PARTNERS FOR ADVANCED TRANSPORTATION TECHNOLOGY
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Connected Corridors: I-210 Pilot Integrated Corridor Management System

Systems Engineering Management Plan

October 29, 2015

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REVISION HISTORY

Date	Sections	Change Description
06/04/2015	All	Initial document
09/17/2015	3.3	Updated project schedule
10/29/2015	3.3	Updated project schedule

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1. INTRODUCTION

This document presents the Systems Engineering Management Plan, or SEMP, that was developed to guide the design, building, and deployment of an Integrated Corridor Management (ICM) pilot situated along a section of the I-210 corridor in the San Gabriel Valley sub-region of Los Angeles County in California. This pilot implementation, referred to as the "I-210 Pilot" hereafter, is scheduled to begin operations in 2017. It is part of the Connected Corridors Program administered by the California Department of Transportation (Caltrans) and Partners for Advanced Transportation Technology (PATH) at the University of California, Berkeley. The general objective of this program is to design, deploy, and evaluate corridor-wide transportation management strategies for addressing multi-modal travel needs when incidents and special events affect corridor operations.

When starting a complex project, managers must ask themselves how a quality product or solution would be delivered and what processes or methods would be employed to ensure a reliable, efficient use of stakeholders' time and funds. To help address these questions, both Caltrans and the USDOT recommend using the systems engineering methodology for executing complex projects. Both as the project manager for the I-210 Pilot and an early supporter of the use of systems engineering principles, PATH agrees with that recommendation and has decided to follow the systems engineering methodology for the development of the proposed I-210 Pilot ICM system. One of the early deliverables of this process is a document filling out the generic systems engineering methodology with workflow processes and deliverables specific to the I-210 Pilot. That is what this document aims to provide.

This introductory section presents some general information about systems engineering and the purpose of the SEMP. Specific elements addressed in the following subsections include:

- Background on the systems engineering process
- Purpose of the SEMP
- Level of detail included in the SEMP
- Intended audience for the SEMP
- Outline of this document

1.1. SYSTEMS ENGINEERING PROCESS

Systems engineering is an interdisciplinary approach to help ensure success in the planning and development of complex systems. This approach focuses on defining customer needs and required functionality early in the development cycle of a product, as well as adequately documenting requirements, before proceeding with the design, development, and validation of the proposed system. It also attempts to take into account all elements that may affect the development of a solution to a particular problem, such as the system operational environment, cost and schedule constraints, system performance requirements, training and support needs, system testing and validation processes, and system life cycle expectations. The general goal is to plan for project activities up-front in order to minimize risks to budget, scope, and schedule.

In simpler terms, the systems engineering methodology is based on answering as early as possible questions about how to deliver a quality product or solution to a specific problem. Numerous examples demonstrate that it is possible to expend considerable resources and still deliver a poor-quality product.

To help ensure that a quality product is delivered, the systems engineering methodology proposes that the following steps be performed in the order shown:

1) Create, assemble, and manage resources and processes
2) Develop a product concept
3) Refine the product concept to detailed product requirements
4) Build and test product components and assemble them into a final product
5) Deploy and validate the product
6) Operate the product

While these steps may seem obvious, political and financial pressures, as well as a lack of experience in managing large complex efforts, can sometimes encourage the building of a promised product before there is a full understanding of the problem to be solved or before the processes to be used to solve the problem effectively are clearly defined. This is what the systems engineering process attempts to prevent.

Given the six-step process defined above, the systems engineering process attempts to define how each of the steps will be performed to allow deliverables of good quality to be produced. This leads to seeking answers to the following six questions:

1) How to assemble and manage resources and processes
2) How to develop a product vision
3) How to refine the initial product vision to detailed product requirements
4) How to build and test the product
5) How to deploy the product in the field
6) How to operate the product following its launch

The general objective behind providing answers to these questions is to avoid poorly managing resources, defining a bad vision for the product, developing poor requirements, building low-quality products, and deploying systems that do not satisfy the user needs for which they were developed. While the systems engineering process was not defined to provide specific answers to the questions, it lays out a general process that can be followed to help develop the needed answers.

A general guide to the systems engineering process can be found in the *Systems Engineering Guidebook for ITS, Version 3.0* [1]. Figure 1-1, commonly known as the "Systems Engineering V Diagram," illustrates the basic steps of the process. The left side of the diagram focuses on the definition and decomposition of the system to be built, the base on the building of the system components, and the right side on the integration and testing of system components, as well as acceptance and operation of the system. There are significant interactions between the two sides of the diagram: Verification and validation plans developed during the decomposition of the system on the left side are used on the right side to make sure that the resulting components and integrated system meets the needs and requirements of the stakeholders. Throughout the process, "control gates" are further used as decision points to determine if a particular step has been completed to the satisfaction of the established criteria.

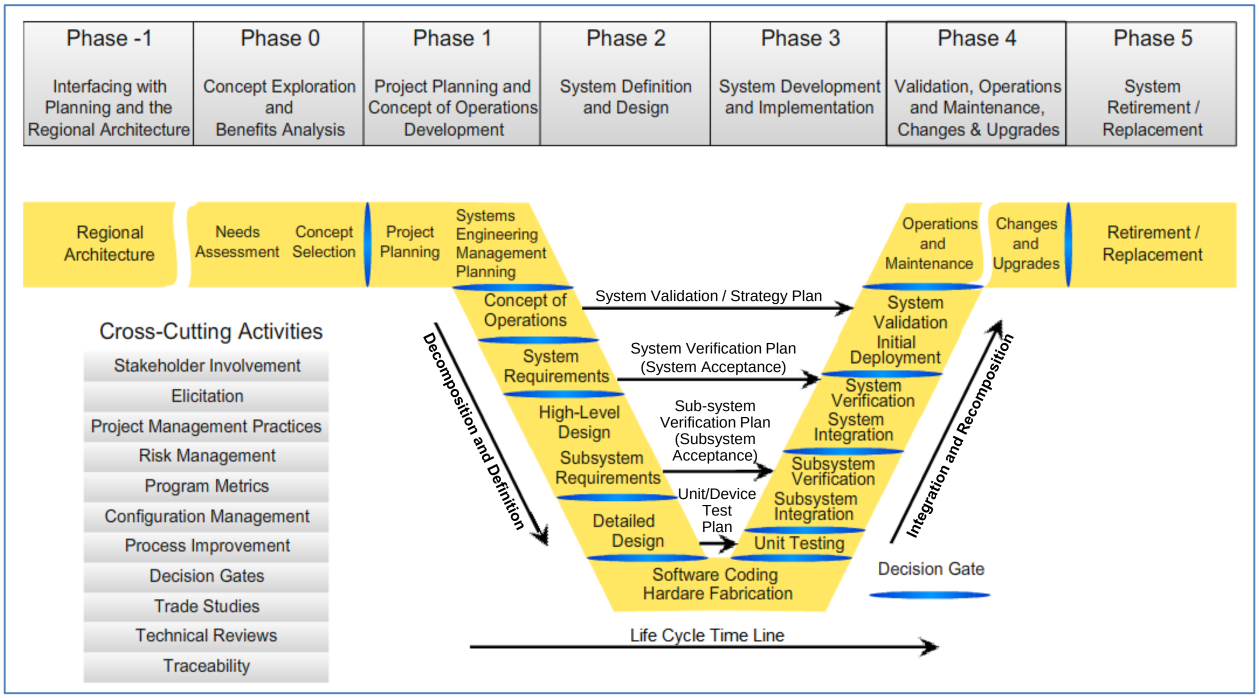

Figure 1-1 – Systems Engineering Process

A key outcome of the systems engineering process is the writing of various documents detailing how the project is to be managed and how specific tasks are to be executed. The following are examples of documents typically produced as part of the process:

1) **Project management plans** – Documents describing how various aspects of the project are to be managed and executed
2) **Concept of Operations** – Document developing a vision for the product to be developed
3) **Requirements specifications** – Document describing what the proposed system is to do, under what conditions it will operate, and how well it is to perform
4) **Design specifications and deployment/integration plans** – Documents describing how system components are to be built, integrated, and deployed
5) **Verification and validation plans** – Documents describing how the developed system components are to be verified and validated
6) **Operations and maintenance plan** – Document describing how the finished system will be operated and maintained

1.2. PURPOSE OF THE SEMP

Figure 1-2 illustrates how the SEMP relates to the systems engineering process. The document is typically developed early in the process as a supplement to the Project Management Plan (PMP). While the PMP addresses general project management details, such as project scope, participating personnel, schedule of activities, task scheduling, and costs, the SEMP focuses on the technical plans and systems engineering activities that will be used to carry the project to its end. Its purpose is to detail the processes that will be used to support the design, implementation, integration, verification, and eventual operation of the proposed system. Its development typically uses the foundation laid by the PMP to build the framework for implementing the technical tasks of the project.

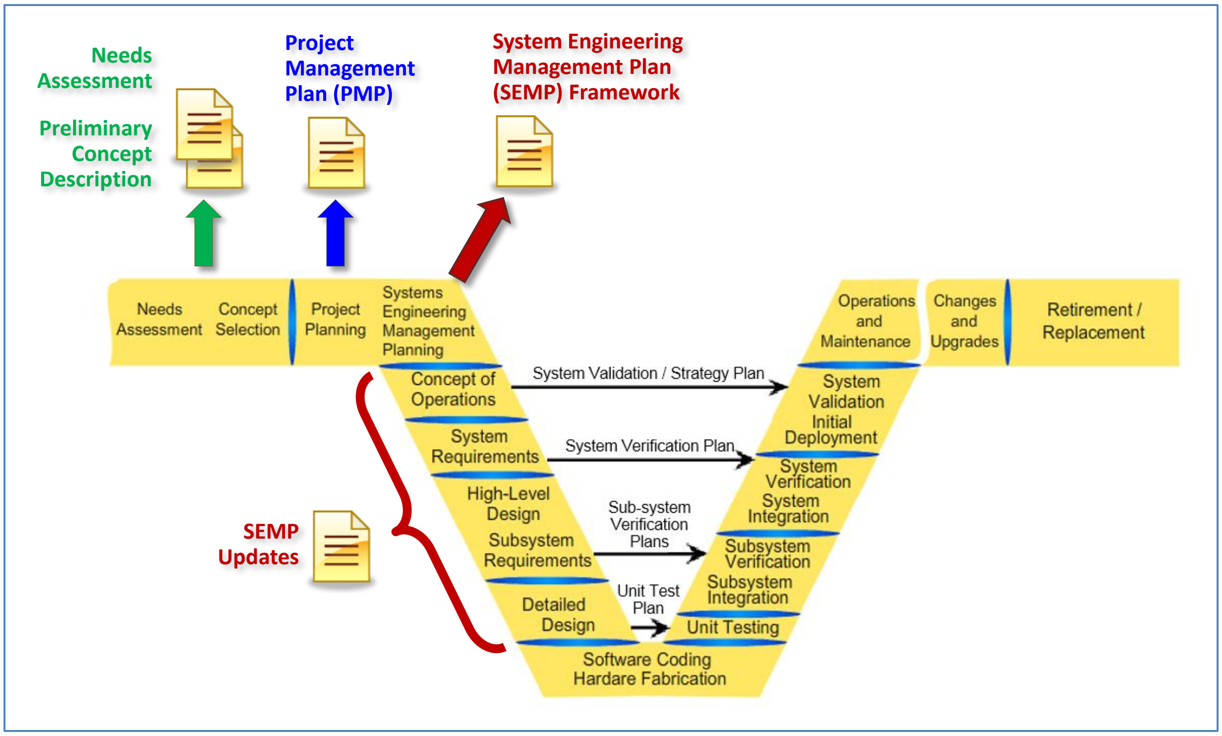

Figure 1-2 – SEMP Development within Systems Engineering Process

The SEMP does not attempt to answer what is to be done, but rather how what needs to be done should be executed. For example, the SEMP does not seek to define w*hat the product concept is.* It asks instead *how the product concept is to be determined.* This distinction between "*how*" and "*what*" is important in understanding the purpose of the SEMP. While the SEMP answers "*how*" questions, the various documents and processes it describes are used to answer the "*what*" questions.

Because the SEMP is developed early in the life cycle of a project, it is generally written with only a partial understanding of what is to be developed. Available information typically includes only the results of preliminary corridor operational evaluations and needs assessments, as well as preliminary concept explorations that might have been conducted to assess project feasibility. As a result, several versions the SEMP may be released during a project, usually within the first half of the systems engineering process, as shown in the annotations of Figure 1-2:

- A first version is generally produced by the project management staff early in the project life cycle to define the framework within which systems engineering activities are to be conducted. At this stage, only enough detail is included to allow the identification of all needed tasks and important constraints on the execution of each task.
- As the project progresses through the Concept of Operations, definition of system requirements, and system design, the various sections or plans identified in the SEMP framework are gradually completed. Examples of elements that are commonly defined at this stage include details of the tools that will be used to manage the requirements, the methodology that will be used to design

software components, the processes that will be used to manage system configurations, methods to be followed for verifying system components, etc.

As indicated, the SEMP is not meant to be a static document. Instead, it is meant to be a living document subject to various updates until it reaches a final, stable version.

1.3. LEVELS OF DETAIL IN THE SEMP

Within the SEMP, the decomposition of project activities normally stops at a level of detail suitable for the effective management of project activities. The SEMP is not intended to repeat the full content of other technical or administrative documents that may generated or planned to be used in the systems engineering effort. The SEMP ordinarily includes only high-level technical details and system overviews, and frequently references other, more detailed documents written by staff responsible for executing the specific activities those documents address. However, the SEMP can still include detailed guidance for carrying out those other processes if it seems useful and appropriate. The decision on the level of detail to include in the SEMP is normally left to the discretion of the Project Management Team.

The description of a specific process in the SEMP also does not imply that there will be only one way of accomplishing a specific task. The SEMP presents an early view of how a particular task may best be executed based on information known to the project team at the time of its development. As a project progresses, this view may change and may result in the identification of alternate processes better suited to the project. This is why a SEMP is viewed as a living document. It is to be updated as a project progresses. The key element of the SEMP is to keep answering the various “how” questions outlined in Section 1.1 or other “how” questions that may be brought to the attention of the Project Management Team.

1.4. INTENDED AUDIENCE

The primary intended audience for the SEMP includes individuals from Caltrans District 7 and the University of California, Berkeley, who will be tasked with project management duties. However, it is also expected that the plan will be distributed to other project partners to help coordinate activities among team members.

1.5. DOCUMENT OUTLINE

The Systems Engineering Management Plan is organized as follows:

- **Section 2 – Scope of Project:** Provides general information about the project for which this SEMP was developed.
- **Section 3 – Technical Planning and Control Plan:** Identifies the technical plans, documents, and control gates that will be used to manage the project.
- **Section 4** – **Systems Engineering Process Application**: Describes the processes that will be used to guide activities during each phase of the project.
- **Section 5** – **Transitioning Critical Technologies**: Expands on the risk management strategy pertaining to the technical issues, as described in the Project management Plan.

- **Section 6 – System Configuration Management Plan**: Describes the processes for establishing and maintaining configuration control of the products and documentation of the project.
- **Section 7 – System Integration and Deployment Plan**: Outlines the processes that will be used for bringing together the developed components and subsequently deploying the resulting system on the I-210 corridor.
- **Section 8 – System Verification Plan**: Describes the activities that will be conducted to verify that the system being built meets the identified system requirements.
- **Section 9 – System Validation Master Plan**: Describes the activity to be conducted to validate that the developed system meets its intended purpose and the stakeholder needs that were identified in the Concept of Operations.
- **Section 10 – System Evaluation Plan**: Describes the general approach that will be used to evaluate the benefits provided by the deployed system against metrics jointly agreed to by Caltrans and corridor partners.

2. SCOPE OF PROJECT

This section presents some general information about the project for which this SEMP was developed. Key elements presented here include:

- Project motivation
- Problem background
- Project definition
- Boundaries of the I-210 corridor
- System stakeholders
- Stakeholder roles
- Transportation systems under consideration
- Primary problems to be addressed
- Project goals and objectives
- Technical capabilities sought

2.1. PROJECT MOTIVATION

Southern California has the second-worst traffic in the country, behind Washington D.C. Recent statistics compiled by the Texas Transportation Institute indicate that commuters within the Los Angeles area spent on average 61 hours per year stuck in traffic in 2012, compared to 37 hours in 1982 [2]. This time is estimated to carry an annual cost of about $1,300 in both wasted time and wasted fuel. The region is also second behind Washington D.C. in the unreliability of its freeways. Incidents often significantly affect the time that travelers may need to travel to a given destination. As population and car ownership continue to grow, more time is spent in gridlock, more money is lost on wasted energy, and more air pollution is generated. This trend is expected to continue if nothing is done to address the problem.

In the past, government agencies across the country would have addressed the problem of urban congestion by widening highways; building new roads, tunnels, and bridges; and providing multi-modal options where feasible, particularly for shorter urban trips. However, due to both financial and space constraints , the emphasis has now shifted from building new infrastructure to seeking a more efficient use of what has already been built. Except in very select situations, safety, mobility, and environmental improvements can no longer be achieved through expensive capital improvements alone. Nor do they need to be, as new technologies and improved organizational cooperation can deliver a better traveler experience with minimal infrastructure modifications.

Similar to the way the manufacturing sector has raised efficiency through better software, hardware, and supply integration, the transportation sector can use technology to improve the performance of existing infrastructures. Several studies have indicated that technological advances may be used to improve the operations of freeways, arterials, and other transportation systems at a much lower cost than the traditional infrastructure-based approach. While notable gains can be expected in the operations of transportation systems, the greatest potential gains in operational performance and travelers' quality of life are likely to come from multi-facility, multi-modal, and multi-jurisdiction solutions considering the overall transportation needs of a corridor rather than the needs of specific elements.

2.2. PROJECT BACKGROUND

Throughout most of its history, the California Department of Transportation, or Caltrans, has been a freeway-centric agency. Agency activities predominantly centered on building and managing freeways. In 2011, Caltrans leadership sought to change this situation and established a new focus seeking collaboration and coordination with other agencies to maximize scarce resources and, ultimately, to improve system-wide performance.

To help achieve its new multi-modal, multi-agency collaborative vision, Caltrans developed in early 2012 the Connected Corridors program. The purpose of this program is to look at all opportunities to move people and goods within transportation corridors in the most efficient manner possible, to ensure the greatest potential gains in operational performance across all relevant transportation systems. This includes seeking ways to improve how freeways, arterials, transit, and parking systems work together. Travel demand management strategies and agency collaborations are also actively considered. The program is a collaborative effort to research, develop, test, and deploy a new framework for corridor management in California. It aims to change the way state and local transportation agencies, as well as any additional entity having a stake in the operation of transportation system elements, manage transportation challenges for years to come.

Starting with a pilot system deployment on a section of the I-210 corridor in the San Gabriel Valley sub-region of Los Angeles County, Caltrans aims to eventually expand the application of ICM concepts to numerous other corridors throughout California over the next ten years. In this context, the I-210 Pilot is to serve as a test bed to demonstrate how an ICM project can be developed by engaging and building consensus among corridor stakeholders, to address congestion for the betterment of an entire network.

2.3. PROJECT DEFINITION

The general objective of the I-210 Pilot is to reduce congestion and improve mobility within a section of the I-210 corridor in the San Gabriel Valley sub-region of Los Angeles County through the coordinated management of the I-210 freeway, key surrounding arterials, supporting local transit services, and other relevant local transportation systems. Operational improvements will be achieved through the design, development, implementation, and evaluation of a prototype ICM system to help transportation system managers and operators in their decision-making tasks. The overall goal is to achieve performance gains by enabling transportation systems managers and operators, control systems, vehicles, and travelers within a corridor to work together in a highly coordinated manner.

At the heart of the proposed ICM system will be a Decision Support System (DSS). The system will use information gathered from monitoring systems and predictive analytical tools to estimate current and near-future operational performance and develop recommended courses of actions to address problems caused by significant incidents or events. More specifically, the deployed system is expected to:

- Improve real-time monitoring of travel conditions within the corridor
- Enable operators to better characterize travel patterns within the corridor and across systems
- Provide predictive traffic and system performance capabilities
- Be able to evaluate alternative system management strategies and recommending desired courses of action in response to incidents, events, and even daily recurring congestion
- Improve decision-making from transportation system managers

- Improve collaboration among agencies operating transportation systems within the corridor
- Improve the utilization of existing infrastructures and systems
- Provide corridor capacity increases through operational improvements
- Reduce delays and travel times along freeways and arterials
- Improve travel time reliability
- Help reduce the number of accidents occurring along the corridor
- Reduce incident clearance times
- Reduce greenhouse gas emissions
- Generate higher traveler satisfaction rates
- Increase the overall livability of communities in and around the I-210 corridor

A preliminary project scope for the I-210 Pilot includes the design, development, installation, testing, and operation of components of the proposed ICM system, including the development of interfaces with existing monitoring systems. However, given the experimental nature of the project, Caltrans has already indicated that the system will not be permitted to control Caltrans-owned traffic management systems directly. Additional agencies may opt to do the same. In such cases, the design for interactions with these systems will need to consider how system operators may effectively communicate the desired control interventions to the various targeted systems.

While development of the proposed ICM system is under the financial sponsorship of Caltrans Headquarters, the system will be primarily developed by local transportation agencies that have agreed to participate in its operation, with potential help from other stakeholders. The system will also draw from the experiences and lessons learned in other recent successful ICM projects, both in the United States and abroad.

2.4. CORRIDOR BOUNDARIES

Figure 2-1 locates the corridor for the I-210 Pilot relative to downtown Los Angeles. This corridor is located approximately 9 miles from downtown Los Angeles and covers a 25-mile section of the I-210 freeway running through the cities of Pasadena, Arcadia, Monrovia, Duarte, Irwindale, Azusa, Glendora, San Dimas, and La Verne. It extends from the Arroyo Boulevard interchange in Pasadena (Exit 22B) northwest of the SR-134 interchange to the Foothill Boulevard/SR-66 interchange in La Verne (Exit 47) east of the SR-57 interchange.

This SEMP covers project activities for Phase 1 of the proposed ICM system deployment. As shown in Figure 2-1, this phase includes only that portion of the corridor west of the I-605 freeway. Management of transportation systems east of the I-605 will be added to the system later, in a second project phase.

As the figure illustrates, the I-210 freeway provides a vital link between various communities in the northern end of the Los Angeles metropolitan area. From the Sylmar district at the north end of the city of Los Angeles, the freeway links the city of Pasadena, communities in the San Gabriel Valley and Pomona Valley, and, further east, communities in the San Bernardino area. Moreover, this corridor runs through a predominantly urban environment and includes the most frequently and heavily congested sections of the freeway.

