice.[6] These information

[6] It is important to show voice-only communications in the ICMS architecture, as such "manual" coordination and collaboration will continue to be an important element of ICMS. These voice links also reflect institutional integration.

flows depict the corridor integration by illustrating the information links between networks and agencies within the corridor. As previously discussed, this integration is not only technical, but operational and institutional as well. The system interfaces that are defined require cooperation and the distribution of shared responsibilities on the part of the owners and operators of each participating system.

Table 6-1. Define Interfaces (Key Activities)

Identify Connections:

- Based on the inventory, needs, ICM strategies, Concept of Operations, and functional requirements, identify inventory elements (e.g., network systems) that will exchange information.
- Consider whether existing person-to-person connections may or should evolve into automated interfaces between ITS systems.
- Document the high-level status for each connection (existing or planned).
- Use the National ITS Architecture to identify potential connections; add custom connections as necessary.

Define Information Flows:

- Based on the interconnect decisions made by the stakeholders; and the needs, ICM Strategies, Concept of Operations, and functional requirements; define the actual information content (information flows) exchanged on each interface.
- Document the high-level status for each information flow (existing or planned).
- Use the National ITS Architecture to identify potential information to be exchanged (termed “architecture flows”).
- Identify auxiliary information flows that are not defined in the National ITS Architecture, but are important to your region.
- Describe each information flow by a source element (where the information originates), a destination element (where the information is sent) and a descriptive name for the information itself.
- While discussing the actual information to be exchanged, verify that assumptions made during development of ICM strategies, operational scenarios, Concept of Operations, and the functional requirements remain valid.

Topology

An important aspect of a system architecture is its overall “topology”; that is, the structure defining the paths and switches that provide the communications interconnection among the nodes (systems and TMCs) of a network, and defining the functional responsibilities of each node. It is an axiom of network design that the relationship between computers (i.e., systems) should mimic the organization it serves. Several topologies exist, but given this axiom, the most likely to be found in a corridor-based center-to-center network are “hierarchical” and “mesh,” as summarized below:

- A **mesh** organization is one in which all participants are peers. All computers in the mesh can essentially access the same types of information. This type of communications is similar to the Internet, in that any center can request information from, or provide information to, any number of centers. This is the likely approach for an ICMS architecture where no corridor operating entity (i.e., “corridor manager”) exists; that is, all agencies and systems must interact on an equitable basis (and managed via working groups). However, even in a peer-to-peer topology, there may be restrictions on the types of information that can be accessed by certain participants (e.g., control of individual devices).
- In a **hierarchical** organization, the “boss” should have access to the top computer in the network. Such a topology might be used where a corridor organization exists that oversees and/or coordinates corridor operations and the deployment of strategies on an on-going basis.

An ICMS may utilize a mix (i.e., hybrid) of topologies; for example, most information flows (traffic flow and transit status, device status, incidents) may conform to the mesh organization, whereas command and control during specific events may be implemented by a hierarchical organization.

A related issue is the use of “hubs” to tie the systems or centers together and how to incorporate them in the ICMS architecture. For example, all information exchanges between the corridor stakeholders and their systems could go through a hub, and in some corridors, the hub(s) may be viewed as a key component of the ICMS architecture, (perhaps functioning as the ICMS Control Center). Explicitly including hubs in the architecture has an ancillary benefit in that such architectures normally have fewer connections and information flows to define and maintain than equivalent architectures that depict the point to point connections between all systems served by a hub. Other corridors may decide that a hub is really a part of the communications infrastructure implementation and therefore should not be reflected in the interfaces defined in the architecture. Both views are valid. A major consideration is the functionality (if any) that the hub includes. A hub that implements ICM functions (e.g., data translation and aggregation, decision support) should probably be included in the ICMS architecture, while hubs that only implement communications functions (e.g., routing, protocol conversion) may be excluded. Regardless, the architecture should reflect the stakeholders’ “natural” view of the systems in the corridor and ICM. If the hub is largely transparent to the stakeholders, then it probably should be transparent in the architecture. If it is viewed as an integral part of the overall ICMS, then it should be included as an important part of the architecture.

ICMS Standards

ITS standards need to be identified for each information flow. Of particular interest are the numerous standards that have been developed (and continue to be enhanced) to accommodate the diverse needs of various subsystems and user services of the National ITS Architecture. These ITS standards are intended to handle these needs in two areas: center-to-field (C2F), and center-to-center (C2C), with C2C communications focusing on messages sent between two or more transportation management systems. Several sets of C2C standards have been developed, including:

- NTCIP (National Transportation Communications for ITS Protocol) suite of standards for data exchanges between centers.
- TCIP (Transit Communications for ITS Profiles) family of standards for the automated exchange of information in transit applications.

- IEEE family of standards for incident management communications.
- ATIS standards for data exchanges to support traveler information.

While the focus of ICMS is center-to-center, C2F standards may also need to be addressed in the architecture, particularly for those strategies geared toward improving the operational efficiency of the network junctions (e.g., signal priority for transit, coordination between arterial signals and ramp meters).

Standards for sharing video between corridor systems and stakeholders should also be defined. There are several options to consider, including analog and digital (e.g., MPEG, JPEG, and H.261). New processes such as Video over IP (Internet Protocol) and streaming video allow for the broadcast of video incident images to many user agencies via low-cost communication networks.

Legacy Systems

One of the basic assumptions behind Integrated Corridor Management is that the individual agencies within the corridor are already actively managing their respective networks via ITS systems. As such an ICMS will probably involve several “legacy” systems. A legacy system is, by definition, currently operational and may represent the latest technology embodying the principles of open architecture; however, it may be a closed system with proprietary interfaces, databases, and protocols, as well as limited documentation. In the latter case (i.e., proprietary), full center-to-center integration may not be possible, in which case a simpler system interface (e.g., separate workstation, separate email or browser interfaces) may be the most appropriate approach. Even if the legacy system is not completely closed (as compared to an open systems architecture), it still may be necessary to add a data exchange protocol to the legacy system to facilitate information exchange.

