ITS Project Development Guidelines

2016

TN TDOT Department of Transportation

Traffic Operations Division

Effective Date: July 20, 2016

Table of Contents

1 Introduction

> ***What is ITS?***
> According to 23 CFR 940, *Intelligent Transportation Systems (ITS)* are electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system.

The purpose of the Tennessee Department of Transportation (TDOT) Intelligent Transportation Systems Project Development Guidelines (ITS Guidelines) is to outline a consistent approach to project development steps unique to intelligent transportation systems (ITS) projects in Tennessee. In particular, this document identifies an approach for TDOT and its partnering agencies to follow a systems engineering process in implementing ITS solutions. All ITS projects funded by in part or whole with funds administered by TDOT, including projects sponsored by local public agencies, shall follow the approach outlined in this document.

2 ITS Federal Rule/Policy – 23 CFR Part 940

Title 23, Code of Federal Regulations, Part 940 (23 CFR 940) requires that Intelligent Transportation Systems (ITS) projects carried out using funds from the Highway Trust Fund, including the Mass Transit Account:

- Conform to the National ITS Architecture and applicable ITS standards
- Are based upon a **systems engineering analysis**

State funded projects will follow the same process for consistency. Conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a regional ITS architecture (RITSA), and the subsequent adherence of all ITS projects to that RITSA.

Systems engineering is a structured process for arriving at a final design of a system. The final design is selected from a number of alternatives that would accomplish the same objectives and considers the total life-cycle of the project including not only the technical merits of potential solutions but also the costs and relative value of alternatives.

According to the Project Implementation section of 23 CFR 940, the required systems engineering analysis for ITS projects shall include, at a minimum:

1. Identification of portions of the regional ITS architecture being implemented (or if a regional ITS architecture does not exist, the applicable portions of the National ITS Architecture);

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; and
7. Procedures and resources necessary for operations and management / maintenance of the system.

The bulk of these ITS Guidelines will describe how ITS projects in Tennessee will follow a systems engineering process and by that process arrive at a documented systems engineering analysis that conforms to the applicable regional and National ITS Architectures.

The text 23 CFR 940 can be found at *http://www.ecfr.gov/*

2.1 National ITS Architecture

National ITS Architecture (also "National Architecture") means a common framework for ITS interoperability. The National ITS Architecture comprises the logical architecture and physical architecture which satisfy a defined set of user services. The National ITS Architecture is maintained by the United States Department of Transportation (DOT).

The National ITS Architecture is available at http://www.its.dot.gov/arch/

2.2 Regional ITS Architecture

Regional ITS architecture (RITSA) means a regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects or groups of projects. **"**Region" is the geographical area that identifies the boundaries of the RITSA and is defined by and based on the needs of the participating agencies and other stakeholders. In metropolitan areas, a region should be no less than the boundaries of the metropolitan planning area (MPA). Development of the RITSA should be consistent with the transportation planning process for statewide and metropolitan transportation planning.

2.3 Definition of ITS Project

23 CFR 940 describes 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." In more general terms, the "FHWA Federal-Aid ITS Procurement Regulations and Contracting Options" guidance document also offers the following

description (*Publication Number: FHWA-RD-97-145 available at* [*http://ntl.bts.gov/*](http://ntl.bts.gov/)):

Intelligent Transportation Systems consist of a group of advanced technologies and systems that collectively offer the opportunity to address such surface transportation issues as safety, efficiency, congestion, mobility, and quality of life. […] The functional areas include advanced traffic management systems, advanced traveler information systems, advanced vehicle control systems, commercial vehicle operations, advanced public transportation systems, and advanced rural transportation systems. […]

ITS systems are complex, versatile, and diverse. They often leverage the latest in telecommunications, computers, software, sensing, and electronics technologies to effectively meet the management needs of surface transportation systems. They are often designed to incorporate one or more of the user service areas and technologies and are deployed either incrementally or all at once. These technologies can be included in tailored or standalone projects, legacy system expansion projects, or deployed as part of traditional roadway construction projects.

In Tennessee ITS projects are classified as Low-Risk or High-Risk. Some projects are also related to ITS, but are not in fact "ITS projects." TDOT's process for identifying and classifying ITS projects will be discussed further in Section 3.4.

3 ITS Project Development

3.1 Overview

All ITS projects funded in whole or part by TDOT shall be based on a systems engineering (SE) analysis. SE steps differ somewhat from the "Traditional Road Building Process" typically used by agencies to build highways.

3.2 Traditional Road Building Process

The Traditional Road Building Process (TRBP) project development as shown in Figure 1 has been used for many years. Over the years, requirements have become well defined, designs are well documented and proven, product performance is solid, and the technology is proven. The key milestones in the TRBP are shown in Figure 1 below.

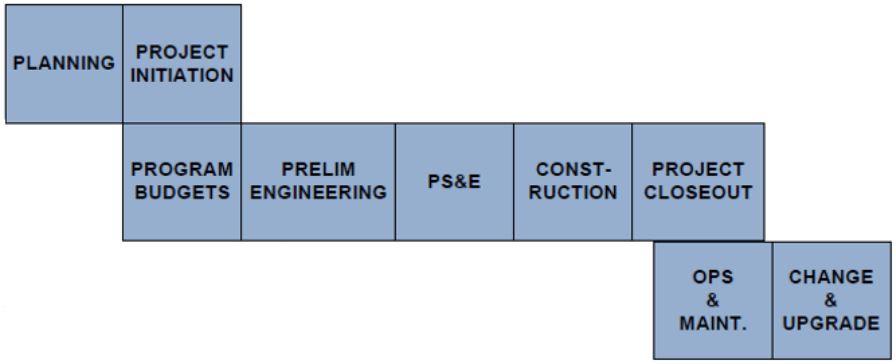


Figure 1 – Traditional Road Building Process

3.3 Systems Engineering Process

ITS projects have features unique to other types of highway projects, and the implementation of these features can pose certain risks (termination, time delays or cost increases). Often, the TRBP does not account for the critical project development complexities of ITS projects. Additional elements are needed in the process of development to mitigate the higher risks as shown in Figure 2. These additional elements can be thought of as extensions to the TRBP and are documented within a “Systems Engineering Analysis,” or SEA.

