INNOVATE 680
IMAGINE THE POSSIBILITIES

I-680 ADVANCED TECHNOLOGY PROJECT COORDINATED ADAPTIVE RAMP METERING (CARM)

DRAFT Systems Engineering Management Plan (SEMP)

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Review History

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0.5	Updated draft for internal review	11/30/2023	SMP
0.6	Updated draft for client review	1/17/2024	SMP

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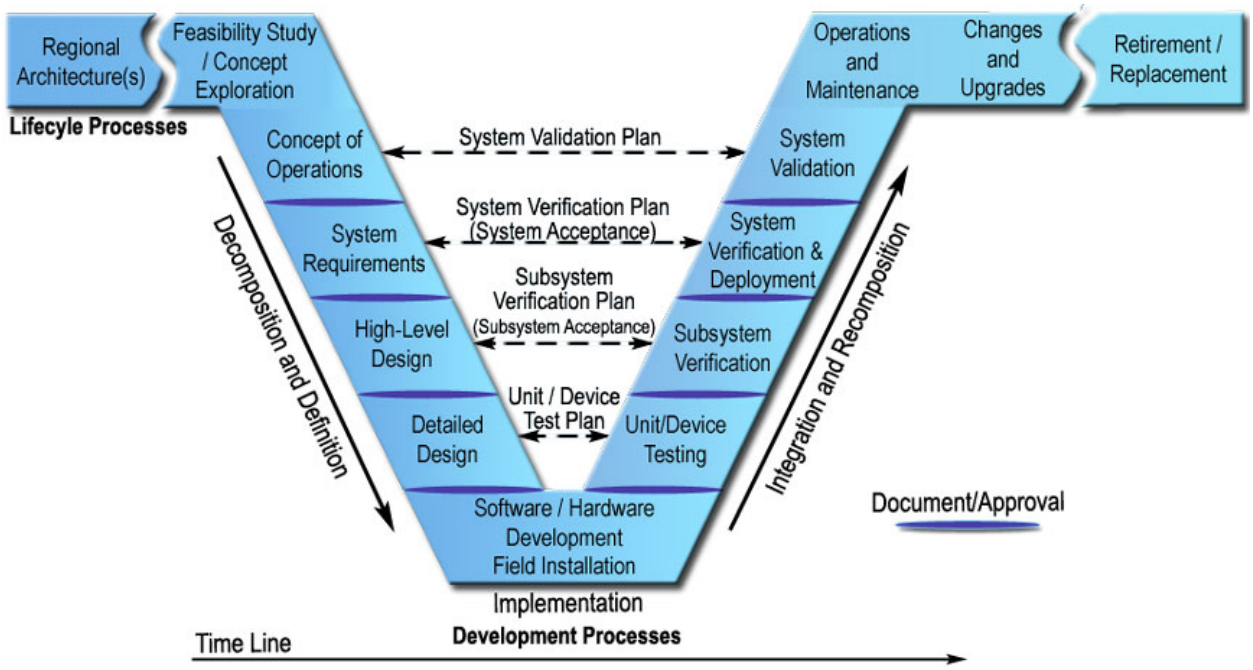
1 Purpose of Document

The purpose of the Systems Engineering Management Plan (SEMP) is to assist stakeholders in the implementation of the Innovate 680 Advanced Technologies (AT) Coordinated Adaptive Ramp Metering (CARM) Project, and to provide information on the systems to be utilized and integrated for Innovate 680 CARM operations. This document will identify, at a high level, the engineering challenges, schedule, and the necessary actions required to deliver a successful implementation of the Smart Freeways CARM concept on I-680 in Contra Costa County, with the first phase of implementation on northbound I-680 between Alcosta Blvd and Olympic Blvd.

The Innovate 680 AT CARM Project is following the FHWA's System Engineering Process. The process involves the decomposition and definition of project needs and procedures into the integration and decomposition of those needs, resulting in a well-defined system. Decomposition is defined as the process of successively breaking down the system into components that can be built or procured. The V-Diagram that outlines this process is shown in Figure 1-1. This document is being prepared concurrent to early design and development efforts to provide guidance for Project stakeholders.

Figure 1-1 Systems Engineering V Diagram



Source: Federal Highway Administration, 2007.

2 Scope of Project

This section provides a brief description of the elements of the Innovate 680 AT CARM Project and the purpose of the system.

2.1 Project Elements

I-680 is a major interstate highway facility within Contra Costa County carrying interstate, interregional and intraregional traffic. This area is projected to experience substantial growth for goods movement and passenger vehicle traffic. I-680 is one of the major north-south corridors in Contra Costa County and is listed by the Metropolitan Transportation Commission (MTC) as one of the ten most congested freeways in the San Francisco Bay Area.

The Innovate 680 AT CARM Project corridor spans a 14-mile portion of northbound I-680 from Alcosta Blvd at the Contra Costa/Alameda County line to Olympic Blvd near the SR-24 interchange. It should be noted that these limits have been identified as the initial Segment 1 CARM corridor for project development and operation as part of a multi-phased implementation intended to accomplish CARM in both directions along the full length of I-680 in Contra Costa County. The deployment of the CARM system on other segments of I-680 in Contra Costa County is proposed for future development based on funding availability.

The purpose of the Segment 1 AT CARM project is to demonstrate the effectiveness of CARM managed with the STREAMS® Active Traffic Management System (ATMS) platform along with other ITS components to improve mainline traffic operations, air quality and safety by stabilizing and controlling traffic flow.

It should be noted that CARM operations requires a comprehensive freeway management system for managing the various components of system operations, as well as an advanced suite of ramp metering algorithms capable of responding to real-time traffic conditions to simultaneously manage both freeway mainline and ramp conditions on a corridor-wide basis. The STREAMS® platform developed by Transmax is currently the only commercial system capable of meeting the needs of the CARM concept, and authorized to use the ALINEA and HERO suite of algorithms. As such, the Transmax STREAMS® freeway management platform has been selected for the Innovate 680 AT CARM Project. At the time of this writing, the Contra Costa Transportation Authority (CCTA) is coordinating with Caltrans to prepare a Public Interest Finding (PIF) for the use of STREAMS® for the initial Segment 1 AT CARM deployment on I-680.