Another consideration is that no single C2C standard exists for an Integrated Corridor Management System. There are, in fact, many such C2C standards to consider (NTCIP, TCIP, IEEE). This leads to a potential issue of “semantic interoperability” between these various C2C standards; that is, are the common data elements and message sets defined in exactly the same way. It may be necessary to incorporate “translators” into the ICMS design that will enable a legacy system to present a standard interface to the other systems and the CCC in the generic corridor. Some translation may also be needed between data elements within different standard messages, although over time, further harmonization of the standard data elements by the standards development organizations should eliminate any such need. It will also be necessary to ensure that all of the desired information and data elements necessary to support the ICM strategies are covered by these standards and their respective data dictionaries and message sets.

Deployment of an integrated corridor management system should use the various C2C standards as appropriate to the individual networks and their respective stakeholders. The integration of an ICMS will likely involve some degree of C2C harmonization (i.e., developing unique corridor-specific translators to define the data being exchanged by systems), particularly where C2C communications and standards are already in place and if automated decision-support mechanisms are going to be used for corridor response plan management. As experience is gained with these C2C translations, the various standards may evolve to provide the necessary harmonization of the data dictionaries and message sets required to minimize the effort needed for corridor integration.

A related issue involves the interfaces to CAD systems that are used by public safety agencies. Many of these are proprietary systems. Moreover, regardless of how these CAD systems are integrated into the ICMS, the interfaces must include appropriate filters to prevent sensitive information from being released, shared, or otherwise compromised.

Finally, it must be remembered that the regional ITS architecture development process includes the identification of specific standards and protocols for communications and information exchange between systems. These regional standards and protocols should serve as the foundation for defining the ICMS C2C linkages, interfaces, and standards, and the selected ICMS standards should be compatible and consistent with the regional standards, whether this involves making adjustments to the recommended corridor standards, regional standards, or some combination of the two.

DETAILED DESIGN

During detailed design, each system and sub-system is decomposed into components of hardware, software, database elements, firmware, and /or processes. Component designs then describe in great detail how each component will be developed to meet the required functions of the system, resulting in “build to” specifications and plans that will be used to build or procure the individual components. For hardware components, this step will describe the components and the associated technology in enough detail to be fabricated or purchased. For software, enough detail will be given such that developers can design and then write the individual software modules. If commercial-off-the-shelf equipment is being used, this step is where the alternative candidate products are evaluated and a selection made.

The detailed design activities must also address any additions and enhancements that are required to the existing network-based ITS systems for Integrated Corridor Management. These might include additional field components (surveillance, DMS, CCTV) along the network, the cross-network connections, and / or the network interfaces (e.g., park & ride lots), additions to the central software (e.g., protocol translators), enhancements to the central hardware and software (e.g. upgrading a signal system from a proprietary closed-loop to an “open” and more centralized system to accommodate real-time plan changes), or some combination.

As is the case with all stages of the ICMS life-cycle, stakeholder involvement is a crucial element. This includes periodic technical reviews and a final critical design review to obtain final approval. The types of questions to be addressed at these reviews include: Do the details meet the requirements? Is each component buildable? Are the interfaces and information flows satisfied? Are the details well documented? Do the details of the design map to all allocated requirements (traceability)? Has sufficient redundancy been built into all mission-critical components? etc.

7. PROCUREMENT

This stage of the ICMS process is not explicitly shown in the “V” diagram (Figure 1-2). Rather, it is a cross-cutting activity encompassing much of the left-side of the “V,” particularly overlapping the design stages. Whereas the design activities define how the ICMS will be built from a technical perspective, the Procurement Stage focuses on how the ICMS will be built from an institutional and procedural perspective. This is a critical issue. As noted in NCHRP 3-77: “Guide to Contracting ITS” (Reference 13), “the procurement of goods and services to support ITS deployments represents a major obstacle for transportation agencies responsible for deploying ITS. This obstacle can be attributed to the challenges associated with the procurement of goods and services to support the deployment of complex information technology (IT) systems.” Key activities during the Procurement Stage are briefly discussed below.

PROJECT DEFINITION, SEQUENCING AND FUNDING

“Projects” are individual, well-defined actions and activities that will make up a substantial portion of an ICM program along with policies, procedures, and related coordination. The development and implementation of these projects are how an ICMS is realized and subsequently updated and expanded. In all likelihood, the initial development and deployment of an ICMS will entail multiple projects, with each project requiring a specific form of stand-alone procurement documents incorporating a sub-set of the system design. Potential projects in this regard might include:

- Procurement and deployment of additional ITS field devices (such as CCTV, surveillance, and DMS) along the various networks and cross-network connections. It is also possible that this specific activity may involve multiple projects, with each agency having a project covering its specific network.
- Installation or expansion of a communications network connecting the various Transportation Management Centers serving the corridor.
- Infrastructure improvements such as minor roadway widening, expansions of park and ride lots, etc.
- Central hardware procurement (several agencies often purchase servers, workstations, and related equipment off an agency or statewide contract).
- Software development, including new ICMS software programs and enhancements to existing network-specific software and firmware.
- Systems integration.

Of course, many of these potential individual projects may be combined into one or several projects. Regardless, it is important that the ICMS projects be included in the traditional planning documents like the Transportation Improvement Program (TIP), Statewide Transportation Improvements Program (STIP), and other regional plans.

The Regional ITS Architecture Guidance Document (Reference 8) includes a step entitled “Define Project Sequencing” which is directly applicable to an ICMS. The following activities are summarized as follows:

- Gather initial project sequence information from existing regional planning documents.