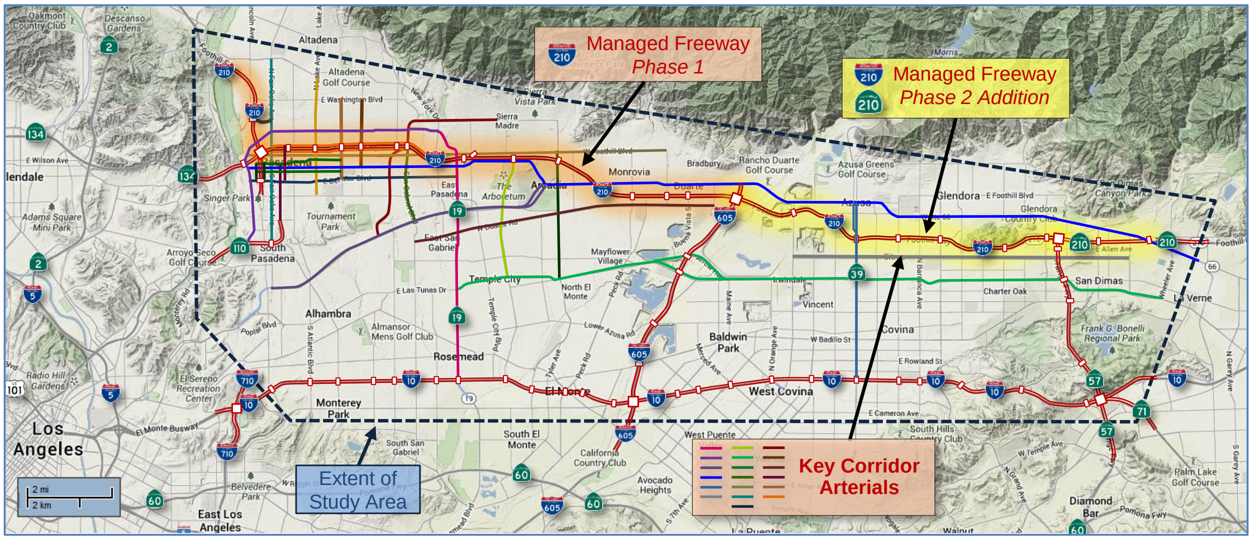

Figure 2-1 – I-210 ICM Corridor Study Area

South of the I-210, the study area is shown to extend to the I-10 freeway. While the proposed ICM system explicitly focuses on improving operations along I-210, the close proximity of the I-10 and the presence of two interconnecting freeways, the I-605 and SR-57 freeways, create some operational interdependencies between the two freeways. Incidents or events affecting operations along the I-10 often affect operations along the I-210, and vice versa. Even though the project does not aim to develop traffic and travel management strategies for the I-10, the operational interdependency between the two freeways creates a need to consider what may be happening on I-10 when developing operational strategies for the I-210 freeway.

2.5. TRANSPORTATION NETWORKS UNDER CONSIDERATION

The transportation networks under consideration for the first deployment phase of the I-210 Pilot include the following freeway, arterial, and transit system elements:

- The core freeway section to be managed by the proposed ICM system is the section of I-210 extending from the Arroyo Boulevard interchange in Pasadena to the I-605 freeway interchange in Duarte. Short sections of the SR-134 and I-605 freeways are also considered for inclusion.
- Figure 2-2 identifies the arterial segments that may potentially be recommended as detours around freeway or arterial incidents occurring within the corridor. All the segments considered are locally important travel routes and, in some cases, segments that are already often used as alternate routes by motorists to the I-210 freeway.
- Figure 2-3 maps the two primary rail systems serving the corridor. These include the light-rail Gold Line operated by Metro and the San Bernardino commuter rail line operated by Metrolink.
- Figure 2-4 further maps the express bus routes of potential interest. While not shown in the figure, various local fixed bus routes operated by Metro, Pasadena Area Rapid Transit System, and Foothill Transit may also potentially be included in the development of responses to incidents and events.

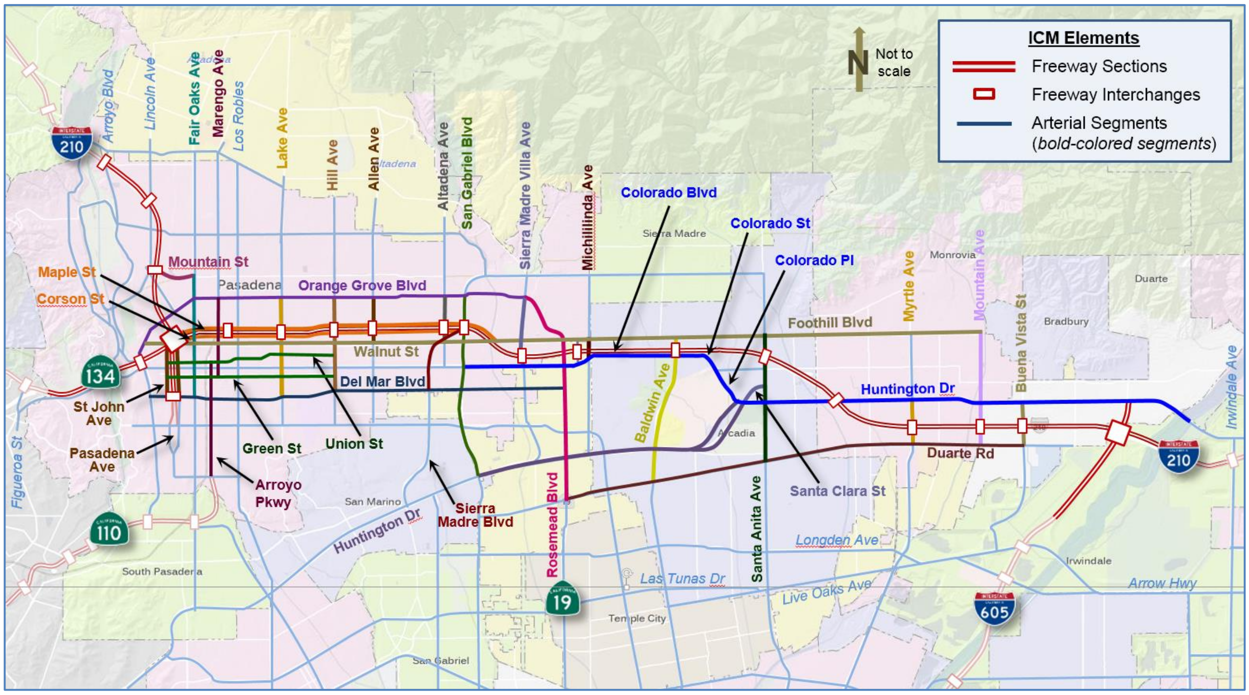

Figure 2-2 – Candidate Freeways and Arterials Segments

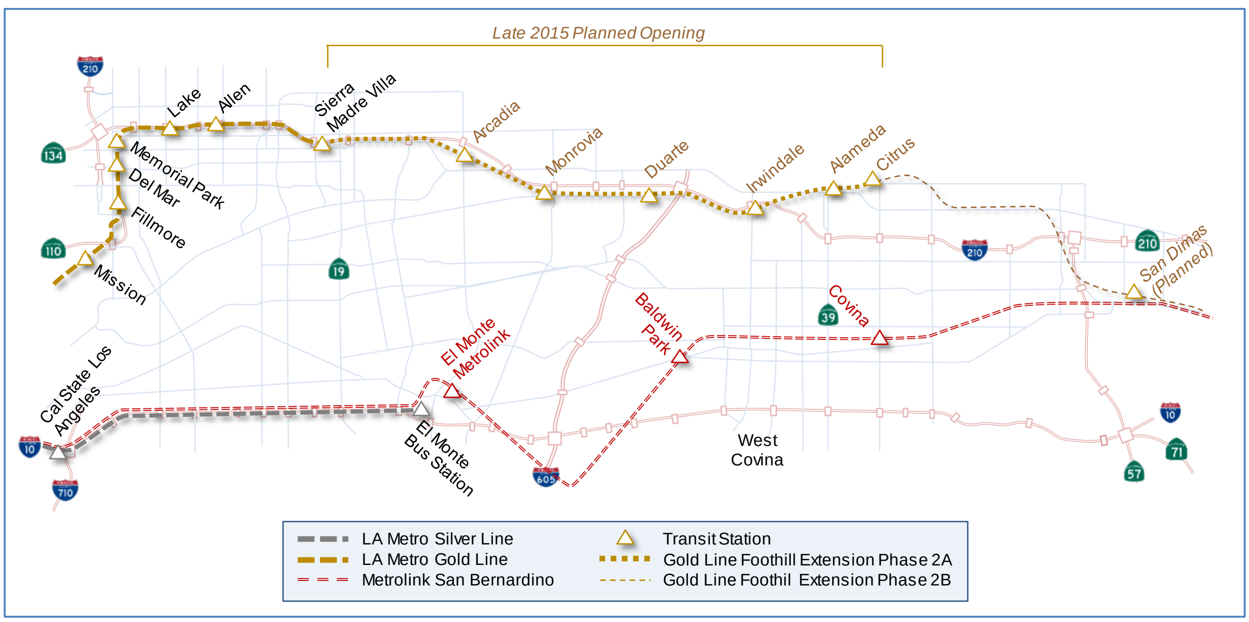

Figure 2-3 – Light-Rail and Commuter Rail Transit Services

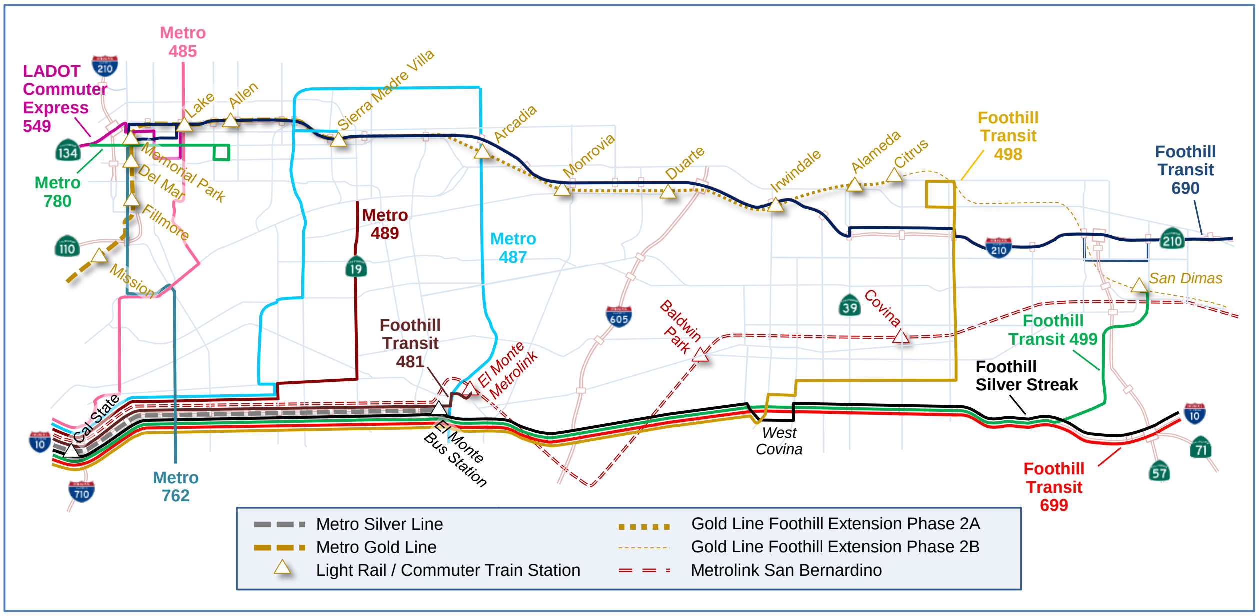

Figure 2-4 – Express Bus Services

2.6. SYSTEM STAKEHOLDERS

Stakeholders in the I-210 Pilot include agencies and groups having a direct interest in system operations and in how the proposed system might affect travel conditions in the corridor. Participation by and coordination among the stakeholders is vital to the project's success. Stakeholders, listed alphabetically, include:

- California Highway Patrol (CHP)
- Caltrans District 7 and Headquarters
- City of Arcadia
- City of Duarte
- City of Monrovia
- City of Pasadena
- Foothill Transit
- Los Angeles County Service Authority for Freeway Emergencies (LA SAFE)
- Los Angeles County Department of Public Works (LADPW)
- Los Angeles County Metropolitan Transportation Authority (Metro), including Metro Bus and Metro Rail
- Pasadena Transit
- San Gabriel Valley Council of Governments (SGVCOG)
- Southern California Association of Governments (SCAG)
- University of California, Berkeley – PATH
- US Department of Transportation (USDOT)

The above list of stakeholders constitutes the core project partners. As the project moves forward, it is likely that additional stakeholders will be identified and engaged in the project.

2.7. STAKEHOLDER ROLES

Table 2-1 indicates the key roles the various project stakeholders play in the management and operations of the corridor. These roles are categorized according to the following schema:

- **Freeway operators** – Entities managing freeway traffic
- **Roadway operators** – Entities managing local arterials and regional highways
- **Rail transit operators** – Entities providing commuter rail and light-rail transit services
- **Bus transit operators** – Entities providing fixed-route transit services
- **Paratransit operators** – Entities providing on-demand transit services
- **Parking operators** – Entities managing parking garages and parking lots within the corridor
- **Motorist aid services** – Entities responsible for providing aid to stranded motorists
- **Emergency responders –** Entities tasked with responding to emergency incidents and situations
- **Information providers** – Entities using information produced by the ICM system to generate and distribute value-added travel information for use by corridor travelers
- **Information consumers** – Entities using information produced by the proposed ICM system to help plan their movements within the managed corridor

Table 2-1 – Roles of I-210 Pilot Stakeholders

Stakeholder	**Freeway Operator**	**Roadway Operator**	**Rail Transit Operator**	**Bus Transit Operator**	**Paratransit Operator**	**Parking Operator**	**Motorist Aid Services**	**Emergency Responder**	**Information Provider**	**Information Consumer**	**Local Transportation Planning**	**Regional Planning**	**Technical/Policy Advisor**	**Application Developer/Integrator**
Caltrans – District 7	●	●				●			●	●	●	●	●	
Caltrans – Headquarters													●	
Los Angeles County Metropolitan Transportation Authority			●	●		●			●	●		●	●	
Los Angeles County		●			●	●		●	●	●	●	●	●	
City of Pasadena		●		●	●	●		●	●	●	●			
City of Arcadia		●			●	●		●	●	●	●			
City of Monrovia		●			●	●		●	●	●	●			
City of Duarte		●		●		●			●	●	●			
Foothill Transit				●					●	●				
Pasadena Area Rapid Transit System (Pasadena Transit)				●					●	●				
LA County Service Authority for Freeway Emergencies (LA SAFE)							●	●	●	●				
California Highway Patrol (CHP)							●	●	●	●				
Southern California Association of Governments (SCAG)												●	●	
San Gabriel Valley Council of Governments (SGVCOG)												●	●	
University of California, Berkeley – PATH Program													●	●
US Department of Transportation (USDOT)													●	

- **Local transportation planning** – Agencies planning transportation system development at a local level
- **Regional planning** – Agencies forecasting regional travel demand patterns and developing long-range transportation improvement plans
- **Technical/policy advisor –** Entities involved in developing and applying regional standards and policies
- **Application developer and system integrators** – Entities responsible for developing, and possibly operating, devices and systems used within the corridor

2.8. PROBLEMS TO BE ADDRESSED

The intent of the I-210 Pilot is to coordinate the various transportation networks and control systems in use within the I-210 corridor to enable them to operate in a cohesive and integrated manner. Achieving this presents a unique set of technical, procedural, and organizational challenges. To achieve the stated objective, the project team will need to investigate tools and technologies and to develop processes that will help Caltrans and other corridor partner agencies enhance their real-time collaborative decision-making capabilities.

Figure 2-5 maps various issues that preliminary corridor operational evaluations and early concept explorations have identified as important to the development of an ICM system for the I-210 corridor.

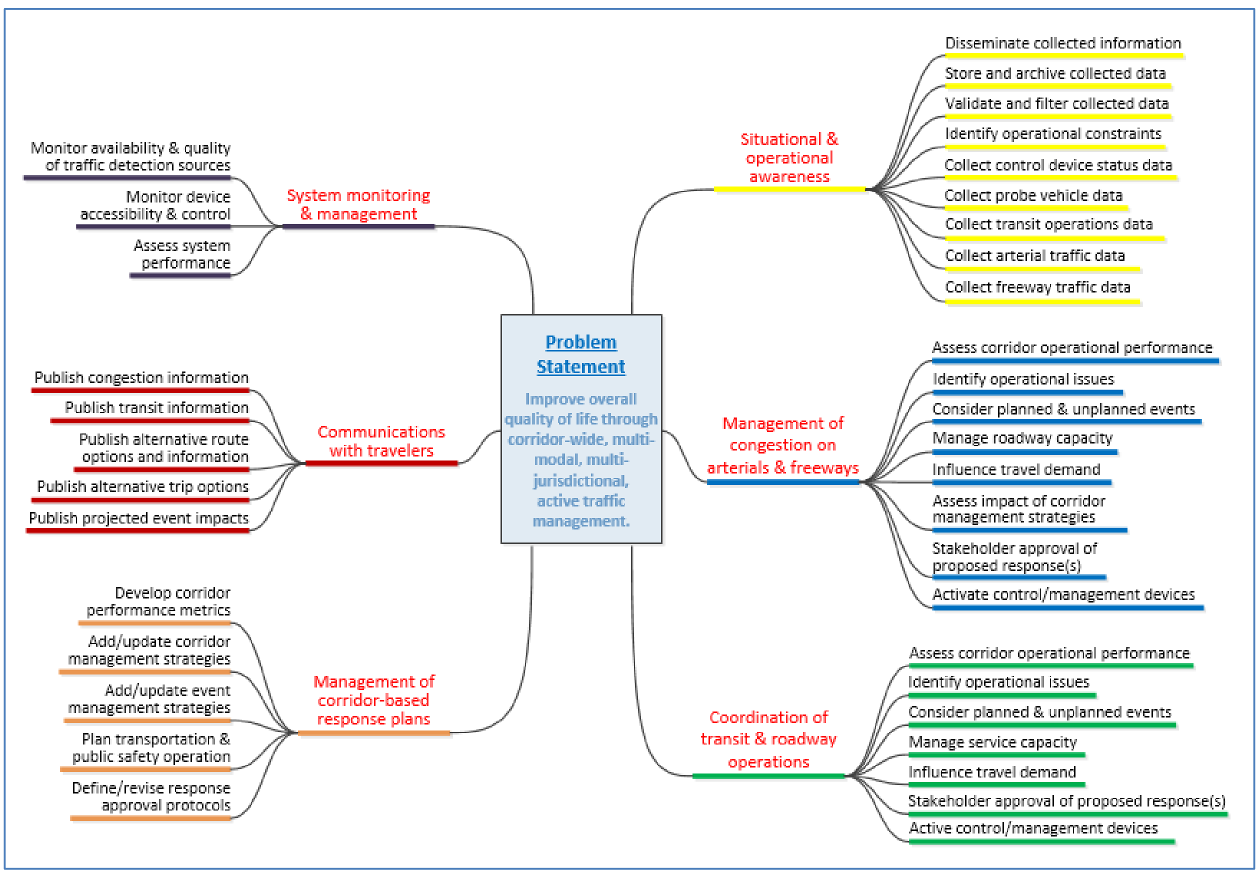

Figure 2-5 – Mapping of User Issues to General Corridor Management Needs

Since this mapping was developed as part of preliminary evaluations, its content should therefore be viewed only as elements framing the development problem at hand, as the final list of problems to be addressed will be identified later in the project life cycle, during the development of the Concept of Operations documents and the definition of system requirements.

The figure lists the following six general operational issues to be addressed by the project team in the development of an integrated corridor management solution for the I-210 corridor:

- Management of congestion spanning freeway and arterials
- Coordination of transit and roadway operations
- Enhancement of situational and operational awareness for system operators and managers
- Management of corridor-based response plans
- Enhancement of communication with system users
- Monitoring and management of the deployed ICM system

The following subsections provide additional information about the nature of the problems associated with each of these operational issues.

2.8.1. ENHANCEMENT OF SITUATIONAL AND OPERATIONAL AWARENESS

The need for adequate monitoring is influenced by the fact that both the capacity of transportation systems and the travel demand placed on transportation networks are somewhat dynamic. Arterial capacity, for instance, is heavily influenced by the operation of traffic signals at intersections. Roadway capacity can be influenced by incidents, construction and maintenance activities, inclement weather, and driver behavior. The capacity of transit services is a function of service frequency and type of vehicles used. Moreover, while travel demand is somewhat repetitive on a day-to-day basis, variations can occur over time. While there are obvious differences between week and weekend days, travel demand may fluctuate on a month-by-month basis and be influenced by business cycles. In this context, up-to-date measurements of corridor performance and travel demand will allow agency operators to determine appropriate pre-approved corridor management strategies designed to meet specific, agreed-upon corridor performance metrics.

The challenge of achieving adequate situational and operational awareness is associated with the deployment of comprehensive supportive monitoring systems. While many agencies have devoted significant efforts to deploying real-time monitoring systems in the operation of their transportation networks, significant gaps remain in the capacity to support adequately the corridor-based performance and operational objectives of this project. For instance, while extensive real-time monitoring capabilities already exist along the I-210 freeway, current real-time traffic data collection capabilities along arterials are somewhat limited, with large variations from one operating agency to the next. Real-time information sharing among agencies is also only partially available.

A lack of appropriate monitoring can significantly impede the ability of transportation system operators to devise optimal response strategies for operational issues. Similar to other aspects of this project, the development of a suitable real-time corridor monitoring system is a problem with multiple facets. The type of data that could be collected from freeway, arterial, transit, and other monitoring systems must first be determined. Then, the frequency with which data can be retrieved must be assessed, as well as the need to validate and filter the collected information to remove erroneous data. In turn, the problem of how to store and disseminate the collected information to facilitate use by corridor systems and stakeholders must be considered. Finally, the problem of how to best visualize the collected information to facilitate interpretation must be considered.

2.8.2. MANAGEMENT OF CONGESTION SPANNING FREEWAY AND ARTERIALS

Traffic congestion across the I-210 freeway and surrounding arterials is the primary problem to be addressed. Congestion occurs when demand for travel along a roadway segment exceeds the capacity of the existing infrastructure. Congestion can happen on a recurring basis, such as during peak travel periods on weekdays; during anticipated events, such as the Rose Bowl or other special event; or because of unanticipated events causing roadway capacity reductions in an unplanned and unexpected manner, such as traffic accidents, wild fires, or other events.

While many transportation system operators already dedicate significant effort to addressing the congestion that affects their transportation systems, those efforts often remain confined to their specific network. For instance, Caltrans typically tries to resolve congestion issues along freeways, while cities along the I-210 corridor normally focus only on what happens on surface streets. However, congestion often spreads across networks: Congestion on the freeway often spreads onto local streets; on local street networks, congestion also often spreads across jurisdictional boundaries.

The problem of addressing congestion has multiple aspects. It first involves identifying the extent and potential cause of the problem based on the results of performance assessments of individual field elements. This evaluation must also take into consideration planned and unplanned events that may influence system operations. Once operational issues have been identified, actions may be taken to adjust the capacity of roadway elements and influence, to the extent possible, travel demand within the corridor to maximize system performance. The actions to be taken will depend on previously identified and approved response strategies, as well as on the ability to activate the related control devices.

2.8.3. COORDINATION OF TRANSIT AND ROADWAY OPERATIONS

While local transit operators are already devoting significant effort to provide efficient services to the I-210 corridor, further improvements could be achieved by coordinating transit and roadway operations. For instance, transit agencies could alter bus routes or offer additional rides in response to major roadway incidents. Another strategy may be to provide comprehensive information to travelers about available transit options, such as comparative travel times to key destinations using car or transit.

The major value proposition of the I-210 Pilot for transit agencies is increased travel time reliability and improved transit ridership within the corridor through the coordinated use of existing assets and infrastructures. One of the effects of congestion along the corridor is the inability to provide transit services with desired travel time reliability. This has a significant effect on customer service, as travel time reliability is a major factor in how travelers select a particular mode of transportation. In this case, the ability to use transit service effectively to support corridor operations will depend on several factors. These include the availability of adequate parking near transit stations, the ability of existing transit vehicles to accommodate additional passengers, the ability to put additional transit vehicles into service, the ability to monitor transit operations in near real-time, the ability of transit operators to coordinate their operations, and the ability to communicate information to motorists and transit riders effectively.