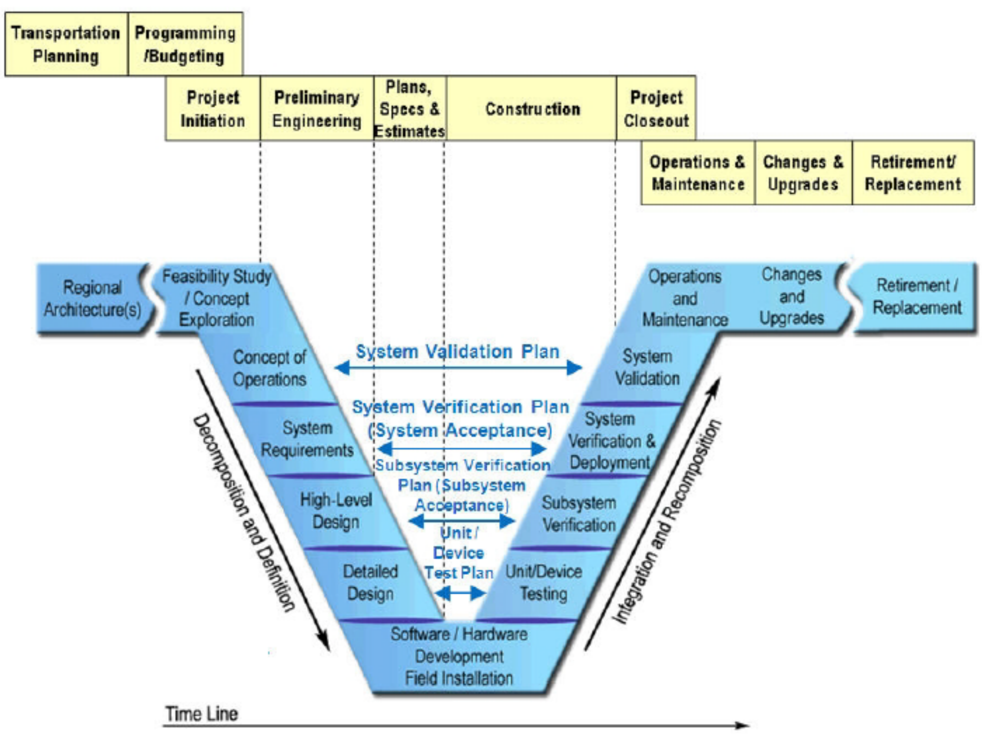


Figure 2 – Systems Engineering Process

However, not all ITS projects are equal, and Federal regulations stipulate that SEAs must be commensurate with the project scope. Therefore, to ensure SEA documentation is neither too sparse nor too complicated, TDOT has adopted a tiered, risk-based classification and documentation process dependent on the features of each project.

3.4 ITS Project Classification Guidelines

There are two main categories of ITS projects in Tennessee: **Low Risk** and **High Risk.** Project risk considers:

- Number of jurisdictions and modes;
- Extent of software creation;
- Extent of proven hardware and communications technology used;
- Number and complexity of new interfaces to other systems;
- Level of detail in requirements and documentation;
- Level of detail in operating procedures and documentation;
- Service life of technology applied to equipment and software.

General criteria for the determination of risk include:

- Technology: functions are not fully identified, user interface not right, unrealistic technical requirements, component shortcomings;
- People: personnel shortfalls;
- Physical Environment: external dependencies, device placement;
- Political Environment: adding requirements that are not tied to a need, do you have a champion;
- Contract Issues: unrealistic schedules and budgets, requirements change;

3.4.1 Projects Not Requiring Systems Engineering Analysis (Non-ITS)

It is important to note that many projects seem like ITS projects, and may have some relationship to ITS, but are not ITS projects and do not require a Systems Engineering Analysis (SEA). For these, all activities of the traditional roadway project development life-cycle process will be followed. Nevertheless, for projects that have some relationship to ITS, TDOT requires the completion of an ITS Project Identification Form (see Section 4 for more details). If completion of the ITS Project Identification Form indicates that the project is non-ITS, no further ITS-related action is necessary.

Non-ITS projects do not add new functionality to the ITS infrastructure.

The following are examples of non-ITS projects and do not require a Systems Engineering Analysis:

- Upgrades to an existing traffic signal – This may include, for example, adding or revising left turn phasing or other phasing, adding pedestrian-crossing displays;
- Installing an "isolated" traffic signal – This is a signal not connected to any type of external signal-control system, nor likely to be in the future because of its isolation;
- Traffic signal timing projects – This includes all studies whose purpose is to change the coordination parameters for controlling a group of signals – but with no installation of new hardware or software;
- Studies, Plans, Analyses – This includes ITS Master Plans, Deployment Plans, Technology Studies, etc. whose product is only a document, with no new hardware of software installed.
- Routine Operations including the operation and maintenance of any ITS elements or systems – with no new hardware or software installed.