- Define the projects for the corridor in terms of the ICMS architecture prepared in previous steps.
- Evaluate each ICMS project, considering:
  - Costs and benefits.
  - Technical feasibility.
  - Institutional issues.
  - Readiness (agreements in place, funding available, policy decisions, data requirements, etc.).
- Identify the dependencies between ICMS projects based on the inventory, functional requirements, and system interfaces. Identify projects that must be implemented before other projects can begin.
- Develop an efficient project sequence that takes the feasibility, benefits, and dependencies of each project into account.
- Similar to traditional planning, project sequencing is a consensus building process and should not be viewed as a ranking of projects. Stakeholders should begin with existing planning documents and focus on short, medium and long term planning decisions.

As with any crosscutting program, funding for ICM projects and the continuing operations and maintenance of the system will likely come from a wide variety of sources, including Federal-aid, State and individual agency budgets. Due to the multi-agency nature of many of the ICMS projects, the funding for such projects will also be multi-agency in nature. Moreover, other resources, such as equipment and personnel, may also be shared across jurisdictional boundaries. Additional information on funding opportunities for ICMS, including the pooling of agency funds, is provided in Technical Memorandum 3.5.

PROCUREMENT MECHANISM

Several mechanisms exist for procuring ICMS services and deploying the associated projects, each with a variety of selection options. Each necessitates a different level of direct participation and technical expertise by the acquiring agency. The type of contract selected will also dictate the form of the procurement specifications and the management structure needed to oversee the process.

The goal in choosing a procurement option is to give the corridor stakeholders and system owners the greatest flexibility and to manage project risk appropriately. The choice depends on the type and nature of work being done, with some projects and activities lending themselves better to one type of procurement mechanism over another. As noted in NCHRP 3-77 (Reference 13), “the use of inappropriate procurement methods may result in project cost-overruns, final designs that do not satisfy functional requirements, and long-term maintenance failures. An appropriate method of procuring ITS (including ICMS) must be flexible enough to accommodate the uncertainties of complex system acquisitions, while at the same time rigid enough to ensure that the responsibilities of the participants are fully defined and their interests protected. In order to overcome the challenge of procuring ITS, transportation agencies must institutionalize innovative procurement methods.”

This NCHRP reference includes a process to identify an appropriate procurement approach for a specified ITS project. This decision model includes the following activities and considerations:

- Making fundamental decisions, such as the possibility of outsourcing and the procurement of consultant services.
- Determining whether the procurement should be performed as a single contract or multiple contracts.
- Categorizing the project with respect to complexity and risk.
- Assessing transportation agency resources and capabilities as well as the environment in which the project will be procured.
- Selecting the applicable systems engineering processes and candidate procurement packages, and then applying differentiators to the candidate procurement packages to reduce their number.
- Involving agency procurement personnel to assist in making the final selection of the most appropriate procurement package.
- Selecting the necessary terms and conditions to be included in the contract.

It is also critical that, regardless of the number of projects and their respective procurement approaches, a single entity be identified as having the ultimate responsibility and accountability for delivering a fully functional ICMS. Moreover, concomitant with this assignment of responsibility and accountability must be the necessary authority and flexibility to control and manage the associated risks.

ICMS PROCUREMENT DOCUMENTS

The procurement documents for each ICMS project will incorporate the detailed designs and plans developed during the design stage along with the necessary terms and conditions. These procurement documents should include specifications and plans addressing other important elements of the ICMS implementation, including:

- The integration of all the hardware, software, and/or database components into a fully functional ICMS, including responsibilities for developing and inputting ICMS and individual network system database information (e.g., response plans, any graphic displays).
- The testing procedures, including criteria for acceptance of each component, sub-system, and system. These specifications should also address who is responsible for developing and approving the test procedures, who is responsible for conducting and monitoring the test, and procedures in the event a test is not completed successfully.
- The training and documentation that are to be provided by the hardware and software suppliers and the system integrator, and when they are to be delivered.
- Warranties and on-going system support.
- Intellectual property.

With respect to the latter, Reference 14 describes this “problem” as follows: “Debate over the ownership and use of intellectual property developed jointly by the public and private sectors has caused delays in ITS deployment projects. While a fundamental business incentive of the private sector for investing in research and development is to use the results of research for profit, a primary incentive of the public sector is to protect the way in which public funds are spent." Two types of licensing agreements need to be addressed in the procurement documents:

- Pre-existing technologies and privately funded developments brought to the ICMS project.
- Hardware and software developed during and for the ICMS project using public funds.

In this way, interested private sector companies seeking to participate and provide services for the ICMS are aware of the intellectual property rights, policies, and standards for the corridor stakeholders and agencies. These companies can then incorporate their understanding of them into their technical and cost proposals.

Overall Program Plan

The ICMS Program Plan (which was initially developed at the beginning of the process in terms of the Systems Engineering Management Plan) should be expanded to describe the entire set of tasks that each ICMS project requires as the program moves into the Implementation and Deployment Stages. Specific activities to be addressed include the following:

- **Definitions for all Projects and Project Tasks.** All work tasks and activities needed to accomplish the ICMS goals need to be defined, including, but not limited to, overall project management, construction management, testing and acceptance, participation in training, and other administrative tasks such as financial and contract support.
- **Budgets**. The cost for each project and the associated tasks need to be estimated (including contingencies) and funding sources and responsibilities identified.
- **Needed Resources.** The resources for each task, including which agencies are responsible for providing these resources, must be identified and obtained. This may include personnel, equipment, test equipment, and other facilities. The time frame for when these resources are needed also is identified.
- **Schedule.** An understanding of the individual ICMS projects and their dependencies, the associated project tasks, and the needed resources and budgets are combined into an ICMS Program Schedule, showing key milestones and inter-dependencies between projects and tasks.

Some ICMS projects and programs may warrant preparation of separate plans for specific tasks and supporting activities. Many of the activities addressed in the next section on the Implementation and deployment stage have technical planning documents associated with them (e.g., verification and validation plan, component and integration test plans, system acceptance test plan).