2.8.4. DEVELOPMENT OF COORDINATED STRATEGY MANAGEMENT

Once the situational awareness issues have been addressed, the problem of defining what to do under different operational environments arises. This is crucial, as a lack of coordination among corridor stakeholders can result in the implementation of less effective solutions than what might be achievable through coordinated control. In some cases, a lack of coordinated control may also be responsible for degrading corridor operations.

Regional transportation partners need to have an ability to define, select, communicate, and implement strategies that support jointly developed corridor management objectives and performance metrics. Effective coordination of different operational systems will require the establishment of agreed-upon processes and corridor performance metrics based on common operational philosophies and corridor management objectives. A need for such coordination exists as current corridor operations are typically fragmented. Each transportation system is usually managed as an independent system, with only occasional considerations given to cross-system or cross-jurisdictional issues. This prevents implementation of synergistic strategies that could be implemented through a coordinated ICM system.

2.8.5. ENHANCEMENT OF COMMUNICATION WITH SYSTEM USERS

The leading part of the problem statement in Figure 2-5 is to improve overall quality of life. A key part of achieving that involves consistently meeting system users' reasonable expectations. This means first meeting corridor performance metrics, and then communicating reliable information to travelers. Depending on the extent of the traffic management system developed, the information provided to travelers may include the location and severity of congestion hotspots, data for transit services, routing options around congestion hotspots or problem areas, and data for alternate trip options. For instance, the last option may include providing comparative statistics for trips made by car or using transit, or for trips delayed by a certain amount of time. Information about the projected impacts of incidents or events may also be published to provide travelers advance information about future traffic conditions and enable them to respond well ahead of time to a given situation.

2.8.6. MANAGEMENT AND MONITORING OF DEPLOYED ICM SYSTEM

The effectiveness of traffic management is highly dependent on the quality and completeness of the information used to monitor the operations and performance of individual systems, and the ability to implement desired control actions. While suitable field equipment may be deployed to enable adequate information gathering and system control, these devices can degrade over time due to exposure to weather, traffic, construction activities, vandalism, or other causes. To maintain an appropriate level of operations, it is imperative to monitor deployed equipment continuously and advise system operators about equipment health. This may require developing methods and metrics for assessing equipment and overall system health based on the equipment status and the monitoring information.

2.9. PROJECT GOALS AND OBJECTIVES

As indicated earlier, the project's end goal is to improve overall corridor performance. This is to be done by managing incidents or events more efficiently with existing systems and infrastructures, using cross-jurisdictional traffic and demand management strategies that consider all relevant modes of transportation. This translates into the following specific goals:

1. Improve operational situational awareness
2. Promote collaboration among corridor stakeholders
3. Improve incident response
4. Improve travel reliability
5. Improve overall corridor mobility
6. Empower travelers to make informed travel decisions
7. Facilitate multi-modal movements across the region
8. Promote transportation sustainability by reducing impacts on the environment
9. Improve corridor safety

For each of these goals, Table 2-2 further identifies the main operational objectives. Many of the objectives are similar to those of traditional transportation improvement projects. Many, however, also support a vision that operational and managerial gains can be achieved by implementing more comprehensive travel and system status monitoring systems, improved operational forecasting, improved information dissemination to travelers, enhanced data-sharing capabilities, novel demand management approaches, and improved collaboration among transportation system operators.

Table 2-2 – ICM System Goals and Objectives

Goals	Objectives
1. Improve situational awareness – Improve the availability and quality of data characterizing travel conditions within the corridor	• Establish minimum requirements for data collection to support system management • Increase data collection opportunities from arterials and local roads • Improve the collection of real-time operational data from non-traditional sources, such as probe vehicles • Develop a comprehensive corridor informational database covering all relevant travel modes within the corridor • Improve the quality, accuracy, and validation process of collected data • Increase the ability to estimate travel demand patterns in a multi-modal environment • Improve the ability to forecast near-future travel conditions based on known incidents, road conditions, weather, and local events • Develop performance metrics considering all available travel modes
2. Promote collaboration among corridor stakeholders – Facilitate the exchange of information and consensus-building among agencies operating roadways, transit services, and traveler information services	• Strengthen existing communication channels among corridor's institutional stakeholders • Explore new opportunities, where appropriate, for new communication links between corridor stakeholders • Improve cooperation and collaboration among corridor stakeholders • Develop regional/joint operations concepts • Identify new and established methods of collaboration leading to successes • Extend corridor performance metrics to the network level • Investigate new types of agreements in addition to memorandum of understanding (MOUs), cooperative agreements, etc.
3. Improve response to incidents and unexpected events – Reduce the time needed to return operating conditions to normal following incidents or unexpected situations	• Reduce the time needed to identify the existence of an incident or unexpected situation • Reduce the time needed to respond to incidents • Enhance the coordination of activities among first responders, traffic management agencies, and transit agencies to minimize impacts on system operations • Reduce the time needed to implement control actions to address congestion resulting from an incident • Reduce the time needed to disseminate recommended travel options around an incident
4. Improve travel reliability – Develop a multi-modal transportation system that adequately meets customer expectations for travel time predictability	• Improve travel time predictability along the corridor • Reduce the impacts of incidents and events on network operations • Improve incident notification for first responders and network operators • Improve incident notification to travelers and fleet operators • Provide travelers and commercial vehicle operators affected by an incident an enhanced ability to seek alternate routes or mode of transportation

Table 2-2 - ICM System Goals and Objectives (cont'd)

Goals	Objectives
5. Improve overall corridor mobility – Facilitate the movement of vehicles, people, and goods across the corridor	• Reduce delays incurred by travelers • Reduce the impacts of incidents and events on network operations • Efficiently use spare capacity along corridor roadways to plan necessary detours around incidents or events • Promote strategies to induce desirable travel demand patterns • Coordinate the management of freeway and arterial bottlenecks • Promote increases in vehicle occupancy • Promote increases in transit ridership
6. Empower system users to make informed travel decisions – Deliver timely, accurate, and reliable multi-modal information to transportation system users, allowing them to make informed choices regarding departure time, mode (for travelers), and route selection	• Improve the dissemination of real-time, multi-modal travel information • Enhance the use of infrastructure-based informational devices (freeway CMS, arterial trailblazer signs, kiosk, etc.) to provide en-route information to travelers • Enable individuals to receive travel information on connected mobile devices • Make archived historical data available to information service providers • Support the dissemination of travel information by third-party providers
7. Facilitate multi-modal movements across the region	• Promote the integration of commuter rail and commute bus services with corridor operations • Facilitate transfers across modes during incidents and events • Provide relevant regional travel information to travelers • Direct travelers to park-and-ride facilities with available spaces
8. Promote transportation sustainability – Reduce the impacts of transportation activities on the environment, and improve the impacts on the economy and quality of life	• Reduce fuel consumption • Reduce vehicle emissions • Identify financially sustainable solutions that account for long-term system operations and maintenance • Encourage the use of transit, walking, and bicycling where appropriate • Support locally preferred alternatives compatible with corridor objectives • Develop and implement performance metrics reflecting environmental goals • Educate the public about transportation sustainability through media outlets
9. Improve corridor safety – Reduce deaths, injuries, property losses, and economic losses by reducing the occurrence of preventable accidents and the severity of occurring accidents	• Reduce collision rates • Reduce the severity of collisions • Reduce the number of fatalities • Reduce the impacts of primary and secondary incidents on network operations through improved incident management

2.10. TECHNICAL CAPABILITIES SOUGHT

To help manage travel activities within the corridor during incidents and events, the following technical capabilities are specifically sought in support of the goals and objectives identified in Section 2.9:

- Gather and archive information characterizing traffic operations, transit operations, and the operational status of relevant control devices within the I-210 corridor.
- Identify unusual travel conditions on the I-210 freeway or nearby arterials based on the monitoring of data provided by various traffic, transit, and travel monitoring systems.
- Identify situations in which an incident on transit facilities significantly affects travel conditions within the corridor.
- Provide corridor-wide operational evaluations to traffic managers, transit dispatchers, and other relevant system managers, including projected assessments of near-future system operations under current and alternate control scenarios.
- Identify recommended detours around incidents or routes leading to the site of an event, considering observed travel conditions within the corridor. Depending on the need, and final system capabilities, specific detours may be recommended for motorists and transit vehicles.
- Identify recommended signal timing plan to be used at signalized intersections to improve and/or accommodate traffic flow influx during incidents and events and improve overall corridor mobility.
- Identify recommended ramp metering rate to use on individual I-210 freeway on-ramps and connectors to maintain overall corridor mobility.
- Identify messages to post on available freeway and arterial CMSs to inform motorists of incidents and events.
- Provide guidance to motorists on the I-210 freeway and surrounding arterials using available freeway CMSs, arterial CMSs, and arterial dynamic trailblazer signs regarding which detour to take to go around an incident or which route to follow to reach the site of an event.
- Provide information to motorists about the availability of parking and transit services to help travelers make alternate mode-choice decisions.
- Provide uniform traffic management strategies across jurisdictional boundaries during incidents and events.

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3. TECHNICAL PLANNING AND CONTROL

This section lays out the plan for the systems engineering activities. It describes, in general terms, the activities, technical plans, and decision gates that will act as controls on the project's systems engineering work. Specific elements presented in this section include:

- Key development stages for the proposed I-210 ICM system
- Work Breakdown Structure
- Key technical deliverables
- Control gates
- Deliverable review and approval process
- Roles and responsibilities for the systems engineering activities

3.1. KEY SYSTEM DEVELOPMENT STAGES

As illustrated in Figure 3-1, six distinct stages define the process by which the proposed I-210 ICM system is to be designed, built, and deployed. The list below describes the focus and anticipated principal outcomes of each of the development stages.

- **Phase 1: Needs Assessment and Preliminary Concept Exploration –** Exploratory activities to assess the needs for a project. This includes an analysis of corridor operations to assess existing operational gaps and needs, the development of potential high-level concepts to address the identified needs, the identification of potential stakeholders in the proposed concept, funding needs analyses, the identification of potential funding sources, etc. Anticipated key outputs of this phase include:
    - Inventory of current corridor assets
    - Identification of current corridor operational issues

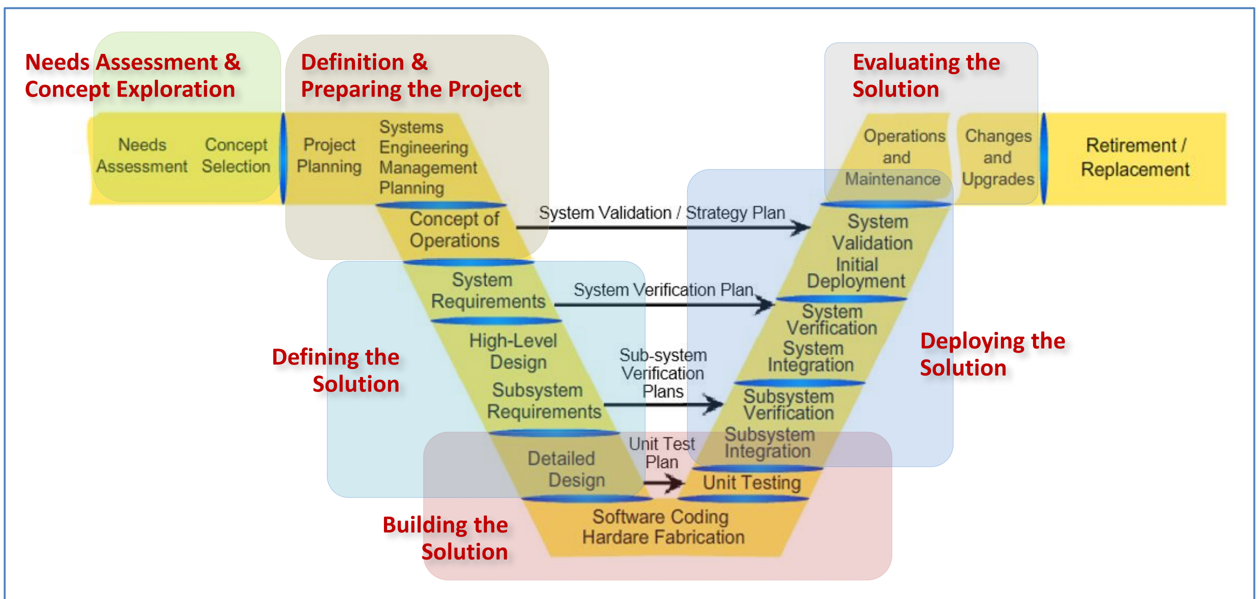

Figure 3-1 – Key ICM System Development Stages

  - Preliminary needs assessment
  - Identification of general solution concepts that may be used to address the identified operational issues
  - List of potential corridor stakeholders
  - Funding needs and possible funding sources

- **Phase 2: Defining and Preparing the Project** – Organization of project activities following a formal decision to proceed. This includes activities aiming to engage stakeholder participation in the project, identify the specific needs to be addressed by the project, identify core project resources, allocate available resources to specific tasks, etc. Principal anticipated outputs of this phase include:
  - Overall project management plan
  - Human resource assignments
  - Funding allocations and, if needed, requests for additional funding
  - Outreach effort to engage identified stakeholders in the project
  - Concept of Operations, User Needs, and High-Level Requirements for the proposed ICM system developed collaboratively by all stakeholders
  - Project Charter signed by all relevant stakeholders

- **Phase 3: Defining the Solution** – Expansion of the preliminary solution agreed upon by corridor stakeholders in Phase 1 into detailed system requirements specifying the various system components, what each of these components is expected to do, and how each component is to accomplish its assigned tasks. This includes defining data-gathering processes, data communication processes, decision support processes, and processes for approving and implementing recommended corridor management actions. Anticipated key outputs of this phase include:
  - List of system requirements
  - Design documents detailing the organizational processes and software/hardware systems to be developed and/or implemented
  - Definition of what constitutes an incident or event that must be responded to
  - Definition of detailed management scenarios indicating how the system is to respond to identified incidents and events
  - Memoranda of Understanding signed by system stakeholders indicating that they agree on the identified response processes and traffic management scenarios for the identified incidents and events
  - Initial plans for testing, verifying, and validating system components and the overall system

- **Phase 4: Building the Solution** – Utilization of the system requirements defined in Phase 3 to construct the proposed ICM system. This includes the building of physical system elements, such as software and hardware components, as well as the development of organizational structures or processes needed to support system operations. The following are the anticipated key outputs from this phase:
  - Detailed design documents for software and hardware components to be developed
  - Developed software and hardware components
  - Organizational elements and work processes to support system operations
  - Traffic management scenarios to be implemented in response to incidents

  - Decisional processes identifying whether actions are needed in response to an incident and event and what these actions should be
  - An integrated system composed of physical and organizational components capable of gathering information, determining a strategy, and implementing that strategy
  - Refined plans for system tests and verifications
  - Results of executed system tests and verifications

- **Phase 5: Deploying and Operating the Solution** – Field deployment and operation of the system components and processes that were defined and built in Phase 3 and 4, followed by an evaluation/validation of how well the system is meeting the needs that led to its development. Principal anticipated outputs of this phase are:
  - Operational and maintenance agreements with system stakeholders
  - Field deployment of developed system components
  - Implementation of organizational processes supporting system operations
  - Overall system validation plan
  - Results from the overall system validation
  - If needed, refinement of system components

- **Phase 6: Evaluating the Solution** – Evaluation of the operational benefits provided by the deployed solution to system operators and travelers. Key anticipated outputs of this phase are:
  - Operational evaluation results
  - Lessons learned

3.2. WORK BREAKDOWN STRUCTURE

A preliminary Work Breakdown Structure (WBS) was defined in the Project Management Plan (PMP). As indicated below, this structure identifies 2 general project management tasks and 15 technical tasks designed to move the project across the six development phases identified in Section 3.1.

- **General Project Management Activities**
  - **Task 1: Project Management** – General project management activities, such as staffing, budgeting, contracting issues.
  - **Task 2: Outreach & Communication** – Corridor stakeholder engagement, coordination of activities among stakeholders, release of information to the public, etc.

- **Phase 1 – Needs Assessment and Preliminary Concept Exploration**
  - **Task 3: Preliminary Concept Exploration & User Needs** – Evaluation of current corridor operations, identification of high-level user needs, and identification of operational gaps.

- **Phase 2 – Defining the Project**
  - **Task 4: Corridor Preparation** – Activities to ensure that the monitoring and control systems currently in place along the corridor are operating adequately, as well as to manage equipment upgrade requests prior to ICM system deployment.

  - **Task 5: Analysis, Modeling, & Simulation** – Use of analytical and simulation tools to evaluate the improvements that may be provided by various candidate strategies.
  - **Task 6: Systems Engineering Management Plan (SEMP)** – Identification of systems engineering activities that will guide the development of the proposed ICM system.
  - **Task 7: Concept of Operations (ConOps) & Validation Plan** – Development of the Concept of Operations and preliminary Validation Plan for the I-210 Pilot ICM system.
- **Phase 3 - Defining the Solution**
  - **Task 8: System Requirements & Verification Plans** – Development of system requirements and Verification Plans for the I-210 Pilot ICM system.
  - **Task 9: Organizational & Procedural Design** – Identification of organizational changes that may be implemented to enhance corridor-based operations.
  - **Task 10: Technical Design** – Design of system architecture and technical components of the I-210 Pilot ICM system.
- **Phase 4 - Building the Solution**
  - **Task 11: Component Development** – Development of technical components of the I-210 Pilot ICM system; execution of unit tests on developed system components to ensure they are operating according to specifications.
  - **Task 12: System Integration** – Integration of developed system components into a coherent corridor-based traffic management system, and execution of verification tests to ensure that the components are operating according to specifications.
- **Phase 5 - Deploying and Operating the Solution**
  - **Task 13: Institutional Deployment** – Implementation of approved identified organizational and procedural changes.
  - **Task 14: Technical Deployment** – Field deployment of the I-210 Pilot ICM system, and development of the final operations and maintenance manual for the system.
  - **Task 15: User Training** – Training of system operators and administrators.
  - **Task 16: System Validation & Acceptance** – Verification that the deployed I-210 Pilot ICM system satisfies the user needs identified in the Concept of Operations.
  - **Task 17: System Operations** – Operations of the deployed I-210 Pilot ICM system.
- **Phase 6 - Evaluating the Solution**
  - **Task 18: System Evaluation** – Evaluation of the operational benefits provided by the I-210 Pilot ICM system.
  - **Task 19: Lessons Learned & Best Practices** – Documentation of lessons learned and best practices.

3.3. PROJECT SCHEDULE

Figure 3-2 illustrates the baseline project schedule developed in the PMP to track project progress. This schedule has been aligned with the Work Breakdown Structure (WBS). It shows a project start date of October 1, 2013 and a target end date of September 2018.

Development of the SEMP is associated with Task 6 in the WBS. To reflect the potential for future updates, activities related to the development of the SEMP have been divided into two phases. A first phase focuses on the development of the initial version of the SEMP, labeled SEMP Framework, while a second phase includes all activities that may subsequently be carried out to update the document as the project progresses through the definition of system requirements and the design process.

It should be noted that the project end date is a target date. The end date of September 2018 is based on currently available and anticipated future project resources, the assessed time that will be needed to develop appropriate agreements with corridor stakeholders, and the anticipated required time to design, develop, implement, and evaluate a complex, multi-jurisdiction prototype traffic management system along the I-210 corridor. It must also be understood that the implementation of the proposed corridor management system can be influenced by ongoing changes in working relationships, gradual improvement of corridor ITS elements, and uncertainties associated with the use of new, less-tested technologies. In this context, the illustrated schedule shows an overall estimated timeline for the completion of the project based on reasonable assumptions.

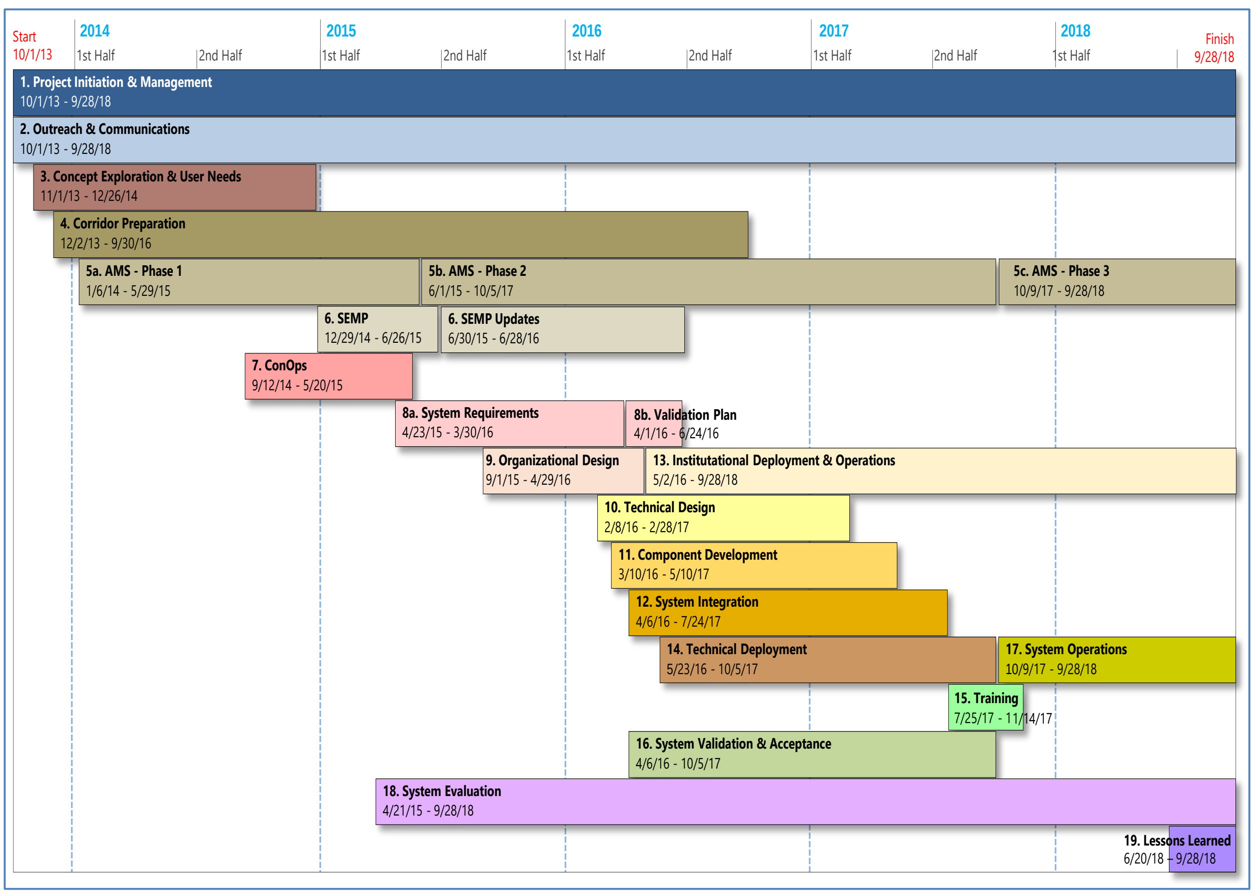

Figure 3-2 – Anticipated Project Schedule

3.4. SYSTEMS ENGINEERING DELIVERABLES

Table 3-1 identifies the key documents to be produced during each of the six major project phases identified in Section 3.1. For each document, the table provides a brief description of its purpose and content and identifies the parties responsible for the creation of the document and authorized to approve it. At this point, it should be noted that several documents mentioned in Table 3-1 will likely be developed in stages. A preliminary document defining the framework of the plan may be developed early in the project life cycle, with document updates produced at relevant times during the project when sufficient information has been gathered to define the plans in detail.