3.4.2 Low Risk ITS Projects

Low-Risk ITS projects are often referred to as ITS infrastructure expansion projects. Standard Plans, Standard Specification, and Standard Special Provisions are usually well documented.

Low Risk ITS projects will have ***all*** of the following characteristics:

- Single jurisdiction
- No software creation – commercial-off-the-shelf (COTS) or proven software
- Proven COTS hardware & communications technology
- No new interfaces
- System requirements fully documented
- Operating procedures fully documented
- Project life-cycle not shortened by technology service life
- Agency has previous experience

The following are examples of Low Risk ITS projects:

- Expanding a pre-existing system/network by adding field ITS elements (e.g.: DMS, CCTV, RWIS) with no other changes to the system and how it is used;
- Expanding existing communications systems – this consists of extending existing fiber-optic or wireless communications systems, using the same technology and specifications as the preexisting system;
- Expanding a Traffic Signal System by adding additional intersection(s), with no changes needed to the central system;
- Installing an existing parking management system at 2 additional garages – with no changes
- Leasing turnkey services only (e.g., website-based information service) – with no hardware or software purchases.

3.4.3 High Risk ITS Projects

High Risk ITS projects are often referred to as ITS system development projects. High Risk ITS projects implement regional ITS initiatives that are multijurisdictional, multi-modal, or otherwise affect regional integration of ITS. An ITS project is considered High Risk when it involves new/unfamiliar technology and custom software development.

High Risk ITS projects have *one* (or more) of the following characteristics:

- Multi-jurisdictional or multi-modal
- Custom software is required
- Hardware and communications are "cutting-edge" or not in common use (new hardware integration)
- New interfaces to other systems are required
- System requirements not detailed or not fully documented
- Operating procedures not detailed or not fully documented
- Technology service life shortens project life-cycle
- New technology applications.

The following are examples of High Risk ITS projects (when the technology is new to the operating agency):

- Implementation of Traffic Signal Systems with:
  - Adaptive Signal Control Technology (ASCT)
  - Traffic Responsive Plan Selection (TRPS)
  - Transit Signal Priority (TSP)
  - Centrally controlled management
- Traveler information systems that collects data from multiple agencies or modes
- Electronic fare-payment systems
- New traffic management centers (TMCs)
- Active traffic and demand management (ATDM) systems, such as:
  - Dynamic lane control systems
  - High-occupancy toll lane (HOT) implementation
  - Adaptive ramp metering implementation

3.5 ITS Project Attributes and Risk Factors

A comparison of typical Low Risk and High Risk factors is shown in Table 1 below.

	Low-Risk Project Attributes	**High-Risk Project Attributes**	**Risk Factors**
1	Single jurisdiction and single transportation mode (highway, transit or rail)	Multi-jurisdictional or Multimodal	With multiple agencies, departments, and disciplines, disagreements can arise about roles, responsibilities, cost sharing, data sharing, schedules, changing priorities, etc. Detailed written agreements are crucial!

2	No software creation; uses commercial-off-the-shelf (COTS) or proven software	Custom software development is required	Custom software requires additional development, testing, training, documentation, maintenance, and product update procedures - all unique to one installation. This is very expensive, so hidden short-cuts are often taken to keep costs low. Additionally, integration with existing software can be challenging, especially because documentation is often not complete and out-of-date.
3	Proven COTS hardware and communications technology	Hardware or communications technology are "cutting edge" or not in common use.	New technologies are not "proven" until they have been installed and operated in a substantial number of different environments. New environments often uncover unforeseen problems. New technologies or new businesses can sometimes fail completely. Multiple proven technologies combined in the same project would be high risk if there are new interfaces between them.
4	No new interfaces	New interfaces to other systems are required.	New interfaces require that documentation for the "other" system be **complete and up-to-date.** If not (and often they are not), building a new interface can become difficult or impossible. Duplication of existing interfaces reduces the risk. "Open Standard" interfaces are usually well-documented and low risk.
5	System requirements fully detailed in writing	System requirements not detailed or not fully documented	System Requirements are critical for the procurement process. They must describe in detail all of the functions the system must perform, performance expected, plus the operating environment. Good requirements can be a dozen or more pages for a small system, and hundreds of pages for a large system. When existing systems are upgraded with new capabilities, requirements must be revised and rewritten.
6	Operating procedures fully detailed in writing	Operating procedures not detailed or not fully documented	Standard Operating Procedures are required for training, operations, and maintenance. For existing systems, they are often out-of-date.
7	None of the technologies used are near end of service life	Some technologies included are near end of service life	Computer technology changes rapidly (e.g. PC's and cell phones become obsolete in 2-4 years). Local area networks using internet standards have had a long life, but in contrast some mobile phones that use proprietary communications became obsolete quickly. Similarly, the useful life of ITS technology (hardware, software, and communications) is short. Whether your project is a new system or expanding an existing one, look carefully at **all** the technology elements to assess remaining cost- effective service life.

Table 1 - ITS Project Attributes and Risk Factors

4 ITS Compliance Guidelines

4.1 Overview

The application and oversight process for ITS projects is summarized in Figure 3. There are four key participants involved in the process, each with distinct roles:

- ➢ **Metropolitan planning organizations (MPOs),** who will program the funds in the transportation improvement program (TIP) and maintain the regional ITS architecture (RITSA);

- ➢ **Local public agencies (LPAs),** who may be managing the contracts for ITS projects within their jurisdiction, possibly with assistance from consultants.

- ➢ **Tennessee Department of Transportation (TDOT)**, who is often the contracting agency for ITS projects on Interstate, U.S., and State highway routes.