Another important plan is the **operations and maintenance plan**. This plan defines how the ICMS will be operated and maintained on a daily basis, including the responsibilities of each corridor stakeholder or agency and their respective staffing and budget needs. These needs are defined based on the following:

- Functions to be performed by each of the agencies (e.g., corridor information to be provided, responsibilities for implementing ICM strategies, evaluating and updating corridor scenario plans).
- Equipment and software to be maintained by each of the agencies (e.g., ICMS servers, video distribution hardware, communications network).
- Service costs (e.g., leased communications, in-house and outsourced staff).
- Other activities and equipment in support of operations and maintenance (e.g., manuals, training, standard procedures, tools, vehicles).
- Methods for monitoring the effectiveness of ICMS operations and maintenance.

The operations and maintenance plan concentrates on additional needs on agency staff and resources as a result of the elements to be deployed as part of the ICMS projects. In general, it is expected that agencies will continue to perform their current transportation management and maintenance functions as before.

Institutional Issues

Achieving institutional integration is an on-going process of coordination and collaboration between corridor stakeholders. Moreover, it starts at the very beginning of the ICMS and systems engineering processes (e.g., Concept Exploration: Establish Corridor Stakeholder Group). Several of the associated institutional issues (e.g., system procurement and implementation approaches and individual agency responsibilities, funding, operations and maintenance functions and responsibilities) have already been noted in this discussion of the procurement stage. By the time this procurement stage is completed, all the remaining institutional issues, including the identification and distribution of all responsibilities between the corridor stakeholders and the organizational and administrative framework to support ICMS operations and stakeholder coordination, should be resolved.

Agreements among the different stakeholder agencies and organizations will typically be required to document the resolution of these institutional issues, as well as the various operational issues (e.g., responses and scenario plans, policies for route or modal shifts to optimize spare capacity) and technical issues (e.g., standards), and to explain the associated details. These cooperative ICM agreements may take the form of resolutions, memorandums of understanding (MOUs), intergovernmental agreements, or some combination of these methods. The number of agreements and the level of formality and structure of each agreement will be determined by the stakeholders and agencies involved. In general, as ICM becomes more complex (e.g., proactive approaches and strategies and/or more formal organizational approaches and institutional frameworks), the need for interagency agreements also becomes greater. Regardless of the structure, most of the agreements contain the similar key elements as shown in Table 7-1.

Table 7-1. Key Elements for ICM Agreements

• Participants and Operational Coverage • Purpose, Need, and Authority • Roles and Responsibilities • Adoption, Duration, Amendment, and Termination • Funding and Financial Arrangements • Appendices (e.g., management plans or other technical supporting documents).

Source: NCHRP Synthesis 337 "Cooperative Agreements for Corridor Management." Additional information is provided in Technical Memorandum 3.4.

Reference 12 summarizes several characteristics of effective agreements (listed below), which also pertain to the broader challenge of achieving institutional integration:

- An agreement should be pursued in a spirit of mutual compromise. A willingness to compromise and to treat others as equal partners helps establish an environment that is conducive to cooperation. Each participant should take the time to gain an understanding of the issues that affect the other partners and to be cognizant of those issues when generating alternatives. The potential benefits to each party through participating in and supporting the process should be made as clear as possible.

- It is vital to proactively confront the tough corridor management issues through direct involvement of the affected parties. It is important to keep all parties to the agreement appraised of substantive developments throughout the process to ensure a smooth transition from the corridor management plan to the agreement.

- Establish a joint committee or multiparty amendment process for the administration of a corridor management plan. Establishing an administrative structure through the agreement, such as a committee to administer a corridor management plan or a provision for multiparty approval of amendments, can help formalize the decision-making process, improve intergovernmental coordination and communication, and reduce the potential for amendments that conflict with corridor management objectives.

With respect to the last bullet, a White Paper from the 4th Integrated Traffic Management System (ITMS) Conference[7] on Maintenance and Operations states: "the development of agreements should be started well in advance of when the agreements are needed. An important strategy used for meetings where agreements are discussed is to consider all agencies to be equal and not have one of them be in charge of the meeting (i.e., meetings are arranged, facilitated, and documented by non-agency resources.) This strategy reduced the risk of any agency forcing their agenda on the other agencies just because that agency was responsible for the meeting."

[7] July 2001, Newark New Jersey, Sponsored by the TRB Committees on Freeway Operations and Traffic Signal Systems.

8. IMPLEMENTATION and DEPLOYMENT

Integration is an iterative process, taking hardware and software components and forming them into complete sub-system elements, and then taking the sub-systems and combining them into larger sub-systems or systems until all the subsystems and network systems are combined into a complete and functioning ICMS. This process consists of several system engineering stages as shown on the right side of the “V” diagram. Integral to these system integration activities are system verification and validation processes:

- **Verification.** Ensuring that all functions implemented in the ICMS have been implemented correctly (i.e., “building the system right”).
- **Validation.** Ensuring that the desired functions have been implemented in the delivered ICMS (i.e., “building the right system”).

There is a relationship between the activities performed on the left side of the “V” (operational concepts, requirements, designs) and the integration and verification activities on the right side. Each stage of integration is tested and verified against the left side of the “V” through verification plans. For example, the “System Requirements” stage is directly across from the “System Verification” phase. Thus, the various system acceptance tests ensure that the required system functionality, as documented in the ICMS requirements document and traceability matrix, is being satisfied.

A complex ICMS effort may need a written **integration plan**. This plan, which should be viewed as an extension of the SEMP/Project Plan, documents the process for integrating the ICMS, including:

- Sequence in which the various components of the system should be integrated.
- Resources, schedule, and coordination activities that are required.
- Product (implementing a related set of functionality) resulting from each integration step.