This approach to CARM was pioneered on the Melbourne M1 Freeway by the Victoria Department of Transportation (VicDOT). The Innovate 680 AT CARM Project will have several components as described below:

- **Coordinated & Adaptive Ramp Metering.** The coordinated ramp metering system involves controlling the entrance ramps of I-680 within the project limits to operate as a single managed system. This will allow for freeway flow to be monitored and optimized using a single management system and to maximize the storage and flow management capabilities of each ramp entry.

- **Extensive Vehicle Detection Systems.** As a part of the project, detection devices will be installed throughout the corridor along the freeway mainline and ramps. The devices will be spaced along the mainline at critical control points to ensure real-time lane occupancy (a proxy for density), vehicle speed and volume information is available throughout the corridor. Detection will also be installed along entrance and exit ramps to ensure real-time data on ramp queues, and entry and exit flows. In all locations, detection should be available at a high level of accuracy as required for successful CARM operations. Vehicle detection devices installed specifically for CARM operations will be connected to STREAMS® effectively operating separately from the existing California Department of Transportation (Caltrans) ATMS for the initial phase of operation, although it will be possible to provide a data feed to the existing Caltrans ATMS if desired.

- **Responsive Flow Management.** Another element of the CARM system involves the deployment of the STREAMS® ATMS integrating the ALINEA[1] and HERO[2] suite (AHS) of ramp metering control algorithms. The collective system will use real-time freeway occupancy, speed, and volume data to optimize flow rates throughout the corridor and apply the appropriate metering rates recalculated every 20 seconds across the system to optimize traffic flows and prevent flow breakdown within the corridor.

- **Optimizing Vehicle Storage.** The configuration of freeway entrance ramps is an important consideration for effective CARM operation. Ramp storage and discharge capacity will be expanded as necessary to ensure the operational flexibility necessary to support coordinated ramp metering, where feasible. The provision of adequate ramp storage and discharge working in conjunction with CARM is key to ensuring the system can effectively balance ramp queues and wait times on all ramps along the entire corridor while also optimizing mainline traffic flows to achieve maximum productivity on the freeway and avoiding ramp queues spilling over onto local streets.

2.2 Project Environment

The Innovate 680 AT CARM Project will demonstrate the effectiveness of the Smart Freeways CARM concept to control traffic flows and alleviate recurrent chronic congestion. The primary goal of the project is to provide more efficient, productive, and reliable freeway traffic flows through the project corridor using advanced transportation management technologies and Intelligent Transportation System (ITS) devices without the expense and disruption of constructing additional roadway capacity.

Phase 1 of the project will feature the installation of a CARM system and associated ramp modifications at eleven northbound service interchanges in the project area listed below.

- Alcosta Blvd Interchange
- Bollinger Canyon Rd Interchange
- Crow Canyon Rd Interchange
- Sycamore Valley Rd Interchange

[1] ALINEA = Asservissement LINéaire d'Entrée Autoroutière (Freeway Entrance Linear Control in English)
[2] HERO = HEuristic Ramp Metering coOrdination

- Diablo Rd Interchange
- El Cerro Blvd Interchange
- El Pintado Rd Interchange
- Stone Valley Rd Interchange
- Livorna Rd Interchange
- Rudgear Rd Interchange
- Olympic Blvd Interchange

Future phases of the project are proposed to expand the CARM system to other interchanges along I-680, to create a contiguous CARM corridor between the Martinez Bridge and the Contra Costa/Alameda County line in both the northbound and southbound directions.

The Innovate 680 AT CARM project will also feature the installation of various ITS infrastructure to support the CARM system and address traffic flow disruptions. These ITS infrastructure installations include additional vehicle detection devices to enhance data accuracy and coverage, as well as new ramp meter signals, controllers, and supporting communications infrastructure. Variable message signs (VMS) located on the approaches to entrance ramps displaying ramp status information and additional closed circuit television cameras (CCTV) to ensure all ramps are visible to remote operators represent additional ITS equipment to be installed as part of the project.

The Smart Freeways concept relies on advanced, highly precise vehicle detection to monitor traffic flows and inform the suite of algorithms that are used to determine ramp metering requirements that control freeway access on a continuous basis. It uses CARM to ensure traffic on the freeway achieves optimum flow without breaking down into a congested state.

2.3 Project Challenges & Complexities

Key challenges that must be addressed during the System Engineering process for the Innovate 680 AT CARM Project are listed below:

- **Interdependencies of Involved Parties:** The Innovate 680 AT CARM Project will involve multiple stakeholders. The systems engineering, design, and construction process must define the arrangement among the stakeholders and involved parties described in Section 2.4.

- **Coordination with Caltrans SHOPP Project:** Caltrans has initiated a State Highway Operation and Protection Program (SHOPP) project (EA 04-1Q720) proposing ramp metering improvements on all of I-680 in Contra Costa County as well as adjacent freeway segments in Alameda and Solano counties. The Caltrans SHOPP Fiber/Traffic Operations System (TOS)/Ramp Metering project is using 2020 funding to install a fiber-optic cable communication trunk line, upgrade the traffic-operations system, upgrade ramp metering equipment, and widen selected ramps to provide high occupancy vehicle (HOV) preferential lanes on I-680 in Contra Costa County. It is currently expected that the Innovate 680 AT CARM Project improvements would be additive to the Caltrans SHOPP Fiber/TOS/Ramp Metering Project. As such, the

Innovate 680 team will coordinate closely with Caltrans staff on project design, requirements, and system operation. CCTA and the Innovate 680 team will also work with Caltrans to determine the appropriate sequencing of the commencement of ramp metering operations within the I-680 corridor.

- **Coordination with Innovate 680 Program Projects:** The Innovate 680 AT CARM Project will also be coordinated with the greater Innovate 680 Program. CARM is one of several Innovate 680 elements, in addition to the I-680 Express Lanes Completion and Part-time Transit Lanes/Transit Bus on Shoulder (TBOS) projects, and the Coordinated Adaptive Traffic Signals (CATS) project involving adjacent arterial traffic signals. In particular, the TBOS and CATS elements may be further integrated into the Segment 1 AT CARM project as user needs and requirements for those proposed systems are further developed.

- **System Rollback:** The CARM system will differ from typical ramp metering operations within Caltrans District 4 and will be deployed as a separate system. However, the design of ramp meter signals, ramp detection, and ramp meter signal controllers will generally follow the Caltrans Ramp Metering Design Manual requirements, to allow conversion to Caltrans standard operations, if/when such a conversion is desired.