- ➢ **TN FHWA Division Office**, who will obligate federal funding and may oversee some ITS project development.

4.2 Steps to ITS Compliance

The general process TDOT has adopted for ITS project development while meeting the requirements for documenting an SEA is shown in Figure 3 below, and will be discussed in detail in this section.

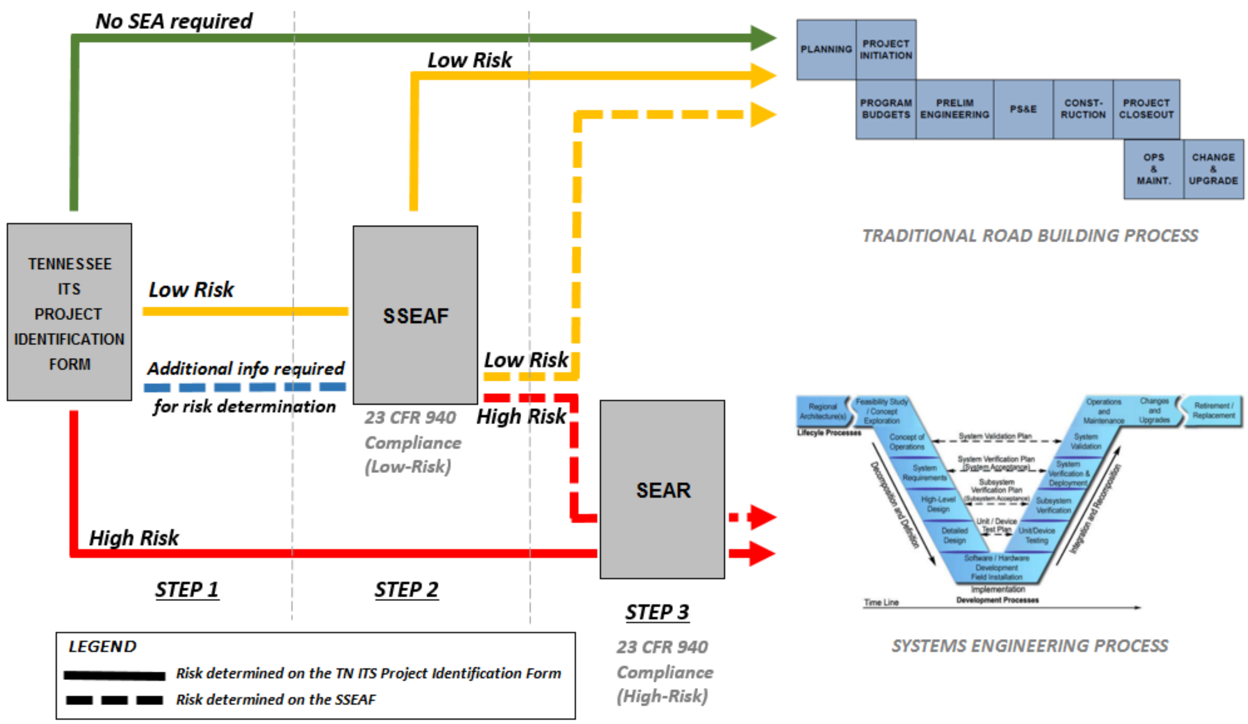


Figure 3 – TDOT's process for ITS systems engineering documentation

<u>**Step 1**</u> is initiated by TDOT or the local agency in coordination with the MPO. In Tennessee, MPOs, comprised of various urban local officials, have a structure to identify and prioritize proposed transportation improvements. As projects are submitted for inclusion in the TIP each project should be evaluated by the submitting agency to determine if the project is related to ITS. If the project relates to ITS, then the project

needs to be reviewed by the MPO to determine if the ITS elements in the project are in conformance with the regional ITS architecture (see Sections 7.2 and 7.3). For projects outside regional ITS Architecture, TDOT/TOD will ensure conformance of the ITS elements with the Tennessee Statewide ITS Architecture TIPs, once adopted, are forwarded to TDOT for inclusion by reference into the STIP.
. Federal-aid projects must be included in a TIP or a STIP in order to receive Federal funds.

➡ For **all** projects related to ITS (including non-ITS traffic operations improvements described in 3.4.1), TDOT requires completion of the **Tennessee ITS Project Identification Form**, available at https://www.tn.gov/tdot/section/its, and electronic submission to the TDOT Traffic Operations Division TDOT_ITS@tn.gov

It is the responsibility of TDOT to validate if a project is an ITS project, and if so, to verify the need and extent of the Systems Engineering Analysis required and to notify, in writing, the MPO and the project sponsor of the determination and of any additional required documentation. In areas not served by an MPO, the TDOT Traffic Operations Division Office representative will complete the ITS Project Identification Form and notify the project sponsor of the determination in writing.
If the project is non-ITS, then the remainder of the process is exactly the same as for a traditional road building project (see Section 3.2). No further ITS-specific action is necessary.

- If TDOT needs additional information to determine the appropriate Risk factor for the project, *or* if TDOT determines an ITS project to be Low-Risk through information on the ITS Project Identification Form, then the project moves to **Step 2**.
- If TDOT determines an ITS project to be High-Risk through information on the ITS Project Identification Form, then the project moves to **Step 3**.

Step 2 occurs when TDOT determines that an ITS project is Low-Risk or when additional information is necessary to determine the appropriate Risk factor for the project.