HARDWARE / SOFTWARE DEVELOPMENT

This step involves the fabrication and construction of hardware, the coding and development of software, and the procurement and configuration of COTS products in accordance with the requirements and detailed design documentation. Quality control is an essential element of this stage, including software engineering and code development standards (e.g., ISO 9000) and walk-throughs of developed programs where programmers review the work of another programmer to determine whether any errors exist.

UNIT, SUBSYSTEM, AND SYSTEM TESTING AND VERIFICATION

Verification is used by the corridor stakeholders to show that the as-built system and sub-systems meet all their requirements and match the design. Integration and testing and verification are closely linked processes in which one follows the other until the entire ICMS is ready for operational deployment. The system components are tested and verified as individual units. These components are then integrated and verified as sub-systems. This process may involve multiple levels of subsystems, with smaller sub-systems integrated into larger subsystems and verified, with the entire process continuing until all sub-systems are finally integrated (as a system) and verified.

A **verification plan** documents the procedures for testing and verifying the components, sub-systems, and system(s). The plan establishes a test case and verification technique for each requirement and for each design element (with each test mapped to a specific requirement via the traceability matrix). Each test case includes step-by-step procedures for conducting the test and the expected outcomes. Additionally, the verification plan provides general guidance for all verification activities, including identification of the verification participants and their respective roles and responsibilities, a schedule of the verification activities, and the identification of any required test equipment and simulation software. The preparation of verification plans should commence at the same time the requirements are developed as a means to show that the requirements, as written, can be verified. The test cases and verification procedures should be written at the end of the detailed design effort.

SYSTEM DEPLOYMENT, VERIFICATION AND ACCEPTANCE

Following verification of the ICMS subsystems (including any enhancements to network systems within the corridor) the ICMS is integrated into its intended operational environment. ICMS verification is done in two parts:

- Under a controlled environment (i.e., factory acceptance test).
- Within the environment in which the ICMS will operate (i.e., site acceptance test).

System verification may take several weeks to complete (sometimes referred to as the system start-up or burn-in period) to ensure that the ICMS operates satisfactorily. Many system issues (e.g., memory leaks) may surface and become apparent only when the ICMS is operating in the real world environment for an extended period of time. These start-up issues can take time to address and the schedule should provide time for shaking out any problems encountered during system verification.

Once the system verification is completed, the ICMS is accepted by the corridor stakeholders and moves into the system validation and operations and maintenance stages.

SYSTEM VALIDATION

Validating the ICMS is a key activity of the corridor stakeholders, and constitutes the initial phase of evaluation. It is here that the system's performance is assessed against the needs, goals, objectives and expectations as documented in the Concept of Operations. The validation effort should commence as soon as possible following system acceptance in order to asses the strengths and weaknesses of the ICMS, and to identify new opportunities. As a result of the validation, new needs and requirements may be identified. It is emphasized that this activity does not check the work of the ICMS integrator or the system suppliers; that is the purpose of system verification.

The validation plan should be developed to indicate who will be involved in the ICMS validation and their responsibilities, the schedule, how and where the validation will take place (e.g., before and after study), what resources are needed, and the criteria against which the assessment of the ICMS will be based (i.e., needs, goals, and objectives).

OTHER ACTIVITIES

During system integration, in preparation for ICMS verification and validation (and on-going operations and maintenance), several additional activities need to occur, including:

- Develop and input ICMS database (e.g., device locations and names, graphic displays, and Scenario / Response Plan information including locations, contacts, route and modal shifts, implementation rules, DMS messages, CCTV presets, traveler information, etc.).
- ICMS operation and maintenance documentation (e.g., system description, operation manual, system administration manual, equipment maintenance and service manuals, as-built drawings).
- Training the agency staff and other users (including development of the training plan and related materials).

9. OPERATIONS, MAINTENANCE, AND EVALUATION

This is the longest stage, the one in which the ICMS is utilized to improve the movement of people and goods through the corridor. The system must be continually evaluated to ensure that the performance objectives are being met. It is also crucial to ensure that the ICMS continues to function properly through on-going operations and regular maintenance, the definitions and responsibilities for which have previously been identified and documented in the **Operations and Maintenance Plan** (see Section 7).

OPERATIONS AND MAINTENANCE

Operations and maintenance involves planning for and then executing several activities. Operations focuses on operating the ICMS on a day to day basis (i.e., monitoring travel conditions and events within the corridor, and activating and monitoring the appropriate response plans), hiring and training system operators, and updating and revising the response plans (i.e., “tuning” the ICMS as well as the network systems) as needs and conditions dictate.

Maintenance involves all processes that keep the ICMS, and the network-specific ITS system, performing satisfactorily. This can include inspection and proactive actions such as cleaning and replacement of components prior to the end of their rated life (i.e., preventive maintenance), making repairs and correcting faults when they occur (i.e. remedial maintenance), replacing components that have become obsolete or unsupported, and hiring and training maintenance staff. Software maintenance involves both correcting malfunctions (bugs) when they are discovered and making minor modifications as needed to improve functionality. Any upgrades of equipment and software enhancements to improve the system’s performance should be carried out in accordance with the systems engineering process.

EVALUATION

The initial evaluation of the ICMS is the “system validation” as discussed in the previous section. Following this initial validation effort, the system should be continuously evaluated for its overall effectiveness in terms of meeting the objectives and performance metrics as defined during the System Conception stage. If not, it may be necessary to improve the response plans under which the ICMS is operating. It may also be necessary to modify the corridor boundaries and/or enhance the operational strategies included in the ICMS, followed by new scenario plans that incorporate these new or modified borders and strategies.

The evaluation process should also include re-calibration of the corridor models, based on actual operating experience, followed by new performance analyses (i.e., simulating the corridor under modified or new operational scenarios, different boundaries, and combinations of ICM strategies). Such a performance analysis should also be used to evaluate any major enhancements of the ICMS.