- **ITS Device Integration:** Many of the existing ITS devices in the project corridor are insufficient to meet the needs of the Innovate 680 AT CARM system. New ramp meters would be needed at all entrance ramps to facilitate coordinated and adaptive ramp metering. New traffic detection devices would need to be installed along the northbound I-680 mainline and ramps to provide real-time data at a higher level of accuracy. The AT CARM project is intended to utilize the STREAMS® traffic management system, which is a proprietary traffic management system platform developed and owned by Transmax. Compatible ramp controllers will be needed to integrate with Transmax field processors to accommodate the STREAMS® system. The system will also be heavily reliant on the existing and planned Caltrans fiber communications network. These new devices would need to be integrated with existing and planned infrastructure to produce the new working system.

- **Enforcement:** Success of the Innovate 680 AT CARM Project is dependent on the ability of the ramp metering system to control throughput of vehicles onto the I-680 freeway. If there are a high number of ramp meter violators, the ability of the system to reduce congestion will be hindered. This puts an emphasis on the need for adequate enforcement in the event a high number of ramp meter violations are observed.

- **Traffic Volumes:** Pre-design feasibility analysis of the I-680 project corridor relied on existing Caltrans Performance Monitoring System (PeMS) traffic data from limited existing vehicle detector locations, as well as pre-pandemic count data and forecasts. The limited detection creates gaps in knowledge of existing corridor conditions. More reliable data will not be available until after new detectors have been installed as part of the project. Since the feasibility data is based on existing conditions, unforeseen increases in future volumes could impact the ultimate performance of the system.

- **Uncontrolled Entry:** The Innovate 680 AT CARM Project will only control the entry of vehicles from entrance ramps within the project limits. Therefore, increased volumes entering from upstream of CARM corridors can have a negative impact on the

system's ability to control congestion. For Segment 1 of the AT CARM project, northbound I-680 volumes from south of Alcosta Blvd will be uncontrolled.

- **Downstream Bottlenecks:** Along with uncontrolled entry volumes, the AT CARM system will only be able to manage conditions within the project corridor where there is sufficient mainline detection and CARM sites to respond to bottleneck formation. If a bottleneck forms downstream of the Segment 1 CARM corridor (e.g., on northbound I-680 in the vicinity of traffic merging from eastbound SR-24) back-ups could lead to degraded conditions in the I-680 AT CARM project corridor.

2.4 Project Stakeholders

The Innovate 680 AT CARM Project will involve several key stakeholders:

- **Contra Costa Transportation Authority (CCTA):** The lead agency overseeing the funding, development, implementation, operation, and evaluation of the Innovate 680 AT CARM Project improvements. CCTA will coordinate with additional regional and state agencies, FHWA, and local stakeholders on issues relating to CARM development and operations.

- **Caltrans District 4:** The main public agency responsible for the management and maintenance of freeways within the California Bay Area. Caltrans District 4 is also responsible for the maintenance and operation of ITS devices and assets within the Bay Area including along the I-680 corridor and will be a key project partner for the delivery of the AT CARM project. District 4 is also leading the development of the Caltrans SHOPP Fiber/TOS/Ramp Metering project on I-680.

- **Caltrans Headquarters:** Caltrans HQ is the ultimate owner of freeway assets throughout California, including the I-680 project corridor. Caltrans HQ will have input on CARM system design and operations, particularly on device configuration and integration with the Caltrans network and the Bay Area Transportation Management Center (TMC).

- **Federal Highway Administration (FHWA):** FHWA will be closely involved in the project, since the I-680 CARM system will be developed along the interstate highway system and will potentially utilize federal transportation funding sources. FHWA will have input in the systems engineering, design, and validation of performance requirements of the AT CARM project.

- **California Highway Patrol (CHP):** The CHP will be the lead enforcement agency for the Innovate 680 AT CARM Project. Enforcement agencies will play a vital role in the success of the CARM project, which is in part dependent on vehicles adhering to ramp metering signals.

- **Bay Area Infrastructure Financing Authority (BAIFA):** The BAIFA oversees the financing, planning, and operations of MTC Express Lanes, including the existing northbound Express Lane between Alcosta Blvd Livorna Rd within the Segment 1 AT CARM corridor. BAIFA will share a role in operations within the Segment 1 corridor and will coordinate with the Innovate 680 CARM team during system design and operations.

- **Local Jurisdictions:** The Innovate 680 AT CARM Project corridor traverses multiple local jurisdictions including the City of Dublin, City of San Ramon, Town of Danville, and the City of Walnut Creek, as well as unincorporated areas of Contra Costa County. Local jurisdictions maintain the arterial network infrastructure adjacent to I-680, including the eleven intersecting routes, and parallel frontage roads and arterials. Segment 1 of the proposed AT CARM project will impact northbound I-680 entrance ramps from Alcosta Blvd to Olympic Blvd.

The Innovate 680 AT CARM Project also includes consulting and contractor staff to assist with project development, implementation, and operations. These parties are described below:

- **WSP USA:** WSP will act as the overall consultant team project manager and will lead the preparation of environmental compliance documents and design. WSP will oversee the preparation and delivery of project approval documents including the Project Report and documentation for environmental clearance through a California Environmental Quality Act (CEQA) Categorical Exemption/National Environmental Policy Act (NEPA) Categorical Exclusion (CE/CE) determination. WSP will also oversee delivery of the Systems Engineering Analysis (SEA) and Plans, Specifications, and Estimates (PS&E) for final design for the Segment 1 AT CARM project.

- **GHD Inc.:** GHD will act as the Innovate 680 Corridor Manager, responsible for the overall coordination of Innovate 680 Advanced Technologies Project. GHD will also provide subject matter expertise on the Australian CARM system and oversee systems engineering, project development, and design for the Segment 1 AT CARM project.

- **Emergent Transportation Concepts:** Emergent Transportation Concepts will lead stakeholder engagement for the Segment 1 AT CARM project. This role will be critical to manage communications and process with the many project stakeholders. Emergent Transportation will also serve as the meeting facilitator between the various agency stakeholder groups, and the greater Innovate 680 program, and will contribute to the preparation of the Innovate 680 program systems engineering documents including the program level concept of operations and the CATS concept of operations.

- **Convey:** Emergent Transportation Concepts will lead public outreach efforts for the Segment 1 AT CARM project. This role will be critical to interface with the public, and to provide educational materials on the purpose, goals, scope, and performance of the CARM project.

