SYSTEMS ENGINEERING GUIDELINES

Version 1.1 – February 2022

MDOT MARYLAND DEPARTMENT OF TRANSPORTATION

STATE HIGHWAY ADMINISTRATION

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Revision History

Version	Date	Author(s)	Reviewer(s)	Summary of Changes
0.1	8/05/21	DRIVE	MDOT SHA Rybinski Engineering	Initial Draft
0.2	8/10/21	DRIVE	Jacobs Rybinski Engineering	Internal review
1.0	8/16/21	DRIVE	MDOT SHA	
1.1	02/15/22	DRIVE	MDOT SHA	Minor revisions to address Stakeholder comments

Document References

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2. United States Department of Transportation, Federal Highway Administration - Systems Engineering Guidebook for Intelligent Transportation Systems, Version 3, Deliverable Templates and Checklists https://www.fhwa.dot.gov/cadiv/segb/views/index.cfm
3. United States Department of Transportation, Federal Highway Administration, Code of Federal Regulations Title 23, Subchapter K, Part 940 – Intelligent Transportation System Architecture and Standards https://www.fhwa.dot.gov/legsregs/directives/fapg/cfr0940.htm
4. United States Code Title 23 https://www.fhwa.dot.gov/map21/docs/title23usc.pdf
5. United States Department of Transportation, The National ITS Reference Architecture Version 9.0 (ARC-IT) https://local.iteris.com/arc-it/index.html
6. National Cooperative Highway Research Program Report 560, Guide to Contracting ITS Projects http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_560.pdf
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    a. Systems Engineering and Regional ITS Architecture for ITS Projects Version 2.0, October 2017 https://www.dot.nd.gov/divisions/maintenance/docs/SE-User-Guide.pdf
    b. ITS Project/Architecture Checklist Systems Engineering Compliance, Version 5.0 https://www.dot.nd.gov/forms/sfn60212.pdf
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Acronyms and Definitions

Acronym	Definition
ARC-IT	Architecture Reference for Cooperative and Intelligent Transportation
CDR	Critical Design Review
CFR	Code of Federal Regulations
ConOps	Concept of Operations
COTS	Commercial Off-the-Shelf
DMS	Dynamic Message Sign
FHWA	Federal Highway Administration
IAAP	ITS Architecture Advisory Panel
INCOSE	International Council on Systems Engineering
ITS	Intelligent Transportation Systems
MDOT	Maryland Department of Transportation
NHS	National Highway System
NITSA	National ITS Architecture
O&M	Operations and Maintenance
OTMO	Office of Transportation Mobility and Operations
PDR	Preliminary Design Review
PM	Project Manager
RITSA	Regional ITS Architecture
SE	Systems Engineering
SEGs	Systems Engineering Guidelines
SEMP	Systems Engineering Management Plan
SERF	Systems Engineering Requirements Form
SHA	State Highway Administration
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TOC	Traffic Operations Center
TSMO	Transportation Systems Management and Operations
USDOT	United States Department of Transportation

1 Introduction

The Maryland Department of Transportation (MDOT) State Highway Administration (SHA) Office of Transportation Mobility and Operations (OTMO) identified the need to implement Systems Engineering Guidelines (SEGs) to ensure compliance with Code of Federal Regulations (CFR) Title 23, Rule 940 (hereinafter, "23 CFR 940") and standardize usage of Systems Engineering (SE) processes for Intelligent Transportation System (ITS) projects. The target audience for this document includes multidisciplinary teams from MDOT SHA, OTMO, other state and local agencies, contractors, and consultants involved in ITS deployment projects in Maryland. The primary objectives for the implementation of the SEGs provided in this document include the following:

- Comply with 23 CFR 940 for federally funded ITS projects
- Maintain qualifications to obtain federal funding for ITS projects
- Align ITS deployments with MDOT's strategic plan
- Ensure effective deployment, integration, and operations and maintenance (O&M) of ITS to increase the reliability and longevity of ITS
- Support cost efficiency
- Enhance SE knowledge and ability to tailor SE processes to the scope and complexity of ITS projects
- Ensure individual and project team accountability for SE tasks
- Manage ITS project risks
- Provide checklists and other tools to support SE analysis and tailoring

This document was developed after extensive research of 23 CFR 940, the United States Department of Transportation (USDOT) Systems Engineering Guidebook v3[1], and multiple Peer-Agency SE resources to identify and incorporate federal regulations and SE best-practices into MDOT's SEGs. A complete list of resources researched as part of the development of MDOT SEGs are identified in the **Document References** section provided above.

The development of TSMO projects and initiatives is of the utmost priority to MDOT as an agency. As a result, the basic tenant of this document is to describe the SE process for TSMO focused ITS

[1] https://www.fhwa.dot.gov/cadiv/segb/files/segbversion3.pdf

projects. More information about MDOT's TSMO projects and strategies are available in the TSMO Master Plan.

Other agencies (e.g. transit, metropolitan planning, etc.) may use the SEGs provided in this document; however, it is important to note that other agencies will need to coordinate with their respective federal funding sources and decision making entities to ensure their specific requirements for SE are met.

1.1 Purpose

The purpose of this document is to:

- Provide a working knowledge of 23 CFR 940 and SE analysis requirements; and
- Define SEGs to be followed for applicable ITS projects within MDOT's jurisdiction.

1.2 Scope

This document includes information necessary to establish SEGs for ITS projects within MDOT's jurisdiction.

Chapter 2 provides a summary of 23 CFR 940 is to highlight key requirements, define its applicability to ITS projects, describe MDOT roles and responsibilities pertaining to compliance, and identify the MDOT ITS Architecture impacted by 23 CFR 940 requirements.

Chapter 3 provides an overview of SE to introduce the SE "V" Model, instill a working knowledge of SE processes and best-practices, and provide references to deliverable templates and additional resources.

Chapter 3 also provides SEGs to summarize what each step of the standard SE process entails, identify associated deliverables, and indicate the relationships among steps.

Appendix A provides SE checklists to guide SE analysis efforts and ensure 23 CFR 940 compliance for different types of ITS projects.

Appendix B provides an example of MDOT's Systems Engineering Requirements Form (SERF) to demonstrate the layout and level of detail necessary for projects requiring a SERF to be completed.

Appendix C provides an example of an MDOT Systems Engineering Management Plan (SEMP) to demonstrate the layout and level of detail necessary for projects requiring a SEMP to be completed.

1.3 MDOT's Systems Engineering Process at a Glance

For those with experience in SE, a snapshot of MDOT's SE process is shown in the flow chart in **Figure 1** below for brevity and convenience. Within the flow chart, references are provided to the document sections that explain each step in detail.

For those with little or no experience in SE, it is recommended that this document be reviewed in its entirety.

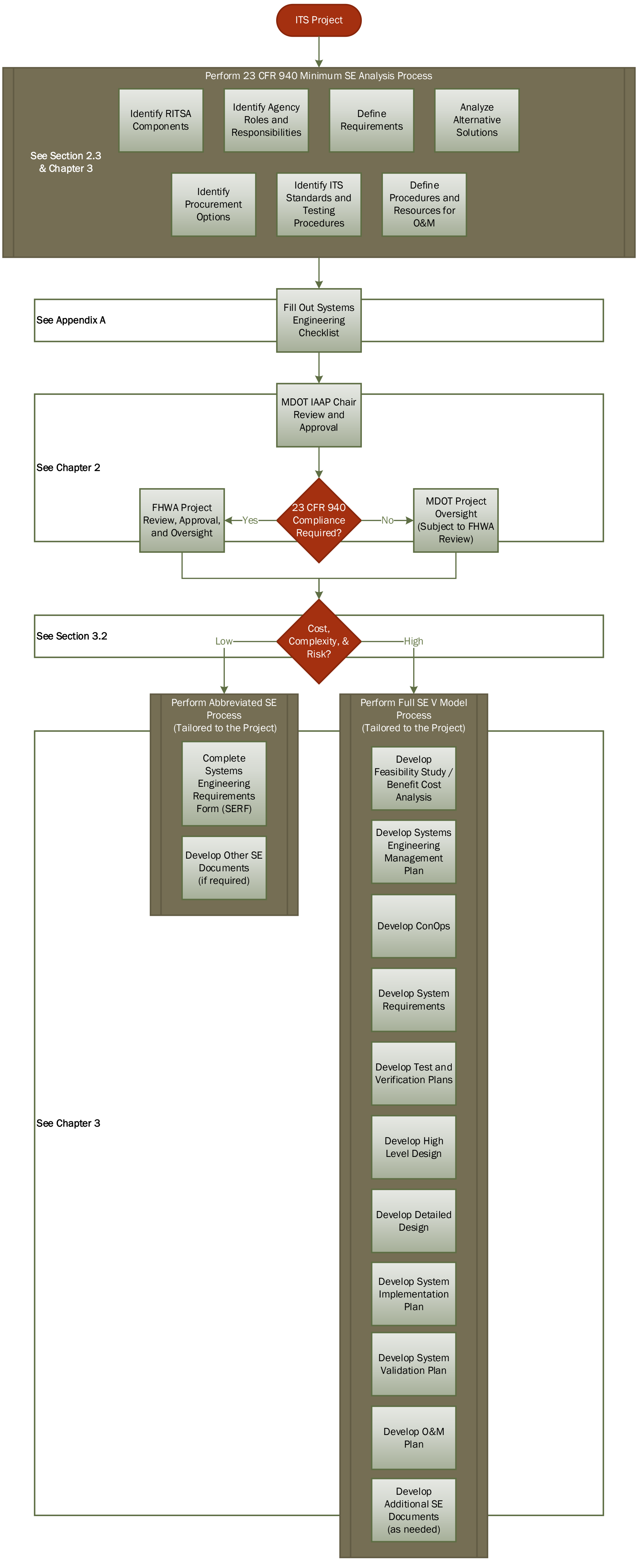

Figure 1 - MDOT Systems Engineering Process Flow Chart

2 Compliance with 23 CFR 940

One of the primary needs for SEGs is to ensure compliance with 23 CFR 940, which requires a minimum level of SE analysis for federally funded ITS projects. 23 CFR 940 defines an ITS project as:

> "… any project that in whole or in part funds the acquisition of technologies or systems of technologies that provide or significantly contribute to the provision of one or more ITS user services as defined in the National ITS Architecture"

The remainder of this chapter provides guidance for determining the applicability of 23 CFR 940 to ITS projects in Maryland, identifies the minimum steps of SE analysis required for compliance, defines MDOT roles and responsibilities, and identifies ITS Architecture(s) impacted by 23 CFR 940.

Please Note: 23 CFR 940 can be found at the link provided in the footnote below.[2] Project developers must review and understand 23 CFR 940 in its entirety to determine project applicability and ensure requirements are met.

2.1 Federally Funded ITS Projects

Per 23 CFR 940, compliance is required for all ITS projects funded in whole or in part with the Highway Trust Fund, including those on the National Highway System (NHS) and on non-NHS facilities. The SE Checklist provided in **Appendix A** must be completed and submitted to the MDOT ITS Architecture Advisory Panel (IAAP) Chair and Federal Highway Administration (FHWA) Maryland Division for review and approval. The FHWA has final determination regarding formal SE documents and level of detail required to be produced as part of the project. Federally funded projects will be overseen by FHWA.

Future changes in legislation may impact the level of FHWA oversight of ITS projects. This is a living document that will be updated to address any changes regarding 23 CFR 940.

[2] https://www.fhwa.dot.gov/legsregs/directives/fapg/cfr0940.htm

Please Note: 23 CFR 940.7 denotes potential exceptions for ITS projects funded by the Highway Trust Fund. Exceptions as stated in 23 CFR 940 are provided below for convenience:

1. Projects designed to achieve specific research objectives outlined in the National ITS Program Plan under section 5205 of the TEA-21, or the Surface Transportation Research and Development Strategic Plan developed under 23 U.S.C. 508; or
2. The upgrade or expansion of an ITS system in existence on the date of enactment of the TEA-21, if the Secretary determines that the upgrade or expansion:
   a. Would not adversely affect the goals or purposes of Subtitle C (Intelligent Transportation Systems Act of 1998) of the TEA-21;
   b. Is carried out before the end of the useful life of such system; and
   c. Is cost-effective as compared to alternatives that would meet the conformity requirement of this rule.
3. 23 CFR 940 does not apply to funds used for operations and maintenance of an ITS system in existence on June 9, 1998

2.2 Non-Federally Funded ITS Projects

23 CFR 940 compliance is not required for ITS projects that do not use federal funds; however, MDOT requires the minimum SE analysis as defined in **Section 2.3** to be completed as a standard practice. The SE Checklist provided in **Appendix A** must be completed and submitted to the MDOT IAAP Chair for review and approval. MDOT requires a Systems Engineering Requirements Form (SERF) to be completed for all ITS projects at minimum; however, the IAAP Chair has final determination regarding formal SE documents required to be produced as part of the project. An example of a completed SERF is provided in **Appendix B**. The level of detail required for SE documents may vary and will be determined on a case-by-case basis. Non-federally funded projects will be overseen by MDOT, subject to FHWA review.

2.3 Minimum SE Analysis Requirements

ITS projects must be developed based on SE analysis as defined by 23 CFR 940.11, which states the SE analysis should be on a scale commensurate with the project scope. **Table 1** below provides the minimum SE analysis requirements stipulated by 23 CFR 940.11 and provides references to the associated SEG sections in this document where additional guidance and context can be found.

Table 1 - Minimum SE Analysis Requirements

#	23 CFR 940.11 Requirement	Associated SEG Section(s)*
1	Identification of portions of the Regional ITS Architecture (RITSA) being implemented, or if a Regional ITS Architecture does not exist, the applicable portions of the National ITS Architecture (NITSA)	**3.3**
2	Identification of participating agencies' roles and responsibilities	**3.3**
3	Definition of requirements	**3.6** through **3.8** **3.15**
4	Analysis of alternative system configurations and technology options to meet requirements	**3.4** & **3.15**
5	Identification of procurement options	**3.4** & **3.8**
6	Identification of applicable ITS standards and testing procedures	**3.3** **3.5** through **3.8** **3.10** through **3.13**
7	Definition of procedures and resources necessary for operations and management of the system	**3.5** & **3.14**

Chapter 3 *of this document provides an overview of the full SE process and additional guidance for completing each SE analysis step. Although 23 CFR 940 requires only the minimum SE analysis activities listed above, project developers should review and understand the entire SE lifecycle and the relationships/interdependencies among steps. Certain ITS projects may require the full suite of SE processes and associated deliverables.*

The following subsection defines MDOT SHA roles and responsibilities for meeting the minimum SE analysis requirements established by 23 CFR 940.11.

2.4 Roles and Responsibilities for SE Analysis

Per 23 CFR 940.13, compliance with 23 CFR 940.11 must be demonstrated prior to authorization of highway trust funds for applicable construction or implementation of ITS projects. Compliance is monitored under Federal-aid oversight procedures as provided under 23 U.S.C 106 and 133[3].

The MDOT SHA Project Manager (PM) and IAAP Chair are dually responsible for ensuring 23 CFR 940 requirements are met and documented properly. **Appendix A** provides SE Checklists which satisfy the requirement for demonstrating compliance with 23 CFR 940 prior to federal authorization of funds. As a reminder, MDOT requires completion of the same SE Checklists for all ITS projects, not just those required to comply with 23 CFR 940.

Basic responsibilities by role are summarized below:

1. The PM shall:
    - Perform minimum SE Analysis as described in **Section 2.3;**
    - Fill out and submit the completed checklists provided in **Appendix A** – SE Checklists to the IAAP Chair for initial review; and
    - Revise the checklists as necessary and resubmit to the IAAP Chair until it is approved internally.
2. The IAAP Chair shall submit the completed forms and supporting documentation to the FHWA Maryland Division, if 23 CFR 940 compliance is required.

Completion of the above-mentioned forms and supporting project documents will satisfy 23 CFR 940 requirements for demonstrating compliance.

2.5 ITS Architecture

23 CFR 940.9 requires development of a RITSA for all ITS projects in accordance with the NITSA. For the purposes of this document, the term RITSA refers specifically to Maryland's State ITS Architecture. Maryland's RITSA satisfies this requirement; however, project developers must still identify portions of the RITSA that will be implemented by the project as part of required SE analysis. In cases where the existing RITSA does not include architecture components to be

[3] https://www.fhwa.dot.gov/map21/docs/title23usc.pdf

implemented by the project, the PM must identify the new ITS architecture components that must be added to the existing RITSA to comply with 23 CFR 940.9.