➡ The contracting agency is required to fill out the **Simplified Systems Engineering Analysis Form (SSEAF)** available at https://www.tn.gov/tdot/section/its and submit it electronically to TDOT Traffic Operations Division Office TDOT_ITS@tn.gov

The SSEAF provides responses to the seven requirements for systems engineering analysis (see Section 5.3) within 23 CFR 940 and has the following objectives:

- Document 23 CFR 940 compliance if the ITS project was determined as Low-Risk on Step 1; or
- Provide additional information to assist TDOT in determining if the project is Low-Risk or High-Risk.

It is the responsibility of TDOT to verify the Risk factor (Low-Risk or High-Risk) and to notify, in writing, the MPO and the project sponsor of the determination and of any additional required documentation.

- If the ITS project is **Low-Risk**, no additional documentation is necessary, the remainder of the process is exactly the same as for a traditional road building project (see Section 3.2).

- If the ITS project is **High-Risk,** additional documentation is necessary, and the project will proceed to **Step 3**.

Step 3 – For **High-Risk** ITS projects, a detailed SEA Report will be necessary to document 23 CFR 940 compliance.

➡ The contracting agency is required to complete a **Systems Engineering Analysis Report (SEAR)** and submit it electronically to TDOT Traffic Operations Division Office TDOT_ITS@tn.gov. SEARs can vary in length, but should be thought of as an independent report that vigorously explains and justifies how the SE process was followed in meeting all 7 requirements of 23 CFR 940. **Section 5** of these ITS Guidelines describes, at length, how a SEAR can be completed. The TDOT Traffic Operations Division, in cooperation with the FHWA Tennessee Division, is available to help clarify documentation requirements and provide technical assistance for partner agencies in completing SEARs.

TDOT reserves the right to ask for additional documentation regarding ITS projects and regarding ITS compliance any time during the process.

4.3 Summary of TDOT Required ITS Documentation

1. **Tennessee ITS Project Identification Form** – to be submitted to or completed by TDOT for any project that *relates* to ITS (TDOT_ITS@tn.gov).

2. **Simplified Systems Engineering Analysis Form (SSEAF**) – to be completed if an ITS Project is determined to be Low Risk or if additional information is required to determine the ITS project risk level. (TDOT_ITS@tn.gov).

3. **Systems Engineering Analysis Report (SEAR**) – see Section 5 – to be submitted if an ITS Project is determined to be High Risk. (TDOT_ITS@tn.gov).

5 Guidelines for Developing a Systems Engineering Analysis Report (SEAR)

5.1 Overview

There are two main processes that support systems engineering (SE): technical processes and project management processes. Technical processes are depicted in the "V" systems engineering model (see Section 5.3) and are performed to develop an ITS project that meets the user's needs. Project management processes (or cross-cutting activities) are activities that support the steps of the technical processes and are used to plan, monitor, and control the ITS project so that it is completed on time and on budget.
SE focuses on defining stakeholder's needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. SE provides an opportunity to identify and correct defects as early as possible in the process. Other benefits include:

Improved quality of Intelligent Transportation Systems
Systems engineering thinking promotes increased up-front planning and system definition prior to technology identification and implementation. Documenting stakeholder needs, expectations, the way the system is to operate (Concept of Operations), and the system requirements (what the system is to do) prior to implementation leads to improved system quality.

Reduced risk of cost and schedule overruns
Systems engineering promotes stakeholder involvement throughout project development and improves project control with clearly defined decision points (Control Gates). With the up-front planning described above, the risk of costly rework and schedule slips during later stages of implementation are greatly reduced.

Wide stakeholder participation
Participation of stakeholders is essential for successful system developments. Using a

common and standard development process enables stakeholders to understand and actively participate in the development. Plus, it reduces the learning curve when new stakeholders get involved in a project. A common process ensures a wider set of resources (staff, expertise) that agencies can draw upon within the project life cycle.

Documented plan to maintain, operate, and evolve the Intelligent Transportation System
Project developments that use a systems engineering approach will improve the documentation of the system (requirements, design, verification, development, and support documentation). Having such documentation will improve the long-term operations & maintenance, of the system. Good documentation will make it easier to upgrade and expand the system.

Maintained consistency with the regional and state ITS architectures
Once a regional ITS architecture is developed and projects are defined, a common and clear roadmap for ITS project development is laid out. A systems engineering approach enables consistency with the regional ITS architecture to be verified and maintained.

Flexibility in procurement options for the agencies
Intelligent Transportation Systems that are well documented have greater flexibility for procurement options. Proprietary developments are minimized, proprietary sub-systems are identified, and the use of industry standard interfaces are promoted. This enables alternate system integrators and consultants to support the agencies in upgrades and system expansion. In other words, it minimizes the agencies' need to be "locked into" a specific vendor or system integrator.

Consideration of the rapid evolution of technology
One of the challenges for agencies is staying current with the rapid changes in technology. Intelligent Transportation Systems are long term investments for agencies. So it is important to avoid technology obsolescence. In other words, when field devices fail, the agency should be able to replace them without a major development effort and without maintaining large inventories of obsolete technology. Systems engineering promotes system modularity and the use of standard interfaces where possible. When a technology changes or is unavailable, the functionality can be replaced with minimal impact to other parts of the system (goal of plug and play).

5.2 Scope of a SEAR

For High Risk ITS projects, a detailed Systems Engineering Analysis Report (SEAR) will be required. 23 CFR 940 states that the systems engineering analysis should be on a scale commensurate with the project scope. Therefore, tailoring the SEAR for ITS projects is particularly important because so many ITS projects are smaller, less complex, less risky projects. Nevertheless, even for small projects, you still should have documented requirements, design, and verification procedures. Tailoring is not an invitation to skip steps. Tailoring allows you to adjust the amount of formal documentation and reviews and to focus the process on those steps that are most critical to your project's success. In order to decide on the process that is appropriate for your project, you should perform a risk assessment to understand the complexities involved and how many unknowns there are. Some ITS projects are much larger and more complex than others, which makes them a greater risk and thus candidates for more rigorous processes. See Section 3.4.