- **BayPac Consult Inc.:** BayPac will assist with project team and agency coordination during project development of the Innovate 680 AT CARM Project. In particular, BayPac will serve as the main point of contact between the consulting team and Caltrans for project coordination on systems engineering, Project Approvals and Environmental Documentation (PA&ED) and design (PS&E).

- **Transmax:** Transmax is the developer and owner of the STREAMS® intelligent transport management system. Transmax will be responsible for STREAMS® system set-up, testing, hosting, tuning and calibration, and support during CARM operations. Transmax will also be an integral part of system architecture and configuration, given the vitally important role of the STREAMS® platform in the success of the proposed project.

- **ITS Installation & Civil Contractor:** Following the completion of AT CARM project design, a contract will be awarded for ITS device installation and related civil improvements. The actual contractor is not known at this time. However, they represent a key stakeholder as the installer and initial testing entity for key ITS devices.

- **ITS Maintenance Contractor:** The reliance of the AT CARM system on accurate real-time data underscores the need for functional devices, and timely responses to any reported device faults. As such, the ITS device maintenance resources will also be a key stakeholder for the Innovative AT CARM Project.

- **Operations Staff:** The Australian Smart Freeways concept relies on the real-time observation of CARM operations during peak-periods to monitor system performance, place overrides on particular ramps due to crashes or operational issues, diagnose device faults and coordinate responses for system support or device maintenance. At this time, it is unknown whether this role will be performed by CCTA, Caltrans, or an operations contractor.

3 Technical Planning & Control

The purpose of this section is to lay out the plan for the systems engineering activities to be completed as part of the Innovate 680 AT CARM Project. Because the project will incorporate an existing software package, and system configuration will be largely separate from existing Caltrans processes, the systems engineering activities are somewhat abbreviated relative to a larger scale ITS implementations.

3.1 Key Development Stages

The Innovate 680 AT CARM Project can be divided into multiple development stages:

- **Feasibility:** The *I-680 Advanced Technology Project Coordinated Adaptive Ramp Metering – Corridor Evaluation* was conducted from 2020-2022 to evaluate the feasibility of applying the Australian Smart Freeways CARM concept in Contra Costa County. As part of that process, the I-680 corridor was confirmed as a location that could benefit from implementation of the CARM system. In addition, the viability of existing corridor ramp configurations and ITS devices were evaluated for CARM, and initial recommendations were made on ramp improvements and detection technologies. This process also identified the northbound portion of I-680 between Alcosta Blvd and Olympic Blvd as a suitable initial segment for the AT CARM concept to be deployed due to the isolated nature of recurring peak period bottlenecks within the segment, more compatible corridor geometry, available right-of-way (ROW), and lack of environmental and permitting challenges. The feasibility segment also confirmed that the Segment 1 AT CARM segment could be funded based on committed sources and delivered concurrently with the Caltrans SHOPP Fiber/TOS/Ramp Metering project.

- **Project Approvals and Environmental Documentation:** The PA&ED phase of the Innovate 680 AT CARM Project involves the analysis and preparation of documentation necessary to obtain Caltrans approval of the Segment 1 project prior to proceeding with final design. Project approvals will adhere to the Caltrans Project Development Process (PDP). This process incorporates preliminary design and cost estimates presented in a Project Report, and documentation to support environmental clearance. Since construction impacts are anticipated to be minor, and the project will fall entirely within the existing state-owned ROW, it is anticipated that a Categorical Exclusion/Categorical Exemption (CE/CE) under the National Environmental Policy Act (NEPA) and California Environmental Quality Act (CEQA) respectively, with associated technical studies, will be the appropriate level of environmental documentation. This phase will also include the early stages of the systems engineering process, including the preparation of this SEMP document and the corresponding AT CARM Segment 1 Concept of Operations (ConOps).

- **Final Design:** The preparation of Plans, Specifications, and Estimates (PS&E) will occur after completion of the PA&ED phase. This phase will include the preparation of final design sheets and specifications for both civil ramp improvements, and the installation of ITS devices associated with ramp metering and vehicle detection. PS&E documentation will detail proposed communication system configuration, integration, and testing procedures of the CARM system. This phase will also involve the preparation of Functional Requirements and a Requirements Traceability Matrix,

that will link user needs, ConOps elements, and system requirements as part of the systems engineering process.

- **Construction & Installation:** The construction phase follows the completion of the design phases and includes physical modifications to selected entrance ramps, installation of new vehicle detectors, and installation and/or configuration of ITS cabinets, signals, and signage. These construction improvements are considered prerequisites to the deployment of the CARM concept. At the time of this writing, it is assumed that construction and installation of the Phase 1 CARM segment will be delivered as an integrated part of the Caltrans SHOPP Fiber/TOS/Ramp Metering project planned for the I-680 corridor.

- **Integration & Testing:** The integration and testing phase of project development will occur during the later stages of construction during the ITS device commissioning process. As part of this phase, individual devices and communications infrastructure will be tested and commissioned following acceptance testing. This phase will also involve the set-up, configuration and testing of the STREAMS® operating environment for CARM operations.

- **Operations**: This phase will involve the day-to-day operations of the Innovate 680 AT CARM Project within the Segment 1 CARM limits. Operations of CARM will be managed through the STREAMS® platform and supplemented by CCTV and field observations. Prior to the commencement of STREAMS® CARM operations, at least 12 weeks of existing traffic conditions data will be collected using the newly installed detection devices to serve as a baseline to support tuning and calibration of the system as well as subsequent performance evaluations. Ongoing system tuning and performance monitoring will occur with the commencement of STREAMS® operations. As discussed previously, the AT CARM system is proposed to be the first ramp metering system to operate along the I-680 Segment 1 AT CARM corridor to manage public and stakeholder expectations and driver experience, as CARM will operate substantially different than standard Caltrans ramp metering.

- **Maintenance:** This phase will ensure the ATMS and individual ITS devices installed for the Innovate 680 AT CARM Project remain operational. During CARM operations, the STREAMS software will be maintained by Transmax as part of their normal product hosting and support. ITS devices, including vehicle detectors, field processors, and ramp signals will be maintained by the ITS Maintenance Contractor through a performance-based maintenance contract.