SEGs for the ITS architecture process are provided in **Section 3.3.**

ITS Architecture requirements from 23 CFR 940.9 are provided below for convenience:

1. A regional ITS architecture shall be developed to guide the development of ITS projects and programs and be consistent with ITS strategies and projects contained in applicable transportation plans. The National ITS Architecture shall be used as a resource in the development of the regional ITS architecture. The regional ITS architecture shall be on a scale commensurate with the scope of ITS investment in the region. Provision should be made to include participation from the following agencies, as appropriate, in the development of the regional ITS architecture: Highway agencies; public safety agencies (e.g., police, fire, emergency/medical); transit operators; Federal lands agencies; State motor carrier agencies; and other operating agencies necessary to fully address regional ITS integration.
2. Any region that is currently implementing ITS projects shall have a regional ITS architecture by April 8, 2005. All other regions not currently implementing ITS projects shall have a regional ITS architecture within four years of the first ITS project for that region advancing to final design.
3. The regional ITS architecture shall include, at a minimum, the following:
    a. A description of the region;
    b. Identification of participating agencies and other stakeholders;
    c. An operational concept that identifies the roles and responsibilities of participating agencies and stakeholders in the operation and implementation of the systems included in the regional ITS architecture;
    d. Any agreements (existing or new) required for operations, including at a minimum those affecting ITS project interoperability, utilization of ITS related standards, and the operation of the projects identified in the regional ITS architecture;
    e. System functional requirements;
    f. Interface requirements and information exchanges with planned and existing systems and subsystems (for example, subsystems and architecture flows as defined in the National ITS Architecture);
    g. Identification of ITS standards supporting regional and national interoperability; and

   h. The sequence of projects required for implementation.

4. Existing regional ITS architectures that meet all of the requirements of paragraph (3) of this section shall be considered to satisfy the requirements of paragraph (1) of this section.
5. The agencies and other stakeholders participating in the development of the regional ITS architecture shall develop and implement procedures and responsibilities for maintaining it, as needs evolve within the region.

3 Systems Engineering Guidelines

This chapter provides an overview of the standard SE "V" model and provides specific SEGs to support the completion of tasks inherent to each step of the SE process. In combination with **Chapter 2** and the checklists provided in **Appendix A**, this chapter serves as a convenient resource to guide project developers through key steps of SE. The information provided in this chapter is adapted for MDOT's needs based on the USDOT SE Guidebook v3 and best practices from peer agency SEGs identified in the **Document References** section of this document. As a refresher, key subsections correlating directly to 23 CFR 940 SE analysis requirements are identified in **Section 2.3 – Table 1**.

3.1 Overview of Systems Engineering

The International Council on Systems Engineering (INCOSE) defines systems engineering as:

> "An interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem."

At its core, the SE process is a systematic and iterative approach to ensure the final design of a system addresses stakeholder needs and accomplishes performance and operational objectives. To determine the final design and ensure compliance with 23 CFR 940, the SE process is used to evaluate multiple design options, costs, and associated relative value of options from a lifecycle perspective, from initial project planning through eventual retirement/replacement.

Although several SE models exist, the SE "V" model is the most prevalent and widely used model in the transportation industry. The SE "V" model defines a standard set of structured steps for ITS projects as shown in **Figure 2** below.

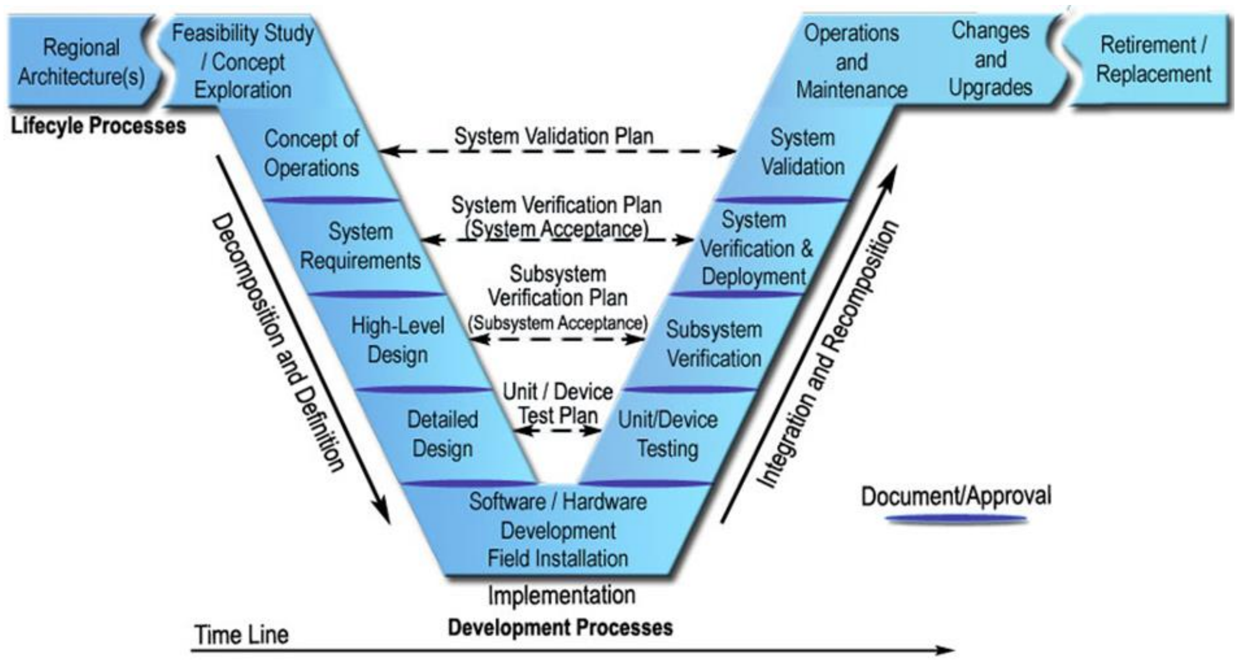

Figure 2 - SE "V" Model

The project lifecycle flows from left-right. At a high-level, the left side of the "V" represents the stages of planning and design; the bottom of the "V" represents implementation; and the right side of the "V" represents testing, integration, and O&M of the system. Although not explicitly shown in the "V" model, critical initial steps of the SE process include identifying stakeholder needs and explicitly defining the problem, as well as tailoring the SE process to be appropriate for the project scope and complexity. These initial steps are typically performed during concept exploration.

In addition to the steps shown in the "V" model, there are several best practices inherent to SE that are performed continually throughout the project lifecycle. The USDOT refers to these best practices as "crosscutting activities," which support progression through one or more of the SE processes. Adapted from the USDOT SE Guidebook v3, crosscutting activities are described in **Table 2** below:

Table 2 - Crosscutting Activities

Crosscutting Activity	Best Practice
Stakeholder Involvement	Involve stakeholders early and often during the project to fully understand needs and requirements of the system. Garner stakeholder feedback on progress as well as any changes and upgrades on a regular basis.
Elicitation	Gather and document information needed to develop the system. Define goals, objectives, and expectations. Resolve information conflicts, validate information, and gain consensus among those involved in the project.
Project Management	Establish a support environment for project development activities. Provide, monitor, and control resources, project schedules, and budgets. Communicate and coordinate with those involved with the project.
Risk Management	Identify, analyze, and monitor risks. Plan for how to mitigate, avoid, transfer, or accept risks.
Project Metrics	Define measures to track and monitor project progress and performance of technical system development to assess whether the project is on-track.
Configuration Management	Manage changes throughout the project lifecycle to ensure functional and physical integrity of the system.
Process Improvement	Monitor and improve processes continuously throughout the project to learn from past efforts and enhance future work.
Decision Gates	Implement formal decision points to review and accept work products and determine readiness for the next step(s) in the project. These are represented in the V model by the blue "document/approval" lines. *Note:* Additional decision points may be added. For instance, a project planning and systems engineering management plan decision point may be added between the concept exploration phase and concept of operations phase if needed.
Decision Support and Trade Studies	Compare alternative solutions and evaluate all options to determine the solution with the best relative value.

Crosscutting Activity	Best Practice
Technical Reviews	Review the quality and completeness of work products, identify shortcomings, and ensure consensus among team members regarding technical direction.
Traceability	Ensure all needs are mapped to testable requirements. Ensure all requirements are implemented, verified, and validated.

The remainder of this chapter provides SEGs for each step of the SE process. First, SEGs are provided for tailoring the SE process to specific projects based on project scope, complexity, and risks. Then, each step of the SE "V" model, key activities, and associated deliverables are described in detail.

Additional resources, including deliverable templates and checklists for each step of the SE process, can be found on the USDOT SE Guidebook v3 website[4].

3.2 Tailoring the SE Process to the Project

The SE "V" model establishes a comprehensive set of steps and deliverables spanning the entire lifecycle of ITS projects; however, not every ITS project will require each step to be completed in its entirety. As mentioned previously, 23 CFR 940 states that the SE process should be tailored to correspond with a project's scope, complexity, and risk. For instance, a standard deployment of a standalone Dynamic Message Sign (DMS) is generally well-known with minimal risk and may not require or constitute the costs incurred by completing the full suite of SE activities for each specific project.

In contrast, a large or complex project deploying brand-new integrated software or technology systems may require each step of SE to be completed in full, including the development of detailed project specific deliverables and documentation associated with each step of the SE process. Projects falling under this category are not necessarily limited to new software or technology, and could include large-scale deployments of standard systems in multiple phases, implementation of new operational strategies coinciding with deployments, and/or integration of systems with interfaces for functions beyond basic device operations (e.g. additional data

[4] https://www.fhwa.dot.gov/cadiv/segb/views/index.cfm

sharing among agencies, enhanced performance monitoring, automated maintenance ticketing, etc.).

To tailor the SE process to specific projects, project developers must analyze project scope, complexity, and risks to determine the optimal level of SE analysis and associated documentation needed to adequately develop the system and mitigate project risks, while maintaining 23 CFR 940 compliance if applicable. In some cases, the optimal level of SE for a specific project may surpass what is required at minimum by 23 CFR 940. PMs shall coordinate with the IAAP Chair to determine tailoring of the SE processes to the project, especially in cases where a project may constitute going beyond minimum 23 CFR 940 SE analysis requirements. In all cases, project developers should leverage SE analyses and associated SE documentation completed previously for directly applicable ITS projects to the extent possible.

Generally, projects classified as low risk will require an abbreviated SE process, requiring minimum SE analysis as defined in **Section 2.3** and the completion of a SERF (as seen in **Appendix B**) of appropriate detail for the project. In contrast, project classified as high-risk are recommended to follow the full SE "V" model process, including development of each SE deliverable throughout the project lifecycle. Again, the level of detail of associated deliverables is tailored to the project.

Common risk factors to consider when tailoring the SE process to the project are provided below:

- Project complexity, including technology, external/internal interfaces, and institutional concerns
- Potential for cost overruns and re-engineering
- Schedule and budget constraints
- Advancements in technology
- Communications and data needs – existing capacity or need to upgrade
- Number and type of stakeholders – sharing, control, and ownership of data
- Security
- Availability of existing documentation vs. development of new documentation

Appendix A – SE Checklists includes a series of questions to aid in classifying projects as low or high risk as well as tailoring the SE process and identifying required documentation for the project. A flow chart demonstrating the risk classification and tailoring process is provided in **Figure 3** on the following page.

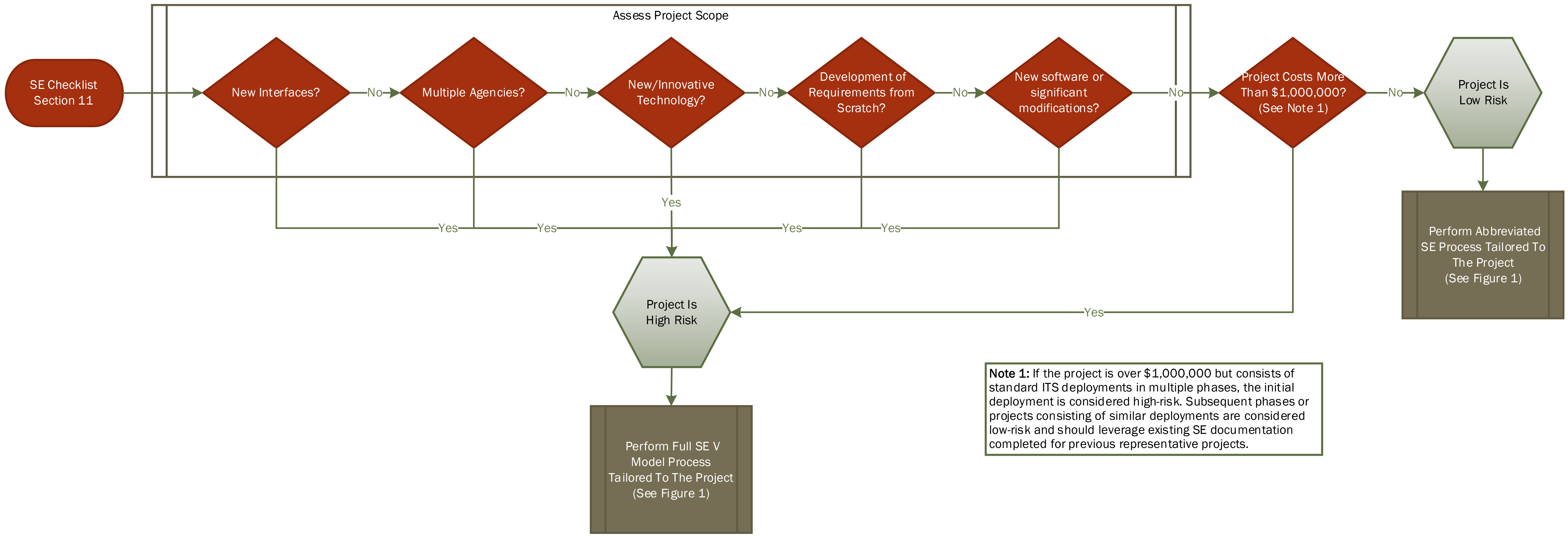

Figure 3 - Project Risk Classification Flow Chart

3.3 Regional Architecture Review and Development

The first step shown in the SE "V" model involves the review and development of the RITSA associated with the project. The RITSA is critical to ensuring that ITS devices, communications, data, and accompanying software systems are incorporated into the overall transportation network in an integrated fashion. Simply put, the RITSA formally documents how ITS components are integrated and used within a region by stakeholders and provides a framework for efficient planning and execution of ITS projects now and in the future. RITSA components include the following items:

- Architecture scope
- List of stakeholders
- Connection of architecture to regional planning goals, objectives, and strategies
- Inventory of ITS elements
- Regional ITS services
- User needs
- Operational concept (stakeholders' roles and responsibilities)
- System functions and requirements
- System interfaces supporting the services
- Communications and device standards
- Interagency agreements to support ITS services and projects
- Sequence of regional ITS projects

Figure 4 below provides a visual representation of ITS architecture components and how they are connected.

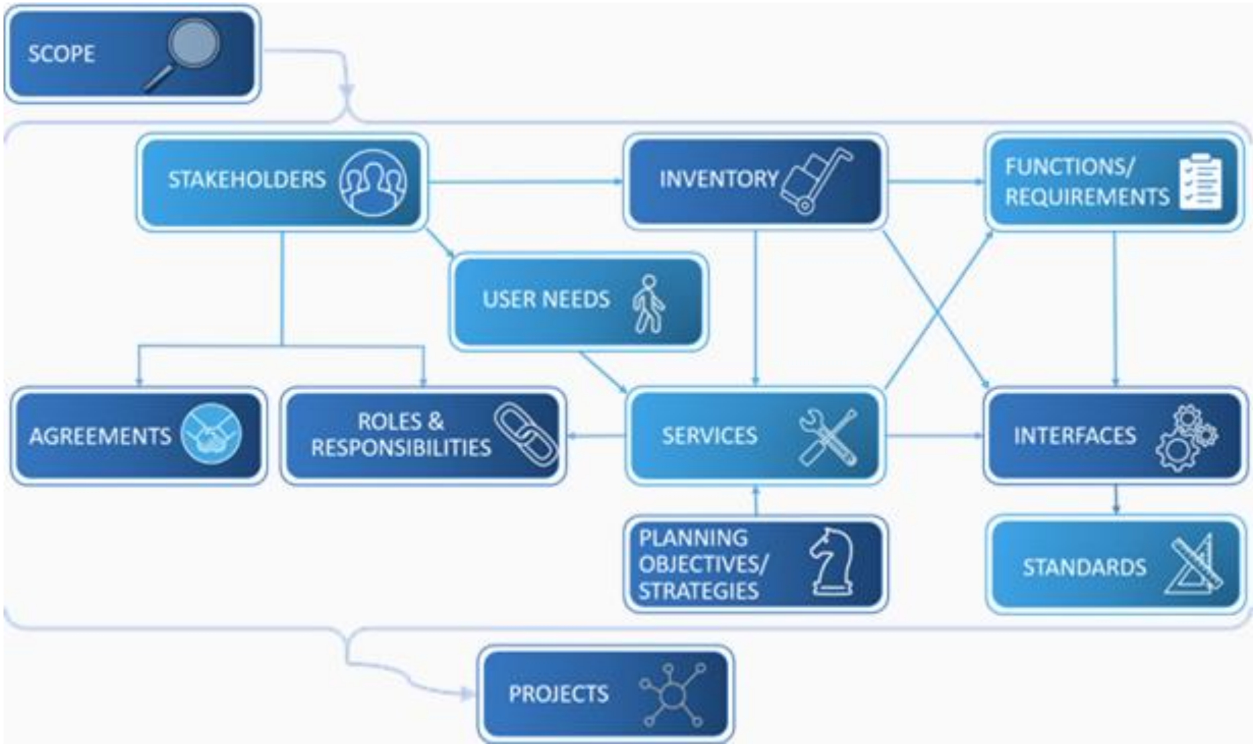

Figure 4 - ITS Architecture Components

Source: USDOT Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT)

After careful review and development of the RITSA, the following items must be identified and formally documented on the SE Checklist provided in **Appendix A** to comply with 23 CFR 940:

- Stakeholders impacted by the project
- Stakeholder roles and responsibilities
- Portions of the RITSA being implemented by the project (i.e. service packages)
- Updates or additions to the RITSA needed by the project, if applicable
- ITS and communications standards

Additional resources and tools pertaining to RITSA review and development can be found at the USDOT Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT), provided as a link in the footnote below[5].