5.3 The Systems Engineering "V" Diagram

According to the Project Implementation section of 23 CFR 940, the SEA shall include, at a minimum:

1. Identification of portions of the regional ITS architecture being implemented (or if a regional ITS architecture does not exist, the applicable portions of the National ITS Architecture);
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; and
7. Procedures and resources necessary for operations and management/maintenance of the system.

It is important to realize that the SE approach is actually broader than these seven specific requirements identified in the Rule/Policy. If you implement a good SE process, you will meet or exceed the specific systems engineering analysis requirements identified in the Rule/Policy. TDOT recommends outlining the format of a SEAR to align with the 7 required elements above. Here is an example of aligning SEAR sections (in a recommended sequence) with the 7 required elements:

23 CFR 940 SEA requirements	***Example SEAR section title***
1. Identification of portions of the regional ITS architecture being implemented (or if a regional ITS architecture does not exist, the applicable	Integration with Regional ITS Architecture (see Section 5.7.1)

portions of the National ITS Architecture);	
2. Identification of participating agencies roles and responsibilities;	Concept of Operations (see Section 5.7.3)
3. Requirements definitions;	System Requirements (see Section 5.7.4)
4. Analysis of alternative system configurations and technology options to meet requirements	Alternatives Analysis (see Section 5.7.2)
5. Procurement options;	Procurement Options and Recommendations (see Section 5.7.2 and Section 6)
6. Identification of applicable ITS standards and testing procedures;	System Verification Plan (see Sections 5.7.4 through 5.7.7)
7. Procedures and resources necessary for operations and management/maintenance of the system.	Operations and Maintenance Plan (see Section 5.7.10)

SE processes can take many forms, but FHWA and other agencies have promoted the use of the "V" model for successful application of SE to ITS projects. This is the process TDOT recommends for completing SEARs and the process that will be followed throughout Section 5. An overview of the "V" model is shown on Figure 4 below.

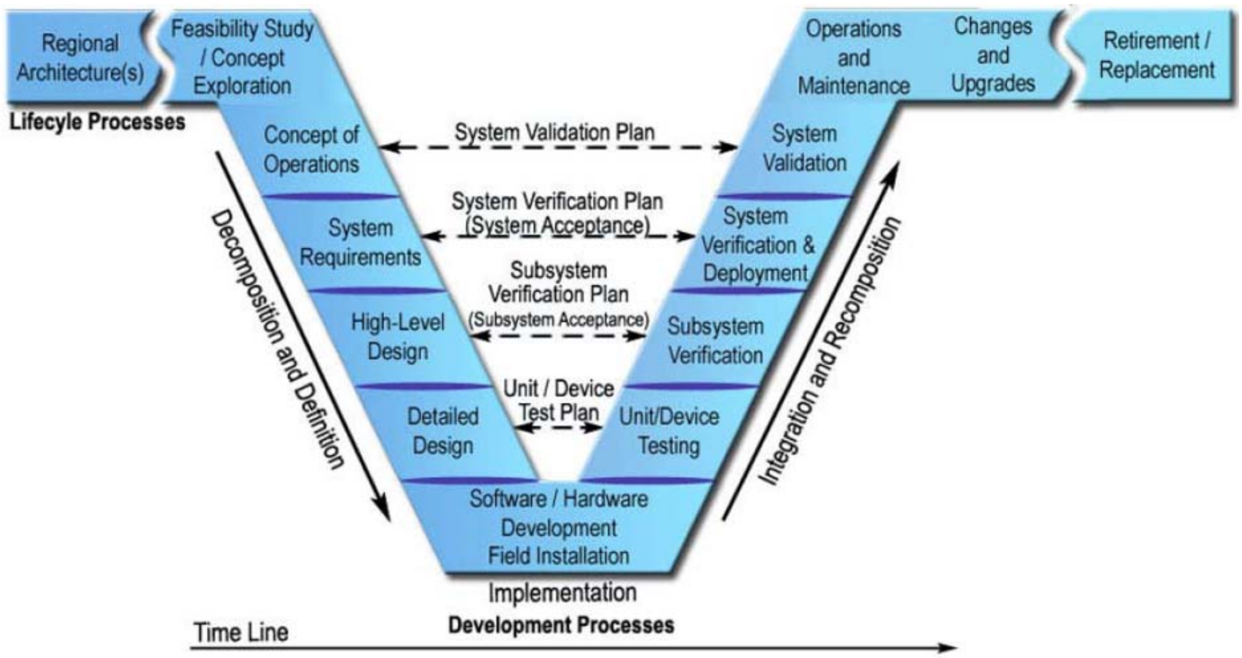


Figure 4 – "V" Diagram - Systems Engineering Analysis

5.4 Cross-Cutting Activities

Cross-cutting activities are instrumental activities that are ongoing throughout the systems engineering analysis. Project management, configuration management or change control, traceability and risk management are some of the cross-cutting activities that support the technical processes of systems engineering as demonstrated on Figure 5.