- **Evaluation:** Regular performance monitoring and reporting will be conducted during operations of the Segment 1 CARM project (as well as subsequently deployed segments). At the conclusion of the first three months of operations, a preliminary assessment memorandum will be completed summarizing the performance of the Innovate 680 AT CARM Segment 1 Project and comparing conditions in the I-680 corridor before and after the activation of the system. The memorandum will be updated on an annual basis to document and compare conditions in the I-680 corridor before and after activation. The Segment 1 AT CARM Project represents an initial deployment of CARM on I-680 that will be evaluated after two years of operations. After two years of operation, the performance evaluation will be expanded to determine the efficacy of this concept and suitability for permanent deployment. The evaluation is expected to include before and after comparison of a

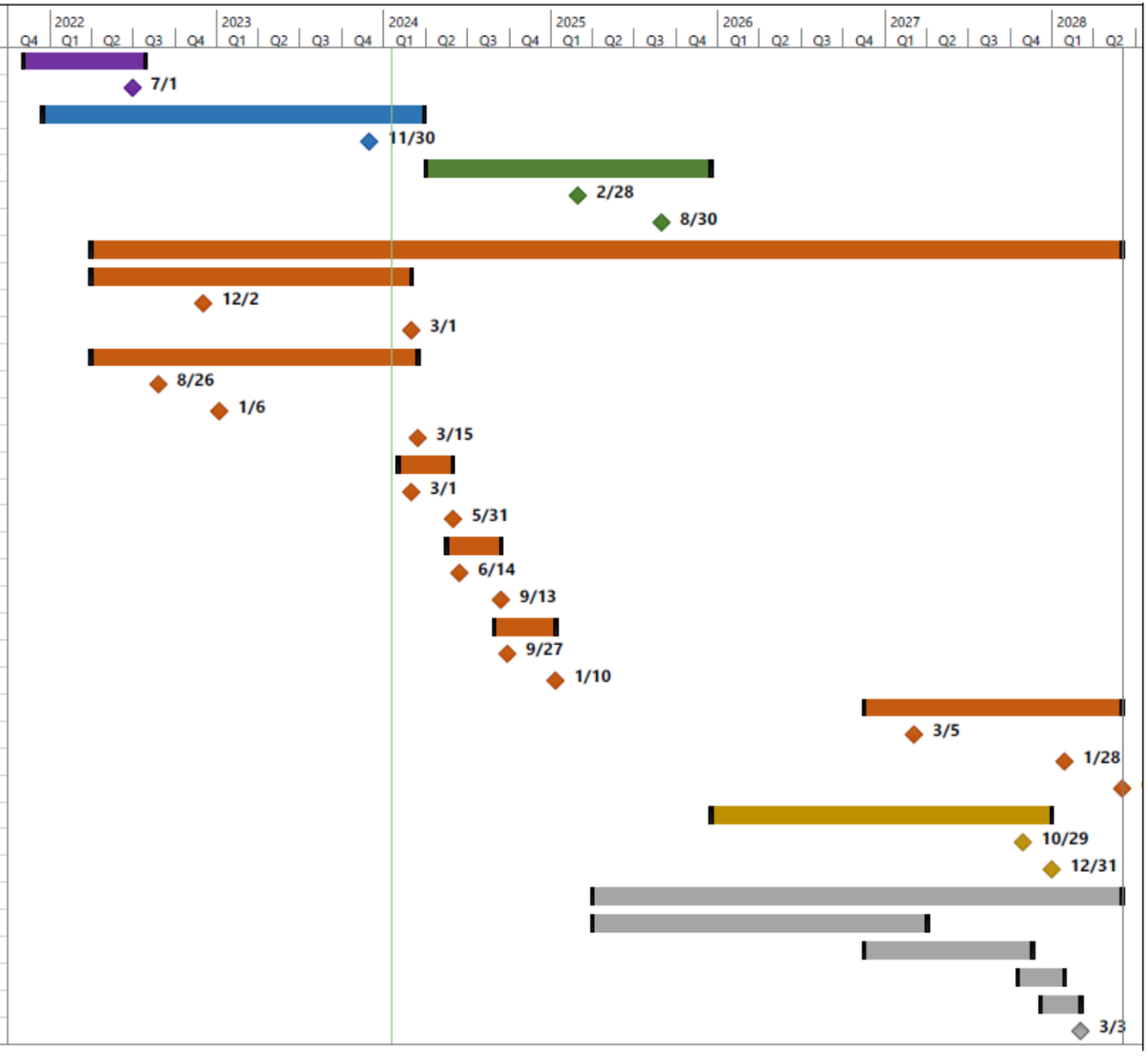
range of performance measures, including changes in travel time, throughput and level of delay, as well as possible comparison to the performance of Caltrans traditional ramp metering deployed along other corridors in the Bay Area region, subject to data availability.

3.2 Work Breakdown Schedule

A schedule summarizing key tasks relating to the Innovate 680 AT CARM Segment 1 Project process was developed to clearly communicate the project development process and milestones to project stakeholders. This schedule is shown in the following pages.