[5]https://local.iteris.com/arc-it/index.html

3.4 Concept Exploration

The second step shown in the SE "V" model involves initial concept exploration, feasibility study(s), and project planning. Generally, this step can be broken down into three (3) key activities that are used to refine the needs, goals, objectives, and vision of the project:

- Refining stakeholder needs
- Conducting feasibility and benefit cost analysis
- Initial project planning

Guidance for each key activity is provided in the following subsections.

3.4.1 Refining Stakeholder Needs

Refining stakeholder needs is a crucial but straightforward crosscutting activity inherent to in the SE process. Using the list of stakeholders and roles and responsibilities developed during RITSA review, the project developer should perform the following activities to refine and formalize project needs:

- Identify system owner and key stakeholders
- Coordinate and meet with system owner and key stakeholders to elicit needs
    - Formally document needs
    - Validate and confirm needs
    - Prioritize needs
- Perform gaps analysis (if required for conflicting needs)
- Cost comparison (if required for conflicting needs)

The activities culminate in a prioritized list of verified needs which will be used to further define the system in subsequent steps.

3.4.2 Feasibility and Benefit Cost Analysis

Following refinement of stakeholder needs, a feasibility study / benefit cost analysis should be performed. During this step, alternative project concepts and procurement options are evaluated based on their ability to meet stakeholder needs, goals, and objectives, and produce the highest benefit to cost ratio. The primary goal of this step is to justify the ITS project and gain buy-in from management to move forward into project planning and system development.

The following items should be included in a formal feasibility and benefit cost analysis report, or memo, based on project scale:

- Problem statement and identification of needs;
- Project vision, goals, and objectives;
- Project constraints (technological, organizational, budgets, schedule, etc.);
- Proposed system concepts, including alternatives (required by 23 CFR 940);
- Evaluation of alternative system concepts, and rationale for the chosen option (required by 23 CFR 940);
- Benefit cost analysis;
- Identification of procurement options, and rationale for the chosen option (required by 23 CFR 940); and
- Recommended system concept.

Once the ITS project concept is deemed feasible, initial project planning can begin. Items required by 23 CFR 940 must be documented on the SE Checklist provided in **Appendix A** of this document.

3.4.3 Initial Project Planning

The final step in concept exploration is initial project planning. At this stage, the PM develops a summary of work and a list of required SE documents tailored to the project based on 23 CFR 940 and MDOT requirements as applicable, as well as a high-level schedule for project implementation. Required SE documents are developed as part of subsequent SE "V" model steps, and serve as control documents to plan, design, and implement the system.

A Systems Engineering Management Plan (SEMP), as seen in **Appendix C**, and other supporting management plans (ex. configuration management plan, risk management plan, etc.) may be required as part of initial project planning based on project scope and complexity.

3.5 Concept of Operations

Building upon the initial concept exploration, the Concept of Operations (ConOps) represents a significant milestone in ITS project development and provides a critical link between stakeholder needs and system level requirements. The ConOps establishes an initial basis for systems design and defines the way the system is expected to operate in an easy-to-understand manner. Notably, the ConOps is directly connected with system validation later in the SE process, as it provides a mechanism to compare and confirm that the system operates as intended. The

ConOps is developed with multiple system users (stakeholders) in mind and considers the operational needs and perspectives of managers, operators, maintenance personnel, and others who will interact with the system.

Consistent with other steps of the SE process, the ConOps should be tailored to be of appropriate detail for the scope, complexity, and risk associated with the project.

3.6 System Requirements

In this step, system requirements are developed based on the user needs, operational scenarios, and system constraints identified in the ConOps. Notably, this step is directly related to system verification and deployment performed later in the SE process, where the system verification plan developed as part of this stage will be used to test and verify system requirements prior to acceptance of the system. Generally, system level requirements detail the following types of requirements, at a minimum:

- Functional requirements: define all functions required to meet stakeholder needs and expectations of the system
- Performance requirements: define how well the system shall perform the required functions
- Non-functional requirements: define under what conditions the system shall operate

System requirements do not normally stipulate how the system must be implemented to allow for innovation or flexibility in implementation. In some cases, requirements may define how the system will be implemented to limit the project to a specified solution. In ITS projects, requirements are commonly developed at both the system and sub-system level. Tasks involved with developing detailed system requirements are as follows:

- Review ConOps and identify required functions, performance needs, constraints, etc.;
- Develop and document requirements;
- Check completeness;
- Analyze, refine & decompose requirements;
- Validate and gain consensus among stakeholders on requirements; and
- Manage requirements and maintain traceability.

System requirements developed as part of this step will be used to further define the system during high-level and detailed design stages. Definition of system requirements is required by 23 CFR 940 and must be documented on the SE Checklist provided in **Appendix A**. For the purposes of the SE Checklist, a summary of key system requirements along with an indication that a formal system requirements document(s) is, will be, or does not need to be completed (with justification) is sufficient for the form.

3.7 High-Level Design

The high-level design process uses the system level requirements established in the systems requirements document to develop a project level ITS architecture for the system and define requirements for sub-systems and the associated hardware, software, ITS communications standards, databases, data processing, and items related to user operations. The process is similar to system level requirements development. Requirements for each sub-system component are refined, documented, and mapped to needs and system requirements until the level of detail necessary for high-level design is achieved. Internal and external interfaces are also defined for each sub-system to establish requirements for integration with other internal and external systems.

The high-level design process results in a formal document that will be used to develop a detailed system design. Additionally, the high-level design provides a mechanism to test, verify, and accept sub-systems through execution of an associated Subsystem Verification Plan during the sub-system verification step performed later in the SE process. Following the completion of the high-level design document, a Preliminary Design Review (PDR) is conducted to obtain stakeholder feedback, address changes, and get approval of the high-level design before progressing to the detailed design stage.

3.8 Detailed Design

Detailed design is the final design step required to develop the system prior to its installation and integration. During detailed design, high-level design requirements are used to specify how the system will be built at the individual system component or device level in a formal detailed design document. Detailed design involves development of detailed "build-to specifications" for all hardware, software, communications, and other system components/devices required to build out the system in accordance with the requirements established. As part of the build-to specification, the detailed design document identifies the specific makes, models, and specifications for any commercial off-the-shelf (COTS) products used in the design, as well as any customized software or hardware that may need to be developed.

Much like previous steps, the detailed design document provides a mechanism to test, verify, and accept system components and devices during the device testing stage through execution of an associated Device Test Plan. Following the completion of the detailed design document, a Critical Design Review (CDR) is conducted to obtain stakeholder feedback, address changes, and get approval of the final detailed design before procuring or building the system components and devices specified in the detailed design. Following review and acceptance of the detailed design, system components and devices are ready to be developed/procured and implemented.

3.9 Software/Hardware Development and Field Installation

The software/hardware development and field installation process encompass the procurement of COTS products, development and manufacture of any customized hardware or software, and the implementation of the system components and devices specified in the detailed design. All installation activities are identified, coordinated, and scheduled in a detailed Implementation Plan prior to execution. During this stage, it is critical for the system owner and stakeholders to monitor progress and conduct regular technical reviews to address any unforeseen issues or changes to the system, ensure requirements are satisfied, and maintain the integrity of approved designs.

A Device Test Plan is also developed during this stage to prepare for post-implementation device testing. The Device Test Plan consists of step-by-step procedures necessary to test and demonstrate how the system components/devices satisfy the requirements established during detailed design. At the completion of this stage, the system components and devices are installed and ready for device testing.

3.10 Device Testing

During the device testing stage, the Device Test Plan is executed for each system component and device to verify the installed system components/devices satisfy the requirements stipulated in the detailed design. Test procedures are required by 23 CFR 940. The results of each test must be documented and provided to the system owner and stakeholders for review and acceptance. If a test fails, punch list items are captured and communicated to the responsible party to fix any issues. In these cases, device tests are repeated until all issues are resolved, and the device successfully passes testing. After formal acceptance of test results, the system is ready to progress to the next stage of integration.

3.11 Subsystem Verification

After device testing is completed, the system advances to subsystem verification. Subsystem verification involves the development and execution of a Subsystem Verification Plan, which provides procedures necessary to verify the subsystem level requirements detailed in the high-level design document. Test procedures are required by 23 CFR 940. However, before subsystem verification begins, a test readiness review should be conducted for each subsystem to confirm they are integrated and ready for verification. The Subsystem Verification Plan is then executed for each subsystem until all subsystems pass verification procedures.

The results of each subsystem verification procedure must be documented and provided to the system owner and stakeholders for review and acceptance. If verification fails, punch list items are captured and communicated to the responsible party to fix any issues. In these cases, subsystem verification procedures are repeated until all issues are resolved, and the subsystem is verified. After formal acceptance of subsystem verification results, the system is ready to progress to the next stage of system deployment and verification.

3.12 System Deployment and Verification

System deployment and verification involves three (3) distinct steps:

1. Factory test
2. On-site testing and verification
3. System burn-in

These steps are performed per the System Verification Plan developed during the system requirements stage. The primary goal of system deployment and verification is to verify that the system conforms with all system level requirements established during system requirements definition.

First, the system undergoes system requirements verification in a controlled environment, commonly referred to as a “factory test”. Next, the system is verified in its actual operational environment, commonly referred to as “on-site testing and verification”. In practice, on-site testing and verification generally involves test procedures designed to verify system functionality and performance from both the field and Traffic Operations Center (TOC) perspectives. For example, on-site DMS system verification would involve verifying communications status, remote reset functionalities, posting of messages, and alarm generation under various scenarios initiated in the field such as pixel errors, light sensor malfunctions, etc. against system requirements. TOC personnel verify with field staff that the DMS is responding to remote commands and operating as intended. Likewise, on-site verification for a Closed-Circuit Television (CCTV) camera system would involve verifying communications, pan-tilt-zoom functions, image clarity, etc. against system requirements both in the field and in the TOC. After successful completion of on-site verification, the system is conditionally accepted, pending final verification as described below.

After completion of on-site verification, the system undergoes what is typically referred to as "system burn-in". System burn-in involves long-term operational testing to verify system requirements are met over a specified duration. Durations vary; however, common practice for ITS is usually sixty (60) days. The intent of this step in the system verification process is to verify consistent operations of the system in its fully integrated state under varying real-world conditions that the system will encounter over the long-term.

Consistent with the other testing and verification stages, test procedures are required by 23 CFR 940. Additionally, the results of each system verification procedure must be documented and provided to the system owner and stakeholders for review and acceptance. If verification fails at any point, punch list items are captured and communicated to the responsible party to fix any issues. In these cases, system verification procedures are repeated until all issues are resolved and the system is verified. After formal acceptance of each step in the system verification process, the system is fully accepted, paid for, and progresses to system validation.

3.13 System Validation

System validation is a critical last step performed prior to entering the ongoing system Operations and Maintenance (O&M) phase. System validation is focused on evaluating performance of the system in relation to project needs, goals, objectives, and operational expectations as defined in the ConOps. To accomplish system validation, the system owner and stakeholders follow a set of system validation procedures defined in the System Validation Plan developed as part of this step in the SE process. As a best practice, system validation should be performed as soon as possible after system acceptance to adequately perform a strengths, weaknesses, opportunities, and threats (SWOT) analysis of the system. Results of the system validation process are documented in a System Validation Report, including a SWOT analysis. Findings from system validation are used to support planning of ongoing O&M of the system, as well as prioritizing potential changes upgrades to the system in subsequent SE steps.

3.14 Operations and Maintenance

The O&M phase of the SE process consists of staff training, operating the system for its intended purpose, and performing preventative and corrective maintenance activities to preserve the system's performance and operational integrity. As such, sufficient resources must be dedicated to O&M of the system to maximize its useful life and maintain its reliability and performance. 23 CFR 940 requires the definition of procedures and resources needed for O&M of the system.

The O&M phase begins after the system is fully accepted and extends until the system is retired or replaced. O&M needs and procedures vary among ITS devices, but generally follow manufacturer recommended maintenance regimes. As part of ongoing O&M, operators and maintainers also identify and recommend changes and upgrades necessary to maximize system performance or accommodate system expansion.

3.15 Changes and Upgrades

After completing the full suite of SE processes identified in the "V" model, the system intent and technical design is well-documented, tested, and verified. However, changes and upgrades to the existing system may be necessary to maintain system performance, extend its useful life, expand the system, or integrate additional components, technology, interfaces, etc. Changes and upgrades to the system should go through the same "V" model process followed for the initial implementation to ensure changes and upgrades are practicable, well-documented, and managed for successful deployment. In some cases, changes or upgrades to an existing system may be more cost-effective or preferable than replacing the system outright.

3.16 Retirement/Replacement

Inevitably, every system will reach the end of its useful life and require retirement or replacement. One or more of the following reasons generally justify retirement or replacement of a system:

- The system may no longer be needed
- The system may no longer be cost effective to operate and maintain
- The system or its key components may become obsolete, or unable to be maintained due to halted manufacturer production or support
- The system may be temporary and planned for replacement by a permanent system

Prior to retiring or replacing a system, a plan for the retirement or replacement should be developed. The plan should include a gap analysis, an evaluation of costs to upgrade the system versus replacing it (if applicable), a replacement or retirement strategy, and identification of the system, subsystem, or system components planned to be retired or replaced.

Appendix A – SE Checklists

MDOT Intelligent Transportation Systems

Systems Engineering Checklist

Section 1 – Project Information

Project Name:	**Project Number:**
Project Manager:	**County:**
Title:	**Municipality:**
Phone Number:	**Route:**
Email:	**Mile Posts:**
Estimated Project Cost:	**Estimated ITS elements Cost:**

Federally Funded (23 CFR 940 Applies): ☐ **State Funded:** ☐

Section 2 – Nature of Work (choose all that apply)

☐ Implementation of ITS	☐ Operations	☐ Maintenance/Equipment Replacement
☐ Software Development	☐ Construction including ITS	☐ Other

If "Other" was selected, please provide a brief explanation:

Section 3 – Regional ITS Architecture Conformance (choose all that apply)

☐ Archived Data Management	☐ Asset Management	☐ Commercial Vehicle Operations
☐ Electronic Payment	☐ Emergency Management	☐ Highway Management
☐ Incident Management	☐ Maintenance and Construction Management	☐ Parking Management
☐ Public Transportation Management	☐ Traffic Management	☐ Traffic Signal Control
☐ Transit Management	☐ Traveler Information	☐ Vehicle Safety

If "Other", please provide a brief explanation:

Does the project require the addition or update of ITS elements in the architecture	☐Yes ☐No

Section 4 – Needs Assessment

1. What is and/or are problem(s) with the present situation?

2. What needs does this project aim to address?

3. How were these needs identified?

Section 5 – Procurement

1. What procurement options apply to the project? (choose all that apply)

Commodity Supplier	Consultant	Design-Build	Low Bid Contractor with CD	Outsourcing	Systems Manager	Other
☐	☐	☐	☐	☐	☐	☐

If "Other" was selected, please identify:

2. What is the recommended option for procurement of the project? Provide a brief justification.

Section 6 – Operations and Maintenance

1. What procedures and resources are needed for ongoing/future operation?

2. What is the estimated annual operations & maintenance cost?

3. What stakeholder(s) are responsible for the maintenance and funding?

Section 7 – Agencies

Identify any agencies contributing to the project. In addition, define the roles and responsibilities that each listed agency has pertaining to the project.

#	Agencies	Roles and Responsibilities
1		
2		
3		
4		
5		
6		

Section 8 – System Alternatives

Identify any alternative system configurations and technology options to meet requirements.

Section 9 – ITS Standards and Testing Procedures

Identify any applicable ITS standards and testing procedures.

Section 10 – ITS Technology (choose all that apply)

If the project contains any of the following ITS technologies, proceed to their respective checklists at the end of the document. After completion, continue to Section 11.