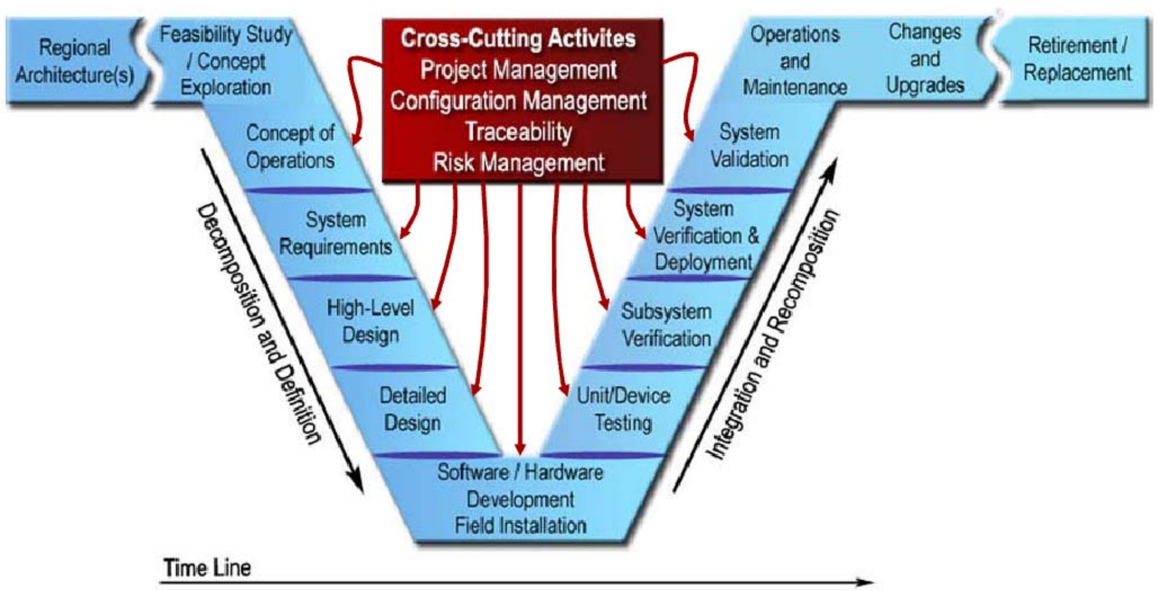


Figure 5 – Cross-cutting activities

5.5 Key Observations for the "V" Development Model

The left side of the "V" is the definition and decomposition of the system into components that can be built or procured. The bottom of the "V" is the construction, fabrication, and procurement of the component items. The right side of the "V" integrates the components into sub-systems then into the final system. Each level of integration is verified against the left side of the "V" through the Verification Plans.

Decision gates provide the system's owner with formal decision points for proceeding to the next step of the process. A decision gate is an interface from one phase of the project to the next. There is an interface between each phase from the left side to the right side.

There is a relationship of the activities performed on the left side of the "V" to the products being produced, integrated, and verified on the right side of the "V" (model versus reality).

The most important view of the system for the system's owner and stakeholders is at the Concept of Operations level. Below that level is the area of most interest to the development team. It is the area for which they are responsible (system's owner responsibility versus the development team responsibility).

Importance of stakeholder involvement is shown on both sides of the "V". It is shown on the left side by defining the system and on the right side by the verification of the system.

The arrow in the "V" diagram shows the time sequence of these activities.

5.6 Basic Systems Engineering Principles

The Systems Engineer should have the following mindset when developing a system:

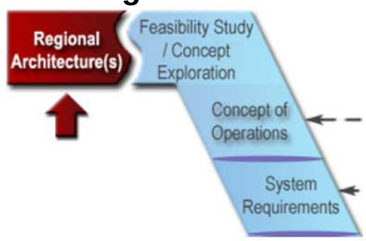
1. View the system from the stakeholder point of view (walk in the shoes of the system's owner and stakeholders). Key processes include needs assessment, elicitation, Concept of Operations, and stakeholder involvement.
2. Start at the finish line to define the output of the system and the way the system is going to operate. Key processes include Concept of Operations and Validation Plan.
3. Address risks as early as possible when the cost impacts are lowest. Key processes include risk management, requirements, and stakeholder involvement (spend more time on the left side of the "V").
4. Push technology choices to the last possible moment. Define *what* is to be done before defining *how* it is to be done (form follows function).
5. Focus on interfaces of the system during the definition of the system. Defining clear and standard interfaces and managing them through the development will ease the integration of the individual elements of the system.

6. Understand the organization of the system's owner, stakeholders, and development team.

5.7 ITS Technical Process Guidelines

The following briefly describe each step of the "V" diagram including objectives, necessary input, key activities performed, output results and review information. This guidance is not all encompassing as ITS projects can vary significantly in scope, but should provide adequate information to address a majority of situations.

5.7.1 Regional Architecture(s)



The regional ITS architecture is the first step in the "V" because the best opportunity for its use is at the beginning of the development process. The architecture is most valuable as a scoping tool that allows a project to be broadly defined and shown in a regional context. Initial use of the regional ITS architecture requires a few basic activities: locating the right architecture(s), identifying the portion of the architecture(s) that applies to your project, and notifying the architecture(s) maintainer of any required regional architecture changes. The Turbo Architecture software tool can be used to accurately define an ITS project architecture and to generate diagrams and reports that fully document the portion of the regional ITS architecture that will be implemented by the project. This step satisfies 23 CFR 940.11 Requirement 1 and partially satisfies Requirement 6.

Objectives

- Define the project scope while considering the regional vision and opportunities for integration.
- Improve consistency between ITS projects and identify more efficient incremental implementation strategies.
- Improve continuity between planning and project.