Table 3-1 – I-210 Pilot ICM Technical Deliverables

Deliverable	Purpose/Content	Location	Drafted by	Approved by
Phase 1 – Needs Assessment and Preliminary Concept Exploration				
Corridor Needs Assessment	Document identifying existing corridor operational issues and potential solutions to the identified issues.	Stand-alone document	PATH	Caltrans
Phase 2 – Defining the Project				
Project Management Plan (PMP)	Document defining the Work Breakdown Structure, schedules of activities, an organizational chart for the I-210 Pilot, in addition to describing the general processes used for project management, guidance, and oversight.	Stand-alone document	PATH	Caltrans
Risk Management Plan	Document identifying significant risks to the project and describing how each risk would be remediated if triggered.	Defined in PMP; stand-alone Risk Registry	PATH	Caltrans
Funding Management Plan	Document describing the approaches that will be used by the project team to seek additional funding and to secure new funding from new available sources.	Stand-alone document	PATH	Caltrans
Outreach & Stakeholder Communication Plan	Document discussing the communications needs with corridor stakeholders of the I-210 Pilot and identifying how those needs will be met.	Stand-alone document	PATH	Caltrans
System Configuration Management Plan	Document describing how changes made to the system components will be tracked to ensure that all developed documents remain up-to-date.	In SEMP	PATH	Caltrans
Procurement Management Plan	Document discussing the strategies to be used to procure relevant system components. Examples of elements to be addressed in the plan include whether to develop open-source software, how to purchase items, the possibility of borrowing specific tools to conduct some tasks, etc.	In PMP	PATH	Caltrans
Systems Engineering Management Plan (SEMP)	Document listing the various documents and processes that need to be defined and written in order to effectively manage the project and deliver the I-210 Pilot.	Stand-alone document	PATH	Caltrans
Concept of Operations (ConOps)	Document identifying the stakeholders and user needs for the proposed pilot ICM system, and describing how the proposed concept may improve freeway, arterial, and transport operations within the I-210 corridor.	Stand-alone document	PATH, with assistance from system stakeholders	All system stakeholders
Analysis, Modeling, and Simulation (AMS) Plan	Document describing how analytical, modeling, and/or simulation tools will be used to assess existing corridor operations, evaluate operational alternatives, and determine optimum set of improvements.	Stand-alone document	PATH	Caltrans

Table 3-1 – Phase 1 Technical Deliverables (cont'd)

Deliverable	Purpose/Content	Location	Drafted by	Approved by
Phase 2 – Defining the Project				
Cooperative Agreements	Documents detailing the operational responsibilities of individual project stakeholders and recording their agreements to participate and support the project, such as Project Charter, Memoranda of Understanding (MOUs), and other official signed documents.	Stand-alone documents	PATH, with assistance from Metro	All system stakeholders
Phase 3 - Defining the Solution				
System Requirements	Document itemizing the specific items that the system software and hardware components must be able to do.	Stand-alone document	PATH, with assistance from system stakeholders	All system stakeholders
High-Level Design	Decomposition of the system to be developed into high-level components and interfaces based on the identified system requirements.	Stand-alone document	PATH, with assistance from system operators	All system stakeholders
System Architecture	Document describing how the overall individual system components will communicate with each other.	Stand-alone document	PATH and Caltrans, with assistance from system operators	All system stakeholders
Detailed System Design	Detailed description of the component to be built for each system component defined in the high-level architecture. This description will not include components that the project team is planning on purchasing or that are already in use.	Stand-alone documents	PATH and Caltrans, with assistance from system operators	All system stakeholders
System Inventory	Document describing the various system components to be developed, integrated and/or deployed. This inventory is to be refined into the Bill of Materials for the system at a later stage of the project (see description below)	Stand-alone document	PATH	Caltrans
Data Dictionary	Description of all the data used by or exchanged between system components. A particular focus of this description is expected to be on data to be maintained in the system's data hub.	Stand-alone document	PATH	All system stakeholders
Phase 4 - Building the Solution				
Software Development Plan	Document defining the methodologies to be used for developing software, which may differ depending on which organization is tasked with developing the software and the associated reliability requirements	Stand-alone document	PATH	Caltrans
Configuration Management Plan Updates	Updates to the previously defined Configuration Management Plan as more details on the components of the system become available.	In SEMP	PATH	Caltrans
Procurement Plan Updates	Updates to the previously defined Procurement Plan to adjust the plan to the latest procurement needs.	In SEMP	PATH	Caltrans
System Integration Plan	Document defining how the many system components will communicate and work together in an integrated environment.	In SEMP	PATH	All system stakeholders
Subsystem Test Plans	Documents defining how the project team will test the subsystems prior to a system test.	Stand-alone documents	PATH	All affected system stakeholders
System Test Plan	Document defining how the project team will test the overall system prior to system verification.	Stand-alone document	PATH	All system stakeholders
Bill of Materials	Document listing all the items comprising the system, including hardware, software, and communication technologies.	Stand-alone document	PATH	Caltrans

Table 3-1 – Phase 1 Technical Deliverables (cont'd)

Deliverable	Purpose/Content	Location	Drafted by	Approved by
Data Communication Plan	Document defining the exact communication methods and protocols to be used in transferring data between system components, with particular attention paid to firewall and other security issues.	Stand-alone document	PATH	All affected system stakeholders
Data Management Plan	Document defining how data will be stored and accessed. This will include descriptions of how data would be organized to facilitate queries in real-time environments and subsequently stored and organized in a data warehouse.	Stand-alone document	PATH	All system stakeholders
Phase 5 – Deploying and Operating the Solution				
System Verification Plan	Document describing how users will verify the developed system meets all its requirements.	In SEMP	PATH	All system stakeholders
System Validation Plan	Document describing how system users will verify that the developed system actually does what it was intended to do, as defined in the user needs.	In SEMP	PATH	All system stakeholders
Deployment Plan	Document describing how the system will be deployed at all necessary locations and how the processes that are needed to run the system will be integrated into normal work processes.	In SEMP	PATH	All system stakeholders
System Evaluation Plan	Document describing how the effects the system is having on corridor operations and mobility will be evaluated.	Stand-alone document	PATH	All system stakeholders
Operations and Maintenance Plan	Document describing the roles and responsibilities of system users, as well the maintenance processes.	Stand-alone document	PATH, with assistance from system operators	All system stakeholders
Training Plan	Document defining the training requirements and delivery media, based on user roles.	Stand-alone document	PATH, with assistance from system operators	All system stakeholders
Security Plan	Document defining security measures to be implemented, from both a physical (hacking) and personal (administrative privileges based on user roles) perspective.	Stand-alone document	PATH	All system stakeholders
Phase 6 - Evaluating the Solution				
System Evaluation Plan	Document identifying how the operational benefits provided by the delivered ICM system to system operators and travelers will be evaluated.	Approach defined in SEMP; detailed plan as stand-alone document		
Evaluation Report	Document identifying the operational benefits provided by the ICM system to the operators of individual transportation systems and travelers.	Stand-alone document	PATH	All system stakeholders
Lessons Learned	Document summarizing for the stakeholders of other corridors the lessons that were learned about the development, deployment, and operation of the I-210 Pilot ICM system.	In Evaluation Report	PATH	Caltrans

Documents themselves will generally be developed using the following steps:

1) Creation of document outline and initial content by the organization responsible for the document. Content at this point will be obtained from early conversations with stakeholders, previous ICM efforts, general industry knowledge, and experience of the responsible organization.
2) Documents will be written in Microsoft Word and follow a standard template (this document is an example of the template). Graphics may be created using Microsoft PowerPoint, Microsoft Visio, and NovaMind mind mapping software. All original graphics will be stored on the web site.
3) One or more meetings with appropriate stakeholders as the document is being developed and refined. As appropriate, early versions of documents will be provided to stakeholders.
4) Final review and approval (as described later in this chapter).
5) Versioning of the initial release of the document. Versioning will be accomplished by including the date of the last change in the document name. Each version of a document will then be archived on the project web site.
6) Updates to the document will likely occur. Depending on the magnitude of the changes and the interest of the stakeholders, these updates may or may not be circulated for review and approval. All significant changes will require either written or verbal approval.
7) All changes to the document will result in a new version of the document.

3.5. DECISION GATES

Within the systems engineering process, decision gates are formal decision points along the life cycle of a project, used to determine if a current phase of work has been completed and whether the project team is ready to move on to the next phase of the project. Decision gates are formal ways of concluding and accepting the products for a particular phase of the project. Key control gates for the project are associated with the six development stages illustrated in Figure 3-1:

- **Phase 1 – Needs Assessment and Preliminary Concept Exploration**
    - *Go/No-Go Decision*. Formal decision by project sponsors to go ahead with the project or not.
- **Phase 2 – Defining the Project**
    - *Approval of Project Management Plan and Systems Engineering Management Plan by project sponsor(s)*. Formal acceptance of the plans covering general project management activities and systems engineering activities by the project sponsor(s).
    - *Approval of the Concept of Operations by all system stakeholders*. Formal acceptance of the proposed multi-modal management concept by transportation system operators and potential users of the proposed ICM system. Development of the system requirements will not be initiated until there is formal approval of the Concept of Operations.

- **Phase 3 – Defining the Solution**
  - *Approval of System Requirements by all system stakeholders*. The design and building of system components will not be initiated until there is a formal agreement on system requirements by all corridor stakeholders.
  - *Approval of design specifications.* The building of specific system components will not start until there is approval by all relevant system stakeholders of the design specifications for the component. It should be noted that this gate is not necessarily a single gate. The building of specific components may be allowed to go forward as long as their design specifications and the specifications of related elements are complete. This will prevent holding up system construction to wait for the final design of minor system components.

- **Phase 4 – Building the Solution**
  - *Unit tests applied on individual system components*. Tests to be conducted on individual system components to ensure that they meet all their specifications. Any component failing this test will not be released for use by other systems.

- **Phase 5 – Deploying the Solution**
  - *Verification tests.* Tests on system components to demonstrate that they meet their requirements. Several of these tests will likely be conducted during the deployment of the system. As noted later in this document, incremental integration and testing permits components to be used prior to their meeting all their requirements. Any component failing its verification test will not be released for use by other system components.
  - *System validation tests.* Tests to demonstrate that system components meet their intended purposes and the user needs for which they were developed. Several of these tests may be conducted throughout the project. Similar to the verification tests, any component failing its validation test will not be released for use by other system components.
  - *Stakeholder acceptance test.* Final validation test to demonstrate to stakeholders that the deployed system meets the user needs for which it was developed. A successful acceptance test will result in the stakeholders accepting delivery of the system and will mark the end of the system deployment.

- **Phase 6 – Evaluating the Solution**
  - *Evaluation Report.* Final evaluation report documenting the benefits provided by the deployed system to the operators of individual transportation systems, first responders, decision-makers, and travelers. Acceptance of this report will mark the formal end of the project.

3.6. DELIVERABLE REVIEW AND APPROVAL PROCESS

Review and approval of all the systems engineering documents that will be produced throughout the project will follow these steps:

- **Initial review by PATH technical team lead** – Review of the document by the leader of the team responsible for the development and writing of the document. This review will focus on the technical completeness of the document.
- **Review by PATH Management Team** – General review of the document by the PATH project managers, including editorial review to ensure that the document adheres to specific presentation guidelines and is free of typographical errors.
- **Review by Caltrans** – Review of document by the Caltrans project manager and, if relevant, Caltrans staff having a stake in what is being discussed in the document.
- **Review by Metro** – Review of document by Metro planning staff to ensure that what is discussed in the document respects regional objectives.
- **Review by corridor stakeholders** – Review of document by all corridor stakeholders having a stake in what is being discussed in it.

It should be mentioned that not all documents would necessarily go through all these steps. The review of some documents may, for instance, stop with Caltrans if Metro staff or other corridor stakeholders don't find it necessary to review them. The extent to which each document should be distributed for review will generally correspond to the information presented in the last column of Table 3-1, which lists the entities responsible for approving each deliverable.

Reviews may occur in three ways:

1) Individual review of the document with comments provided using Track Changes or in a list format
2) One-on-one or small group meetings where feedback is accepted
3) Larger meetings with many stakeholders where feedback is accepted

It should be noted that one or more of these approaches might be used for a given document.

Approval of documents will either be by formal signature, by verbal agreement in standing meetings with all stakeholders, or by agreement that after a certain date if no more comments are received the document is accepted.

3.7. ROLES AND RESPONSIBILITIES FOR SYSTEMS ENGINEERING PROCESSES

Table 3-2 summarizes the roles and responsibilities of members of the project team regarding the management of systems engineering activities. As outlined, the management of these activities is primarily the responsibility of PATH. PATH team members will generally be responsible for developing the systems engineering deliverables described in Table 3-1, with some assistance from Caltrans. Approval of the various documents will vary with the content, knowledge, and interest of other stakeholders.

Table 3-2 – Roles and Responsibilities for Systems Engineering Activities

Stakeholder	Role
PATH	Drafting of systems engineering deliverables outlined in Table 3-1
Caltrans	Review and approval of all systems engineering deliverable outlined in Table 3-1
Other stakeholders	Approval of Concept of Operations, cooperative agreements, system requirements, design documents, data communication and management plans, system integration and deployment plans, system verification and validation plans, operation and maintenance plan, training plan, evaluation plan, and other relevant systems engineering documents that may be produced

4. APPLICATION OF SYSTEMS ENGINEERING PROCESS

The development of the I-210 Pilot project will follow the established systems engineering process. This process, as described briefly in Section 1.1 and illustrated in Figure 1-1, is a best practice approach increasingly used for the development of large and complex systems. The I-210 Pilot qualifies as such a system, as its proposed operation will cross multiple disciplines and modes of transportation and involve numerous hardware, software, and human components.

This section discusses various elements of the plan to apply the systems engineering process to the design, development, implementation, integration, deployment, and operation of the I-210 Pilot ICM system. Specific elements addressed in this section include:

- General approach to the application of systems engineering principles
- Adaptation of systems engineering process to project needs
- Processes for the development of systems engineering deliverables
- Repository for systems engineering documents
- Procurement options
- Integration with Regional ITS Architecture
- Applicable ITS standards
- Systems engineering application challenges

4.1. GENERAL PLANNING APPROACH

As outlined in the project definition, the I-210 Pilot seeks to address the transportation needs of the I-210 corridor by coordinating how freeways, arterials, and transit systems are operated within the corridor. While other projects have recently developed solutions for the coordinated control of other corridors, these solutions are only partially transferable to the I-210 corridor. This difficulty of fully transferring solutions from other corridors is attributable to the unique geometry and operational environment of each corridor. While a general operational framework may be copied, this framework may require significant adaptation to enable the proposed ICM system for the I-210 corridor to satisfy the user needs upon which it will be based. In addition, the in-place systems and regional architectures are different from corridor to corridor, requiring a unique system design for each corridor. While some desired system elements may be known a priori, the specific details of the final solution are likely to evolve as the design of the system progresses and knowledge is gained about how existing systems operate within the corridor.

Given this context, planning of the proposed ICM system for the I-210 corridor will first attempt to draw from the experiences associated with other recent ICM efforts. Key efforts that will be considered include the solutions proposed for the I-15 corridor in San Diego, the US-75 corridor in Dallas, and the I-80 corridor in the San Francisco Bay Area. For each corridor, information about system components that were developed or procedures that were used to design, build, and deploy these components will be identified by reviewing publicly available systems engineering documents and, where possible, from interviews conducted with agency personnel and consulting professionals who had been involved in the design, development, and/or implementation of each solution. At this time, it should be noted that only a subset of these documents is publicly available.

Following the completion of information-gathering, discussions will be held with system stakeholders to identify solution elements and engineering processes that could potentially be imported from other corridors, and elements that will require the development of a solution specifically tailored to the I-210 corridor. This determination will be based on the experience of the project team members in delivering solutions involving people, hardware, and software, as well as the experience of stakeholders in operating and managing the various transportation systems present within the corridor. The objective of this effort will be to define answers to the following questions:

- How are the engineering activities going to be managed?
- How are the deliverables for the project going to be delivered?
- How will the project team provide an operational system to the corridor stakeholders?

4.2. ADAPTATION OF SYSTEMS ENGINEERING PROCESS TO PROJECT NEEDS

The systems engineering process is not a rigid methodology. It is only a suggested framework derived from best practice experiences with the design, building, and deployment of complex systems. The framework, exemplified by the V diagram Figure 4-1, can therefore be adjusted to better suit the needs of a particular project.

The complexity of the solution to be developed for the I-210 corridor naturally calls for the implementation of an incremental development approach with frequent “inspect-and-adopt” steps. This has led the Project Management Team to select the Scrum development framework for the I-210 Pilot. This is a commonly used framework based on Agile software development principles.

The key impact of adopting a Scrum framework for developing the I-210 Pilot is the introduction of an iterative design process within the systems engineering framework, as illustrated in Figure 4-1. Once the requirements are agreed upon, an initial version of the system design is generated. The requirements and system design are used to guide initial system component implementations. Once these initial implementations are complete, refinement cycles utilizing updated requirements and designs based on lessons learned from previous cycles are used to complete the system.

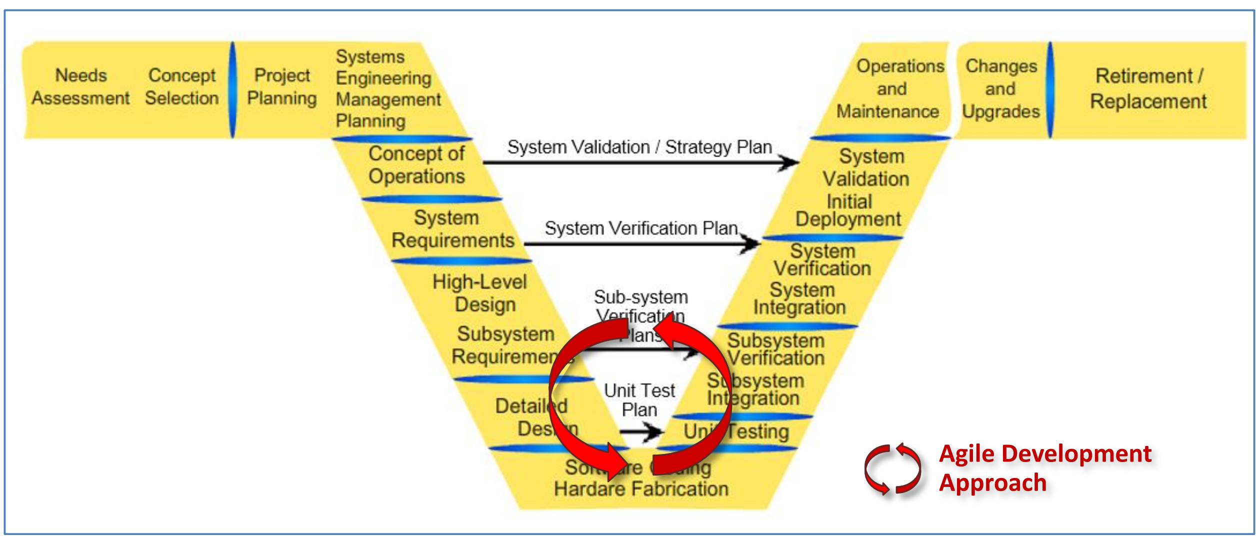

Figure 4-1 – Agile overlay on the Systems Engineering Process Diagram

Two key principles of the Scrum framework are the recognition that stakeholders can change their minds about what they want and need and that unexpected challenges cannot be easily addressed in a traditional waterfall methodology. This leads to the adoption of an empirical, iterative development approach. By accepting that a problem cannot be fully understood or defined from the start, the scrum approach focuses instead on maximizing a team's ability to deliver products quickly and to respond to emerging requirements that may not have been known at the beginning of the process.

For the I-210 Pilot, project development activities will proceed sequentially until the completion of the definition of the overall system requirements. From that point, design of the system will proceed iteratively. Iterations will begin with the design of high-level system elements and continue through the integration and verification of the developed subsystems. While iterations will be individually self-contained, they may overlap to match specific project needs.

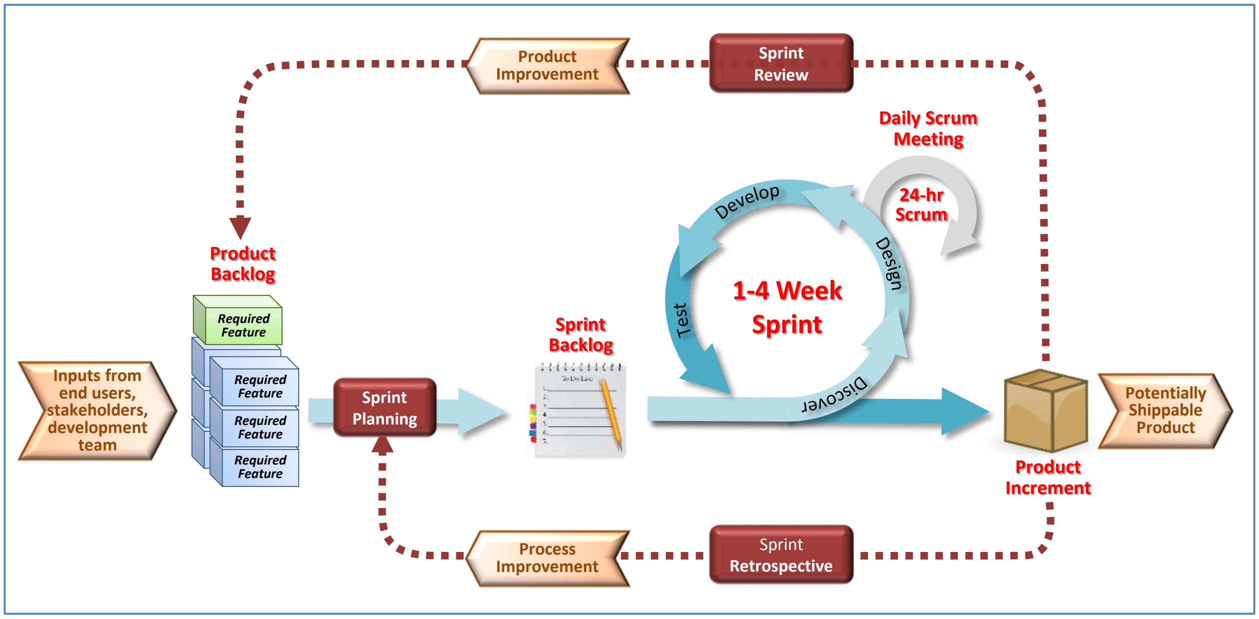

Figure 4-2 – Product Development Iteration Strategy

Figure 4-2 illustrates the general process that will be followed for each iteration. The process first involves selecting the items to be addressed in the next iteration based on needs and available resources. These items will be selected from a repository of needed product requirements, features, enhancements, and bug fixes known as the Product Backlog that the PATH development team will maintain. Following the selection of requirements to address, the Scrum team will formally develop a Sprint. This will involve assigning fixed start and end dates to the Sprint and creating a list of tasks to be executed during the Sprint, commonly referred to as the Sprint Backlog. During the Sprint, burn-down charts and other tools may be used to track progress on the Sprint deliverables and decide when specific items can be removed from the Sprint Backlog, or whether it may be beneficial to push some items to a later Sprint. Issues that remain incomplete at the scheduled end of a Sprint will be moved back into the Product Backlog for consideration in the development of subsequent Sprints. The outcome of each Sprint will be a product increment that will be subject to testing to ensure its completeness, quality, and readiness for release for use by others.