☐**DMS**	☐**CCTV**	☐**Traffic Signal**	☐**Communications**
☐**Road Weather Information System**	☐**Adaptive Signal Control**	☐**Traffic Detection**	

Section 11 – Project Scope

1. Additional new interfaces will be incorporated into systems operated or maintained by other agencies.	☐**Yes** ☐**No**
2. Work including project construction, design, deployment, maintenance, and operations will be managed by several separate agencies.	☐Yes ☐No
3. The project utilizes ITS technology that are either new to the industry or uncommonly applied for similarly developed projects.	☐Yes ☐No
4. The project requires development of new system requirements or require revisions to existing system requirements to document emerging needs.	☐Yes ☐No
5. Software utilized by the project either heavily modifies current software or requires specifications uniquely developed for the project.	☐Yes ☐No

Section 12 – Project Cost

Less than $1,000,000 (Low-Risk)	☐Yes	**Indicate exceptions to cost risk assessment, if applicable:**
More than $1,000,000* (High-Risk)	☐Yes	**Indicate exceptions to cost risk assessment, if applicable:**

If "Yes" was answered for any of the questions in Section 11, the project is deemed "High-Risk". If "Yes" was answered for a project being more than $1,000,000, the project is deemed as "High-Risk" in most cases* (See Note 1 below).

***Note 1: If the project is over $1,000,000 but consists of standard ITS deployments in multiple phases, the initial deployment is considered high-risk. Subsequent phases or projects consisting of similar deployments are considered low-risk and should leverage existing SE documentation completed for previous representative projects.**

Low-Risk (Check): ☐	**High-Risk (Check):** ☐
An abbreviated SE process and completion of the MDOT Systems Engineering Requirements Form (SERF) is required.	All steps and documentation of the V Model Systems Engineering process are required to be completed. (See NOTE 1 above)

Section 13 – Documentation Matrix

The matrix below identifies all documentation relating to the system engineering process. If documentation is deemed "Not Applicable", deviating from the recommended risk level process, justify why it does not apply in the comments.

	Existing	To Be Modified	To Be Completed	Not Applicable	Comments
Feasibility Study/ Benefit Cost Analysis	☐	☐	☐	☐	
Systems Engineering Management Plan	☐	☐	☐	☐	
Concept of Operations	☐	☐	☐	☐	
System Requirements	☐	☐	☐	☐	
High-Level Design	☐	☐	☐	☐	
Detailed Design	☐	☐	☐	☐	
Implementation Plan	☐	☐	☐	☐	
Unit/Device Test Plan	☐	☐	☐	☐	
Subsystem Verification Plan	☐	☐	☐	☐	
System Verification Plan	☐	☐	☐	☐	
System Validation Plan	☐	☐	☐	☐	
Operations & Maintenance Plan	☐	☐	☐	☐	
Other	☐	☐	☐	☐	

If "Other" was selected, please provide a brief explanation:

MDOT Intelligent Transportation Systems

DMS Checklist

Section 1 – Device Status (choose all that apply)

Status:	Deployment Type:
☐New	☐Standard deployment
☐Replace	☐Non-standard deployment
If a non-standard deployment, please provide a brief explanation:	

Section 2 – Nature of Work (choose all that apply)

☐Construction	☐Design
☐Equipment Replacement	☐Evaluation
☐Operations/Management	☐Planning
☐ Research/Development	☐Scoping
☐Software/Integration	☐Other
Other(Please elaborate):	

Section 3 – Project Features (choose all that apply)

☐ATMS software	☐CAV infrastructure system	☐Communications
☐DMS control software	☐Permanent DMS	☐Portable DMS

MDOT Intelligent Transportation Systems

CCTV Checklist

Section 1 – Device Status (choose all that apply)

Status:	Deployment Type:
☐New	☐Standard Deployment
☐Replace	☐Non-standard Deployment
If a non-standard deployment, please provide a brief explanation:	

Section 2 – Nature of Work (choose all that apply)

☐Construction	☐Design
☐Equipment Replacement	☐Evaluation
☐Operations/Management	☐Planning
☐ Research/Development	☐Scoping
☐Software/Integration	☐Other
Other(Please elaborate):	

Section 3 – Project Features (choose all that apply)

☐CAV infrastructure system	☐Communications	☐Permanent CCTV
☐Portable CCTV	☐Video control software	☐Video Management System

MDOT Intelligent Transportation Systems

Traffic Signal Checklist

Section 1 – Device Status (choose all that apply)

Status:	Deployment Type:
☐ New ☐ Replace	☐ Standard Deployment ☐ Non-standard Deployment
If a non-standard deployment, please provide a brief explanation:	

Section 2 – Nature of Work (choose all that apply)

☐ Construction	☐ Design
☐ Equipment Replacement	☐ Evaluation
☐ Operations/Management	☐ Planning
☐ Research/Development	☐ Scoping
☐ Software/Integration	☐ Other
Other(Please elaborate):	

Section 3 – Project Features (choose all that apply)

☐ Accessible Pedestrian Signal	☐ Advanced Warning Flasher	☐ Basic Traffic Signal
☐ Emergency Preemption	☐ Enforcement Lights	☐ Flashing Yellow Arrow
☐ Pedestrian Countdown Sign	☐ Traffic Signal Interconnect	☐ Traffic Signal Priority
☐ Railroad Preemption	☐ Vehicle Prescence Detection	

MDOT Intelligent Transportation Systems

Communications Checklist

Section 1 – Device Status (choose all that apply)

Status:	Deployment Type:
☐New ☐Replace	☐Standard Deployment ☐Non-standard Deployment
If a non-standard deployment, please provide a brief explanation:	

Section 2 – Nature of Work (choose all that apply)

☐Construction	☐Design
☐Equipment Replacement	☐Evaluation
☐Operations/Management	☐Planning
☐ Research/Development	☐Scoping
☐Software/Integration	☐Other
Other(Please Elaborate):	

Section 3 – Project Features (choose all that apply)

☐Commercial Wireless Communications	☐Long Range Communications	☐Short-Range Wireless Communications
☐Short-Range Wireless, Low Latency Communications	☐Short-Range Wireline Communications	☐VPN over Public Internet
☐Wireless (Voice) Radio Network	☐Traffic Signal Interconnect	☐Traffic Signal Priority

MDOT Intelligent Transportation Systems

Road Weather Information System Checklist

Section 1 – Device Status (choose all that apply)

Status:	Deployment Type:
☐ New	☐ Standard Deployment
☐ Replace	☐ Non-standard Deployment
If a non-standard deployment, please provide a brief explanation:	

Section 2 – Nature of Work (choose all that apply)

☐ Construction	☐ Design
☐ Equipment Replacement	☐ Evaluation
☐ Operations/Management	☐ Planning
☐ Research/Development	☐ Scoping
☐ Software/Integration	☐ Other
Other(Please elaborate):	

Section 3 – Project Data Collection

Data Collected	Frequency of Collection	Is Data Archived
Air temperature, humidity, visibility, wind speed and direction, precipitation type and rate		☐ Yes ☐ No
Surface temperature, condition (wet, icy, flooded), salinity, chemical concentration (amount of deicing material)		☐ Yes ☐ No
Water level and temperature		☐ Yes ☐ No

MDOT Intelligent Transportation Systems

Adaptive Signal Control Technology Checklist

Section 1 – Device Status (choose all that apply)

Status:	Deployment Type:
☐ New	☐ Standard Deployment
☐ Replace	☐ Non-standard Deployment
If a non-standard deployment, please provide a brief explanation:	

Section 2 – Nature of Work (choose all that apply)

☐ Construction	☐ Design
☐ Equipment Replacement	☐ Evaluation
☐ Operations/Management	☐ Planning
☐ Research/Development	☐ Scoping
☐ Software/Integration	☐ Other
Other(Please elaborate):	

Section 3 – Project Risk

If the project involves Adaptive Signal Control Technology, FHWA and MDOT consider the project to be "High-Risk".

MDOT Intelligent Transportation Systems

Traffic Detection Checklist

Section 1 – Device Status (choose all that apply)

Status:	Deployment Type:
☐New	☐Standard Deployment
☐Replace	☐Non-standard Deployment
If a non-standard deployment, please provide a brief explanation:	

Section 2 – Nature of Work (choose all that apply)

☐Construction	☐Design
☐Equipment Replacement	☐Evaluation
☐Operations/Management	☐Planning
☐ Research/Development	☐Scoping
☐Software/Integration	☐Other
Other(Please elaborate):	

Section 3 – Project Features (choose all that apply)

☐CAV Infrastructure System	☐Communications	☐Field Traffic Detection Device
☐ Third Party Data	☐Traffic Data Management System	

Appendix B – Systems Engineering Requirements Form (SERF)

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Maryland Division
Federal Highway Administration

SYSTEMS ENGINEERING REQUIREMENTS FORM (SERF)
Office of CHART & ITS Development

In accordance with the 23 Code of Federal Regulations 940.11 – Project Implementation, all Intelligent Transportation Systems (ITS) Projects funded in whole or in part by highway trust funds shall be based on a Systems Engineering (SE) Analysis. The regulation states that the analysis shall be on a scale commensurate with the project scope and the systems engineering analysis shall contain the following at a minimum:

1. Identification of portions of the regional ITS architecture being implemented
2. Identification of participating agencies roles and responsibilities
3. Requirements definitions
4. Analysis of alternative system configurations and technology options to meet requirements
5. Procurement options
6. Identification of applicable ITS standards and testing procedures
7. Procedures and resources necessary for operations and management of the system

For all non-exempt ITS projects, a Systems Engineering Requirements Form (SERF) or reasonable facsimile shall be completed and submitted to the Federal Highway Administration with the authorization request. For exempt ITS projects the form shall be completed and become part of the project record maintained by the project sponsor.

Project Name: CHART Area-wide Dynamic Message Sign (DMS) Deployment Phase VI

Federal Aid Project Number (FAP#):

SHA Project Number: AT620B55

Regional ITS Architecture: Maryland Statewide ITS Architecture

1. Is this project consistent with the Regional Architecture stated above? Yes ☒ No ☐
2. Are revisions to the architecture required as a result of the project? Yes ☐ No ☒

If you answered **NO** to the above questions, please explain:

If you answered, **YES** to any of the above, please move on to question 3.

3. Identify the portions of the Regional ITS Architecture being implemented:

   The proposed CHART Dynamic Message Sign (DMS) deployment will not alter any portion of the Maryland Statewide Intelligent Transportation Systems (ITS) Architecture. It will enhance the existing communications between elements of the "Centers" and "Field" subsystems within the Maryland Statewide ITS Architecture. As such, no new interconnects or information flows will be introduced by the implementation of this project.

   The implementation of this DMS deployment serves to enhance information being exchanged between the Maryland State Highway Administration's (MD SHA's) "CHART Centers" and "Freeway Field Equipment" elements (*Page 131 of the MD Statewide ITS Architecture*). Specifically, this project addresses an enhancement to the existing "*broadcast traveler information*" information flow as shown in *Figure 1* below.

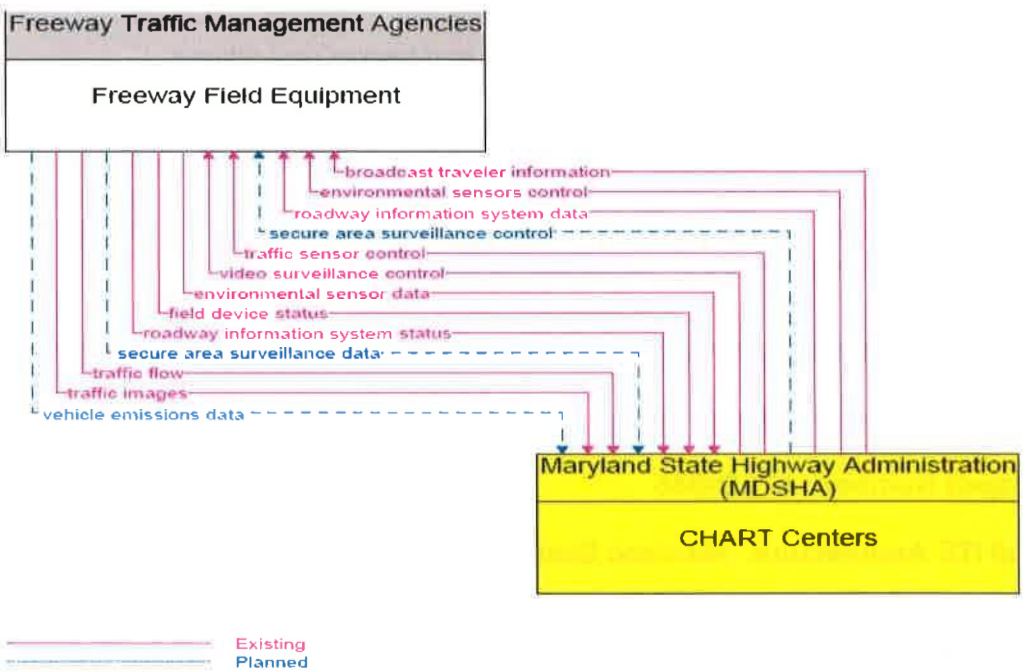

Figure 1: *Information Flow Diagram for the proposed CHART DMS Deployment Phase V*

4. Identify the participating agencies, and their roles and responsibilities:

   The MD SHA's Office of CHART & ITS Development will own, operate and maintain the DMSs being procured. As a result, the MD SHA is the only stakeholder and no external agencies will be involved in deploying, operating or maintaining these devices.

5. Definition of the functional requirements for the project:

   This project consists of the procurement of ten (10) new DMSs, which will be deployed along major highways within the CHART coverage area. It includes DMS deployment along I-495, I-695, I-795, I-83, US-29 and US-50 in Anne Arundel, Baltimore, Howard

Montgomery and Prince George's counties and will increase CHART's information dissemination capabilities.

The functional requirements for the proposed DMS deployment are as follows:

<u>CHART Centers Functional Requirements</u>

- The center shall support an interface with the DMS field equipment.
- The center shall remotely control DMS for dissemination of traffic and other information to drivers.
- The center shall collect operational status for the driver information systems equipment (DMS).
- The center shall collect fault data for the driver information systems equipment (DMS) for repair.
- The center shall provide the capability to remotely control and monitor DMS systems.

<u>Freeway Field Equipment</u>

- The field element shall provide operational status for the driver information systems equipment (DMS) to the center.
- The field element shall provide fault data for the driver information systems equipment (DMS) to the center for repair.
- The field element shall return sensor and DMS system fault data to the controlling center for repair.
- The field devices shall be remotely controlled by the traffic management center.

6. Alternative system configurations and technology options to meet the stated functional requirements:

   MD SHA uses pre-fonted ("discrete matrix") style overhead, pedestal, and ground-mounted DMSs to communicate traffic conditions to motorists. While this format is not as flexible as the newer full-matrix signs (like the ones used in sports stadiums), it has several major advantages:

   a) *Infrastructure*: Pre-fonted DMS have a maximum electrical load that is about half than that of a full-matrix sign.

      - A typical Maryland overhead DMS uses approximately 4,200 watts at maximum brightness. It is fed by a single-phase, 60-ampere branch circuit, but the breaker in the sign cabinet panel is rated at 40 amperes. MD SHA uses a 60 amp breaker at the branch breaker to allow for other ITS devices in the DMS cabinet.

      - An equivalent-size, full-matrix sign has a load rating of approximately 8,900 watts and requires a 100-ampere service, just for itself.

   Although both types of DMS will use the same amount of power with identical text messages, *the electrical design engineer must specify larger wire and electrical equipment sizes for the full-matrix DMS*. Since DMS are usually located along Interstate highways, the lengths of the power feeds often exceed 1000 feet. Step-up/step-down transformers, wire sizes in excess of #4/0, and safety switches with

600-volt or higher ratings may be necessary. This results in substantial increases in installation and maintenance costs for the full-matrix sign.

b) *Maintenance:* In addition to installation costs, an agency must examine the life-cycle maintenance costs associated with both types of sign.

Full-matrix signs have more LED modules and row & column driver boards to replace, require larger and more expensive internal power supplies, and they require more elaborate cooling systems than a pre-fonted sign of equal size. And, some maintenance on full-matrix signs requires closing the traveled lanes under the sign.

- Every aspect of maintenance associated with the Maryland sign, including <u>replacing the Lexan sheeting that protects the LED modules</u>, can be performed from inside the sign without the need for any lane closure. The protective Lexan sign-face consists of individual panels that protect each column of 3 modules. These sheets and all other pieces of equipment can be easily replaced from inside the sign housing.

- Full-matrix signs use a large continuous sheet of Lexan, which can only be replaced with a crane, and in most cases, a total roadway closure. In fact, the sign generally has to be removed from the structure and serviced on the ground.

While the need to replace the Lexan sheeting may never occur, Maryland has a zero roadway closure policy.

c) *Legibility & Brightness:* Pre-fonted DMS are generally more legible and appear brighter than full-matrix signs. One reason is that the density of the LED's in each pixel of a pre-fonted sign can be as high as necessary to achieve the necessary brightness level. MD SHA's signs requires a minimum pixel intensity of 42 candelas (it can reach 48) to counteract the effect of direct sunlight on our east-west Interstates without resorting to the use of double rows of LED's to form each character (called "double-stroking"). Such a density is usually not cost-effective for a full-matrix sign. To offset that, manufacturers of full-matrix signs emphasize the fact that their signs can create "double-stroke" characters to emphasize messages, but double-stroking results in "blooming", which makes messages harder to read at a distance.