Finally, as the ICMS changes and evolves, be it new and additional scenarios and response strategies, improved operations and maintenance practices, new stakeholders, enhanced functionality, and/or expanded corridor boundaries, these institutional agreements between the corridor stakeholders and agencies need to be kept up to date to reflect any such changes.

10. CONFIGURATION MANAGEMENT

It is unrealistic to assume that the environment in which the ICMS concepts and requirements are developed, and in which the system is subsequently deployed, integrated, and operated, will not change. The nature of complex systems is that change is inevitable, whether it be institutional, operational, or technical in nature. What is essential is to manage and control the change processes through "configuration management."

Configuration management (CM) is a part of the entire systems engineering process – a cross-cutting element throughout the life of any system. CM provides a holistic approach for effectively controlling system change. It helps to ensure that any proposed changes to the operational concepts, requirements, subsystems, the network systems within the corridor, and the response plans, including their associated documentation, are considered in terms of the entire ICM program and ICMS, minimizing adverse effects. Configuration management includes standardized procedures and techniques that allow the corridor stakeholders to propose changes, evaluate the impacts of proposed changes, and then to track, verify, and document those changes that are made.

A complete CM program includes provisions for the storing, tracking and updating of all information and documentation on a component, subsystem and system (network and corridor) basis. This provides corridor stakeholders with an up-to-date baseline of the ICMS. Configuration management has two fundamental purposes: to establish system integrity, ensuring that system documentation accurately describes and controls the functional and physical characteristics of the ICMS, and to maintain system integrity by synchronizing any changes to the system with this documentation. This also results in a working baseline that is always available to implement and provide transportation management services within the corridor.

The configuration management process is described in more detail in the document "*Configuration Management (CM) for Transportation Management Systems*" (Reference 6), which includes Figure 10-1 as a graphical description of the CM process. Key activities are summarized below.

- **CM plan**: While not shown in Figure 10-1, a CM plan is integral to the process. The CM plan is the document that guides the CM program for a particular project. This plan should be incorporated into the SEMP and program plan.
- **Configuration identification**: This refers to the activities and processes dedicated to creating and maintaining full documentation describing configuration items (CI). A CI is defined as anything that has a function in the ICMS. The goal of configuration identification is to provide a unique identifier to each item to help track the changes to that item and to be able to understand its place in the system.
- **Change Management:** This is process, sometimes referred to as Change Control, by which the need for a change is identified, the impact of the change on the system (i.e., cost, schedule, operational performance) is analyzed, the proposed change is evaluated by a review body of corridor stakeholders and, if approved, the approved change is incorporated into the ICMS and / or existing network system with its appropriate documentation.

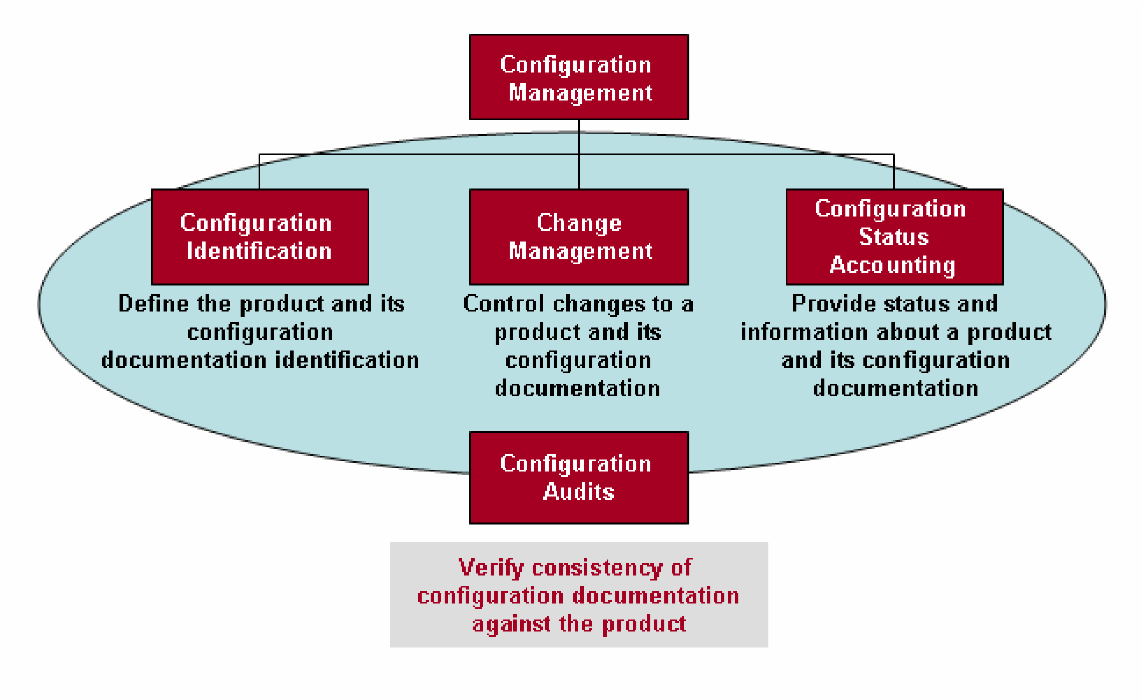

Figure 10-1. Configuration Management Process[8]
(Reference 6)

- **Configuration Status Accounting**: This is record keeping and reporting function of the configuration management process, ensuring that all of the relevant information about an item, particularly the documentation and change history, is up to date and as detailed as necessary.
- **Configuration Audits**: This is a process of analyzing Configuration Items and their respective documentation to verify and ensure that the documentation reflects the current situation. In essence, while Change Control ensures that change *is* being carried out in adherence with the CM Plan, Configuration Audits ensure that the change *was* appropriately carried out.