Note that this methodology is only applicable to components being developed by the PATH project team. Components that will be developed by other stakeholders or by vendors will follow the methods determined to be most appropriate for each organization, as the Project Management Team does not have the authority to define development methodologies for other organizations. While this approach may raise certain risks, the overall integration and system testing process will remain under PATH management. This should permit the final system to operate as required.

4.3. SYSTEMS ENGINEERING PROCESSES

Most of the systems engineering documents identified in Table 3-1 will be produced by a designated member of the project team having relevant experience in the subject matter. This will likely be a PATH member. Where relevant, input from project stakeholders will be sought during the development process. All deliverables are further expected to be reviewed by Caltrans and, where relevant, other stakeholders, before being finalized.

This section provides additional information on the various processes that have been used to develop some of the early deliverables, such as the preliminary needs assessment and PMP, and the processes that will be used to develop the remaining deliverables. Specific processes discussed in this section include:

- Preliminary assessment of corridor needs
- Project management planning
- Risk management
- Systems engineering management planning
- Operational concept development
- Analysis, modeling, and simulation (AMS)
- Requirement analysis
- System design
- Hardware/software development and unit tests
- System integration and verification
- System validation
- System operations and maintenance
- System performance evaluation

4.3.1. PRELIMINARY CORRIDOR NEEDS ASSESSMENT

A preliminary needs assessment for the I-210 corridor was developed by PATH in the early stages of the project, with input from Caltrans and local stakeholders. This preliminary assessment provided a general description of the corridor, a characterization of its jurisdictional environment, an inventory of existing transportation systems and traffic management assets, a general assessment of how the corridor was currently operating, and a summary of desired operational improvements. The information required for conducting this assessment was derived from inventory data supplied by the various agencies operating systems within the I-210 corridor and discussion with various staff members. Previous corridor studies, such as the I-210 Corridor System Management Plan that was released in 2010, and various transportation plans developed by regional or local entities were also consulted. All the collected information was then compiled by PATH to produce a preliminary assessment of needed operational improvements. This was subsequently used to support early project scoping discussions.

4.3.2. PROJECT MANAGEMENT PLANNING

The PMP typically lays out the Work Breakdown Structure, the schedule, and the anticipated organizational structure for the pilot. The PMP is normally viewed as a living document meant to be amended as a project progresses. Information regarding the tasks to be executed, completion dates, and organizational structure are thus expected be periodically modified based on need. This update process is actually essential to ensure that one takes advantage of serendipitous moments, such as unexpected changes in funding or available resources, or the addition of new activities to address previously unknown issues.

To define a realistic Work Breakdown Structure, PATH team members used a decomposition approach. A set of high-level tasks to be executed were first identified based on the sequence of activities defined within the systems engineering methodology. Once these high-level tasks were determined, discussions with Caltrans and various stakeholders then made it possible to assess the potential complexity of each task, its needed resources, and its anticipated outcomes. Using this information, a preliminary set of subtasks providing a logical progression through system design, building, development, and implementation was then defined, again with the understanding that this breakdown structure could be adjusted later if needed to better reflect the project's reality.

When developing the PMP, several educated guesses were taken regarding what the final mix of desired system features might be, what funds might be available to carry out the project's activities, and what development and deployment durations would be acceptable to the project's stakeholders. Making such choices was necessary due to the uncertainties created by the projected multi-year development period. While early project activities could be defined very clearly, the picture often became blurry when addressing activities expected to occur much later, particularly if these activities also depend on the outcomes of earlier tasks. This was the case for several elements of the plan. For instance, when the plan was being developed, there were uncertainties about whether funding would be available to address all the desired ITS improvements. The development of the plan thus went forward assuming that this issue would eventually be resolved. While it could be argued that this was an inadequate decision, assuming that funding would not be available would have likely resulted in the project not getting past the planning stage. The need to find additional funds to cover some system elements was a management risk that the project team felt had a reasonable possibility of being resolved.

4.3.3. RISK MANAGEMENT

The Risk Management Plan defines the general approach that will be used to manage identified risks. This plan is defined in the PMP and is structured around the following four sequential steps:

- **Risk Identification** – Identification of the risks that may potentially affect the project and documentation of the characteristics.
- **Risk Analysis** – Assessment of the potential effects on project activities of each identified risk based on qualitative and quantitative evaluations, and prioritization of risks based on anticipated effects.
- **Response Planning** – Development of options and actions to manage identified risks and to reduce threats to project objectives.
- **Risk Monitoring and Control** – Processes to implement risk response plans, track risks, monitor residual risks, identify new risks, and evaluate risk process effectiveness.

The challenge of risk management lies in determining how to identify potential risks, how to assess their likelihood of occurrence, how to determine their potential consequences on project activities, how to determine if a risk is occurring, and how to mitigate a risk that has been triggered.

Throughout the project, all team members will be instructed to inform the management team of all perceived potential risks to the project. These risks will then be compiled in an Excel-based registry with the following information:

- Project stage to which the risk relates
- Category of risk, such as funding, resources, project scoping, system requirements, etc.
- Description of risk
- Probability of occurrence ("low," "medium," "high," or "very high")
- Level of impact on project if it occurs ("low," "medium," "high," or "very high")
- Person responsible for addressing risk mitigation if triggered
- Preliminary mitigation strategy

All identified risks will further be monitored to determine whether they have occurred or not. This will be done through periodic reviews of project activities and available resources. If a risk is triggered, a specific person will then be tasked with addressing its resolution. Depending on need, the risk registry may then be edited to provide the additional information for the risks that have been triggered:

- Status of risk (monitoring, triggered, mediated, closed, etc.)
- Trigger date
- Resolution date
- Mitigation actions taken

4.3.4. PLANNING OF SYSTEMS ENGINEERING PROCESS

As previously indicated, the development of the proposed I-210 Pilot system is to generally follow the systems engineering process exemplified by the "V Diagram" of Figure 1-1, with the adaptations discussed in Section 4.2. To define the specific activities needed to transform an initial vision into an operational system, guidance was first sought from the *Systems Engineering Guidebook for ITS, Version 3.0* that had been developed by the Federal Highway Administration and Caltrans. Several planning documents that were produced by other transportation projects were also consulted to get a clear idea of what was expected from each of the recommended systems engineering documents. Once a clear understanding was achieved, the PATH project manager and PATH systems engineering manager used their experience, as well as input from other team members, to determine the sequences of activities and specific processes to be used to support the successful delivery of the envisioned system. The outcomes of this planning effort directly led to the development of the various elements described in this document.

4.3.5. DEVELOPMENT OF OPERATIONAL CONCEPT

The I-210 Pilot Concept of Operations identifies the user needs, cross-jurisdictional travel management strategies, and operational scenarios being considered to improve overall corridor operations during significant incidents and events. Contrary to a traditional systems engineering process, where a concept of operations is typically developed following the writing of a SEMP, some elements of the I-210 ConOps were initially developed prior to the development of the project's PMP and SEMP, during the concept exploration phase, to provide support to early discussions with potential stakeholders. These early concept elements were based on preliminary corridor operational analyses, engineering judgment, and elements promoted in various ICM concepts that have recently been developed for other corridors. They were then later refined based on inputs from project stakeholders.

To facilitate discussions among stakeholders during the development of the ConOps, the following three workshops were organized:

- **Workshop 1 – Roadway Operator User Needs** – Workshop to collect information about desired user needs and system features from roadway operators.
- **Workshop 2 – Transit Operator User Needs** – Workshop to collect information about desired user needs and system features from transit agencies interested in participating in I-210 Pilot demonstration.
- **Workshop 3 – ConOps Walkthrough** – Review key elements of the ConOps prior to finalizing it.

To help get agreement from all parties on the vision outlined in the developed ConOps, the following three-step process was implemented for reviewing and refining the document:

- **Step 1** – Review of proposed preliminary concept by PATH staff members.
- **Step 2** – Review and refinement of proposed preliminary concept by Caltrans and Metro.
- **Step 3** – Review and refinement of proposed concept by all corridor stakeholders.

4.3.6. ANALYSIS, MODELING, AND SIMULATION

Analysis, modeling, and simulation (AMS) is an evaluation process used to understand traffic operations along a corridor, identify key transportation challenges, and explore potential management strategies to improve corridor operational performance. This process includes three major types of activities:

- **Analysis** – Collection, processing, and analysis of data about corridor operations.
- **Modeling** – Development and calibration of models capturing existing traffic and operational conditions within the corridor.
- **Simulation** – Utilization of the developed models to conduct simulation evaluations of corridor operations under various scenarios.

AMS activities will be conducted in parallel to other project activities. As illustrated in Figure 4-3, the AMS process is expected to extend across several phases of the systems engineering diagram. AMS activities started in the concept exploration phase of the project and will extend, in various forms, through the system design, deployment, and evaluation phases.

AMS activities are a crucial part of the systems engineering methodology, as they help identify operational issues, provide quantitative measures of the corridor's operational performance, and ensure that solutions are chosen correctly. Within the context of the project, AMS activities will help:

- Develop a better understanding of traffic operations along the corridor
- Identify key transportation challenges affecting corridor operations
- Explore the effectiveness of potential ICM strategies at addressing identified operational issues
- Select the most promising strategies for implementation along the corridor
- Evaluate the effectiveness of developed traffic management algorithms

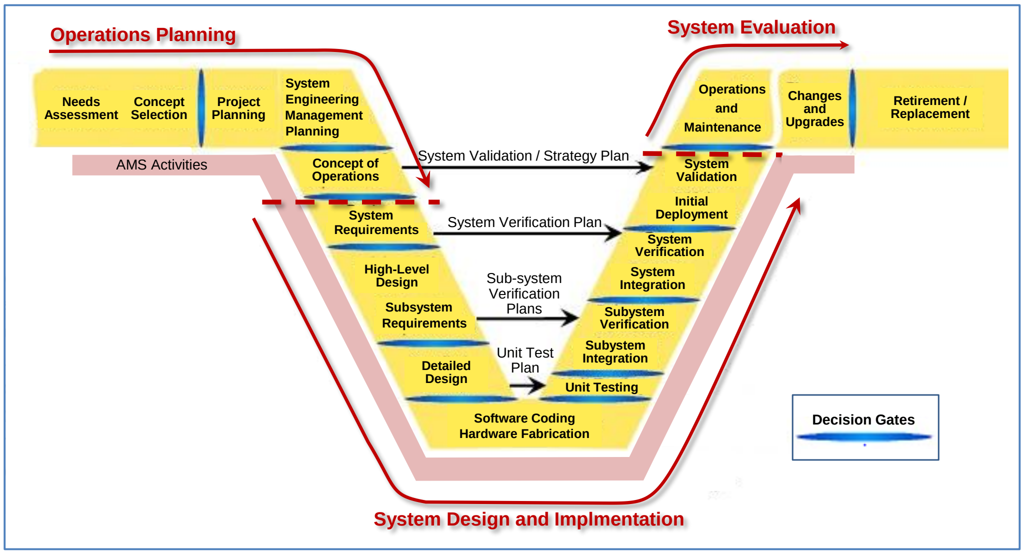

Figure 4-3 – AMS Activities within the Systems Engineering Process

4.3.7. REQUIREMENTS ANALYSIS

Following the completion of the Concept of Operations and its approval by all corridor stakeholders, a system requirements analysis will be performed. This analysis will determine the functionality and operational characteristics of system components in quantitative, measurable terms; the environments in which those components should operate; required human/system interfaces; and constraints that will affect design solutions. Once completed, the requirements will guide the design of the proposed system in later steps of the systems engineering process.

Development of the system requirements will occur in two phases. The first phase will focus on decomposing the identified user needs into high-level requirements, i.e., requirements defining how the proposed system should operate in general. Examples of elements to be considered during this high-level analysis include:

- Input data required for system operations
- Information to display to system users
- Evaluation of corridor performance
- Development of response plans
- Output commands to control devices
- Dissemination of traveler information
- System performance measurement

Development of these high-level requirements will start from the user needs and high-level operational needs identified in the ConOps. From these elements, a preliminary list of high-level requirements first will be developed by the PATH development team based on its understanding of what the stakeholders expect the system to do, known technological and operational constraints, and a preliminary vision of what the system architecture should look like. Once sufficiently developed, these preliminary requirements will then be presented for discussion to the stakeholders and adjusted until concordance is obtained. This process is adopted to mitigate resource constraints from stakeholder agencies that may not have the staffing levels to dedicate large amounts of time to the development of requirements.

Presenting these agencies with partially developed requirements will reduce the time needed to discuss obvious elements and allow the discussions to move more quickly to the more critical requirements.

After establishing the general system requirements, specific subsystem requirements will be developed by conducting a functional analysis of each proposed system component. A key aspect of this analysis will be to ensure that no conflict exists between the system and subsystem-related requirements. Examples of system elements that may have their requirements defined in more detail here include:

- Interfaces among system components
- Interfaces with external systems
- Input data processing module
- Corridor evaluation module
- Decision support system
- Output data processing module
- System access and security
- System configuration

While PATH is tasked with developing early requirements, the final systems and subsystems requirements will be developed in conjunction with all relevant corridor stakeholders. To ensure that the high-level requirements are adequately captured, multiple "requirements walkthroughs" may be held, as needed, to enable corridor stakeholders to review and discuss in detail the developed requirements, propose changes to the requirements, and reach concurrence on them. Based on need, working groups, scenario studies, simulation analyses, prototyping, and trade-off analyses may also be used to facilitate the review and development of high-level requirements with corridor stakeholders.

While some stakeholder involvement is expected for the development of subsystem requirements, it is likely to take a more selective form at this level. For instance, not all stakeholders would be required to review and approve the development of requirements defining how the corridor evaluation module is to operate. In this case, the review would be done almost exclusively by the team responsible for developing the module. However, the development of requirements for interfaces with external systems or systems connected to the ICM system will necessitate the involvement of agencies operating these systems. Similarly, the development of requirements for system configuration will likely require input from all corridor stakeholders.

A key element in the development of requirements will be traceability to user needs. Each requirement will be associated with one or more user needs. Another key element will be clarity. Each requirement will be written in such a way that it is understandable, unambiguous, concise, and comprehensive. A numbering scheme that clearly identifies to which areas of the system a particular requirement is attached will be used.

4.3.8. SYSTEM DESIGN

System design will translate the established system and subsystem requirements into hardware and software design elements. This process will begin with a review of the high-level requirements, subsystem requirements, preliminary architectural vision, and the various data inputs and outputs for the system and its individual subsystems. From these elements detailed data definitions, data flows, and data relationships will be defined and documented.

Additionally, the design team will conduct a functional decomposition of the requirements, defining and assigning specific functions required to address each requirement to its specific subsystem(s). From this, an initial separation of concerns will be developed for the system and each subsystem. Workflows and high-level use cases or user stories defined by the requirements will be reviewed and translated into system process flows, behaviors, and states.

Key design drivers will be identified from this effort. These will be issues expected to have the greatest impact on key performance indicators or to present specific constraints on the system architecture or a higher level of risk to the development and deployment of the system. Examples may include specific system performance needs, limitations of external interfaces, development or acquisition costs, operating and maintenance costs, flexibility required by specific project elements or identified project risks, feature prioritization, project schedule limitations, or security. The design team will identify and document specific trade-offs required by this analysis and the expected impacts on project cost and risk.

With these key design drivers, the team will develop a list of design elements, specific strategies, and system-level design patterns to address the system and subsystem requirements and design drivers. From this an overall system architecture, including the high-level design elements, data flows, data entity relationship diagrams for each data store, system and subsystem components and their functions, and primary system interfaces (external and internal), will be produced.

As indicated in Section 4.2, system design will occur in an iterative process. Iterations will begin with the design of high-level system elements and continue through the integration and verification of the developed subsystems. Each iteration will add new elements to the system design until all system requirements are adequately addressed. It is anticipated that the first iteration will address general design elements, while subsequent iterations will gradually add design elements pertaining to specific system components.

While system design will be conducted under PATH leadership, not all design activities will necessarily be conducted by PATH project members. Various entities will be involved in the design activities. For example, since PATH is expected to develop the decision support system, PATH is expected to design this component. However, the design of interfaces with systems operated by Caltrans or local jurisdictions will be conducted by staff from each agency or by consulting firms hired by these agencies to develop these interfaces. Whether the design of a specific component will be conducted by one entity or another, a significant amount of collaboration is expected to occur among project stakeholders to ensure that design decisions move the project toward a common goal.

An important design decision will be to determine whether individual system components are to be developed by the project team or procured from vendors. Whether to develop or procure a specific system component will be based on project needs, availability of suitable commercial off-the-shelf components, a comparative assessment of the benefits that may be achieved by using available commercial products, timing and budget constraints, and the processes outlined in the Procurement Management Plan defined within the PMP.

To support design activities, PATH will develop and use a comprehensive requirements traceability matrix. This matrix will be used to check if the project requirements are met and to help produce test plans and test cases later in the project. Depending on needs, this matrix may also be used to support the development of requests for proposal and software requirement specifications for work that may be contracted out. In addition to the traceability matrix, trade-off studies, cost/benefit analyses, and risk mitigation alternative analyses may also be conducted by the project team to help design decisions.

System design activities will further be supported by a number of design reviews. Due to the planned iterative nature of the design process, the exact number and nature of the design reviews will be determined at the beginning of the system design stage. However, it is currently projected that the design reviews will include at a minimum the following activities:

- **Preliminary overall system design review** – General review of the defined system architecture and relationship between the various system components prior to initiating the development of specific components.
- **Subsystem design reviews** – Review activities focusing on the proposed design for each major system component. At least one review is to be conducted for each system component at the end of the design stage of the component. However, depending on the need, multiple reviews may be conducted for some components.
- **Final system review** – Review of all system design elements at the end of the design process. A significant portion of this review is expected to focus on changes made to the general system design architecture since the initial review in order to adjust it to modifications required during the design of specific system components.

Approval of the proposed component designs will be conducted by relevant stakeholders. Depending on the case, this may involve all project stakeholders or only specific stakeholders. Approval by all corridor stakeholders will be required for system components meant to be used by all, while approval by specific stakeholders will be required for components implementing agency-specific functionalities, such as interfaces with particular traffic monitoring or control systems

During the design process, PATH will monitor project activities to identify possible technical problems with proposed equipment, commercial off-the-shelf hardware or software, and application software being developed. If it is assessed that technical trade-offs are required, approval from all affected stakeholders will then be requested before incorporating the change into the system design.

4.3.9. HARDWARE/SOFTWARE DEVELOPMENT AND UNIT TESTS

The building and/or procurement of individual system components will be initiated as soon as final design documents for the components have been approved by relevant corridor stakeholders. Because of the modular nature of the proposed ICM system and the proposed iterative design process, the building and/or procurement of some components may be initiated before the design for other components has been completed.

While the development of tasks to build each system component will be the responsibility of the team that will be assigned to its development, the PATH management team will retain oversight on the progress of the development effort. This oversight will allow the management team to track progress against schedule and to bring up for discussion with the relevant corridor stakeholders any major issue that may unexpectedly affect project activities.

4.3.10. SYSTEM INTEGRATION AND DEPLOYMENT

The planning of how developed system components are to be integrated into a coherent operational system and deployed along the I-210 corridor started with the development of this SEMP. The resulting general framework for system integration and deployment is described in Section 7. This early framework will be refined into a detailed plan during the design process, when a clearer picture of what needs to be built and integrated will have been obtained. At that stage, the system development team will be tasked with developing, in collaboration with relevant stakeholders and the Project Management Team, the sequence by which specific system components should be integrated, and identifying who will be responsible for the integration of each. Details of the tests to be conducted to verify that specific components have been successfully integrated will also be developed and documented.

4.3.11. SYSTEM VERIFICATION

System verification refers to activities that test whether developed systems or subsystems meet their requirements and match their planned design. The planning of verification activities started with the development of this SEMP, with the development of the general framework for system verification defined in Section 8. Similar to the system integration activities, this framework will be refined into a detailed verification plan during the design process, when a clearer picture of what needs to be built and integrated will be available. At this stage, the system design team will define, in collaboration with system stakeholders, how the testing is to be accomplished to verify each of the major system components and subsystems, as well as the overall system. This means identifying who will conduct the various tests, where the tests will be done, the hardware and software to be used, the specific test cases to be performed, and what documents to produce to document the test results. Identification of these elements will show that the requirements can be verified as written. Specific test procedures detailing the steps to be taken to verify each requirement and design element will be defined later, at the end of the design effort.

Verification of system elements will be performed iteratively. Verification will start with the integration activities at the component level and then will progress through the subsystem development to the verification of the entire system. Final verification for system acceptance will be done when the deployed system is ready for operation.

4.3.12. SYSTEM VALIDATION

System validation refers to activities that will be conducted to ensure that the deployed ICM system meets its intended purpose. This will involve assessing whether the deployed system meets each of the user needs defined in the Concept of Operations. This will require observing system operations under various conditions, potentially conducting controlled system demonstrations, gathering information from system operators on how they use and perceive the system, and collecting information on how disseminated information is accessed by corridor travelers.

While a preliminary validation strategy is provided in Section 9 of this SEMP, the detailed procedures that will be used to validate the deployed system will be jointly developed by PATH and system stakeholders when system deployment is nearing completion. Actual system validation will occur only after the deployed system has been verified to meet the established requirements and is accepted by its users.

4.3.13. SYSTEM OPERATIONS AND MAINTENANCE

The planning of how the proposed ICM system should be operated and maintained started with the development of the Concept of Operations. This document identifies various elements associated with the operational and support environment. More detailed descriptions of the system operations and maintenance activities will be developed as the project team progresses through the system design and implementation. This will include the gradual development of training material and an operation manual, as well as any other specific material that may be deemed relevant by system operators, such as a systems administrator manual or system maintenance manual.

4.3.14. SYSTEM PERFORMANCE EVALUATION

System evaluation refers to activities that will be conducted to measure the impacts of the deployed system on corridor operations. This is an additional systems engineering task associated with the pilot nature of the project. After the proposed ICM system has been delivered by the project team, Caltrans will need to determine whether the benefits provided by the system justify deploying it to other corridors, either in its current or in an altered form. This decision will largely be based on the magnitude of the operational benefits obtained from the system.

System evaluation activities will focus on comparing corridor operations before and after implementation of the system. This includes gathering information on how the system has changed, on how system operators manage the various transportation networks within the I-210 corridor, and on how the system has changed the ways in which travelers make travel decisions for trips crossing the corridor.

System evaluation will occur once the system has been deployed, accepted, and validated and is fully operational. While a preliminary evaluation framework is provided in Section 10 of this SEMP, the specific processes that will be used for the evaluations will be developed at a later point in the project by the project development team in collaboration with system stakeholders.

4.4. DOCUMENT SHARING

As indicated in the PMP, various applications will be used to facilitate the sharing of information and documents produced as part of the project. The primary application will be the ICM Documentation website (http://ccdocs.berkeley.edu/). Documents posted on this website will primarily consist of final documents or near-final draft documents released for review by stakeholders. The Box.com application sponsored by the University of California, Berkeley, will also be used to store and share work-in-progress documents, as well as various technical documents collected by the project team, such as signal timing sheets, detector layout documents, reports on traffic studies, etc.

4.5. INTEGRATION WITH REGIONAL ITS ARCHITECTURE

The Los Angeles County Regional ITS Architecture was developed in the early 2000s to promote the integration of all regional investments in ITS technology and maximize the benefits that can be obtained from them. For Los Angeles County, this architecture primarily defines the communication capabilities of the RIITS and IEN networks.