7. Procurement options:

Design work for the proposed DMS sites will be conducted by the Office of Traffic and Safety (OOTS) selected engineering consultants under the supervision of the Traffic Engineering Design Division (TEDD). OOTS engineering consultants are appointed through a competitive bid process on a technical and negotiated price basis in accordance with guidelines set by the Maryland Department of Transportation (MDOT).

8. Identification of applicable ITS standards and testing procedures:

The MD SHA conducted an investigation to identify the available ITS standards as developed by the market packages included in the National ITS Architecture for the Emergency, Traffic and Incident Management subsystems. The applicable ITS standards which are associated with these market packages, and specifically this DMS deployment project, are as follows:

- NTCIP C2F: NTCIP Center-to-Field Standards Group
- NTCIP 1201: Global Object Definitions
- NTCIP 1203: Object Definitions for Dynamic Message Signs (DMS)

More information is available via: http://itsarch.iteris.com/itsarch/html/af/af194.htm

With respect to testing procedures, the proposed equipment as part of this ITS device deployment are established commercial off-the-shelf (COTS) technologies that have already been tested and proven by the selected vendor. However, MD SHA will be conducting a "*Prototype and Test*" phase on selected units in an effort to verify the system's capabilities to meet the functional requirements outlined in *Section 5*.

9. Procedures and resources necessary for operations and management of the system:

   The operations and maintenance of the communications infrastructure is the responsibility of the telecommunications service providers available through the telecommunications service contracts. CHART will be responsible for device integration and the center-to-field communications/interface necessary.

I have reviewed the contents of this SERF and found that it satisfies the requirements of 23 CFR 940.11 – Project Implementation

EGUA IGBINOSUN

Printed Name
Division Chief
Programming, Planning and Development Division
Office of CHART & ITS Development
Maryland State Highway Administration
Maryland Department of Transportation

Signature

6/7/17
Date

Edward Jeffers
Printed Name
Safety/Transportation Mgmt. Engineer
Federal Highway Administration

Signature

6/7/2017
Date

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Appendix C – Systems Engineering Management Plan (SEMP)

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Systems Engineering Management Plan

for the OTMO CHART Program's

Advanced Traffic Management System (ATMS)

Emergency Operations Reporting System (EORS)

Lane Closure Permitting (LCP) System and

Web Systems

Contract J2B6400004

MDOT SHA Approval	Signature	Date
Richard R. Dye CHART Systems Administrator		July 13, 2021
FHWA Approval	**Signature**	**Date**
Breck Jeffers Operations and Safety Engineer		July, 21, 2021

July 13, 2021

Revision	Description	Pages Affected	Date
0	Initial Release	All	June 11, 2021
1	New FHWA Format	All	July 13, 2021

1 Purpose of Document

The Systems Engineering Management Plan (SEMP) and associated documents have been developed as guidelines to define the various technical, planning and control, development, and integration of the Office of Transportation Mobility's (OTMO's) Coordinated Highways Action Response Team (CHART) Advanced Traffic Management System (ATMS). On December 18, 2015 the Maryland Department of Transportation State Highway Administration (MDOT SHA) let a Request for Proposal in order to obtain an experienced Contractor to provide technical and business support for the purpose of enhancement and continuity of the current CHART systems. The goal is to fulfill the business process requirements previously defined in the Business Area Architecture (BAA) which is partially implemented in the CHART systems. The Agency intends to issue Work Orders throughout the term of the Contract to meet the Agency's needs for technical and business support, including program support, system development, and operations support within the general scope of work described in the RFP. This includes all training, documentation, warranty, and maintenance for the CHART systems and their stakeholders. As appropriate, the Agency may additionally issue Task Orders within a larger Work Order. The support provides systems development and integration using a well-defined methodology. The contract is structured as both Fixed-Price and Time and Materials.

On May 11, 2016 the State of Maryland's Board of Public Works (BPW) approved SHA06-CHART without comment for five (5) Years. This period runs from June 1, 2016 – May

31, 2021. The BPW minutes also approved 1 – 5-year renewal options with BPW Approval which was approved by the board on April 21, 2021. FHWA approved the current project for FY 19 – 21 on June 17, 2019.

2 Scope of Project

Over the past twenty (20) years, the state has built its primary statewide command and control systems for traffic monitoring, detection and verification, incident and traffic operations, traveler information, emergency operations, performance measurement, and traffic flow analysis in accordance with the requirements identified and documented in the BAA. During this same time period the software has been modified with a specific goal of connecting to external 1st responder systems. The Emergency Operations Reporting System (EORS) module is nationally regarded for its ability to provide real-time situational awareness to managers and public affairs for snow removal and weather emergencies. CHART distributes live roadway video to first responders and the public via secure connection, TV traffic reports and internet. The CHART traffic management system allows for multiple offices, agencies and jurisdictions to input and share incident data as well as distributing incident and roadwork data back to them as well as to the internet where it is used by traffic services and citizens directly. During this time the number of primary as well as secondary users of the system and its data has grown from a handful of freeway-centric traffic operations centers to a web-based system available across the Baltimore and National Capital region ranging from traffic operations, law enforcement and emergency management belonging to many different agencies.

During this time MDOT SHA has consistently deployed approximately two (2) to three (3) major builds and several smaller supporting work orders each fiscal year. Each Work Order for this Contract further validates the BAA for current condition and then updates the BAA for the future work products associated with this contract's approved builds

The releases expected during this SEMP include a wide variety of features as specified in the BAA and detailed in the latest CHART Systems Release Plan, Version 16, Doc# CHART-OPS-015, May 14, 2021. The table below shows some of the major functionality planned for upcoming releases and the subsystems affected. ***Table 4-1 CHART Future Release Functions***

Subsystem	Function
Decision Support	Refactor Alerts subsystem to meet current workflow and support ATM integration.
GUI Management	Operator workflow improvements Dashboards
Active Traffic Management	Variable Speed Advisory Auto Queue Warning on DMS Ramp Metering Lane Control Signals Part Time Shoulder Use Secondary Route Awareness
Device (DMS)	Further support for full matrix NTCIP DMS

3 Technical Planning and Control

MDOT SHA has an experienced Contractor to provide technical and business support for the purpose of enhancement of the current CHART ATMS. The goal is to fulfill the business process requirements defined in the BAA and partially implemented in the CHART ATMS, EORS, LCP and CHART Web.

In providing a solution to the MDOT SHA, the Contractor's responsibilities shall include supplying technical and business subject matter experts' support, design validation, development and/or customization of the product(s), installation and testing through the implementation phase(s), training, documentation, warranty, and maintenance.

The requirements shall be implemented by the MDOT SHA through a budgeted Work Order process that shall utilize established labor categories with applicable fully loaded labor rates. Work Orders directed by the MDOT SHA shall be based on Fixed Price (FP) or Time and Material (T&M) support. From August 2016 to March 2017, and again in calendar year 2020, the Office of Transportation Mobility and Operations (OTMO) completed a comprehensive base design / validation of the BAA. This base design review:

1. Gathered the objectives, requirements and system functionality
2. Facilitated JAD-Type meetings with current CHART, multi-agency operational and support staff to identify new or updated:
    a. CHART traffic management requirements
    b. Relevant-state and federal ITS standards and
    c. Relevant homeland security standards and opportunities.

This BAA is regularly updated with the new case for action, vision of the future CHART System to include business processes, organization, location, application, data, technology, performance objectives, and release strategy.

Following the updated BAA the following "Program Level" documents were updated and delivered to the MDOT SHA:

Title	Description	Current Version
CHART Program Management Plan (PMP)	Documents how the CHART Project Team will plan, execute, monitor, control, and close projects formally approved and tracked as application release work orders.	Version 7.10 CHART-OPS-001-v7.1 December 10, 2020

CHART Staffing Management Plan (SMP)	The Staffing Management Plan details the project's human resources requirements and how those requirements will be fulfilled including Project Roles and Responsibilities, Project Staffing Estimates, Acquisition Strategy, Training Plan and an Organizational Chart	Version 5.0 CHART-OPS-005 v5.0 July 20, 2020
CHART Change Management Plan (CMP)	Description and approach to how changes will be proposed, accepted, monitored, and controlled	Version 5.0 CHART-OPS-003 December 10, 2020
CHART Risk Management Plan (RMP)	Planned processes and responsibilities to routinely perform risk identification, risk analysis, risk response planning, and risk control activities throughout the life cycle of the project.	Version 5.0 CHART-OPS-002 v5.0 July 20, 2020
CHART Communication Management Plan	Defines the processes required to ensure timely and appropriate identification, collection, distribution, storage, retrieval and disposition of project information to the project team, stakeholders Project Sponsor and Executive Sponsor.	Version 5.0 CHART-OPS-004 v5.0 July 20, 2020
CHART Program Test Master Plan	Outlines the testing framework applied to release work orders across the CHART program. This program level plan covers the testing approach used for test activities during a work order as well as the test tools, environments, and resources used for testing	Version 3.0 CHART-TD-001 July 20, 2020

3.1 Software Development Methodology (Move from Waterfall to Agile)

As part of the continuing efforts by the Contractor to increase flexibility in adapting to changing requirements and reduce solution-delivery time, the Contractor's team supporting MDOT SHA adopted an agile Scrum development methodology. The Contractor presented recommendations to transition from waterfall to an agile framework, for selection of an agile methodology, and a high-level approach to implementing the model in a paper titled "agile Scrum Methodology Recommendation" dated August 2015. The Contractor implemented targeted tool and process changes in order to better respond to and support MDOT SHA's increasingly dynamic needs and to support an Agile development methodology.

Maryland Department of Information Technology's SDLC policy now requires an agile methodology over a waterfall methodology for development projects. The Program Management Plan reflects updates to existing program processes in order to align with following an Agile scrum methodology. There are no new project management processes required, only adjustments to existing processes. The updated MD DOIT SDLC policy requires fewer documentation deliverables, and the typical deliverable documentation list reflects this reduction (see Section 2.2, Appendix A, and Appendix C). The Program Management Plan adds the following from the updated MD SDLC deliverables: Appendix D Responsibilities Assignment Matrix and Appendix E Agile Maturity Matrix- Teams. The DOIT template for Agile Maturity Matrix-Organization was determined to not apply to the Contractor and MDOT SHA team and thus are not part of this documentation.

The sprint cycles and frequent meetings with MDOT SHA Product Owners eliminate the need for most of the formal readiness reviews previously conducted using waterfall development methodology. The PMP removes the redundant reviews from the planned formal reviews in Section 5.4.3. The project life cycle to request work orders, respond to and approve work orders, manage and track work orders, and close work orders is not changed. Yet the way the team organizes the work when executing the work order has changed. The estimation process has shifted from use cases estimated by hours to user stories estimated with story points. The demonstration of acceptance criteria at the conclusion of each sprint throughout the project is replacing the multiple JADs or prototype review meetings previously conducted at the beginning of a project. The biweekly backlog refinement sessions facilitate and replace formal AWG meetings to plan new work orders. The backlog refinement session, the sprint planning session, and / or the daily scrum meetings serve in place of the previously used Change Review Board (CRB) meetings. In most cases, the new methodology for managing work within an Agile framework supports the program in the same ways as the formal checkpoints and reviews conducted under waterfall. The feedback is more frequent and less formal, and it keeps the Agile team aligned with MDOT SHA's objectives.

3.2 Requirements Definition

The CHART program performed a revalidation of the Business Area Architecture as its first work order under contract J2B6400004. The CHART Release plan, a BAA auxiliary document, outlines releases of CHART applications for the duration of the program term, which is analogous to the SDLC Planning phase. Ensuing work orders derive from the BAA updates to the CHART requirements and CHART Release Plan. Each subsequent release of CHART applications completes a requirement validation effort for the targeted project scope and conducts the implementation phase of the SDLC. For each project, MDOT SHA provides a Work Order Request that documents the targeted features or capabilities for the release. The Contractor provides a Project Scope

Statement and Management Plan (PSS/MP) in response, which confirms or refines the planned features or capabilities for the project to deliver. Requirements development and analysis occurs as an essential first step in the iterative development efforts for an approved release.

After a work order approval, the agile development team begins work on the features within the work order scope. During backlog refinement meetings, the agile team discusses detailed requirements for upcoming user stories. During the sprint review meetings, the agile team conducts reviews of completed user stories. The MDOT SHA product owner participates in these sprint meetings, and includes other stakeholders as necessary, to provide the mechanism through which MDOT SHA further defines and confirms requirements. The meetings may include state and MDOT SHA staff, support contractors, subject matter experts, and end users of interfacing organizations. This repetitive analysis results in a requirements document for the project, which defines the features for the application changes performed within the project.

3.3 Scope Verification

The requirements for a release work order are tracked from implementation through deployment to operations via the Requirements Traceability Matrix (RTM). Each requirement has a Jira ticket number with user defined acceptance criteria. The Agile team demonstrates accomplishments of each sprint to the MDOT SHA Product Owner during the sprint review meetings in order to confirm that the implementation of the requirements meet the business needs. The MDOT SHA Product Owner reviews the completed story to confirm the story meets the documented acceptance criteria. This ensures requirements are not missed, left out, or expanded beyond the needs of the business. The MDOT SHA Project Manager or Task Lead also reviews the consolidated release code prior to deployment to operations in the MDOT SHA Pre-Release (REL) environment in order to provide feedback and identify issues or missing elements. For release documentation deliverables identified in the project management plan, the project team will use the program-level templates for standard project deliverables listed in Table 2-1 and attached separately as Appendix A. For deliverable documents categorized as operations documentation deliverables (Interface Control Document, User's Guide, Operations and Maintenance Guide, Disaster Recovery Plan, CHART Release Plan, and System Architecture Document), the updates will be made to the last production version of the document instead of starting from a blank template; however the final operations documentation deliverable will based on the approved template. The templates outline the content areas for the document to address, with required sections noted. A minimum criterion for acceptance of any project document deliverable will be submission of a document completed using an approved template. Additionally, the Contractor will address any comments or questions MDOT SHA identifies after initial review with an updated document prior to acceptance.

MDOT SHA's project manager will be responsible for reviewing the document content and identifying issues (gaps, questions, or comments) for the Contractor to address prior to acceptance. MDOT SHA's project manager has the discretion to accept a modified template for any deliverable.

Table 2-1 Typical CHART Release Deliverable Documentation

Deliverables
Project Scope Statement and Management Plan (including Solution Roadmap and Maryland ITS Architecture Conformance)
Software Requirements
Updated Interface Control Document (ICD)
Design Document
Test Report
Implementation Plan
Updated User's Guide
Updated Operations and Maintenance Guide
Updated Application Recovery Documentation
Updated CHART Release Plan
Updated System Architecture
Operations Readiness Review
Deployment Package
Project Closeout Package

The final two deliverables listed in Table 2-1 are the Deployment Package and Project Closeout Package. Each package will contain a VDD and a set of ISO files containing the application source code. The Project Closeout Package will contain the application source code for all deployments within the release and all work order documentation and deliverable documentation produced for the work order.

Each package is comprised of the files as described below. (Note that all applications have ISO files labelled Disc 1 through Disc 3. Only the packages for ATMS will include a fourth ISO disc) **Note: These discs are now delivered electronically ONLY.**

1. **ISO file Disc 1: Installation:** This is the delivered software product.
2. **ISO file Disc 2: Source Code and Documentation (Public):** This is the Version Description Document (VDD) and the application source code and COTS files that may be distributed outside MDOT SHA. The Project Closeout Package includes the work order documentation and all deliverable documentation on this disc.
3. **ISO file Disc 3: Source Code (Private)**: This is code and/or COTS that cannot be distributed outside MDOT SHA.
4. **ISO file Disc 4: Text To Speech (Private)**: For ATMS only, this is the Text to Speech code and COTS files, COTS that cannot be distributed outside MDOT SHA.

The Contractor's Configuration Management (CM) team electronically delivers the ISO image of each disc that make up the Deployment Package to MDOT SHA with each deployment within a work order. At the end of the work order's final warranty period, the Contractor's CM team electronically delivers to MDOT SHA the ISO image of each disc that makes up the Project Closeout Package.

For all Project Closeout Package deliverables, the Source Code and Documentation disc (disc #2 in the list above) includes the work order documentation and all deliverable documentation. The documentation folder structure will be as follows:

Documentation ○ Delivery Package (Summary of Changes letter, VDD, Binder Cover file) ○ Deliverable Documents - Original

○ Deliverable Documents – PDF

The 'Deliverable Documents – PDF' directory will include the original Work Order

Request (WOR), Notice to Proceed (NTP) for the original Project Scope Statement and Management Plan and subsequent Change Orders, and Deliverable Acceptance Forms (DAFs) received from MDOT SHA.