Figure 3-1 Innovative 680 AT CARM Project Work Breakdown Schedule

ID	Task Name	Duration	Start	Finish
1	**Corridor Feasibility Evaluation**	193 days	Wed 11/3/21	Fri 7/29/22
2	Corridor Evaluation Report	0 days	Fri 7/1/22	Fri 7/1/22
3	**Project Approvals (PA&ED)**	597 days	Thu 12/16/21	Fri 3/29/24
4	Draft Project Report	0 days	Thu 11/30/23	Thu 11/30/23
5	**Final Civil & ITS Design (PS&E)**	446 days	Mon 4/1/24	Mon 12/15/25
6	Project PS&E	0 days	Fri 2/28/25	Fri 2/28/25
7	Construction Advertisement	0 days	Sat 8/30/25	Sat 8/30/25
8	**Systems Engineering Analysis [SEA]**	1611 days	Fri 4/1/22	Fri 6/2/28
9	***Systems Engineering Management Plan (SEMP)***	501 days	Fri 4/1/22	Fri 3/1/24
10	SEMP - 1st DRAFT Submittal	0 days	Fri 12/2/22	Fri 12/2/22
11	SEMP - FINAL Submittal	0 days	Fri 3/1/24	Fri 3/1/24
12	***Concept of Operations (Con Ops)***	511 days	Fri 4/1/22	Fri 3/15/24
13	Con Ops - Issues Matrix	0 days	Fri 8/26/22	Fri 8/26/22
14	Con Ops - 1st DRAFT Submittal	0 days	Fri 1/6/23	Fri 1/6/23
15	Con Ops - FINAL Submittal	0 days	Fri 3/15/24	Fri 3/15/24
16	***Functional Requirements***	87 days	Thu 2/1/24	Fri 5/31/24
17	Requirements Matrix - 1st DRAFT Submittal	0 days	Fri 3/1/24	Fri 3/1/24
18	Requirements Matrix - FINAL Submittal	0 days	Fri 5/31/24	Fri 5/31/24
19	***System Verification and Validation Plan***	86 days	Fri 5/17/24	Fri 9/13/24
20	Verification and Validation Plan - 1st DRAFT	0 days	Fri 6/14/24	Fri 6/14/24
21	Verification and Validation Plan - FINAL	0 days	Fri 9/13/24	Fri 9/13/24
22	***Operations and Maintenance Plan***	96 days	Fri 8/30/24	Fri 1/10/25
23	Ops & Maintenance Plan - 1st DRAFT Submittal	0 days	Fri 9/27/24	Fri 9/27/24
24	Ops & Maintenance Plan - FINAL Submittal	0 days	Fri 1/10/25	Fri 1/10/25
25	***Detailed Test Plan and Test Scripts***	405 days	Mon 11/16/26	Fri 6/2/28
26	Detailed Test Plan	0 days	Fri 3/5/27	Fri 3/5/27
27	System Verification Results	0 days	Fri 1/28/28	Fri 1/28/28
28	System Validation Report	0 days	Fri 6/2/28	Fri 6/2/28
29	**Construction and Installation**	534 days	Tue 12/16/25	Fri 12/31/27
30	Device Testing Acceptance	0 days	Fri 10/29/27	Fri 10/29/27
31	Contruction Acceptance	0 days	Fri 12/31/27	Fri 12/31/27
32	**Systems Integration and Testing**	829 days	Tue 4/1/25	Fri 6/2/28
33	***STREAMS Software Development***	524 days	Tue 4/1/25	Fri 4/2/27
34	***System Configuration***	265 days	Mon 11/16/26	Fri 11/19/27
35	***System Testing***	75 days	Mon 10/18/27	Fri 1/28/28
36	***Data Collection & Calibration***	65 days	Mon 12/6/27	Fri 3/3/28
37	Operations GO LIVE	0 days	Fri 3/3/28	Fri 3/3/28



3.3 Deliverables

A listing of deliverables to be provided as part of each Innovate 680 AT CARM Project phase is listed below:

- **Feasibility**
  - The I-680 Advanced Technology Project Coordinated Adaptive Ramp Metering – Corridor Evaluation (final version dated July 2022)

- **Project Approvals**
    - Project Study Report (PSR)
    - Project Report (PR)
    - Preliminary Design Plan Sheets (35%)
    - Preliminary Cost Estimates
    - Design Standard Decision Document (DSDD)
    - Structure Preliminary Geotech Report (SPGR)
    - Advanced Planning Study (APS)
    - Storm Water Data Report (SWDR)
    - ROW Data Sheet
    - Transportation Management Plan (TMP) Data Sheet
  - Environmental Approval Document
    - Initial Site Assessment (ISA)
    - Air Quality Impact Memo
    - Noise Impact Memo
    - Biological Resource Memos
    - Visual Impact Assessment (VIA)
    - Cultural Resources Impact Evaluation Memo
    - CE/CE Form
  - Systems Engineering
    - SEMP
    - Concept of Operations (ConOps)
    - High-level Functional Requirements
    - Requirements Traceability Matrix (RTM)
    - Preliminary System Verification and Validation Plan
    - Preliminary Operations and Maintenance Plan

- **Final Design**
  - Final Design Plan Sheets
  - Standard Special Provisions and Project Special Provisions
  - Cost Estimates

- **Construction & Installation**
  - Construction Advertisements
  - Responses to contractor questions prior to award for construction

- **Integration & Testing**
  - Detailed Device Test Plan
  - System Verification and Validation Results

- **Operations**
  - Initial Performance Assessment Memorandum
  - Annual Performance Assessment Memorandum

3.4 Task Management

Task Management for the Innovate 680 AT CARM Project development and design process is carried out by the following groups:

- **Corridor Management Team (CMT):** Day to day management of the Segment 1 AT CARM project development process is conducted by the Innovate 680 Corridor Management Team, comprised of the CCTA Project Manager, the GHD Corridor Manager, and other consultant team managers. This group performs quality management and conducts initial reviews of all documents and design plans, prior to distributing to other stakeholders for review and comment.

- **CARM Integrated Team:** The CARM Integrated Team is made up of technical representatives from CCTA, Caltrans, FHWA, CHP, as well as project team representatives (WSP, GHD, and BayPac). CARM team meetings will be held monthly to inform the development of CARM design documentation, systems engineering documentation, including ConOps, system requirements, and integration materials. The group will assist in resolving CARM decision elements relating to design, configuration, and operational practices. It is through this forum that CARM design and operational principles from Australia will be adapted and applied to the AT CARM systems engineering documentation.

- **Project Development Team (PDT):** Separate PDT's comprising technical staff from CCTA, Caltrans and the consultant team have been utilized to guide the development of technical work associated with the delivery of the Caltrans SHOPP Fiber/TOS/Ramp Metering and the Innovate 680 AT CARM Segment PA&ED projects, respectively. Starting in early 2023, the respective PDT meetings will be consolidated to occur on the same day as part of progressing toward the formal integration of the two projects for design and/or construction.

- **Strategic Development Team (SDT):** The SDT is made up of representatives from various departments and agencies, including CCTA, Caltrans, as well as representatives from FHWA and the MTC. Through regular meetings and submissions of draft deliverables, the SDT is responsible for reviewing and providing comment on project documents, design plans, technical documentation, etc. In some cases, SDT members are responsible for a formal approval or clearance of design and system engineering documents. The SDT currently meets monthly during the accomplishment of project approvals tasks.

- **Technical Advisory Committee (TAC):** TAC members are made up representatives from local and Contra Costa County agencies. The TAC will coordinate with the groups above on Innovate 680 AT CARM project development and will review and provide comment on Phase 1 AT CARM systems engineering and design documentation.