The CM process should be applied throughout the ICMS life cycle. This allows the corridor stakeholders and ICMS managers to track objectives and requirements through ICMS design, integration, acceptance and operations and maintenance. As changes are inevitably made to the operational concepts, requirements and design, they must be approved and documented, creating an accurate record of the status of the system. The CM process should also be applied to the network systems that comprise the ICMS, thereby ensuring that the network agencies and stakeholders consult with one another before making any changes to their respective systems, and then thoroughly documenting the changes, however routine they may seem to be.

[8] "Configuration Management for Transportation Management Systems," 2003 (Available from the TMC Pooled Fund Study website http://tmcpfs.ops.fhwa.dot.gov).

11. KEYS TO SUCCESS

What make an Integrated Corridor Management Program and System, or any transportation management system for that matter, a "success"? As noted in Reference16, "a system is generally considered successful if it has been designed to meet the needs of the corridor stakeholders and corridor users; if the system has been implemented within a reasonable time and budget; if the various hardware and software components have been installed, integrated, operated, and maintained to function properly; and the system is utilized to its full potential [e.g., all functions and strategies used, optimum response plans, expansions] over a number of years." The degree to which success has been achieved can include quantitative assessments based on the corridor performance measures and metrics. It also requires a qualitative assessment, with an excellent measure being the attitude of the stakeholders (ICMS and network system operators, maintainers, management personnel, decision makers) who interact with the system. If these individuals have faith in the ICMS and its capabilities, then ICM, the system, and the overall process have been a success.

SYSTEMS ENGINEERING PROCESS

Using the systems engineering process to develop and implement the ICMS will contribute greatly to its success. It is not important that the exact sequence of steps defined herein be followed, as long as the basic principles of systems engineering are applied.

Systems engineering helps accomplish four key activities that impact a project's success. These are:

- **Identify and evaluate alternatives.** The feasibility of each alternative, be it ICM approaches and strategies, the ICMS architecture, the component and sub-system designs, or others, must be measured and evaluated from several different perspectives, including technical, operational and institutional, as well as cost and schedule. Usually trade-offs are required, deciding which alternative offers the better value.
- **Manage uncertainty and risk**. If the future could be accurately predicted, it would be easy to avoid mistakes and problems. However this is not the case. In real life, the corridor stakeholders must deal with uncertainty and risk. Systems engineering focuses on three aspects of risk management: identification, analysis, and mitigation.
- **Design quality into the system**. This is accomplished by addressing those factors that can negatively affect quality. Paraphrasing the International Organization for Standardization (ISO), quality may be defined as "the totality of features of a system that bear on its ability to satisfy stated or implied needs." Among the factors that can negatively affect the quality of an ICMS are its complexity, its inflexibility, its lack of standardized components, and its reliability and availability.
- **Handle program management issues that arise.** This requires good plans, including the Systems Engineering Management Plan (SEMP), ICMS Program Plan, Configuration Management Plan, Operations and Maintenance Plan, and the other "specialty" plans (e.g., verification, validation). A good plan is one that is complete, comprehensive, and communicated to all individuals that are involved or affected. It should include all tasks that must be performed, accurately estimate the resources required to accomplish each task, assign the appropriate resources to each task,

define all dependencies among tasks, identify all products or other criteria whose completion signifies that a task is done, and determine how to measure progress against plan when managing the project.

PROGRAM MANAGEMENT

As noted above, good systems engineering starts with planning. The SEMP/ICM Program Plan represents the "roadmap" for achieving success. Then the program must be managed, including:

- Tracking each task. Ensuring that tasks begin and end on schedule and, if they don't, determining what caused the variance from plan.
- Measuring progress. Monitoring the consumption of resources on each task to determine whether the products being delivered are consistent with the time, effort, and money being expended.
- Revising or expanding the overall plan. Updating the schedule, as well as adding more details (e.g., integration, verification and validation procedures, operations and maintenance) as the process continues from one stage to another.
- Addressing obstacles. Identifying a problem is important, but a solution must also be developed that removes the obstacle or reduces its impact on the overall program effort.

Another important program management activity (and one inherent in the systems engineering process) is that of continuous reviews and audits. All the ICMS products, including the concept of operations, requirements report, designs, procurement documents, software code, test plans and results, system performance measurements, and anything else that might give an indication of the ICMS and its quality, are reviewed, thereby gathering stakeholder input and ensuring that the stakeholders know at any time what the system consists of and where all of its parts reside. An essential part of this review process is the concept of **traceability**. All the ICMS products are linked together via "traceability matrices": the system sub-systems and components are mapped back to designs, which are mapped back to requirements, which are mapped back to system objectives, which are mapped back to corridor needs. Additionally, the various verification and acceptance tests are based (i.e., linked) on the various concept, requirements and design documents. This forward and backward traceability is one of the keys to a successful ICMS.

STAKEHOLDER INVOLVEMENT

The importance of stakeholder involvement to the success of an ICM program cannot be over-emphasized. Establishing the corridor stakeholder group is one of the initial activities in the process. As noted in the description of this activity:

> "All appropriate stakeholders need to be brought into the picture early on to make sure their needs are considered, and to determine how they will be involved in the process to plan and develop an ICMS. Bringing together all the stakeholders throughout this process can serve to heighten awareness of the importance and need for integrated corridor management, and to cultivate an interest in coordinated operations and corridor solutions. Moreover, it allows each entity

(e.g., network owner / operator) to understand the specific functions and perspectives of their partner agencies, as well as their respective institutional constraints and barriers, thereby making the collaborations more productive."

NCHRP Synthesis 337: "Cooperative Agreements for Corridor Management" stresses the importance of stakeholder involvement with the following conclusion: "it is vital to proactively confront the tough corridor management issues through direct involvement of the affected parties." Such stakeholder collaboration and coordination must be viewed as a "deliberate, continuous, and sustained activity."