Both Deliverable Documents directories (Original and PDF) will include the Contractor's submitted Project Scope Statement and Management Plan and subsequent Change

Orders. The deliverable documents included in the directory will be the latest version of the deliverable document, not all versions delivered during the release. Any document not formally approved by the MDOT SHA will be marked as such and will be included in the directories. Also, when a document not listed as part of the planned deliverables for a work order is updated and provided to MDOT SHA as part of the release work, then that document will be included in the Deliverable Documents folders.

3.4 Scope Control

The Contractor's project team and MDOT SHA Product Owner will monitor scope for each active work order. All features, enhancements, bug fixes, or changes in code during a release will be tracked in Jira as a Change Request (CR) item with a unique Jira ticket number. The MDOT SHA team, the internal project team members, or the external stakeholder groups can identify changes to the original scope. Changes to the work order scope include adding additional requirements beyond parameters defined in the work order or substantially changing defined requirements. Following the Agile methodology, the MDOT SHA Product Owner has more latitude to change project priorities during a release, which may result in the addition of new requirements to or the removal of requirements from the original project scope. These changes will not always require a Change Order. The project team evaluates the scope changes for an impact to the approved deployment plan, the overall project schedule, or the project budget. When required based on impact to the approved project plan, a Change Order to the Project Scope Statement and Management Plan is presented to MDOT SHA for review and approval. Section 3.4 of the current Change Management Plan defines the Change Order process. The Change Order will also include updates to the project deliverables list based on change. The backlog refinement process followed in the Agile methodology may identify scope changes (additions, deletions or changes) which do not impact schedule or budget. If allowed for in the Project Scope Statement and Management Plan, these non-impact changes are tracked via sprint planning or backlog refinement meetings, and the approved CRs become approved updates to the project scope.

3.5 Schedule Management

The following sections of the Schedule Management Plan describe the planned processes for managing and controlling the baseline schedule throughout the project's life cycle.

The CHART program will manage and monitor project schedules to ensure on time project delivery. The project team will use Microsoft Project to create and manage schedules for release work orders. The project schedule provided in the work order Project Scope Statement and Management Plan will be the baseline upon approval. The project team will track actual dates worked against the approved baseline plan dates in MS Project.

Each project team member is responsible for reporting actual hours worked against approved CRs on a daily basis. The project assistant consolidates the team input on a weekly reporting cycle to determine progress against scheduled tasks. The project team reviews schedule discrepancies during the sprint retrospectives and sprint planning meetings. A monthly evaluation of the schedule measures schedule progress at the sprint level (level two of the WBS). Schedule performance at the task level (level three of the WBS) is reviewed in order to provide supporting information to evaluate the schedule progress.

The program manager provides MDOT SHA with the updated project schedule and the Release Burnup chart each month. The PM includes release schedules and release burn up charts in the monthly Blue Book delivered to the CHART System Administrator, and used for MDOT SHA reporting to the Governance Board, per section 2 of the CHART Communications Management Plan.

MDOT SHA approves changes to the baseline schedule via the change order process defined in Section 3.4 of the Change Management Plan. Changes to scope, staff, or budget can trigger an evaluation of schedule impacts. Depending on the impact of the change to the project, changes to the major milestones or deliverables schedules may be documented via an email to MDOT SHA or as a formal change order.

3.5.1 Agile Schedules

The program has identified optimal scheduling blocks to use for Agile development releases. The scheduling block is a period of time for a development team to work on planned functional improvements, new functionality, and / or technology updates for application(s) supported by the development team, and at the same time adapt to MDOT SHA Product Owner prioritized release content to support business needs. The time block length is selected to allow time for the development team to complete all or part of a desired feature set, and for MDOT SHA to officially review, accept, and potentially deploy planned features while also allowing for MDOT SHA to adjust or change scope based on operational needs. The time block for each team is based on the development team size, so the ATMS team with more developers currently uses a four-month time block, and the Green team (supporting CHART Web, Mapping, EORS, and LCP) uses a six-month time block. This time frame is deemed to be long enough for the team to be able to deliver feature sets and short enough for MDOT SHA to be able to realign the scope to MDOT SHA operational priorities for the application.

3.6 Cost Management

The Contract plans resources for each work order during the work order response activity. Staffing needs for people and skill sets are determined based on the effort estimated for each functionality feature included in the release work order. During the estimating effort for the work order response, the contractor also identifies software, hardware or equipment needs to document to MDOT SHA in the work order response/project management plan document.

3.6.1 Cost Estimating

Labor cost estimates for work orders are based on bottom-up estimating techniques. The work order is comprised of functional application features and each feature is broken down into user stories to represent requirements. Each user story has an assigned story point value and stories are then grouped into sprints based on the historical team velocity, dependencies, and resources. The resources required to deliver the planned scope are identified and the number of sprints required are calculated. The labor category assigned for the resources planned for the release have their associated labor rate applied to the effort estimate for the number of sprints planned to deliver the user stories. When appropriate, contingency reserves are estimated as a portion of the overall project labor estimates, based on historical cost performance and risk assessment of the overall project.

Non-labor cost estimates (for hardware, software, or equipment) are not included in the budget provided to MDOT SHA by the Contractor. Upon request, the Contractor may obtain vendor quotes and provide them to MDOT SHA for their reference to use in the MDOT SHA procurement process.

All cost estimates are updated when a change order is submitted for the work order PSS/MP.

3.6.2 Cost Budgeting

The budget for the work order is the approved project budget in the Work Order Authorization / Notice to Proceed (WOA/NTP) provide by MDOT SHA. This budget amount comes from the cost estimate submitted in the Project Scope Statement and Management Plan. The budget is determined based on the cost estimates for planned resources, estimated contingency, and any additional effort needed for realistic scheduling. The budget is modified only via a change order to the work order response. The project cost estimate is reviewed each time a change order is submitted for the PSS/MP.

3.6.3 Cost Control

The CHART program will manage and monitor project spending to ensure project delivery within budget. The program manager will use labor reports from the Contractor's internal systems to track actual hours reported against the approved baseline plan hours in MS Project.

Each project team member is responsible for reporting actual hours worked against approved CRs on a daily basis. The project assistant consolidates the teams' hourly input on a weekly reporting cycle into MS Project each month to determine progress against planned budget. The program manager performs a monthly evaluation of the project cost comparted to budget. The program manager evaluates cost variances each month for the overall project and for the completed phases. Corrective action is taken based on the degree of cost variance. The higher the cost variance the more detailed the actions and more frequent communication with the project team and management will be required. The program manager reports on the approved, actual, and estimate to-complete costs each month. The Program Manager includes release budgets and cost data in the monthly status reports for work order activity delivered to the CHART

System Administrator. All release budgets are evaluated monthly and at major milestones, and budgets are updated with a formal change order if necessary.

Changes to scope, staff, or schedule can also trigger an evaluation of cost impacts.

Changes to project costs are documented via to MDOT SHA via a formal change order. MDOT SHA approves changes to the baseline budget via the change order process defined in Section 3.4 of the Change Management Plan

3.7 Design Overview

The CHART system design is derived from the results of the BAA and requirements specification efforts and is guided by the CHART vision. Below is a description of the CHART concept of operations as defined in Appendix E of the BAA.

The CHART System concept of operations encompasses of four (4) major categories of business objectives:

- CHART is intended to be a statewide traffic management system, not limited to one or two specific corridors of high traffic volumes, but expandable to cover the entire state as funds, resources, and roadside equipment become available to support traffic management.

- CHART is intended to be a coordination focal point, able to identify incidents, congestion, construction, road closures and other emergency conditions; and then able to direct the resources from various agencies, as necessary, to respond to recurring and nonrecurring congestion and emergencies. It should also manage traffic flow with traveler advisories and signal controls, and coordinate or aid in the cleanup and clearance of obstructions.
- CHART is intended to be an information provider, providing real-time traffic flow and road condition information to travelers and the media broadcasters, as well as providing real-time and archived data to other state agencies and local, regional, inter-state, and private sector partners.
- CHART is intended to be a 7 day per week, 24 hours per day operation with the system performing internal processing and status checks to detect failed system components and resetting or reconfiguring itself where appropriate, or notifying operators and/or maintenance staff where necessary for service.

The CHART system design provides MDOT SHA with a highly available, flexible, and scalable statewide highway traffic monitoring and management system.

The system provides high availability through:

- The geographic distribution of equipment and functions.
- Redundancy for critical components and data.
- Multiple communications paths.

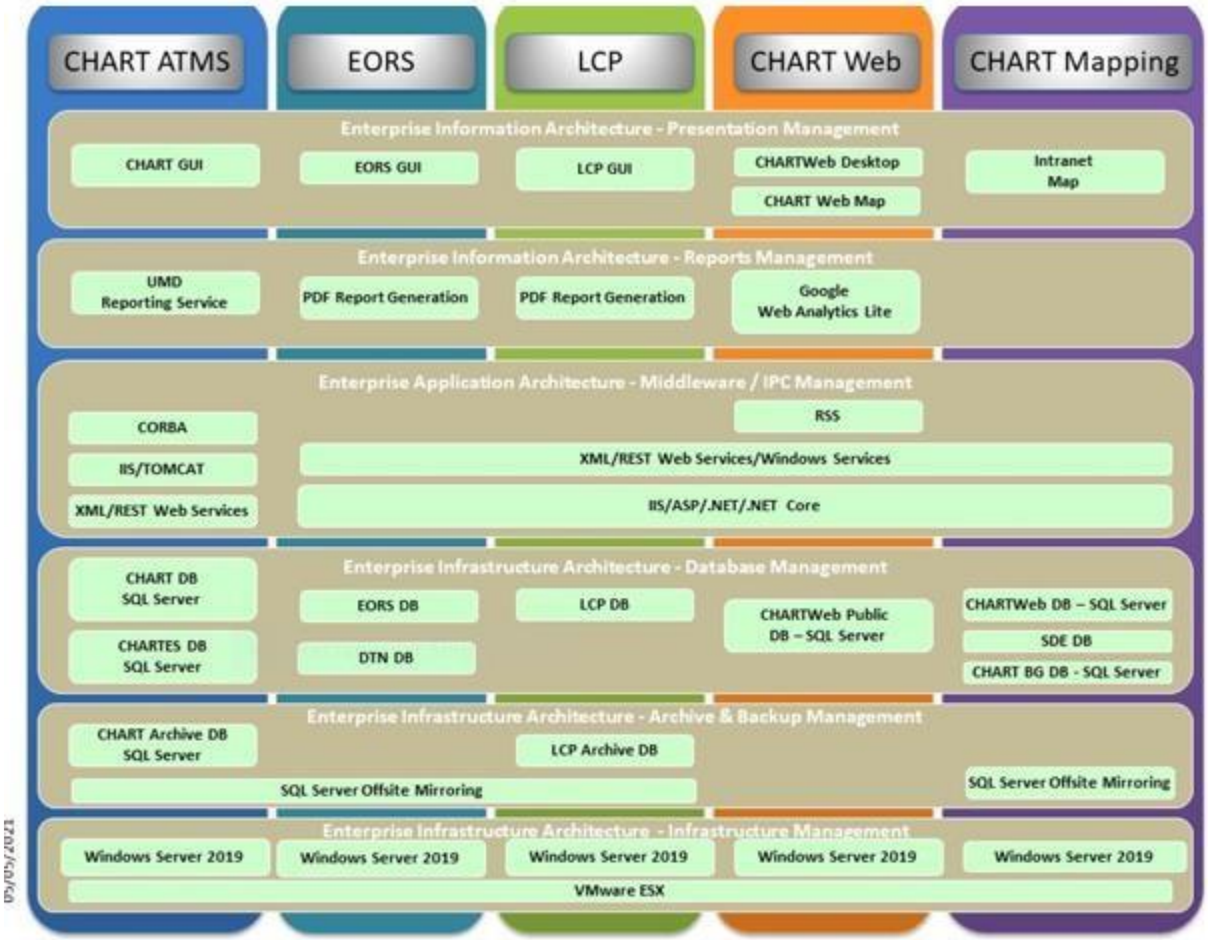
The system provides flexibility through:

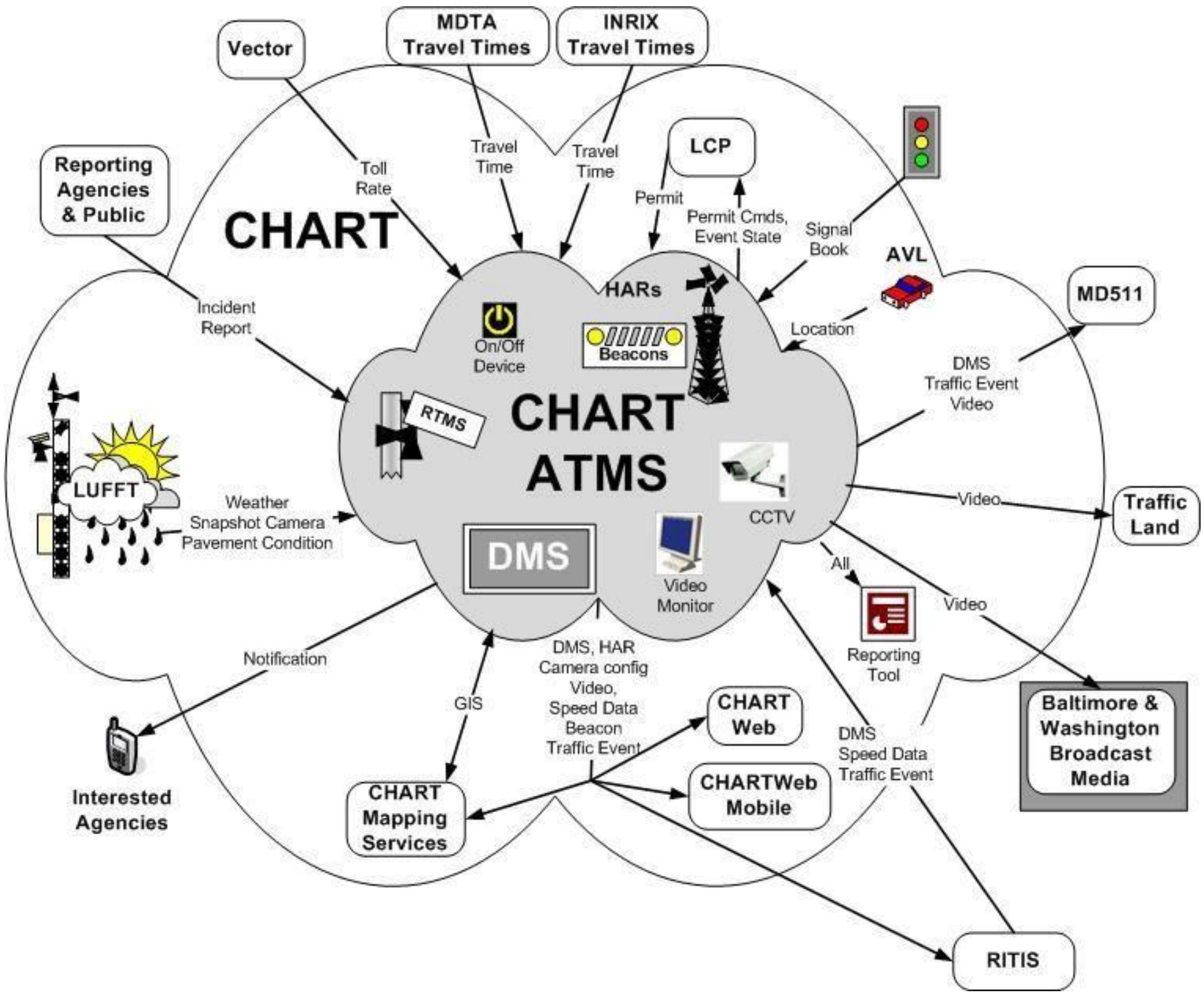
- A modular design that allows new subsystems to be easily integrated.
- The presentation to the user of a single seamless system regardless of where the user is located.

The system provides scalability through:

- A distributed architecture allowing incremental growth.

CHART Systems





The major external interfaces to the CHART system consist of:

- **CHARTWeb** – This public-facing site displays incident reports, lane closures, speed data, DMS messages, and camera configurations obtained from the CHART ATMS via an HTTPS/XML interface. CHARTWeb also displays map and video data from other CHART sources.
- **CHART Mapping Services** – These services provide GIS support for CHART ATMS and other CHART systems. Included in these services is support for location aliases, roadway intersection/exit/milepost lookup, roadway lane configurations, object proximity, AOR configurations, and map background tile overlays. The Intranet Map is included in this suite which provides a geographical view of CHART ATMS objects including incident reports, lane closures, speed sensors, DMS data and camera configurations.
- **Lane Closure Permits (LCP)** – System providing permit information on planned and active road closures and road status. CHART ATMS sends commands to LCP as initiated by CHART ATMS users to perform actions on permits. CHART ATMS also sends LCP messages related to changes made to traffic events that are associated with LCP permits.