4 Systems Engineering Process

This section describes the execution of the System Engineering Processes used to develop the Innovative 680 AT CARM Project. Documentation required as part of the systems engineering process is described below:

4.1 Systems Engineering Analysis

The SEA will document how this project will meet the FHWA Final Rule [23 CFR § 940.11] on systems engineering conformity. The SEA will document how the following requirements of the Final Rule are being met:

- Identification of portions of the regional ITS architecture being implemented.
- Identification of participating agencies and their roles & responsibilities
- Requirements' definitions
- Analysis of alternative system configurations and technology options to meet requirements
- Procurement options
- Identification of applicable ITS standards and testing procedures
- Procedures and resources necessary for operations & maintenance of the system

4.2 Concept of Operations

A high-level reference document containing an operational overview, description of the corridor, description of system characteristics, operational alternatives, operating parameters, performance metrics, and anticipated impacts. The document shall be developed by the project team, specifically WSP and GHD. At the time of this writing, the ConOps is being developed through coordination with the SDT and CARM Integration Team. Within the ConOps, the intended operations of the CARM system are described and the uses of the ITS devices and how they interact within the system is summarized. Additionally, the ConOps will be used to validate the final system's operations as shown in the FHWA Systems Engineering Process V-Diagram. During the design and implementation process, the ConOps document should be updated with any changes to reflect actual conditions. An updated ConOps will facilitate the validation process.

4.3 System Requirements

The System Requirements Document serves as the basis for performance verification and test plans. It serves as the first bridge between the vision for the system and needs of the stakeholders and the implemented system. The document includes all the high-level requirements for the AT CARM system, as derived from the Concept of Operations and verified through coordination with stakeholders. The core of the document will include a Requirements Traceability Matrix that will link user needs, applicable content included in the ConOps document, high-level requirements, and functional requirements. The scope and level of detail of the document will be based on examples provided by FHWA. The System Requirements document and traceability matrix will be developed by WSP and GHD in

coordination with the system's software provider (Transmax), and the CARM Integration Team.

4.4 Integration & Testing Plan

The integration and testing plan will result in a clear layout of how the integration of the STREAMS® intelligent transport system management solution will occur specifically for the Innovate 680 AT CARM corridor. This also includes the device integration approach, how existing and planned ITS systems and infrastructure will be affected, how the new system will be deployed. Additionally, the test strategy will be described, including a summary of the testing procedures and what their purpose is.

4.5 Test Plan

The Test Plan establishes the processes and metrics for testing software and hardware elements in terms of their ability to meet functional requirements. The plan outlines the software testing approach. This includes the testing strategy and high-level descriptions of the test plan and the test cases. The test strategy essentially describes the general methods to test the system. The Test Plan will also document how each individual test will trace to and fulfill individual requirements.

4.6 Verification

The verification step establishes the process for proving the entire operational system meets functional requirements and matches system design requirements. In simple terms, verification seeks to determine that the system was built correctly. The verification process is documented in Test Plans and Test Cases. The test plan describes how the testing stages in the strategy are applied to the project. Finally, the test cases describe the test environment configuration, test resources, and instructions for testing a project release to ensure it meets requirements.

Hardware testing will first be completed by the ITS device supplier. This will include the standard tests manufacturers complete prior to shipping out their products. Additionally, the ITS device supplier will test for compliance with STREAMS®. The ITS contractor will prepare a system testing facility to test the devices for compliancy to the system and to ensure devices are operational before the system is deployed.

The software provider will conduct the system testing, witnessed by Caltrans and CCTA staff and the project team.

4.7 Validation

Validation focuses on confirming that the system that has been deployed effectively achieves its desired outcomes. In simple terms, validation seeks to determine whether the right system has been built. Validation will be completed once the system is fully operational, and it is possible to determine how effectively the system can control traffic flow and reduce flow breakdown. As such, validation will be accomplished as part of the AT CARM performance evaluation of Segment 1 (and any subsequent deployments).

5 Transitioning Critical Technologies

The Australian Smart Freeways concept relies on advanced, highly precise ITS devices to monitor traffic flows and control freeway access on a continuous basis. Full applications of the Smart Freeways concept use CARM and other related traffic management tools such as lane use management systems (LUMS), Variable Speed Limits (VSL), and changeable message signs (CMS) displaying information on traffic conditions to ensure traffic on the freeway achieves optimum flow without breaking down into a congested state. The technology utilizes a comprehensive advanced traffic management system running a suite of algorithms to optimize mainline traffic flows while also balancing the demand for freeway access to manage ramp queuing and wait times throughout the entire corridor on a dynamic, real-time basis. This approach enables the system to manage and optimize traffic flows, distinguishing the Smart Freeways concept from other adaptive ramp metering and integrated corridor management strategies.

To meet the objectives of the Innovate 680 AT CARM Project, which is specifically seeking to demonstrate the effectiveness of the CARM component of Smart Freeways, all the technology proposed for the implementation of CARM are considered critical technologies. The feasibility study and preliminary design phases have examined existing and planned infrastructure and technology to determine any required improvements and additions, based on successful deployments of the concept elsewhere, including the SMART 25 Managed Motorways Pilot Demonstration in Denver, Colorado.

The ConOps document will articulate the sufficient type, number, frequency, and the correct installation locations of vehicle detectors and other technologies to accommodate the system concept. Functional requirements will be used to determine what the system needs to do. Based on the needs, specific devices and configurations will be identified. A System Verification and Validation Plan will then be developed to evaluate how the ITS devices work within the system.

Caltrans District 4 is responsible for the ramp metering operations in the California Bay Area. The current software used by Caltrans District 4 to calculate metering rates from 30-second measured traffic data is installed directly on the ramp meter controller at each field location. No entrance ramps are currently metered in Contra Costa County along I-680.

Caltrans District 4 also utilizes a Ramp Management Information System (RMIS) that centrally monitors all the ramps in operation, and forwards information to the Caltrans Advanced Traffic Management System (ATMS) and Caltrans PeMS.

The new Innovate 680 AT CARM Project is proposed to operate separately from - but in conjunction with - the existing Caltrans ATMS. Existing field devices within the I-680 corridor, and those proposed as part of the Caltrans SHOPP Fiber/TOS/Ramp Metering Project, include: CCTV cameras, inductive loop vehicle detectors, a fiber optic communications network, and ramp meter signals, controllers, and supporting equipment on select corridor entrance ramps.