Other key considerations related to stakeholder involvement include the following:

- The process is most effective when the managers and engineers (i.e., stakeholders) have **domain knowledge** about corridor management, the proposed ICMS system, and the overall process. Domain knowledge includes a fundamental understanding of the technology and operational functions and strategies involved in the system, and the institutional environment in which the system will be built and operated.
- **Champions** are essential to take the lead in the ICM endeavor, to arrange and organize inter-agency meetings, to continuously promote the need for ICM, and to show the individual network stakeholders the benefits that can accrue on both a corridor and individual network basis from integrated corridor management. The champions must also have the authority, ability, and credibility to influence decisions within all agencies and groups. This includes outreach to policy makers.
- **Public safety entities** represent an important corridor stakeholder group, and their continuing involvement in the ICM is crucial. Training and corridor management exercises for various events and incidents have proven effective for engaging public safety in ICM.
- Integrated corridor management will involve numerous individuals and organizations throughout the process, each with specific functions and responsibilities. Coordination and collaboration between these stakeholders is critical. It is also essential that there be a single institution or group which is ultimately responsible and accountable for delivering a fully functional ICMS. Moreover, concomitant with an **assignment of responsibility** must be the necessary authority and flexibility to control and manage the associated risks.

FUNDING

The availability and commitment of funding and other resources to develop, implement, and operate and maintain an Integrated Corridor Management Program and an ICMS is an obvious key to success. The stakeholders should consider innovative ways of funding the system, such as pooling their respective funding sources, and sharing key resources (e.g., equipment and personnel) across jurisdictional boundaries among the network providers. Innovative procurement approaches may also be considered for an ICMS. Of course, these "outside-the-box" approaches require a strong institutional network of ICM stakeholders and detailed inter-agency agreements.

There is a sort of "chicken and egg" challenge here. As noted during one of the corridor site visits, "you need institutional integration (funding) to generate operational integration; however, you need some level of operational integration to demonstrate success and thus gain the support necessary to facilitate institutional integration." As such, outreach is a critical activity for securing funding. As noted in the ITE publication *A Tool Box for Alleviating Traffic Congestion and Enhancing Mobility*, some of the most successful efforts at adopting transportation programs have exhibited the following characteristics:

- Waging an aggressive campaign to inform the public of what is likely to occur if something is not done.
- Clearly stating what the average citizen will gain from these actions.
- Providing opportunities for citizens and interest groups to participate in the planning and decision making process.
- Actively pursuing business support for the proposed actions.
- Seeking media support in editorials and news reporting.
- Developing a cost effective program that appeals to as broad a political base as possible.

As noted in NCHRP Synthesis 337 (Reference 12) : "Create frequent opportunities for educating partners and their stakeholders on the importance of the corridor management effort. Most agencies experience some setbacks in their corridor management efforts, even with formal cooperative agreements. Those having success recognize that corridor management is an ongoing process that benefits from continuous education and periodic technical assistance."

SUSTAINABILITY

As noted above, ICM may require some "outside-the-box" approaches for funding and procurement. After all, managing the movement of people and goods on a corridor basis, transcending traditional agency and network boundaries, is itself somewhat outside the box. Nevertheless, one of the major institutional issues, and a key to long-term success, is sustainability. With the proper pieces in place (e.g., stakeholder group and champions, ICM program plan, configuration management plan, operations and management plan, agency agreements), the path and momentum should be established for making ICM and integral part of each agency's management and day-to-day operations. For example, NCHRP states: "partners should be asked to incorporate the substance of the corridor agreements into their plans, policies, design standards, manuals and regulations to facilitate enforcement."

HUMAN RELATIONS

A recurring theme in this ICM Implementation Guidance is that Integrated Corridor Management is an ongoing, iterative effort requiring collaboration and coordination on the part of numerous agencies and organizations. The various agencies that are involved or impacted by the ICM don't attend and participate in coordination meetings and decision-making processes, per se; rather, it is their representatives that discuss and (hopefully) resolve the numerous institutional, operational and technical associated with ICM and a corridor-based system.

ICM requires the talents of many people. In fact, most institutional challenges and barriers are really about human relations. As stated in the FHWA "Guidelines for Successful Systems" (Reference 16), "excellent human relations are therefore essential to a systems success. In fact, this may be the most critical aspect of the process. If the various participants cooperate, then a successful system is almost assured. On the other hand, when the relationships between individuals disintegrate and they start to work at cross-purposes, the success of the system is seriously endangered." The importance of personal relationships among leaders and staff members of key operating agencies and neighboring jurisdictions, who recognize common problems and opportunities and agree to work together to improve regional transportation systems performance, cannot be overemphasized.

The dependence on the social behavior of different individuals can be a bit unsettling. After all, the most critical element of the process to develop, implement, and operate an ICMS is also the least controllable. Reference 16 notes that the absence of good human relations can be attributed to a variety of causes, including:

- Poor communications between people and organizations, which in turn leads to misunderstandings. Face to face contact can mitigate this problem.
- Insufficient knowledge, experience and/ or information on the part of key individuals.
- Persons in position of responsibility without the appropriate authority.
- Lack of continuity of key personnel throughout the process.
- Significant differences of opinion as to what is required from each organization involved in the process.

The systems engineering process addresses many of these potential problems, For example stakeholder meetings; comprehensive program and operational plans; in-depth walk throughs of requirements, plans, designs, etc; well-written agency agreements all contribute to improving understanding and agreement. Additionally, there are a number of general principles which can help to promote and maintain good human relations, and therefore minimize many of the potential barriers to collaboration and coordination. These principles include:

- Empathy – viewing problems and issues as others do, which requires careful listening.
- Honesty – clearly presenting the facts and being truthful in all dealings.
- Individuality – approaching people as individuals, not as stereotypes.
- Thoughtfulness – showing respect for the opinions and talents of others.
- Positive thinking – showing confidence in the concept of an ICMS.
- Flexibility – recognizing that circumstances change, and being open to new ideas.

Experience has shown that, far beyond any formal processes and written controls, system success depends on informal elements. That is, a successful ICMS must be a human success if it is ever to be a technical and operational one.

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