- **TrafficLand, Baltimore Media, and Washington Media** –These external media organizations receive video from CHART. CHART ATMS users control where the cameras are pointed and are able to selectively block these video feeds on demand.
- **Lufft** – System to supply weather sensor data including pavement conditions to CHART applications.
- **CHART Reporting tool** – Developed and maintained by the UMD CATT Lab, this web site generates reports from replicated copies of the archive CHART ATMS database.
- Regional Integrated Transportation Information System (RITIS) –

  This system was developed by the University of Maryland Center for Advanced Transportation Technology (CATT) Lab. It both imports and exports CHART ATMS information:

  Export – RITIS receives Society of Automotive Engineers (SAE) ATIS standard incident and TMDD standard device configuration and status updates from CHART ATMS via an HTTPS/XML interface. RITIS also receives video feeds from CHART which can be dynamically blocked/unblocked from within CHART ATMS.

  Import – RITIS provides CHART ATMS with SAE ATIS standard regional traffic events and TMDD standard DMS and TSS data via Java messaging service connections. These data are collected from Northern Virginia, Washington Metropolitan Area Transit Authority (WMATA), District of Columbia Department of Transportation (DCDOT), Navteq, SpeedInfo and even MDOT.
- **Interested Agencies** – Requesting agencies receive notifications from CHART ATMS about occurrences of interest via e-mail or text messages. Text messages are sent out as SMTP messages and converted to text by the email provider.
- **INRIX** –Provides roadway travel times to CHART ATMS for display on selected DMSs. CHART ATMS connects to INRIX via an HTTP/XML interface.
- **Kapsch CTH**– MDTA system provides dynamic toll rates to the CHART ATMS. The Kapsch CTH system connects to CHART ATMS via an HTTP/XML interface.
- **MD511** – Receives incident reports, DMS messages, and video feeds from CHART. Incident descriptions and travel times are converted to audio and played for callers. All collected information is available on its public website. CHART ATMS can dynamically block these video feeds as necessary.
- **Signal Book** – CHART ATMS accesses the MDOT SHA Signal Book database containing locations of non-CHART, state-owned arterial devices including traffic signals, cameras, beacons (school, bridge, and warning), pre-emption signals (fire, bus, and rail), reversible lane signals, and weigh station devices.
- **AVL** – Automatic Vehicle Location system provides real-time vehicle locations over a SOAP interface which CHART ATMS uses to identify the closest incident responders. CHART ATMS also uses it to track when responders actually arrive and depart an incident.

Reporting Agencies and Public – In addition to incident reports coming from the general public, CHART ATMS also receives incident reports from many agencies including MDOT SHA and MDTA personnel, local and state police, and CHART's own Safety Service Patrol (also called CHART Units).

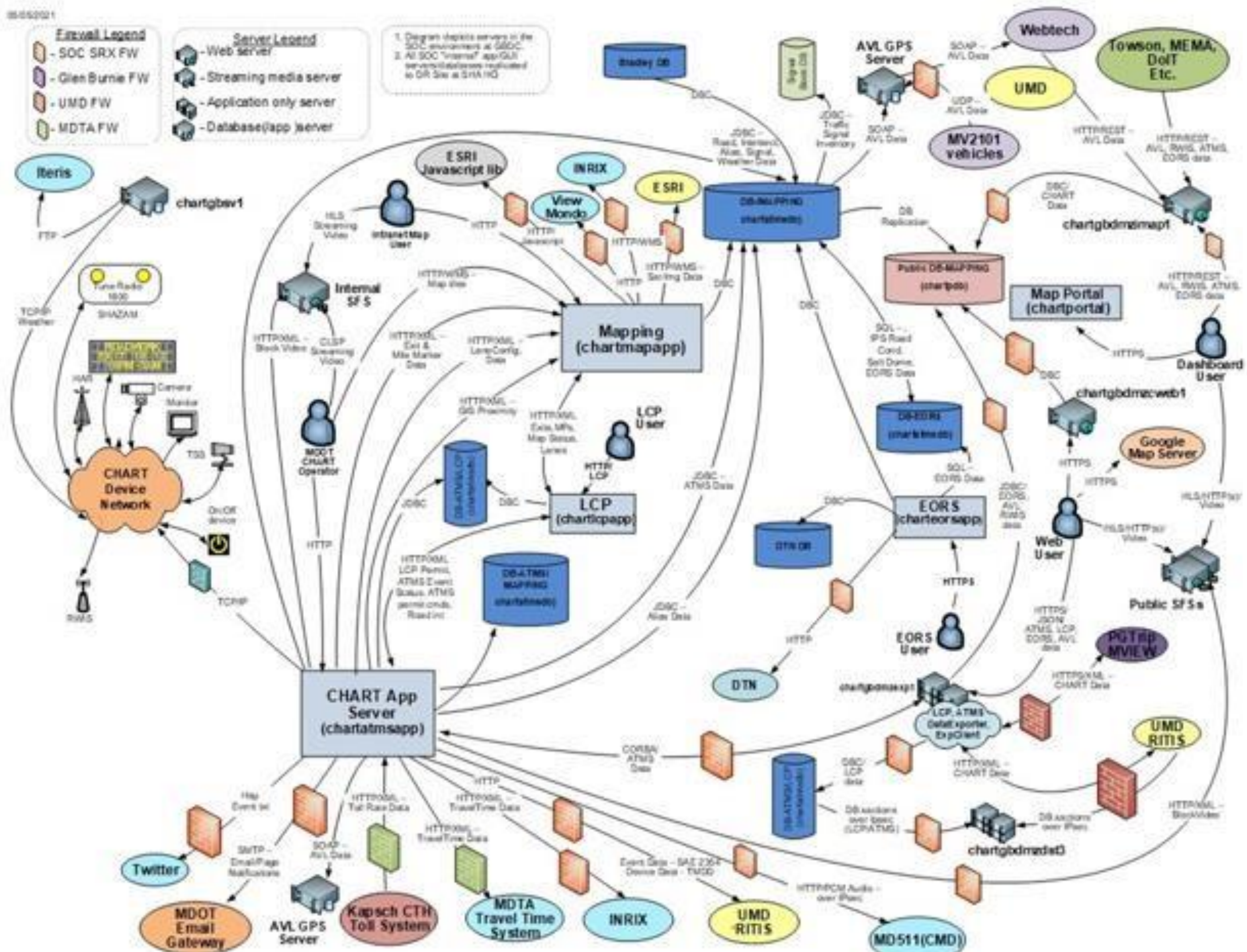
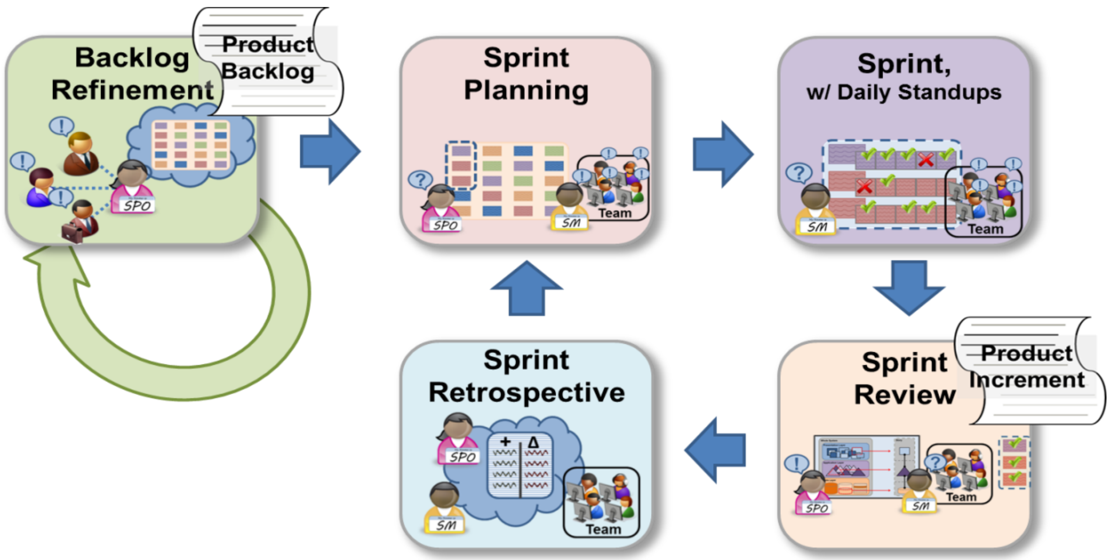


CHART High Level System Architecture

3.8 Communications Plan

Accurate information, presented on a scheduled basis, keeps everyone apprised of the task status, eliminates surprises, and contributes to a team effort.

3.8.1 Development Team Communication



Projects using Agile Methodology are especially dependent on communication because of the team environment and the need for understanding of business requirements through all members of the team. Communication is an important part of any project but is essential when utilizing Agile Methodology. The creators of Agile understood and highlighted the significance of communication and collaboration though this process in the Agile Manifesto, which outlines the basic components and principles of Agile.

It highlights the importance of interactions over processes, collaboration over negotiation, and daily meetings by face-to-face communication over documentation. There is also space for reflection and feedback after each sprint while there should be team driven productivity and decentralized decision making, overall communication is at the root of Agile principles.

The foundation of Agile is a self-organizing team that uses design focused methodology to deliver working software benefits though sprints or phases to receive feedback incrementally.

3.8.2 Program Management Communication

The MDOT SHA CHART Systems Administrator and contractor Program Manager hold weekly program status meetings. The meetings cover activities for the week to include results achieved, milestones achieved, planned activities, items delivered, problems encountered, issues, and risks for each work order. Detailed status for this project will be included in the agenda for the weekly program status meetings.

In addition to the weekly status meeting, a formal monthly report is provided to the MDOT SHA CHART Systems Administrator. The report contains information about technical activities for the month, results achieved, milestones achieved, problems encountered, items delivered, and, briefly, planned activities for the next month. The report is included in the CHART "Blue Book", provided monthly, which also contains project and work order summaries, project schedule, and a glossary. A copy of each month's "Blue Book" is provided to FHWA for their review and oversight.

3.8.3 Senior Management Communication

The contractor Program Manager will present status information to senior Management during periodic management program reviews. Status will include results achieved, items delivered, issues, and financial health of each work order to include this project.

In addition, the contractor Program Manager will attend the periodic CHART Governance Board meetings. CHART Governance Board meetings, which include MDOT SHA and contractor senior management, will discuss accomplishments, status, budget, schedule, and customer satisfaction, to include relevant information from this project.

3.8.4 Stakeholder Communication

CHART stakeholders will be involved in periodic CHART Configuration Control Board (CCB) meetings where changes to the CHART system requirements design and operational baselines are discussed and approved. Stakeholders are also involved in requirements joint application development (JAD) sessions held early in each release to capture and verify requirements.

4 Systems Engineering Process

4.1 Regional ITS Architecture

Intelligent Transportation Systems (ITS) encompasses a wide range of diverse technologies, which include information processing, communications, control and electronics. ITS standards encourage safety and efficiency for travelers on the nation's highways through the use of ITS technologies and standard communications protocols for more reliable, efficient and secure communication between devices. The contract provides policies and procedures for implementing section 5206(e) of the Transportation Equity Act for the 21st Century (TEA–21), Public Law 105–178, 112 Stat. 457, further enacted by Section 53005 (d) of the Moving Ahead for Progress in the 21st Century Act (MAP-21), Public Law 112-141, 126 Stat. 405, pertaining to conformance with the National Intelligent Transportation Systems Architecture and Standards. 940.11 Project implementation.

Appendix A of each Project Management Plan maps directly to the required sections of the programmed reference on page 36 of the Maryland Statewide ITS Architecture (itsmd.org/wp-content/uploads/MD-Statewide-ITS-Architecture_11-17-16s.pdf) which states:

CHART Operating Software Development - Continuous development of MDOT SHA's CHART Program operating software to include several new features and upgrades over a five-year period.

The CHART Element of the Maryland Statewide ITS Architecture is defined as:

CHART Centers

Coordinated Highways Action Response Team (CHART) Centers is a specific element that represents the systems and personnel responsible for improving the real-time operations of Maryland's highway system through teamwork and technology. This includes the Statewide Operation Center (SOC), CHART Traffic Operations Centers (TOCs, including CHART Frederick TOC 7, CHART Greenbelt TOC 3, and CHART

Golden Ring TOC 4) and the Maryland State Network Operations Center (NOC) in Hanover. The CHART SOC is located in Hanover, MD. This center houses the backbone database for multiple transportation operations in Maryland, and provides a connection between the regional CHART

Traffic Operations Centers (TOCs) located throughout the state, as well as various other transportation Stakeholder agencies.

Specific systems housed at the SOC include the CHART ITS operating system, the Emergency Operations Reporting System (EORS), the CHART Website, among others. CHART is responsible for operating ITS systems, traffic control, coordinating with other agencies during incidents, and performing other traffic engineering to improve highway operations.

The CHART Operational Concept and Data Flows defined in the Maryland Statewide ITS Architecture are too numerous to mention here but can be referenced online at: [MD-Statewide-ITS-Architecture_11-17-16s.pdf (itsmd.org)]

In addition to the above, it should be noted that this project serves to enhance the existing interconnects and information flows associated with the "Centers" and "Field" subsystems of the Maryland Statewide ITS Architecture and, as such, will not adversely impact the content. However, if any task to add new features should require a revision, these features/upgrades will be reflected in the next update of the document.

Needs Satisfied and Benefits to the users

Since CHART is a mature, multi-jurisdictional operating system, each new build will include varying degrees of the following:

1) New Functionality for the Operators:
2) Architecture / Sustaining Engineering Updates:
3) Regional Data Sharing:
4) Problem Report Fixes:

Users of the Project

The primary users of the project will be current CHART personnel and other regional first responders through the RITIS Data Share program. In addition to regional first responders, RITIS users may be local arterial agencies, MDTA, US Park Police, DDOT, VDOT, MIEMSS, MEMA, and others.

Geographic Areas Served

CHART is a Maryland Statewide system. CHART data will be exported to data consumers all along the I-95 corridor.

Stakeholders

The MDOT SHA is the lead participating agency and operates the software that will be upgraded through its CHART Program. See Table 4-1 for a list of supporting agencies, their roles, and responsibilities.

Table 4-1 – Participating Agencies and Their Roles/Responsibilities

Agency-Role	Responsibilities											
	Validation of Planning and Requirements for CHART System	Design of CHART System	Develop and Test CHART System	Integrate and Test CHART System Development	Define Operation of CHART System	Implement CHART System	Document Development of CHART System	Operate CHART System	Maintain CHART System	Support Validation of Planning and Requirements for CHART System	Support Integration of CHART System	Support Operation of CHART System
MDOT SHA - Lead	☐	☐	☐	☐	☐	☐	☐	☐	☐			
Maryland Transportation Authority (MDTA) – Support	☐	☐	☐	☐	☐	☐		☐		☐	☐	☐
Maryland State Police (MSP) – Support										☐	☐	☐
Prince George’s County Department of Public Works and Transportation (DPWT) - Support										☐	☐	☐
Montgomery County DPWT - Support										☐	☐	☐

Agency-Role	Responsibilities											
	Validation of Planning and Requirements for CHART System	Design of CHART System	Develop and Test CHART System	Integrate and Test CHART System Development	Define Operation of CHART System	Implement CHART System	Document Development of CHART System	Operate CHART System	Maintain CHART System	Support Validation of Planning and Requirements for CHART System	Support Integration of CHART System	Support Operation of CHART System
Baltimore City DOT – Support										□	□	□
Baltimore County Police – Support										□	□	□
Baltimore City Police - Support										□	□	□
Maryland Emergency Management Agency (MEMA) - Support										□	□	□
Maryland Institute for Emergency Medical Services Systems (MIEMSS) - Support										□	□	□
Harford County Emergency Operations Center (EOC) - Support										□	□	□
Allegany County 911 - Support										□	□	□
Anne Arundel County EOC - Support										□	□	□
Baltimore County EOC - Support										□	□	□
Cecil County 911 - Support										□	□	□
Anne Arundel County DPWT – Support										□	□	□
U.S. Park Police - Support										□	□	□
District of Columbia Department of Transportation (DDOT) - Support										□	□	□
Virginia Department of Transportation (VDOT) - Support										□	□	□

Howard County Emergency Operations Center (EOC) – Support										□	□	□
Agency-Role	**Responsibilities**											
	Validation of Planning and Requirements for CHART System	Design of CHART System	Develop and Test CHART System	Integrate and Test CHART System Development	Define Operation of CHART System	Implement CHART System	Document Development of CHART System	Operate CHART System	Maintain CHART System	Support Validation of Planning and Requirements for CHART System	Support Integration of CHART System	Support Operation of CHART System
Frederick County Emergency Operations Center (EOC) - Support										□	□	□
Talbot County 911 - Support										□	□	□
Total Traffic, Washington D.C. Office – Support										□	□	□
Worcester County 911 - Support										□	□	□
Ocean City EOC - Support										□	□	□
Wicomico County 911 - Support										□	□	□
Queen Anne's County 911 - Support										□	□	□

4.2 Configuration and Technology Options Considered

The CHART Operating environment consists of servers along with associated storage array and network connection devices. These systems are currently deployed in a virtual environment at the MDOT Data Center in Glen Burnie, and on an identical backup at MDOT SHA Headquarters in Baltimore. Within the virtual environment the CHART Application Server, database server and GUI Web Server are running Microsoft 2019 and the CHART ATMS uses Microsoft SQL Database as its database. The hardware is typically Intel Xeon X5650 2 multi-processor vCPU 2.67 GHz with an attached storage array. Users and remote connections are made via the MDOT

Enterprise Network. CHART Users access the CHART Software via the MDOT

Network and client hardware. The CHART Software will be accessed using the MDOT Standard Web Browser. Field devices are connected via a variety of telecommunications means (Plain Old Telephone Service (POTS), T1, TCP/IP via cellular digital modem, ATM and State-owned fiber.)