New vehicle detection devices will be installed on the mainline and on ramps to improve accuracy for the new CARM system. In addition, ramp meters will be installed at all entrance ramps within the Segment 1 limits, and compatible signal controllers, new ramp meter controller firmware, field processors and other devices will be installed in ITS cabinets to facilitate real-time operations.

The strategy to integrate CARM into existing infrastructure and the system proposed as part of the Caltrans SHOPP Fiber/TOS/Ramp Metering Project will be described in the Integration and Testing Plan. However, initial activities are anticipated to include:

- Configuration, deployment and commissioning of ITS cabinets
- Commissioning the ITS network
- Establishment of a virtual private network (VPN) to provide continuous, secure, robust communication between Caltrans' ITS network and the STREAMS® ITS platform
- Commissioning the field processors
- Commissioning of new detection devices
- Deployment of the STREAMS® system
- Cut-over existing detectors to STREAMS® (where relevant)
- Testing & integration

The commencement of CARM operations will affect both direct users and indirect users of the system. Direct users will actively participate in using the system either through operations or administration. The direct users who operate the system will be from Transmax and CCTA, Caltrans or contracted operations staff and are familiar with the operation of the system. Indirect users include freeway management operators, TMC operators, Caltrans and CCTA engineers, maintenance staff, and managers. Indirect users do not actively participate in the operations of the proposed AT CARM system but will either be traveling in the corridor or may have interest in the system performance. Other indirect users include CHP, local police agencies, local fire departments, Freeway Service Patrol, jurisdictional managers, public information officers, commercial fleet operators, and public travelers.

With the commencement of the new STREAMS® system, there will be associated risks during operations of the Innovate 680 AT CARM Project. These operational and political risks are described below:

- **Enforcement:** Success of the Innovate 680 AT CARM Project is dependent on the ability of the ramp metering system to control throughput of vehicles onto the I-680 freeway. If there are a high number of ramp meter violators, the ability of the system to reduce congestion will be hindered, putting an emphasis on enforcement. Due to this risk, an emphasis will be placed on providing adequate CHP enforcement areas as part of system design. Specific violation performance indicators will be developed later in project development prior to system operations.

- **Traffic Volumes:** Pre-design feasibility analysis of the I-680 project corridor relied on existing traffic data from limited existing vehicle detector locations. More reliable data will not be available until after new detectors have been installed as part of the project. Since the feasibility data is based on existing conditions, unforeseen increases

in future volumes or changes to traffic patterns could impact the ultimate performance of the system. Similarly, ramp storage and configuration improvements proposed as part of the Innovate 680 AT CARM Project are based on available entrance ramp volume information. As such, future changes to volume patterns on certain ramps could impact the operational flexibility and effectiveness of the CARM system. Changes to ramp metering operational parameters will be made where possible to mitigate this risk.

- **Uncontrolled Mainline Entry:** The AT CARM system will only control the entry of vehicles from entrance ramps within the project limits. Therefore, increased volumes entering from upstream or downstream of the AT CARM project limits can have a negative impact on the system's ability to control congestion. For the Segment 1 AT CARM project, northbound volumes from south of Alcosta Blvd will be uncontrolled as well as traffic entering from eastbound SR-24 and entrance ramps north of Olympic Blvd.

- **Maintenance Constraints:** As mentioned previously, the successful operation of individual ITS devices and equipment are critical to the success of the Innovate 680 AT CARM Project. Malfunctioning or non-responsive equipment could have a significant impact on system performance. Therefore, the success of the AT CARM system relies on the ability of maintenance resources to quickly respond to problems. Specific maintenance response targets and performance metrics will be included as part of system implementation and operation, and detailed later in project development.

- **Public Acceptance:** The Innovate 680 AT CARM system will impact typical peak-period travel on the corridor relative to the existing condition, most notably through the introduction of new ramp meters and equipment on all ramps within the AT CARM corridor. New ramp meters and the activation of those ramp meters at different times of day will be needed by the CARM system to support the balancing of downstream ramp queues and optimization of mainline operations. Although these changes are expected to improve overall travel times and delay, these new practices will not be familiar to regular users of the corridor and may prove unpopular to drivers which could result in elevated public scrutiny and political attention. In order to mitigate this risk, stakeholder and public outreach and education will be a key component of system implementation and operation.

Activation of AT CARM and SHOPP ramp metering deployments along I-680 will need to be carefully managed and sequenced to avoid any issues with public and stakeholder acceptance. CCTA has worked extensively with local jurisdictions along the I-680 corridor to explain the unique operational characteristics of AT CARM to build support for deployment of the system and to appease preconceived concerns regarding ramp metering operations within the I-680 corridor. Consistent with these outreach efforts and the expectations of local jurisdictions, it is critical that the AT CARM operational strategy is integral to any ramp metering deployment along the Segment 1 AT CARM corridor to minimize public and stakeholder acceptance challenges.

6 Integration of the System

A Systems Engineering approach is being followed for the development and integration of the proposed CARM system. To elaborate on the specific integration process, an Integration and Testing Plan will be developed. The integration plan will consist of a device integration approach, integration with existing and planned ramp metering equipment and ITS assets, details of the final system, and commencement of CARM operations.

The device integration approach will examine the field devices required for the project, their purpose, and how it will be integrated into the system. The known devices to be integrated include the Transmax Field Processor, the 2070 ATC Ramp Signal Controller (and associated signals), inductive loop detectors, TIRTL Mainline detectors, and changeable message signs.

The existing mainline vehicle detection is currently comprised of inductive loop detectors that are not appropriately located and may not be adequate to meet minimum accuracy requirements. Therefore, mainline vehicle detection is proposed to be upgraded to TIRTL vehicle detectors. The existing ATMS system and ramp metering system outside of the Segment 1 corridor can remain intact during CARM operation. The Integration and Testing Plan will also outline what the final system will look like with existing devices, new devices, and how everything is interconnected.

7 Applicable Documents

The following list of resource documents serve as inputs for the Innovate 680 AT CARM system aspects and the SEMP:

a. I-680 Advanced Technology Project Coordinated Adaptive Ramp Metering – Corridor Evaluation, CCTA, July 2022
b. I-680 Advanced Technology Project Coordinated Adaptive Ramp Metering – Project Study Report, CCTA, November 2021
c. Systems Engineering Guidebook for ITS, version 3.0, FHWA/Caltrans
d. Ramp Metering Design Manual, California Department of Transportation Division of Traffic Operations, April 2016