When developing ICM system functionalities, compatibility will be sought wherever possible with the IEN and RIITS communication requirements outlined in the Los Angeles County Regional ITS Architecture. However, a potential problem in doing so is associated with the age of the architecture. Since its development in 2004, the Los Angeles County Regional ITS Architecture has not been updated. The existing architecture may thus not address many of the proposed functionalities expected to be part of the I-210 Pilot ICM system.

Given this context, project activities may need to establish new architecture standards for the region or implement standards already defined in the National ITS Architecture. If such standards are to be developed or implemented, elements of the Southern California Regional ITS Architecture and the National ITS Architecture will be used as reference. The Southern California Regional ITS Architecture was developed by the Southern California Association of Governments in 2005, and later updated in 2011. The current version of the National ITS Architecture was released in January 2012 and is known as Version 7.0. Use of these two related architectures as reference will be crucial, as it is expected that any new standard developed by the project will ultimately be adopted and incorporated into the Los Angeles Regional ITS Architecture when it is next updated.

Table 4-1 identifies the various market packages defined in the Southern California and National ITS Architectures that will be considered when designing the proposed ICM system.

Table 4-1 – Relevant ITS Market Packages

User Service	Market Package	Southern California Regional ITS Architecture (2011)	National ITS Architecture (2012)
Archived Data Management	AD1 – Data Mart		●
	AD2 – ITS Data Warehouse	●	●
	AD3 – ITS Virtual Data Warehouse	●	●
Traveler Information	ATIS01 – Broadcast Traveler Information	●	●
	ATIS02 – Interactive Traveler Information	●	●
	ATIS04 – Dynamic Route Guidance		●
	ATIS05 – ISP-Based Trip Planning and Route Guidance		●
	ATIS06 – Transportation Operations Data Sharing		●
	ATIS07 – Travel Services Information and Reservation		●
	ATIS09 – In-Vehicle Signing		●
Traffic Management	ATMS01 – Network Surveillance		●
	ATMS02 – Probe Surveillance		●
	ATMS03 – Traffic Signal Control		●
	ATMS04 – Traffic Metering		●
	ATMS05 – HOV Lane Management		●
	ATMS06 – Traffic Information Dissemination	●	●
	ATMS07 – Regional Traffic Management	●	●
	ATMS08 – Traffic Incident Management Systems		●
	ATMS09 – Decision Support & Demand Management		●
	ATMS16 – Parking Facility Management		●
	ATMS17 – Regional Parking Management		●
	ATMS24 – Dynamic Roadway Warning		●

Table 4-1 – Relevant ITS Market Packages

User Service	Market Package	Southern California Regional ITS Architecture (2011)	National ITS Architecture (2012)
Public Transportation	APTS01 – Transit Vehicle Tracking		●
	APTS02 – Transit Fixed Route Operations	●	●
	APTS03 – Demand Response Transit Operations		●
	APTS06 – Transit Fleet Management	●	●
	APTS07 – Multi-Modal Coordination		●
	APTS08 – Transit Traveler Information	●	●
	APTS09 – Transit Signal Priority		●
	APTS10 – Transit Passenger Counting		●
	APTS11 – Multi-modal Connection Protection		●
Emergency Management	EM02 – Emergency Routing		●
	EM04 – Roadway Service Patrols		●

4.6. APPLICABLE ITS STANDARDS

Table 4-2 lists ITS standards that should be considered when developing system functionalities. The exact set of standards to be considered will depend on the specific functionalities being developed for the proposed ICM system and standards adopted within the Regional ITS Architecture.

Table 4-2 – Potential Relevant Standards

Development Organization	Standard Title	Code
AASHTO / ITE / NEMA	Center-to-Center (C2C) Standards Group	NTCIP 1102-1104, 2104, 2202, 2303-2306, 2501-2502
	Center-to-Field (C2F) Standards Group	NTCIP 1101-1103, 2101-2104, 2201-2202, 2301-2303
	Communication between TCM and legacy field devices	NTCIP 1102, 1103, 2101-2103, 2301, 2302, TS 2-2013
	Global Object Definitions	NTCIP 1201
	Object Definitions for Actuated Traffic Signal Controller Units	NTCIP 1202
	Object Definitions for Dynamic Message Signs (DMS)	NTCIP 1203
	Environmental Sensor Station Interface Standard	NTCIP 1204
	Object Definitions for Closed Circuit Television (CCTV) Camera Control	NTCIP 1205
	Object Definitions for Data Collection and Monitoring Devices	NTCIP 1206
	Object Definitions for Ramp Meter Control Units	NTCIP 1207
	Object Definitions for Closed Circuit Television (CCTV) Switching	NTCIP 1208
	Data Element Definitions for Transportation Sensor Systems	NTCIP 1209
	Object Definitions for Signal System Masters	NTCIP 1210
	Objects for Signal Control and Prioritization	NTCIP 1211
	Objects for Network Camera Operation	NTCIP 1212
	Object Definitions for Electrical and Lighting Management Systems	NTCIP 1213
	Object Definitions for Conflict Monitor Units	NTCIP 1214
	Weather Report Message Set for ESS	NTCIP 1301
	Transit Communications Interface Profiles	NTCIP 1400
	TCIP Common Public Transportation Objects	NTCIP 1401
	TCIP Incident Management Objects	NTCIP 1402

Table 4-2 – Potential Relevant Standards (cont'd)

Development Organization	Standard Title	Code
AASHTO / ITE/ NEMA	TCIP Passenger Information Objects	NTCIP 1403
	TCIP Scheduling/Runcutting Objects	NTCIP 1404
	TCIP Spatial Representation Objects	NTCIP 1405
	TCIP On-Board Objects	NTCIP 1406
	TCIP Control Center Objects	NTCIP 1407
	TCIP Fare Collection Business Area Objects	NTCIP 1408
	Communications protocols	NTCIP 2001, 2101-2104, 2201-2203
	Intelligent Transportation System (ITS) Standard Specification for Roadside Cabinets	ITS Cabinet v01.02.15
	Advanced Transportation Controller (ATC) Standard	ATC Standard v5.2b
	Advanced Transportation Controller (ATC) Model 2070 Standard	ATC 2070 v03.03
	Advanced Transportation Controller (ATC) Application Programming Interface (API) Standard	ATC API v02.06a
APTA	Transit Communications Interface Profiles (TCIP)	TCIP-S-001 3.0.4
ASTM	Dedicated Short Range Communication at 915 MHz Standards Group	E2158-01
	5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control and Physical Layer Specifications	E2213-03
	Standard Guide for Archiving and Retrieving ITS-Generated Data	E2259-03
	Standard Practice for Metadata to Support Archived Data Management Systems	E2468-05
	Standard Specifications for Archiving ITS-Generated Traffic Monitoring Data	E2665-08
Caltrans	Assembly Bill 3418	AB3418E
IEEE	Standards for Incident Management Message Sets	1512, 1512.1, 1512.2, 1512.3, P1512.4
	Standard for Message Sets for Vehicle/Roadside Communications	1455
	Standard for the Interface Between the Rail Subsystem and the Highway Subsystem at a Highway Rail Intersection	1570
	Wireless Access in Vehicular Environments (WAVE)	802.11p, 1609
ITE	Traffic Management Data Dictionary (TMDD) Standard v3.03 for the Center to Center Communications	TMDD ver. 3.3
SAE	On-Board Land Vehicle Mayday Reporting Interface	J2313
	Dedicated Short Range Communications (DSRC) Message Set Dictionary	J2735
	Location Referencing Message Specification	J2266
	Message Set for Advanced Traveler Information System (ATIS)	J2354
	Standard for ATIS Message Sets Delivered Over Reduced Bandwidth Media	J2369
	Advanced Traveler Information Systems (ATIS) Family of Standards for Coding of Messages and Phrase Lists	J2540
ANSI	Commercial Vehicle Safety and Credentials Information Exchange	TS285
	Commercial Vehicle Credentials	TS286

4.7. SYSTEMS ENGINEERING APPLICATION CHALLENGES

The following are unique challenges in the application of the systems engineering process to the design, development, and implementation of the I-210 Pilot ICM system that the project team must consider:

- System stakeholders are generally not experienced with the systems engineering process.
- Caltrans and other system stakeholders have limited experience, if any, in integrated corridor management.
- System stakeholders may need to be educated on the value of ICM.
- Funding for the ITS elements needed to perform corridor management has not yet been identified or secured.

- Certain likely deliverables are part of a research effort whose timing and deliverables are difficult to quantify. This is notably the case for the development of a suitable Decision Support System having the ability to project corridor operations over time.
- The project team must design a flexible system architecture that supports continuous modifications, expansions, scaling, testing, calibrations, and deployments.
- It is not clear who is explicitly tasked or funded to provide a number of envisioned system components.
- The proposed ICM system will be required to interface with a variety of existing systems operating in different ways, some of which are legacy systems no longer supported by their original developers.
- While PATH has delivered large projects in the past, there is always a tension between delivering known products and doing research within an academic environment.
- There is significant competition among industry for who will ultimately bring the proposed ICM solution to a production level.
- Since the I-210 ICM system is a pilot project, PATH will not be able to completely integrate the developed systems into Caltrans' production environment. This means potentially conducting some system and software validations in virtual environments.

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5. TRANSITIONING CRITICAL TECHNOLOGIES

This section describes the general processes that will be used to identify critical technologies needed for the I-210 Pilot and ensure that these technologies are effectively transitioned into the proposed ICM system. Critical technologies are defined in this project as important components of the project that cannot be purchased commercially and for which there is no clear development path. The critical nature of these components means they present a risk to project success should the project team fail to develop them. Most of the critical technologies associated with this project are linked to the need to develop new software implementing key system functions.

The following subsections discuss:

- How critical technologies will be identified
- How critical technologies will be evaluated and incorporated into the system being developed
- Who will be responsible for managing critical technologies

5.1. IDENTIFICATION OF CRITICAL TECHNOLOGIES

To identify which system elements are critical to the overall project delivery, the project team will assess each proposed system component based on its importance to achieving the project's goals and objectives. In this context, a critical technology will be defined as a system element having all of the following key attributes:

- Required for the successful delivery of the proposed I-210 Pilot ICM system
- Not available in fully developed form from commercial vendors, i.e., will require partial or full development by the project team
- Significant uncertainty regarding who should be responsible for its development
- Significant uncertainty regarding how the component should be developed

Example of system components likely to be evaluated as critical include:

- Simulation module to be used to evaluate existing and projected corridor operations
- Module implementing the corridor management rules (decision support system)
- Data collection and processing module

All identified critical components will be inventoried and documented by the Project Management Team. Where relevant, this will include adding risk elements to the Risk Registry and developing potential mitigation strategies for the identified risks according to the processes outlined in the Risk Management Plan defined in the PMP.

5.2. EVALUATION AND IMPLEMENTATION OF CRITICAL TECHNOLOGIES

To assess the critical nature of the various components of the proposed ICM system, a group of experts responsible for such assessments will first be assembled. These individuals will be drawn from the various agencies having a stake in the proposed system. If desired experts cannot be found within the stakeholder agencies, individuals from outside consulting agencies contracted to work on the project may also be recruited. A key criterion in the selection of members of this technical group will be to include individuals having sufficient knowledge of the goals and objectives of the project and sufficient technical expertise to assess the software, hardware, and operational needs of the proposed system.

Once formed, the technical group will be tasked with evaluating the development needs of all proposed system components and identifying, from a technological standpoint, which components should be considered critical to the success of the project. This will include assessing:

- Whether various system components could be developed from existing commercial off-the-shelf hardware or software
- The risk that available commercial technologies proposed for the ICM system might soon become obsolete
- Whether external systems the proposed ICM system is expected to interact with are at risk of becoming obsolete
- How many resources the project team would need to dedicate to developing specific system components to obtain a fully functional element meeting the established system requirements
- Whether a proposed technology must be fully developed before it can be used by the ICM system or whether it can be incrementally developed

It is anticipated that members of the technical stakeholder group will rely on their own expertise and judgment to conduct the majority of the evaluations. However, if required, vendor meetings, test bed demonstrations, and targeted literature reviews may also be organized to supplement their technical expertise.

The results of the technology evaluations will lead to the identification of various project risks that will be appropriately documented and added to the Risk Registry. These risks will then be managed according to the established Risk Management Plan. This will include identifying, for each new risk, a person who will be specifically responsible for monitoring that risk and developing appropriate mitigation if the risk is triggered. Appropriate documentation of the process that was used to assess and select critical technologies will also be developed, as such documentation will be critical to allow the team to effectively manage the identified risks and to provide consistency if staff turnover occurs.

After evaluating a proposed technology, members of the technical team will work with system stakeholders in collaboration with the Project Management Team to build consensus for the technology selection and answer any questions or concerns that might not have been previously considered. Following approval of a given technology, the technical team will continue to work with the vendor or software developer selected to provide the technology, to identify customizations that need to be made, assist in determining delivery impact to schedule and budget, understand how to operate the technology, and understand support and maintenance needs.

5.3. ROLES AND RESPONSIBILITIES

Table 5-1 summarizes the roles and responsibilities of project team members in identifying, evaluating, and implementing critical technologies for the I-210 Pilot.

Table 5-1 – Roles and Responsibilities for Evaluating and Implementing Critical Technologies

Project Entity	Responsibilities
Lead of Project Development Team	• Identify the critical new technologies planned for inclusion in the I-210 Pilot • Co-lead the resolution process with PATH Systems Engineer
Members of Technical Advisory Group	• Provide expertise in appropriate technical, process, or integration areas • Help explain issues and alternative solutions to the team
PATH System Engineer	• Assist in the identification and evaluation of critical technologies • Co-lead the resolution process with Lead of Project Development Team • Ensure that all identified risks are appropriately documented and inserted into the Risk Registry • Assist in monitoring the effectiveness of risk mitigation actions
Members of Project Development Team	• Participate, upon request, in the identification and evaluation of critical technologies • Participate in the risk identification process • Assist in monitoring risk action effectiveness
Project Management Team	• Participate in the identification of critical technologies, selection of technologies to pursue, and issue resolution process

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6. SYSTEM CONFIGURATION MANAGEMENT PLAN

This section of the SEMP describes the processes the project team will use to manage the configuration of the I-210 Pilot ICM system. This will typically involve recording and updating information describing the hardware, software, and external systems associated with the I-210 Pilot. While the management of such information may appear straightforward, this activity should not be underestimated, as improper configuration management could significantly affect the functionality and timely delivery of system components.

Configuration management (CM) focuses on evaluating, coordinating, approving or disapproving, and implementing changes in artifacts that are used to construct and maintain systems. In this context, an artifact may be a piece of hardware, a piece of software, a procured system, an external system interfacing with the I-210 Pilot ICM system, or a document detailing a system component.

At its heart, configuration management aims to eliminate the confusion and error brought about by the existence of different versions of specific system components. Throughout the lifecycle of the project, various versions of specific system components are expected to exist due to changes made to these components to correct errors, provide enhancements, or simply reflect the evolutionary refinement of product definition. In this context, configuration management is about keeping the inevitable changes under control. Without a well-enforced CM process, situations could arise where different team members use different versions of an artifact unintentionally, team members create versions of a specific artifact without the proper authority, or where the wrong version of an artifact is used inadvertently in the development process. Ultimately, configuration management seeks to keep a product's performance, functionality, and physical attributes consistent with its requirements, design, and operational information.

Elements presented in this section include:

- Configuration management approach
- Type of bill of materials used
- Depth of information captured in bill of materials
- Processes supporting configuration management activities
- Roles and responsibilities of Configuration Manager

6.1. CONFIGURATION MANAGEMENT APPROACH

System Configuration is often conflated with Software Configuration Management. Software Configuration Management plans typically detail how software will be stored and versioned, and how operating environments will be documented for each of those versions. However, such plans do not normally provide a bill of materials (BOM), i.e., a list of the materials, sub-assemblies, intermediate assemblies, sub-components, parts, and the quantities of each needed to create and deliver a system.

For the I-210 Pilot system, configuration identification will be managed through a bill of materials. At any given time during the life cycle of the project, the project's bill of materials will define the system components as designed, built, or ordered, depending on the case. This document will be the basis by which changes to any part of the system will be identified, documented, and tracked throughout the design, development, testing, and final delivery phases.

6.2. TYPE OF BILL OF MATERIALS USED

For the I-210 Pilot, a multi-level bill of materials will be used to describe the proposed ICM system and manage its configuration. A multi-level bill of materials, also known as an intended bill of materials, depicts parent-child relationships and shows the hierarchical structure of assemblies and their related parts and components. A conceptual example is shown in Figure 6-1. In this case, a four-level structure is illustrated. The finished product is shown at the top. The second level further shows that three subsystems make up the overall system, with one subsystem being itself comprised of four components and another having three components. As illustrated, a multi-level bill of materials is essentially a nested list whose parts or items are listed in two or more levels of detail to illustrate multiple assemblies within a product's bill of materials.

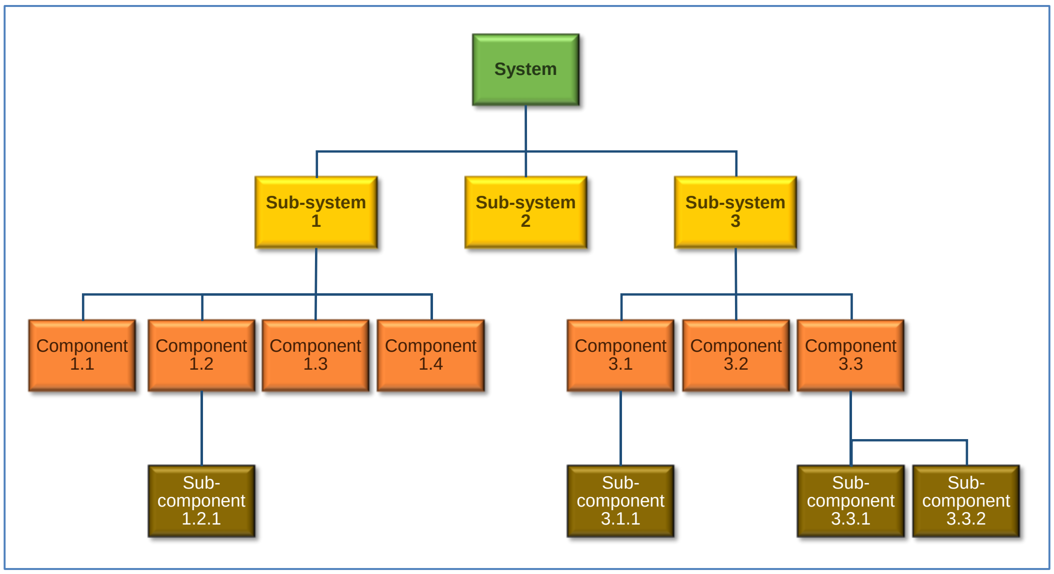

Figure 6-1 – Multi-Level Bill of Materials Concept

6.3. DEPTH OF INFORMATION CAPTURED IN BILL OF MATERIALS

The level of detail (depth) of the bill of materials will be determined by the level of knowledge needed to manage the component and, more to the point, by the level of knowledge available about each system component. While detailed knowledge is expected to be available for components developed directly by the project team, limited information may be available for some subsystems of the proposed I-210 Pilot ICM system. This may be the case for components procured from commercial vendors, connected systems designed to perform multiple functions not all directly related to the Connected Corridors program, and external systems interfacing with the I-210 Pilot but not owned or managed by Connected Corridors program personnel. Portions of the bill of materials describing procured commercial off-the-shelf or external interfacing systems may therefore contain fewer details than portions describing components developed directly by the team.

In other words, the multi-level bill of materials that will be developed for the I-210 Pilot will be decomposed to a level of detail commensurate with the project team's visibility and responsibility for the individual components. This would be acceptable from a configuration management standpoint, as the project team would not and could not be responsible for the configuration of procured commercial-off-the-shelf components or external systems interfacing with the I-210 Pilot ICM system.

6.4. CONFIGURATION MANAGEMENT PROCESSES

Configuration management will rely on the following processes to establish and manage the information contained in the bill of materials:

- **Configuration Planning** – Definition of how configuration management will be implemented.
- **Configuration Identification** - Processes for selecting, describing, and labeling configuration identifications and recording attributes of a specific configuration in the project's bill of materials.
- **Configuration Control** – Processes ensuring that only authorized configuration items are added, removed, or changed in the bill of materials.
- **Configuration Monitoring** – Monitoring and recording of the various changes that were made to a configuration artifact throughout the life cycle of the project.
- **Configuration Verification** – Periodic audits of the bill of materials and other configuration management data to ensure that the information recorded in the bill of materials is accurate and factual.

6.5. ROLES AND RESPONSIBILITIES FOR CONFIGURATION MANAGEMENT

Configuration Management will be the responsibility of a designated Configuration Manager. This manager will be a PATH member of either the Project Management Team or the Systems Engineering Management Team. In either case, it is expected that significant assistance will be provided by members of the Systems Development Team and corridor stakeholders. If desired and deemed relevant, other individuals in other project teams may also be tasked with assisting the designated Configuration Manager.

Key responsibilities for the Configuration Manager may include the following, among potential others:

- Provide support to project teams in configuring and base-lining project items.
- Prepare configuration documentation and maintain the project's bill of materials.
- Responsible for the configuration management processes.
- Maintain quality, integrity, and security of the configuration management data.
- Periodically review the bill of materials for accuracy.
- Maintain proper version controls of software deliverables.
- Analyze configuration issues and propose appropriate resolutions.

As indicated earlier, configuration management responsibilities will be limited to elements for which the project team has visibility. In addition, because of the relatively large nature of the system to be developed, configuration management will mostly pertain to the first few levels of system components.

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7. SYSTEM INTEGRATION AND DEPLOYMENT PLAN

This section of the SEMP describes the processes that will be used to integrate the various components of the proposed I-210 Pilot ICM system into a coherent operational system and to subsequently deploy the resulting system on the I-210 corridor.

The focus here is not so much on the approaches that will be used to integrate various software modules into specific subsystems but rather on how various developed systems will be integrated with existing systems and deployed along the I-210 to obtain a fully functional pilot ICM system. For instance, the focus is not on how various software modules will be put together to create a Decision Support System, but how the resulting Decision Support System will be integrated with other components of the proposed ICM system. How specific components or subsystems will be put together will be determined by the teams responsible for their respective development. The focus here is on the big picture.

Specific elements covered in this section include:

- Integration approach
- Integration frequency
- Prioritization of integration activities
- Integration granularity
- Deployment approach
- Training and education
- Roles and responsibilities of individual(s) managing system integration and deployment
- Summary of adopted integration and deployment approaches

7.1. INTEGRATION APPROACH

Systems integration is the process of bringing together component subsystems into a single coherent system and ensuring that the subsystems function together effectively. For the I-210 Pilot ICM system, this means bringing together various systems designed to collect real-time traffic data and information about traffic signal operations, retrieve historical data from databases, process collected data to generate corridor operational assessments, develop response plans to incidents, distribute recommended actions to stakeholder agencies, and communicate with targeted traffic management and traveler information systems.

To integrate the various system components, one of the following three approaches may be used:

- **Vertical Integration** – Process of integrating subsystems according to their functionality by creating functional entities, or silos. The benefit of this method is that the integration is performed quickly, and it only involves the necessary vendors. This makes this approach cheaper in the short term. However, cost-of-ownership can be substantially higher than in other methods, since the only possible way to implement new or enhanced functionalities is often implementation of another silo. In this case, reusing subsystems to create additional functionality is not possible.