Procurement Options Considered

The project was pursued in accordance with COMAR 21.05.03, Procurement by Competitive Sealed Proposals (Technical & Price.) The project is to contract with an experienced and qualified contractor to provide technical and business support for the purpose of enhancement of the current CHART Suite of Systems (ATMS, EORS, LCP and Web Systems.)

Each proposed build will include procedures for implementing Section 5206(e) of the

Transportation Equity Act for the 21st Century (TEA–21), Public Law 105–178, 112 Stat.

457, further enacted by Section 53005 (d) of the Moving Ahead for Progress in the 21st Century Act (MAP-21), Public Law 112-141, 126 Stat. 405, pertaining to conformance with the National Intelligent Transportation Systems Architecture and Standards. 940.11 Project implementation.

a. All ITS projects funded with highway trust funds shall be based on a systems engineering analysis. The Maryland SDLC will be used for this analysis (see above).
b. The analysis should be on a scale commensurate with each task scope.
c. The systems engineering analysis shall include, at a minimum:
    i. Identification of portions of the regional Maryland ITS architecture being implemented (http://itsmd.org/resources/maryland-itshttp://itsmd.org/resources/maryland-its-architecture/architecture/);
    ii. Identification of participating agencies roles and responsibilities;
    iii. Requirements definitions;
    iv. Analysis of alternative system configurations and technology options to meet requirements;
    v. Procurement options;
    vi. Identification of applicable ITS standards and testing procedures; and
    vii. Procedures and resources necessary for operations and management of the system.

These items will be discussed in a high-level addendum of the initial BAA update (after the Base Design Validation) and in a detailed addendum of each subsequent BAA Update (for future proposed builds)

The contract provides systems development and integration using a well-defined methodology for five (5) years, and one (1) Five (5)-year option. Labor will be based upon approved labor categories and labor rates.

Applicable ITS Standards

The CHART ATMS has been and is being designed to be as compliant with ITS national standards where possible and practical. The system design utilizes existing standards, within four contexts of the system: data storage, external communications, internal communications, and field communications.

4.2.1 Data Storage

In the early years of the project, the CHART ATMS development team made an effort to utilize the TMDD to define attributes stored in the CHART ATMS database. The TMDD contains the national ITS standard data definitions for data elements. Wherever practical, data elements existing in the TMDD and needed by the application were created with TMDD definitions. Additional attributes needed to implement the CHART ATMS system requirements were added to these standard table definitions. These elements, of course, do not interfere with the ability to access the TMDD-standard elements. This effort reached its height during the incorporation of video processing into the CHART ATMS. During this phase several extra CCTV-related TMDD attributes which had no purpose in the planned CHART ATMS processing were nevertheless added to the CHART ATMS graphical user interface and the CHART ATMS database for the sole purpose of achieving the goal of fully conforming to the TMDD: among them, horizontal and vertical datum type, latitude and longitude (back before the CHART ATMS populated these otherwise), height, vertical level, control type, and supported command set.

4.2.2 External Communications

This section describes interfaces CHART ATMS has with other system outside of the CHART ATMS Program.

4.2.2.1 Center-to-Center Communications

Export

The CHART ATMS Data Exporter provides a broad selection of ITS data in XML format using both an on-demand and a subscription-based HTTP transport.

Traffic event messages are compliant with the SAE ATIS J2354 STANDARD (ATIS-Draft03-00-79.xsd) and include extensive customizations. The customizations are implemented per the standard's localization feature, so the resulting messages remain compliant with the standard.

Device messages are compliant with the TMDD standard (TMDD v3.0 Design v2.0) and also include extensive customizations. Like the Traffic Event messages, the device messages also include extensive customizations but again these were accomplished using TMDDs localization feature, so the resulting messages remain compliant with the standard. Device information available over this interface included DMS, HAR, TSS, Beacons, and CCTV configuration; video is not available.

Both traffic event and device messages are currently consumed by the University of Maryland's RITIS system and by MDOT SHA's MD511 Traveler Advisory System.

Import

CHART ATMS imports traffic and device data from the University of Maryland's RITIS system using messages similar to the export messages.

Like CHART ATMS's export messages, the RITIS traffic event messages follow the SAE ATIS J2354 STANDARD (ATIS-Draft-03-00-79.xsd) however their customizations are more modest than CHART's.

Also, like CHART ATMS's export messages, the RITIS device messages follow the TMDD standard (TMDD v3.0 Design v2.0) with modest customizations. Currently CHART ATMS imports DMS and TSS data from RITIS using this mechanism.

4.2.2.2 Data-Specific Communications

CHART ATMS collects roadway travel times from INRIX for displaying travel times on DMSs. Although INRIX messages do not follow a standard themselves, they do include TMC codes in their messages which is an international standard (ISO-14819).

The remaining external interfaces simply follow an HTTP/XML interface standard, however, the content of the messages themselves do not follow any specific standard.

4.2.2.3 Inter-CHART Communications

CHART ATMS shares messages with other CHART systems such as weather systems, AVL, LCP, Mapping, and CHART Web (indirectly via the CHART ATMs ExportClient). These interfaces are not compliant with any recognized standard primarily because no standard exists for these interfaces.

4.2.3 Internal Communications

This section describes interfaces within the CHART ATMS itself. There are two major varieties of interfaces: interfaces between the many processes which make up the CHART ATMS, and communications to CHART field devices.

4.2.3.1 Interprocess Communications

In general, the older CHART ATMS design components use CORBA for transactions between internal software components. When the CHART ATMS (then known as CHART2) was just getting underway, CORBA had been chosen as one of two approved methods of communication between ITS software components by the NTCIP Center to Center committee. So, when the CHART ATMS was originally developed, the design team referenced the burgeoning object model being developed by the Center-to-Center committee. At that time, however, it had not yet defined the system interfaces. Thus, the CHART ATMS was developed to isolate standard interfaces from those that are clearly CHART ATMS specific. (For instance, CHART ATMS includes a class called a "CHART2DMS," which contains data and interfaces thought to be specific to Maryland's implementation of an ATMS, and "CHART2DMS" extends a base class called a "DMS," which contains data and methods considered more universal). CORBA has been dismissed within the IT industry since the original center to center communications standards were defined. As a result, the CHART ATMS has moved towards an HTTPS/XML interface for receiving and sending data from/to entities outside of the CHART ATMS.

4.2.4 Field Communications

In the area of field communications, the CHART ATMS design has been and continues to move towards conformance with NTCIP, which defines the current national standards for communications with field devices in the ITS industry. NTCIP is the National Transportation Communications for ITS Protocol (ITS itself of course being an acronym for Intelligent Transportation Systems). The CHART ATMS currently supports NTCIP communications for DMSs and CCTV cameras. Currently within the CHART ATMS some 99% of the 300+ DMSs communicate via NTCIP. DMS manufacturers were the first to embrace the NTCIP standard. Only about 1% of the approximately 800 CCTV cameras managed by CHART ATMS support the NTCIP standard. The CHART ATMS is designed to add support for NTCIP (and other) protocols with minimal effort. Separate protocol handlers are designed and coded separately from the base code which manages the devices themselves, thus, adding support for a new protocol does not require significant amounts of code to be written to manage devices that communicate via a new protocol. Prior to development and widespread support of NTCIP, this design was used initially to add support for non-NTCIP devices. Lately this approach has been used to add support for NTCIP communications, by adding an NTCIP protocol handler for DMSs and an NTCIP protocol handler for cameras.

5 Transitioning Critical Technologies

5.1 Identified Technologies

Two new technologies from the BAA have been identified so far for this SEMP. These include those required for Part Time Shoulder Use (PTSU) on I-695 and those required for Queue Warning on I-70. In both of these cases all engineering and systems documents will be provided by the individual projects. As all systems created for CHART ATMS, these new subsystems will be built to be expandable statewide.

5.1.1 PTSU

I-695 from I-70 to MD 43 is a critical roadway in the Baltimore Region, serving over 190,000 vehicles per day in 2018 and projected to serve over 210,000 vehicles per day in 2040. MDOT SHA's 2019 Mobility Report indicates that the Project Area contains 3 of the top 5 most congested roadway segments in Maryland. To address these concerns, the MDOT SHA has committed $143M to implement a Transportation Systems Management and Operations (TSMO) solution in the corridor. The focal point of the project is the provision of part time shoulder use (PTSU) for the entire limits of the Project Area. FHWA's Use of Freeway Shoulders for Travel publication states that PTSU converts roadway shoulders to an area used for travel during portions of the day as a congestion relief strategy. It is an element of Performance-Based Practical Design which can be a cost-effective solution for improving operations and safety by providing additional capacity when it is most needed, while preserving the use of the shoulder as an area of refuge during the majority of the day.

MDOT SHA has engaged a contractor under project BA0065172, I-695 TSMO – I-70 TO MD 43, to complete this work. The CONOPS provided to the CHART Systems Division for this project states that the deployment of the ITS to support the proposed I-695 PTSU lane require the following major steps:

- Systems Engineering: This step will include development of the ConOps and Interface Control Document (ICD).
- Design: This step will include detailed design for the proposed ITS systems.
- Software Development: This step will include development of software modifications for the CHART ATMS and SwRI ActiveITS using the ICD as a guide for interconnection of systems.
- Construction: This step will include building the ITS structures and supporting infrastructure.
- Testing and Commissioning: This step will include all testing required to meet the requirements of the contract and to ensure the system/devices functions at the site level and as a whole system. This step will include the burn-in period.
- System Acceptance and Operations: This step will take place once the burn-in period has elapsed and MDOT SHA has accepted the system for maintenance and operations.

Since the project above will be providing the SWRI Active ITS to perform the actual PTSU activities under this project, all this CHART ATMS subsystem will be doing is passing data back and forth through a programming interface so the CHART operators can monitor the PTSU through their normal CHART ATMS Graphical User Interface.

5.2 Queue Warning System

A previous project in Maryland had a high-level requirement for a Queue Warning and Dynamic Speed Advisory (QW/DSA) system. Engineering and Systems documents were developed but the project was dropped before deployment.

Based upon direction from the TSMO Executive Steering Committee meeting of October 31, 2019, and subsequent CHART Board meetings, Release 24 of CHART ATMS will primarily consist of Queue Warning and Dynamic Speed Advisory (QW/DSA) that can initially be deployed on I-70. According to the CONOPS provided to CHART Systems Division, "A QWS displays real-time warning messages to alert motorists that significant slowdowns are ahead. This system is typically combined with a Dynamic Speed Advisory (DSA) system, which displays the safe speed based on travel conditions. The QWS part of the overall system gives motorists more time to adjust their speeds, thus reducing rear end crashes and improving safety and justifies the speed reductions shown on the DSA. As traffic conditions are monitored in real time, the warning messages are adjusted based on the locations and severity of the queues and slowdowns."

6 Integration of the System

The CHART ATMS is a mature, statewide system that is designed for incident response as well as active traffic management. The Agile methodology required by the Program Management Plan described in section 3 above ensures that all stages from requirements to integration to training and maintenance and taken into account.

7 Integration of the Systems Engineering Effort

7.1 The management methodology for the CHART Program consists of technical, management, and support process elements drawn principally from the vendor's internal development methodology, PMI PMBOK, the Federal Highway

Administration's System Engineering "V" and Maryland's SDLC methodology.

Technical elements support the methodology's lifecycle during which the

Contractor's team analyzes, designs, implements, tests, deploys, and maintains a product solution. Management process elements span the entire lifecycle with planning activities proceeding and providing the approval to conduct technical work. Highlights of the methodology employed on the CHART Program include the following:

- Program management provides the global oversight and defines the general management approach.
- Empowered Agile project teams provide the technical leadership necessary for the delivery of a planned product on time and within budget.
- Configuration Management manages and executes baseline changes.

- Configuration Management provides the elements through which individual project product solutions and ongoing maintenance work is coordinated and controlled as it is verified, validated, and approved for deployment to operations.
- Engineering oversight examines change against the architectural model and requirements.
- Quality Management monitors and assesses product quality and adherence to process.

7.2 The Communication Management Plan defines the processes required to ensure timely and appropriate identification, collection, distribution, storage, retrieval, and disposition of project information to the project team, stakeholders, Project Sponsor, and Executive Sponsor. This plan includes:

- Identification of stakeholder communications requirements
- Information collection sources and responsibilities
- Communication distribution channels
- Frequency and recipients of communication
- Assignments for information collection and distribution
- Guidelines for effective and efficient meetings
- Schedule of project team meetings
    - Storage, retrieval, and disposition methods

8 Applicable Documents

Title	Description	Current Version
CHART Business Area Architecture	Describes: • A developed, aligned, and communicated business vision	Version 17.0 Doc# CHART-OPS014-v17
	Designed business processes including relationship to organizations, technology, and facilities Defined, distributed, and integrated applications and data entities across platforms and locations A developed architecture at the conceptual level for technical infrastructure Defined, interrelated, and scheduled releases within the business change program	March 15, 2017

CHART Systems Release Plan	This document lists the complete set of requirements derived from the CHART 2016 BAA workshops and change requests compiled during the June 2020 BAA review. This document also describes the strategy used to prioritize and group a sub-set of these requirements into releases during the contract period in order to best support CHART's mission. The resulting release plan lays out planned work for all CHART systems for the remainder of the contract term and extension years, with room to add lower priority requirements where resources or time permit. This plan is reviewed on a regular basis and may be adjusted, using the release strategy process, to meet CHART's new requirements when identified or as reprioritized from this original list.	Version 16 Doc# CHART-OPS-015 May 14, 2021
CHART Program Management Plan (PMP)	Documents how the CHART Project Team will plan, execute, monitor, control, and close projects formally approved and tracked as application release work orders.	Version 7.10 CHART-OPS-001-v7.1 December 10, 2020
CHART Staffing Management Plan (SMP)	The Staffing Management Plan details the project's human resources requirements and how those requirements will be fulfilled including Project Roles and Responsibilities, Project Staffing Estimates, Acquisition Strategy, Training Plan and an Organizational Chart	Version 5.0 CHART-OPS-005 v5.0 July 20, 2020
CHART Change Management Plan (CMP)	Description and approach to how changes will be proposed, accepted, monitored, and controlled	Version 5.0 CHART-OPS-003 December 10, 2020
CHART Risk Management Plan (RMP)	Planned processes and responsibilities to routinely perform risk identification, risk analysis, risk response planning, and risk control activities throughout the life cycle of the project.	Version 5.0 CHART-OPS-002 v5.0 July 20, 2020
CHART Communication Management Plan	Defines the processes required to ensure timely and appropriate identification, collection, distribution, storage, retrieval and disposition of project information to the project team,	Version 5.0 CHART-OPS-004 v5.0 July 20, 2020
	stakeholders Project Sponsor and Executive Sponsor.	
CHART Program Test Master Plan	Outlines the testing framework applied to release work orders across the CHART program. This program level plan covers the testing approach used for test activities during a work order as well as the test tools, environments, and resources used for testing	Version 3.0 CHART-TD-001 July 20, 2020

J2B6400004 – CHART PROJECT CHARTER	Document approved by the project manager, project sponsor, agency IT director and executive sponsor explaining the project purpose, justification, objectives, success criteria, requirements, assumptions, constraints, preliminary risk statement, milestones, budget and governance.	Version 1 June 17, 2021
BA0065172 I-695 TSMO – I-70 TO MD 43 CONCEPT OF OPERATIONS (CONOPS)	This Concept of Operations provides a detailed description of the ITS system to be deployed for the implementation of part time shoulder use in the Project Area.	MARCH 16, 2021
TSMO System 1 Concept of Operations	ConOps provide a high-level user-oriented view of the proposed system being considered that focuses on needs and functions that must be met, and not on technologies or technical details of the proposed system. The goals of this document are to develop a shared understanding among the system owners, developers, operators, and maintainers.	June 17, 2020
Maryland Statewide ITS Architecture	This document represents the regional ITS architecture for the entire state of Maryland. The most recent update was done in calendar year 2016	Partial Update, November 2016
TSMO Master Plan	The TSMO Master Plan presents seventeen (17) TSMO Systems that make up Maryland's most significant corridors and presents analyses and recommendations for TSMO treatments/strategies within each sub-system.	July, 2020