- **Star Integration** - Process of integration where each system is interconnected to each of the remaining subsystems. When observed from the perspective of the subsystem that is being integrated, the connections have the shape of a star. However, the connections often look more chaotic when the overall diagram of the system is presented. The costs associated with this approach can vary significantly because of the need to build interfaces with various types of subsystems. For instance, building interfaces with subsystems exporting heterogeneous or proprietary data can lead to a substantial rise in integration costs. Time and costs needed to integrate subsystems can increase exponentially when adding additional subsystems. Despite higher potential cost, this method often seems preferable from a feature perspective due to the extreme flexibility of reusing functionalities.

- **Horizontal Integration** – Process of integration where a specialized subsystem is dedicated to communication between other subsystems. This allows cutting the number of interfaces required for each system to only one interface dedicated to sending and retrieving information from a common communication bus. This allows cutting integration costs and provides extreme flexibility in how the integration can be achieved. In this case, it is not only possible to completely replace one subsystem with another subsystem providing similar functionality, but also possible to export different interfaces. The only action required is to implement new interfaces between the communication bus and each new subsystem.

The integration methods chosen for the I-210 Pilot should be complementary with the proposed architecture of the system. The following are key relevant features of this architecture that must be considered:

- The proposed Connected Corridors system will be composed of a central Decision Support System that will receive and send information to separate software packages hosted within at least four distinct Transportation Management Centers. In addition to communicating with the DSS, these software packages will also send and receive data from various field devices used for traffic management, such as traffic detection loops, traffic signal controllers, and changeable message signs.
- The basic functionalities of the system, such as traffic signal management, will be implemented more than once in the system. For example, each of the participating roadway agencies have already chosen an approach to manage the traffic signals under their jurisdiction. In most cases, commercial off-the-shelf applications have been used to fill these requirements. This results in variations in how specific traffic signal control actions may be sent to different systems.

As can be seen from the information presented above, many systems the proposed I-210 Pilot ICM system is expected to interface with are "black box" systems, i.e., systems that were designed and implemented independently of the project. This means that the project team will have limited influence, if any, in defining the system integration methods for these products. Since there will be multiple implementations of the same functionality, it is therefore not possible to utilize a vertical integration approach.

Within Los Angeles County, two communication systems already allow agencies within the corridor to exchange information with other agencies: the Regional Integration of Intelligent Transportation Systems (RIITS) and Information Exchange Network (IEN). RIITS enables Caltrans, the Los Angeles Department of Transportation, and various transit agencies to communicate traffic detector and vehicle location data to other agencies. IEN further allows various roadway agencies to communicate traffic signal timing and traffic flow data among participating agencies. In both cases, data is already being sent to a central hub for routing. As a supported solution, it makes both political and financial sense to use either, or both, of these systems. Since the deployment of these systems is based on the concept of horizontal integration, it thus make sense to adopt the same approach for the project. While there may be some need to build special interfaces from one subsystem to another, these would be the exception.

The adoption of a horizontal integration approach brings to the table the need to reduce data conversions from one system to another. While procured commercial off-the-shelf systems may operate using a proprietary data format, a common data format should at least be used to exchange information from one system to another. This means selecting a common data format and developing interfaces to enable each system to send the data in the appropriate format or to read the data they receive. Since interfaces have already been developed for the various systems connected to the RIITS and IEN systems, it makes sense to have the proposed I-210 Pilot ICM system consider the existing data format used by the communication system that would be selected as the primary communication backbone. To facilitate data translation, it would also make sense to use any existing established data standards, such as the Traffic Management Data Dictionary (TMDD) standard produced by the Institute of Transportation Engineers.

7.2. INTEGRATION FREQUENCY

Another important question to address in addition to which integration approach will be used is how often system integration is to be performed. Options include the following three approaches:

- **Single-phase integration** – Integration occurs once, when all of the subsystems are completed. This approach is simple and cost-effective but is highly risky, as it is hard to manage integration problems effectively when all components have already been developed. This approach should only be used when other methods are impractical or when the interfaces between systems are simple and unequivocal.
- **Incremental** – Only small subsystem additions/updates to the system are allowed for each integration cycle. Incremental integration fits well with the agile development methodology but is difficult to apply to larger systems whose subsystems are provided by multiple organizations with different funding, timing, and development methodologies.
- **Multi-phase integration –** Related subsystems are added/updated to a partially complete system during each integration phase. This approach provides a balance between single phase and incremental integration. It requires more resources than the single-phase approach, but allows identifying issues earlier in the integration process.

For the integration of the I-210 Pilot ICM system, use of a multi-phase integration approach appears to be the best solution. Since some system components may be ready for implementation before others, this approach will allow integrating those components as soon as they become available. The multi-phase approach is also well suited for projects where development phases cannot be determined more than a few months in advance due to considerable flexibility in the timing of subsystem availabilities.

7.3. PRIORITIZATION OF INTEGRATION ACTIVITIES

One of the challenges of integrating the I-210 Pilot ICM system is that different agencies use commercial off-the-shelf systems developed in different ways and funded by multiple agencies following different schedules. This introduces a high degree of uncertainty in functional quality and delivery times.

To address this complexity and facilitate the integration of disparate components, the project team's first priority will be to assemble the skeleton of a working system as early in the process as possible. This means focusing first on the ability to retrieve data from various existing interfacing systems. Once this is achieved, integration activities could then successively focus on the ability to send data to the various connected systems and the ability to develop traffic management plans based on the collected information. This approach will allow the project team to gradually implement and test new functionalities and to identify early operational problems that may affect the development and integration of specific system elements.

The project team will opportunistically choose subsystems to be integrated in each integration cycle. While providing continual focus on the core data exchange functionality, new functionalities will be integrated as early as possible so that they can be tested for reliability and be evaluated by their expected users to ensure that they meet their needs.

7.4. INTEGRATION GRANULARITY

While it has already been established that a horizontal integration approach, performed in phases and prioritized by data transfer capabilities, will be followed, a final question remains: Will there be a single integration effort at each phase or multiple integration efforts occurring simultaneously?

Potential integration approaches that may be followed include:

- **Top-down approach** – Approach where the overall ability of the system to function is tested through only one integration effort.
- **Bottom-up approach** – Approach where integration is done through sub-functions without testing the overall capabilities of the system until later in the development life cycle. This approach provides for simultaneous integration efforts.
- **Mixed approach** – Combination of the top-down and bottom-up approaches, providing for simultaneous efforts but focused on continual testing of the overall system as its components become available.

For the development of the I-210 Pilot ICM system, the project team will use a mixed approach, integrating and testing system components in multiple efforts based on the availability of functions for integration. This mixed approach is thought to be best suited for the project, which calls for the development of a system with multiple functionalities and in which the availability of some functionalities is a prerequisite for the development of other functionalities.

7.5. DEPLOYMENT APPROACH

Deployment is the process of providing system functionality to developers, users, operators and maintainers for use in acceptance testing, validation testing, and day-to-day operations. This also includes training activities to enable the various system users to access and operate it.

From a schedule perspective, the tasks associated with system deployment provide the most risk to the delivery of the proposed system. These risks even exceed those associated with the use of new technology, the development of inadequate system requirements, or the possibility of inadequate funding for planned project activities. These risks are greatly associated with the potential problems that may be uncovered as a developed component is implemented and integrated with other systems. In this case, unexpected problems may not only introduce significant delays in the planned deployment of other system components but also drain available resources.

For the I-210 corridor, the least-risk approach to deployment would be to set up specific integration and testing environments where overall systems functionalities could be deployed and tested in controlled situations without affecting existing corridor operations. However, since the proposed system is expected to include existing subsystems that are currently in operation along the corridor, it will not be possible to provide integration and testing environments that are completely separate from currently operating systems. The use of separate environments will be possible for testing the functionalities of some components, but not for testing overall system operations. Thus, while the use of separate test environments will be sought wherever possible, the project team will need to consider carefully how various system functionalities may be deployed and tested in an environment in which some supporting systems are already operating live.

In essence, the Connected Corridors system is already partially deployed. For example, system components that will be tasked with monitoring traffic conditions within the corridor will rely for the most part on existing traffic monitoring systems used by roadway agencies to support their traffic signal operations. Planned upgrades to most existing subsystems are not under the control of the project development team. Similarly, the delivery of several new subsystems will not be under the direct control of the project team but under the control of the agency expected to operate the system. In this context, the project team will need to work with the schedules, funding opportunities, and priorities of the project's partners and stakeholders.

The above elements lead to the adoption of an agile deployment process, where deployment plans will be updated periodically based on the integration and deployment status of various system components. For the deployment of system components whose development the project team has full control over, an incremental deployment approach will likely be followed. Components critical for the operation of other ICM system components, such as those enabling the collection of data supporting system operations, will be deployed first. After the successful deployment of these key components, additional components will then gradually be deployed based on availability and need. For commercial off-the-shelf software or hardware procured by the project development team or other corridor stakeholders, deployment will follow the specific rules set up by the organization responsible for the procurement of the components.

The current partial deployment of the system, the lack of central control for the development of all system components, and normal uncertainties associated with product development further lead to the selection of low-risk deployment processes for the implementation of the proposed ICM system. This approach will require the project team to consider fallback plans carefully, the training needs of operational staff, and systematic deployment and testing activities. It will also require the development of methods to determine if a new deployment is having unintended side effects on existing operational systems. This approach also ensures the project team can quickly, but carefully, modify deployment plans to handle unexpected delays or to take advantage of unexpected opportunities.

7.6. TRAINING AND EDUCATION

Training and education includes all activities needed to ensure that managers, developers, users, operators, and maintenance personnel achieve and maintain the knowledge and skills necessary to operate the proposed ICM system efficiently and effectively. This is conceptually illustrated in Figure 7-1. While training and education often appear to be synonymous concepts, they are not. Training is typically undertaken to provide specific skills, such as how to access or operate the proposed ICM system. Education, however, is typically undertaken to grow an individual's knowledge and intellect. In this context, when training is focused on disseminating broad new categories of knowledge or problem-solving approaches, it can also be referred to as education.

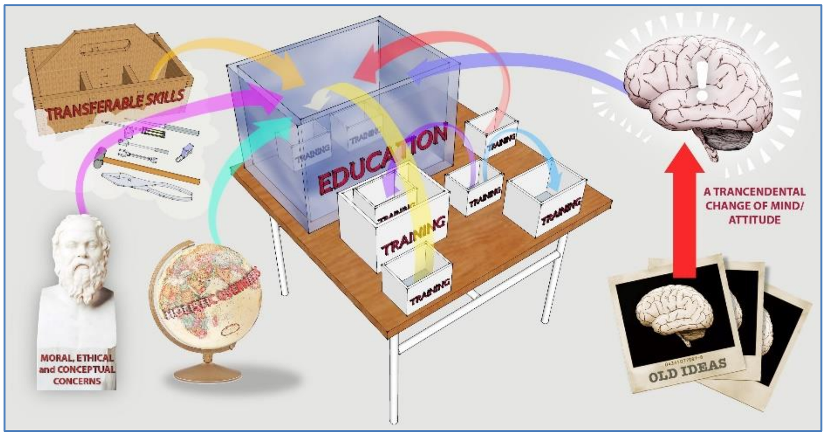

Figure 7-1 – Difference between Training and Education

During the course of the project, training and education will be performed through the following activities:

- Meetings and presentations
- Formal presentations by experts or users of similar systems
- Videos and online material
- Formal classes
- Informal work sessions
- Hands-on practice sessions

The interactions and presentations to be conducted throughout the project will generally include some training or educational component. It is anticipated that agency personnel will require significant learning to assimilate new corridor management concepts. The following is a summary of the various training and education topics that may be included in the discussions and presentations:

- **Corridor management concepts** – Actively managing traffic at the corridor level involves new management paradigms that may differ significantly from the traditional methods used to manage freeways and local road networks. In this context, broad-based introductions to corridor management concepts may need to be provided and/or reinforced.
- **Systems engineering process** – Since the systems engineering approach is new to many of the stakeholders, every step will need to be explained and discussed. Some stakeholders may even need to attend classes.

- **New job responsibilities** – The introduction of corridor management approaches will likely alter traditional job responsibilities. Once the roles and responsibilities required of personnel performing corridor management have been defined, training for these new responsibilities will need to be developed and provided.
- **Scientific training** – Certain roles will require some individuals to develop a deep understanding of the processes used to analyze data generated by traffic monitoring systems or the ICM system.
- **Tool training** – The introduction of new management tools will require certain individuals to become familiar with how to use those tools. This will require providing user manuals and training sessions.
- **Information technology training** – The system will contain computer and software components. Training in the maintenance of these systems will thus be required.

Because of the broad nature of the training and educational needs and the distributed nature of the organizations, the core stakeholders will be responsible for actively transferring to their staff the knowledge they will acquire during the execution of the project. Individual agencies will also be responsible, with the help of PATH, for defining and presenting supporting material. This is based on the concept that training and educational material presentation is most effective when it is tailored to the individuals receiving the training and takes into account their specific skill sets, experience, and interests. Development of training material will occur in the later stage of the project, when related system components have been developed and when the personnel who will be involved in the operation of the system have been identified.

The training and educational material that will be developed by project team members will focus on new functionalities directly provided by the project. This will include material showing how to use software developed by the project team, how to approach corridor management issues, etc. This will not include material describing how to operate existing systems currently in use by stakeholder agencies or commercial off-the-shelf systems that may be procured by specific agencies in support of the project. It is assumed that training for those systems will be developed and delivered by the vendors and paid for by the purchasing organizations.

In summary, because the project is tasked with demonstrating new approaches to traffic management, training and education will be a core component of its associated activities. While specific training in focused areas will be needed, the Pilot will also be measured by how successfully it achieves the broader education of stakeholders and program personnel in how to accomplish effective multi-jurisdictional corridor management.

7.7. ROLES AND RESPONSIBILITIES

The overall degree of risk and uncertainty associated with system integration and deployment activities will require careful management. These requirements will be managed by a designated System Integration Manager with support from the systems engineering team. The designated System Integration Manager will be highly involved in the development and execution of the specified integration and deployment processes. This individual will also be required to provide rapid decision-making, to perform agile allocation of resources, and to interact with relevant stakeholders in a timely manner. Based on the responsibilities listed above, the selected individual is likely to be the PATH Project Manager or another carefully selected member of the project team.

7.8. INTEGRATION AND DEPLOYMENT APPROACH SUMMARY

The following list summarizes the key elements of the approach that has been adopted for the integration of system components and the deployment of system elements in the I-210 corridor:

- Components of the proposed I-210 Pilot ICM system will be integrated into a coherent, functional system using a horizontal approach performed in phases, prioritized by data transfer capabilities, and using both top-down and bottom-up integration processes. The program managers believe that this approach to system integration will substantially reduce risk by ensuring important political and technical issues are discovered early in the process.
- Deployment of system components along the corridor will follow an incremental approach compatible with the adopted agile integration methodology. Critical system components will be deployed first, followed by phased upgrades to the deployed system. These deployments will be opportunistic and focused on overall system data transfer functionality.
- Integration and deployment activities will be supported by ongoing training and education activities aimed at providing future system operators, as well as decision-makers, with the appropriate knowledge needed to manage the I-210 corridor effectively.

8. SYSTEM VERIFICATION PLAN

Verification activities seek to ensure that a developed system performs as specified, i.e., satisfies the system requirements that were defined and approved by its stakeholders. Verification activities must be distinguished from validation activities, which focus on assessing whether a developed system meets the user needs for which it was developed.

For the I-210 Pilot, verification activities will start with tests conducted on individual system components to verify that each item operates as intended and will end with a test performed on the final, integrated system. How each of these tests will be performed will be defined later in the project, and the nature of verification activities to be conducted will depend on the specific characteristics of each system component to be developed. The current verification plan simply presents the general approach that will be used to conduct verification activities. Specific elements addressed in this plan include:

- Scope of verification activities
- Verification approach
- Traceability matrix
- Identification of test environments
- System configuration tracking

8.1. SCOPE OF VERIFICATION ACTIVITIES

All developed system components for which system requirements are defined are to be verified. While the exact list of system components to be verified will be developed during the drafting of the system requirements, it is expected that verification activities will at least cover developed software implementing the following system elements:

- Interfaces with external systems
- Data communication capabilities between agencies
- Input and output data processing routines
- Historical data storage and management
- Processes used to identify and characterize incidents and events
- Corridor evaluation module
- Processes used to develop, evaluate, and select response plans
- Processes used to implement recommended control actions
- Information display interfaces
- System health monitoring functions

Verification activities will be limited to system components that will be specifically developed as part of the project. The following elements summarize the principles that will be used to determine what components and systems will be verified as part of the project activities:

- **I-210 Pilot ICM components built by the project team** – All system components that will be directly developed by the project team will be subject to verification activities.
- **External systems not modified as part of the project** – Existing external systems that will be integrated with the I-210 Pilot ICM system but not modified as part of the project will not be subject to verification. Only the interfaces developed to communicate with these systems will be

verified to ensure that they enable appropriate communication and data exchanges with the external systems to be connected to the I-210 Pilot ICM system.

- **External systems modified as part of the project** – Existing external systems that will be integrated with the I-210 Pilot ICM system and modified to enable them to provide specific functionalities will be subject to verification. In addition to verifying the interfaces that will have been developed to enable these systems to communicate with the I-210 Pilot system, verification activities will also assess whether the desired modifications have been appropriately implemented in each external system. Examples of verifications that may be made include testing the ability of particular systems to receive and process detector data, receive commands from the ICM system, and implement specific control actions. In this case, it is expected that the entity that will be tasked with modifying each external system will be responsible for conducting all the verification activities associated with this system.

8.2. VERIFICATION APPROACH

Specific activities to be conducted to verify system components will be developed by the system development team based on the requirements for the I-210 Pilot ICM system that will have been identified and approved by the system stakeholders.

As illustrated in Figure 8-1, verifications activities will occur at three levels of system development:

- **Unit tests** – Verification of requirements associated with specific software elements developed by the project team or commercial off-the-shelf hardware or items procured by the team and integrated into the system being developed.
- **Subsystem tests** – Verification of requirements associated with system modules incorporating multiple system components.
- **System tests** – Verification of functionalities of the integrated system as a whole.

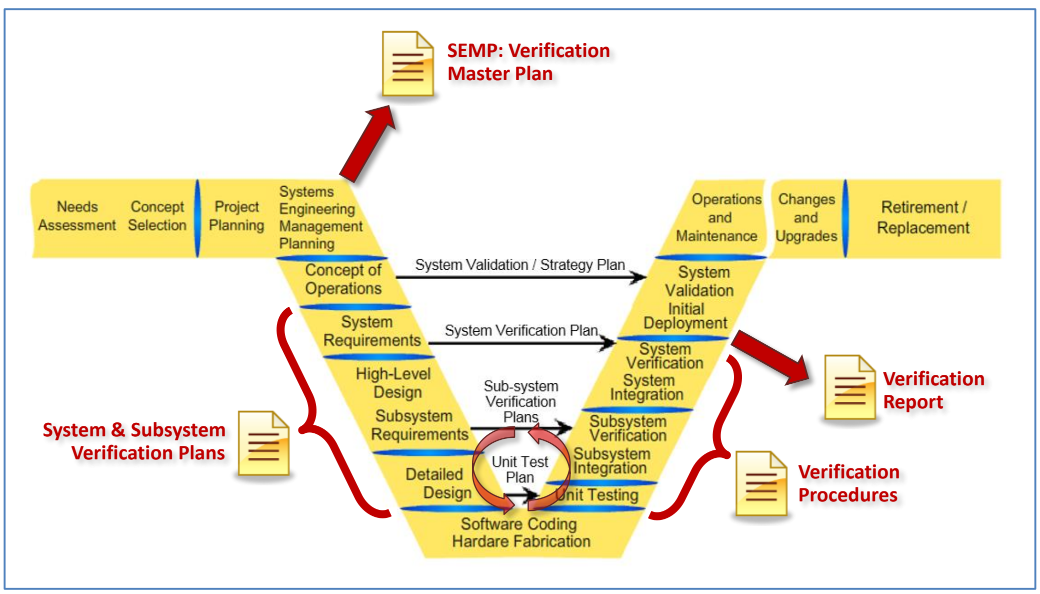

Figure 8-1 – Verification Activities

For each of the defined requirements, the system development team will identify at which level the requirement will need to be verified, an appropriate verification method, and specific procedures to follow to conduct the verification.

The following are basic techniques that will be used by the project to verify each of the requirements:

- **Test –** Direct measurement of system operations. During tests, defined inputs are typically provided and outputs are measured to verify that the requirements have been met. Use of tests is typically more prevalent during early verification, when component-level capabilities are being exercised and verified.
- **Analysis –** Verification of system requirements using logical, mathematical, and/or graphical techniques. Activities in this category include looking at developed computer code or output files, or executing specific mathematical computations. Analyses are frequently used when verification by test is not feasible or prohibitively expensive.
- **Demonstration –** Witnessing of system operations in an expected or simulated environment without the need for measurement data. For instance, demonstrations may be used to verify that an alarm or specific output is produced under certain conditions. Use of this verification technique is more prevalent in system-level verification, when the complete system is available, to demonstrate end-to-end operational capabilities.

For each requirement to be verified using tests, the requirement will be demonstrated by the execution or one of more test cases. The specific test cases to use will be defined by the system development team prior to executing the verification. Each test case will define an operational scenario that will allow one or more logically related requirements to be verified together.

As each verification is performed, all actions and system responses observed during a test or demonstration will be recorded. Results of analyses will also be documented. Unexpected responses or outcomes will then be analyzed to determine their cause and define a corrective plan. Depending on the case, corrective actions might involve repeating the test or demonstration, revising the test case or demonstration scenario, or fixing the system. Associated requirements might be changed, with approval from the system stakeholder, if the identified problem is linked to an ill-defined requirement. Any change to the test cases, the requirements, or the system made in this context will be managed through the configuration management process.

Identified problems, errors, failures, or malfunctions that do not comply with the established requirements are to be assigned to one of the following categories:

- **Severity 1** – A hardware or software problem that results in the permanent absence of one or more required features of the system.
- **Severity 2** – A hardware or software problem that causes occasional failure of, or disruption of access to, one or more required features of the system.
- **Severity 3** – A hardware or software problem that causes a required feature of the system to be incomplete, out of tolerance, incorrect, or otherwise fails to fulfill a requirement.

These categories will allow the team to prioritize the work needed to fix active system issues and to determine when specific verification activities may take place.

Several system requirements are likely to be verified several times during the development and integration process. For example, when releasing a new software item that adds new capabilities or fixes previously identified defects, it will be important not only to verify the new features or the bug fixes that were implemented but also to make sure that all previously verified requirements are still satisfied. As the verification proceeds in a bottom-up fashion, some requirements may also be verified at various levels. For instance, a requirement stating that a specific action shall be implemented by system X may be verified at the component, subsystem, and system level. In this case, the capability to define a specific action to take might first be verified at the component level. The capability of the target system to receive the recommended action might then be verified at the subsystem level, while the ability to implement the action might be verified at the system level.

8.3. REQUIREMENTS TRACEABILITY MATRIX

The development and maintenance of a requirements traceability matrix will be a key part of the verification process. An example is shown in Table 8-1. The development of this matrix will allow the project team to trace each defined requirement to a specific test, thus ensuring that no requirement is forgotten in the verification process.

Table 8-1 – Requirements Traceability Matrix Example

Requirement Identification Number	Requirement Description	Applicable System(s)	Applicable Subsystem(s)	Applicable Component(s)	Verification Method	Test Scenario	Test Case	Test Status	Notes

An initial requirements traceability matrix for the I-210 Pilot will be developed by the project development team concurrently with the development of the initial list of requirements. The resulting matrix will then be adjusted as needed as the project progresses through the design of the system and as test protocols are defined and finalized.

For each requirement, the matrix will initially identify the system(s), subsystem(s) and component(s) affected by the verification activities, the verification method, and the test scenarios and test cases to use to verify the requirement. As verification activities progress, the verification status of each requirement will then be added to the matrix and updated as needed.

8.4. IDENTIFICATION OF TEST ENVIRONMENT NEEDS

Before the execution of any verification, it will be necessary to have the proper support hardware and software set up to facilitate the execution of the verification activities. It will be the responsibility of the system development team to identify in detail the required setup environment for each verification procedure. It is anticipated that this setup will likely vary from case to case. The specific environment needed for each verification will be determined based on the specific objective of the verification, the test case being considered, and the test procedure(s) to be used.

8.5. SYSTEM CONFIGURATION TRACKING

Because of the iterative nature of verification activities, it will be important to keep strict configuration control over the system components and documentation. To ensure that the appropriate tests are conducted on the appropriate system elements, the configuration of each component and the test-case version will be verified and noted as part of the verification results.

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9. SYSTEM VALIDATION MASTER PLAN

Validation activities seek to ensure that a developed system meets the needs of its customer, i.e., satisfies the various user needs that prompted its development. Validation activities should be contrasted to verification activities, which primarily seek to check that a developed system meets the various functional requirements that were defined by system stakeholders early in the design process. As indicated in Figure 9-1, verification typically occurs throughout the design, building, integration, and deployment phases of a system, while key validation efforts occur after the system has been deployed and accepted. Verification focuses on the system requirements and ensures that the project has *built the product right,* while validation focuses on the user needs and system goals and objectives defined in the Concept of Operations and confirms that the *right product has been built*.

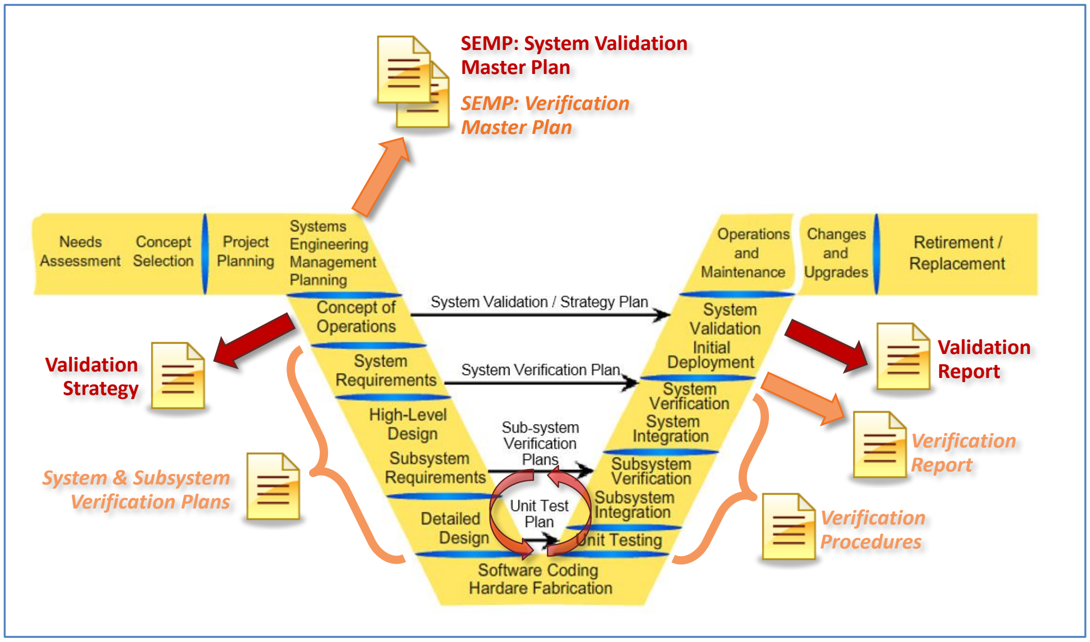

Figure 9-1 – Validation and Verification Activities

This validation master plan lays out the overall expectations for assessing how well the delivered I-210 Pilot ICM system meets the user needs at the base of its development, as well as the goals and objectives of the pilot development project. Specific elements addressed in this plan include:

- Validation approach
- Development of validation procedures
- Development of validation test cases
- Outputs of validation effort

While several of the items listed above are only succinctly described in the current plan, these elements will be developed in more detail by the project team as the project progresses.

9.1. VALIDATION APPROACH

As indicated in the introduction, the goal of the validation activities will be to demonstrate that the delivered I-210 Pilot ICM system performs as designed and intended. This means assessing the system's functionalities and performance against the user needs, goals, and objectives defined in the Concept of Operations that was collaboratively developed and approved by the corridor stakeholders.

While traditional systems engineering guidance documents indicate that system validation typically occurs after a system has been deployed and accepted by its stakeholders, validation efforts for the I-210 Pilot ICM system will start before this stage. To maximize the chances of successful system validation at the end of the project, an in-process validation process will be followed to provide system stakeholders several opportunities to review proposed or developed system elements throughout the system's development and deployment process. Such a process will also help system stakeholders develop an early understanding of the subtleties of the system and potential issues as they arise. Implementing an in-process validation will foster an environment in which system stakeholders are provided with multiple opportunities to examine what the proposed system is attempting to achieve and to engage in critical discussions regarding system functionalities. Since validation is to be performed along the way, there should be fewer surprises during the final system validation, as the delivered system will have already been designed to meet the user's expectations, and the user's expectations will have been set to match the delivered system.

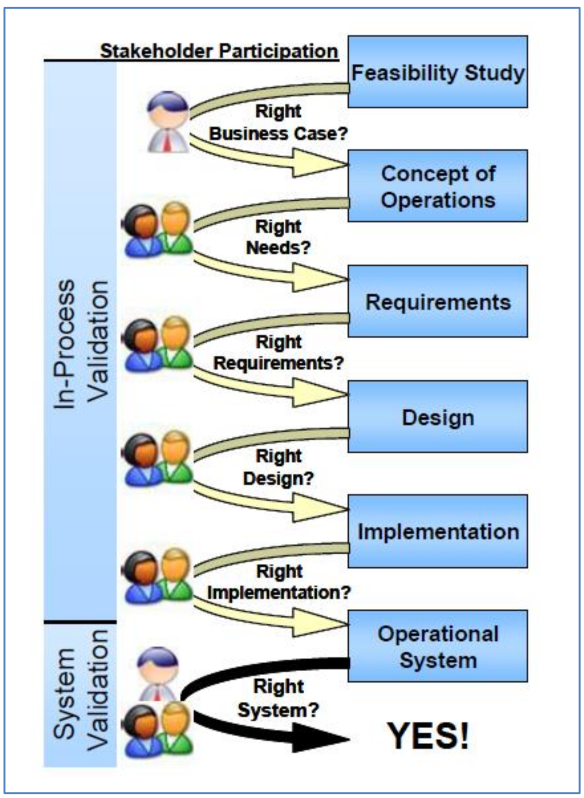

Figure 9-2 – Continuous Validation Approach

As illustrated in Figure 9-2 [3], the proposed validation process has already allowed systems stakeholders to review and validate the goals and objectives of the project, and to contribute to the identification, development, and approval of user needs that will be at the base of the validation efforts. Examples of additional expected stakeholder contributions to the validation effort throughout the project include:

- Review and approval of functional requirements for the proposed I-210 Pilot ICM system.
- Validation of proposed designs for system components and interfaces prior to initiating the building of these elements.
- Operational review of functionalities or outputs provided by individual system components.

Final system validation will occur after the I-210 Pilot ICM system has been deployed and accepted by the corridor stakeholders. At this stage, validation activities will be achieved through the following activities:

- **Observation of live system operations** – Observation of how the delivered system responds to incidents and events occurring in and around the I-210 corridor.
- **Controlled system operational demonstrations** – Demonstrations to corridor stakeholders in controlled environments of how the delivered system would respond to specific situations.
- **Operator surveys and interviews** – Assessment through interviews and/or surveys of how transportation system operators use the deployed ICM system and how they perceive its usefulness.
- **Traveler surveys and interviews** – Assessment through interviews and/or surveys of how travelers access and use multi-modal information disseminated by the ICM system.

9.2. DEVELOPMENT OF VALIDATION PROCEDURES

The specific procedures that will be used to validate the delivered system will be developed by the PATH management team in collaboration with relevant corridor stakeholders later in the project, when approaching final system delivery. Only procedures judged to be required for validating the system will be developed. The development of needed procedures may include the identification of supporting data collection needs, the identification of operational situations to review, the development of observation protocols, the development of survey mechanisms to use to collect information from system operators and travelers, and the development of demonstration protocols to examine system operations under hard-to-observe situations. This development will also include the identification of who will be responsible for managing the data collection activities, surveys, interviews, demonstrations, and analyses, as well as the identification of who will be responsible for the execution of specific validation activities.

In addition to defining what is to be done and how, the project team will define the processes for handling potential validation failures. This will include defining what information to record to appropriately document the failure; how to determine whether a validation process should be stopped, restarted, or skipped; how to resolve the cause of a failure (e.g., fix the software, reset the system, and/or change the requirements), and how to determine whether re-validation activities are necessary because of the failure.

9.3. DEVELOPMENT OF VALIDATION TEST CASES

In addition to defining validation procedures, the project team will develop, where required, specific validation test cases. Validation test cases are a logical grouping of functions and performance criteria that are to be validated together. For example, a validation test case may include a series of tests to be conducted to validate that all the arterial traffic control elements in play during the development and implementation of an ICM response plan are considered and responding as intended.

The specific validation test cases to be used during the system validation efforts will be identified and developed by the team members responsible for conducting the validation. These test cases will be developed sufficiently ahead of the start of the validation effort to allow appropriate review by all the relevant corridor stakeholders.

Each defined test case is expected to contain, at a minimum, the following information:

- A description name and a reference number.
- A complete list of needs and scenarios to be validated by the test case. For ease of tracing elements into the validation plan and other documents, the needs and scenarios will be given specific identification numbers so they can be accurately and conveniently referenced without having to repeat their description.
- A description of the objective of the validation case, usually taken from the wording of the need or scenario, to aid the reader in understanding the scope of the case.
- Any data to be recorded or noted during the validation, such as the expected results of a step or a specific performance measurement.
- A statement of the pass/fail criteria.
- A description of the validation configuration, i.e., of the hardware and software items needed for validation and how they should be connected.
- A list of any other important assumptions and constraints necessary for conducting the case.

An important question to address is how comprehensive to make the validation effort. Due to the variability of incident characteristics and of the operational conditions within which incidents occur, it will be impossible to validate all possible combinations of actions under all possible operational situations. To address this situation, system validation will be conducted using a representative set of validation test cases covering commonly occurring situations. These cases will be developed by the project team in consultation with corridor stakeholders using, as an initial set, the various operational scenarios defined in the system's concept of operation. This implies considering at a minimum the following test cases:

- Normal, day-to-day operations
- Moderate freeway incident
- Major freeway incident
- Major arterial incident
- Transit incident
- Special event

9.4. OUTPUT OF VALIDATION EFFORT

The execution of system validation activities will result in a document trail that will include:

- Up-to-date validation plan(s)
- A description of the validation procedures used to conduct the validation

- A validation report documenting the results of the validation effort, including how identified deficiencies were addressed by the project team

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10. SYSTEM EVALUATION PLAN

System evaluation will be the last systems engineering activity associated with the deployment of the proposed I-210 Pilot ICM system. As was illustrated in Figure 3-1, these activities will occur during the operations and maintenance phase of the systems engineering process, i.e., after the proposed system has been launched and has been in operation for some time. The focus of this evaluation will be on assessing the operational benefits provided by the deployed solution to determine its effectiveness and assess whether the deployed system may require additional enhancements before being deployed to other corridors.

A detailed evaluation plan will be produced later in the project, when design of the system is complete. This section of the SEMP thus only provides general information about how the project team proposes to conduct the evaluation of the system to be deployed. Specific elements covered in this section include:

- Evaluation objectives
- Evaluation approach
- Potential evaluation metrics
- Supporting data collection needs
- Evaluation roles and responsibilities

10.1. EVALUATION OBJECTIVES

The objectives behind the evaluation of the proposed I-210 Pilot ICM system are closely related to the pilot nature of the proposed deployment. After the proposed ICM system is delivered by the project team, Caltrans will determine whether the benefits provided by the system justify deploying it to other corridors, either in its current or in an altered form. This decision will largely be based on the magnitude of the operational and community benefits obtained from the system.

In that context, system evaluation activities will primarily be conducted to try to quantify the operational benefits provided to system operators and travelers, as well as the operating costs associated with the deployed solution. More specifically, evaluation activities will be defined and structured to assess the degree to which each of the following expected benefits associated with the general objectives of the project is achieved:

- Improve real-time monitoring of travel conditions within the corridor
- Enable operators to better characterize travel patterns within the corridor and across systems
- Provide predictive traffic and system performance capabilities
- Have the capability of evaluating alternative system management strategies and recommending desired courses of action in response to incidents, events, and even daily recurring congestion
- Improve decision-making by transportation system managers
- Improve collaboration among agencies operating transportation systems within the corridor
- Improve the utilization of existing infrastructures and systems
- Provide corridor capacity increases through operational improvements
- Reduce delays and travel times along freeways and arterials
- Improve travel time reliability
- Help reduce the number of accidents occurring along the corridor
- Reduce incident clearance times

- Reduce greenhouse gas emissions
- Generate higher traveler satisfaction rates
- Increase the overall livability of communities in and around the I-210 corridor

10.2. EVALUATION APPROACH

Evaluation activities will focus in great part on comparing corridor operations before and after implementation of the proposed ICM system, and gathering information on system operating costs. The following are examples of evaluation activities that are being considered by the project team:

- **Before/after roadway operational analysis** – Comparison of traffic performance within the corridor before and after the deployment of the proposed system.
- **Before/after transit operational analysis** – Comparison of transit operations within the corridor before and after the deployment of the proposed system.
- **Interviews with system operators** – Interviews with the operators of transportation systems connected to the ICM system to collect information on how the deployed system has affected how they manage their individual systems.
- **Before/after traveler surveys** – Distribution of surveys to travelers to collect information on how the deployed system has affected how travelers make trip and routing decisions within the I-210 corridor.
- **Assessment of system operating costs** – Compilation of direct and indirect costs associated with the operation and maintenance of the delivered system.

The execution of before/after analyses and surveys will require the project team to collect data characterizing corridor operations and travel behavior before changes are made to the corridor and after the I-210 Pilot ICM system has become operational. More information about these data collection needs is provided in Section 10.4 below.

10.3. POTENTIAL EVALUATION METRICS

The ability to quantify how the delivered ICM system produces corridor improvements satisfying all stakeholders will depend on the metrics used for assessing corridor operations. Several metrics frequently used by system operators to assess the operational performance of freeways, arterials, transit, and parking systems were identified in the Concept of Operations for the I-210 Pilot ICM system. While all the identified metrics could be considered for validating the system, this approach would not be practical. First, not all metrics are easily measurable. Second, collecting data supporting the estimation of all metrics may be cost- and time-prohibitive based on available project resources. For these reasons, system validation activities will focus instead on the utilization of a restricted set of metrics mirroring the key performance measures that system operators are likely to use to assess corridor operations.

Based on consultations with system stakeholders, key performance metrics to be used in support of system validation efforts are to include:

- **Reduction of vehicle-hours of delay** (both on a nominal and percentage basis), to measure improvement in traffic conditions.

- **Reduction of person-hours of delay** (both on a nominal and percentage basis), to measure improvement in general corridor mobility.
- **Reduction in travel time variability**, to measure potential reduction in uncertainties associated with highly variable traffic conditions.
- **Reduction in the number or severity of secondary collisions** (both on a nominal and percentage basis), to measure the safety benefits of the implemented corridor management strategies.

In addition to the above performance metrics, the following metrics will be used to assess potential changes in travel demand within the corridor, particularly when comparing data characterizing situations before and after system implementation:

- **Change in vehicle-miles traveled** (both on a nominal and percentage basis), to assess increases or decreases in vehicular traffic within the corridor.
- **Change in person-miles traveled** (both on a nominal and percentage basis), to assess increases or decreases in overall traffic demand within the corridor.

Where possible, the above performance metrics are to be compiled for specific transportation systems to allow the validation of system-specific elements. In addition to compiling corridor-wide statistics, this means compiling statistics covering only freeway elements, local arterial networks, transit services, etc.

Changes in person-delay will be the primary metric for validating that the delivered system has a positive impact on corridor mobility. However, a potential problem with the use of this metric is knowing how many individuals are present in each vehicle. While information about the number of occupants in each vehicle is typically unavailable, average values may be used to characterize the typical occupancy of passenger cars and various types of transit vehicles. Such values can be obtained from occasional vehicle occupancy surveys conducted by transportation agencies. While using average values would not allow developing an *exact* operational assessment, it must be understood no existing technology currently allows such an assessment to be made. While imperfect, using average vehicle occupancy estimates provides the only practical approach to consider the relative carrying capacity of passenger cars and transit vehicles in the current evaluation context.

In addition to quantitative performance measures, the system validation will also measure how satisfied the users are with the system. This is a qualitative assessment that will be conducted using surveys, interviews, in-process reviews, and direct observation.

Metrics related to the technical performance of the delivered system will further be monitored. This will include compiling the following information describing ICM system operations:

- **Number of incidents/events responded to**, to assess the frequency at which the system is being used.
- **Number of recommended plans rejected by operators**, to assess the ability of the ICM system to develop suitable plans.
- **Number of incidents/events requiring review/approval of recommended plans**, to assess the degree to which system operators trust the quality of the developed recommendations.

10.4. SUPPORTING DATA COLLECTION NEEDS

Evaluation of the deployed I-210 Pilot ICM system will require at a minimum the collection of data characterizing the following elements before and after implementation of the ICM system:

- Operation of freeway segments under direct ICM management. This includes the sections of the I-210, SR-134, and I-605 freeways included in the boundaries of the pilot corridor.
- Operations of freeways surrounding the pilot corridor. This primarily includes the I-10 freeway to the south of the corridor, and possibly operations of the SR-57 freeway to the east.
- Operation of arterial networks operated by Pasadena, Arcadia, Duarte, Monrovia, and Los Angeles County.
- Operation of the Gold light-rail line operated by Metro.
- Operation of relevant fixed-route bus service operated by Metro, Foothill Transit, and Pasadena Transit.
- Operations of park-and-ride facilities within the corridor.
- Processes followed by system operators to respond to incidents and manage corridor traffic in general.

The above evaluation requirements translate into a need to collect the following technical information:

- **Freeway operations**
    - Volume counts on freeway mainline and HOV lanes
    - Volume counts on on-ramps, off-ramps, and freeway connectors
    - Loop occupancy on freeway mainline and HOV lanes
    - Speed estimates, or segment travel times, on freeway mainline lines and HOV lanes
    - Implemented ramp metering rates
- **Arterial operations**
    - Approach volume counts at key intersections
    - Turning counts at intersections with significant turning volumes
    - Approach speed estimates or link travel times
    - Stop line queue measurements, where available
    - Implemented signal timing plans
- **Transit operations**
    - Ridership data on the Gold light-rail line
    - Ridership data on relevant surface bus routes, mostly to assess average vehicle occupancy
    - Schedule adherence data, mostly to collect information about major incurred service delays
- **Park-and-ride facility operations**
    - Facility occupancy
- **Traveler behavior**
    - Routes used by motorists to detour around freeway and arterial incidents

- **Corridor management processes**
  - Information describing activities conducted by system operators to manage incidents and traffic in general
- **Event/incident logs**
  - Records of incidents that have occurred on the freeway and arterials
  - Incident logs from transit dispatch centers
  - Lane/roadway closures for maintenance
  - Information describing special events that have occurred within and around the corridor
- **Environmental data**
  - Weather information

The execution of before/after studies will necessitate the collection of data characterizing performance of the I-210 before and after deployment of the pilot ICM system. The following are key principles that will be considered to determine when to initiate the collection of that data:

- Data characterizing the "before" situation will need to be collected before any changes are made to the way traffic is managed on the corridor, to ensure that observed differences are primarily attributable to the deployed ICM system. This means conducting data collection before the implementation of any procedural changes in how corridor operations are managed. However, this does not include the installation of new traffic detection equipment, upgrades to the communication networks used to transfer data, or signal timing improvements that would have occurred regardless of the project.
- The collection of data characterizing the "after" situation will be initiated no sooner than six months after the official system launch. This interval should give enough time to system operators to become familiar with how the ICM system operates and to fine-tune system operations. It should provide enough time for the execution of marketing campaigns to inform travelers of what the deployed system can do for them.

While a suggested approach for comparing "before" and "after" system operations is to compare corridor operations under similar incidents before and after system implementation, the inherent variability of traffic conditions makes it very difficult to implement this comparative approach. While incidents with relatively similar characteristics are likely to be identified before and after system implementation, changes in traffic demand and variations in traffic conditions will likely make it very difficult to find situations with matching incidents and traffic conditions. A best approach will therefore simply be to attempt to assess average corridor operations under various categories of incidents before and after system implementation.

10.5. ROLES AND RESPONSIBILITIES

Evaluation of the deployed I-210 Pilot ICM system will be conducted under PATH leadership, with significant assistance from the various agencies having a stake in the operation of the system. If deemed relevant, external consultants may be used to help with the data collection. The following is a summary breakdown of expected responsibilities regarding the evaluation of the system:

- **University California PATH**
    - Development of detailed evaluation plan that is to be produced later in the project
    - Identification of potential corridor evaluation metrics that may be used to conduct the evaluations
    - Identification of data that will need to be collected to support the evaluation
    - Collection of data characterizing traveler behavior
    - Collection of traffic performance data that cannot be provided by agencies participating in the operation of the system
    - Analysis of collected data
    - Development of evaluation report
- **Stakeholder agencies**
    - Assistance in the selection of key evaluation metrics
    - Collection of operational data from the systems operated by each agency
    - Feedback on how the delivered ICM system has affected each agency's ability to manage their transportation systems and networks
    - Review of data analysis results

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APPENDIX A - ACRONYMS

The following acronyms and abbreviations are used in this document.

AASHTO	American Association of State Highway and Transportation Officials
AMS	Analysis, Modeling, and Simulation
ANSI	American National Standards Institute
API	Application Programming Interface
APTA	American Public Transportation Association
ASTM	American Society for Testing and Materials
ATC	Advanced Transportation Controller
ATIS	Advanced Traveler Information Systems
BOM	Bill of materials
Caltrans	California Department of Transportation
C2C	Center-to-Center
C2F	Center-to-Field
CC	Connected Corridors
CCTV	Closed Circuit Television
CHP	California Highway Patrol
CM	Configuration Management
CMS	Changeable Message Sign
ConOps	Concept of Operations
DMS	Dynamic Message Sign
DSS	Decision Support System
DSRC	Dedicated Short Range Communications
ICM	Integrated Corridor Management
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation System
LADPW	Los Angeles County Department of Public Works
LA SAFE	Los Angeles County Service Authority for Freeway Emergencies
Metro	Los Angeles County Metropolitan Transportation Authority
MOU	Memorandum of Understanding
NEMA	National Electrical Manufacturers Association
PATH	Partners for Advanced Transportation Technology
PMBOK	Project Management Body of Knowledge
PMP	Project Management Plan
RIITS	Regional Integration of Intelligent Transportation Systems
SAE	Society of Automotive Engineers
SCAG	Southern California Association of Governments
SEMP	Systems Engineering Management Plan
SGVCOG	San Gabriel Valley Council of Governments
TCIP	Transit Communications Interface Profile
TMDD	Traffic Management Data Dictionary
USDOT	United States Department of Transportation
WAVE	Wireless Access in Vehicular Environments
WBS	Work Breakdown Structure