Input

- Relevant regional ITS architecture(s)
- Regional/national resources supporting architecture use
- Other planning/programming products relevant to the project

Key activities

- Identify regional ITS architecture(s) that are relevant to the project
- Identify the portion of the regional ITS architecture that applies
- Identify applicable ITS standards

- Verify project consistency with the regional ITS architecture and identify any necessary changes to the regional ITS architecture

Output

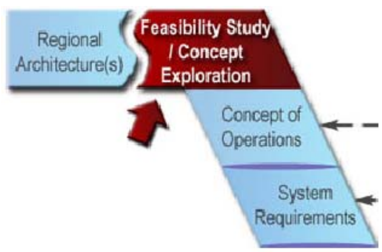
- List of project stakeholders and roles and responsibilities
- List of inventory elements included in or affected by the project
- List of requirements the proposed system(s) must meet
- List of interfaces and the information to be exchanged or shared by the system(s)
- Regional ITS architecture feedback as necessary

Review

Proceed only if you have:

- Demonstrated consistency with the regional ITS architecture and identified needed changes to the regional ITS architecture, if applicable
- Extracted the relevant portion of the regional ITS architecture that can be used in subsequent steps
- Reached consensus on the project/system scope

5.7.2 Feasibility Study / Concept Exploration



The proposed ITS project is assessed to determine whether it is technically, economically, and operationally viable. Major concept alternatives are considered, and the most viable option is selected and justified. While the concept exploration should be at a fairly high level at this early stage, enough technical detail must be included to show that the proposed concept is workable and realistic. The feasibility study provides a basis for understanding and agreement among project decision makers – project management, executive management, and any external agencies that must support the project, such as a regional planning commission.

Objectives

- Identify superior, cost-effective concept, and document alternative concepts with rationale for selection
- Verify project feasibility and identify preliminary risks
- Garner management buy-in and necessary approvals for the project

Input

- Project goals and objectives
- Project purpose and need
- Project scope/subset of the regional ITS architecture

Key activities

- Define evaluation criteria
- Perform initial risk analysis
- Identify alternative concepts
- Evaluate alternatives
- Document results

Output

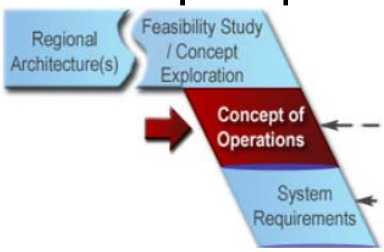
- Feasibility study that identifies alternative concepts and makes the business case for the project and the selected concept

Review

Proceed only if you have:

- Received approval on the feasibility study from project management, executive management, and controlling authorities, as required
- Reached consensus on the selected alternative

5.7.3 Concept of Operations



The Concept of Operations (ConOps) is a foundation document that frames the overall system and sets the technical course for the project. Its purpose is to clearly convey a high-level view of the system to be developed that each stakeholder can understand. The Concept of Operations provides a bridge between the needs that motivated the project to begin with and the specific technical requirements. A good ConOps answers who, what, where, when, why, and how questions about the project from the viewpoint of each stakeholder.

- Who – Who are the stakeholders involved with the system?
- What – What are the elements and the high-level capabilities of the system?
- Where – What is the geographic and physical extent of the system?
- When – What is the sequence of activities that will be performed?
- Why – What is the problem or opportunity addressed by the system?
- How – How will the system be developed, operated, and maintained?

  This step satisfies 23 CFR 940.11 Requirement 2 and Requirement 7.

Objectives

- High-level identification of user needs and system capabilities in terms that all project stakeholders can understand

- Stakeholder agreement on interrelationships and roles and responsibilities for the system
- Shared understanding by system owners, operators, maintainers, and developers on the who, what, why, where, and how of the system
- Agreement on key performance measures and a basic plan for how the system will be validated at the end of project development

Input

- Stakeholder lists, roles and responsibilities, and other components from the regional ITS architecture
- Recommended concept and feasibility study from the previous step
- Broad stakeholder input and review

Key activities

- Identify the stakeholders associated with the system/project
- Define the core group responsible for creating the Concept of Operations
- Develop an initial Concept of Operations, review with broader group of stakeholders, and iterate
- Define stakeholder needs
- Create a preliminary System Validation Plan

Output

- Concept of Operations describing the who, what, why, where, and how of the project/system, including stakeholder needs and constraints
- Preliminary System Validation Plan defining the approach that will be used to validate the project delivery

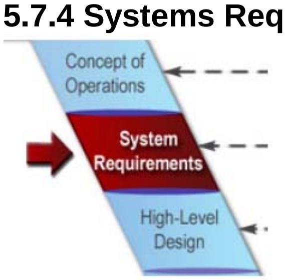
Review

Proceed only if you have:

- Received approval on the Concept of Operations from each stakeholder organization
- Received approval on the preliminary System Validation Plan from each stakeholder organization

A template is available at:
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_5.cfm

5.7.4 Systems Requirements



The stakeholder needs identified in the Concept of Operations are reviewed, analyzed, and transformed into verifiable requirements that define *what* the system will do but not *how* the system will do it. One of the most important attributes of a successful project is a clear statement of requirements that meet the stakeholders' needs. System requirements are also essential for the development of contract specifications language. There is no need to develop a set of new requirements specification from scratch for every project. Projects that enhance or extend an existing system should start with the existing system requirements. Each of the requirements listed in this document must be linked to a corresponding need described in the Concept of Operations. If you define a requirement that cannot be traced to a statement of need defined in the Concept of Operations, then either the Concept of Operations document must be revised (so its readers will clearly understand why the requirement exists), or the requirement should be deleted. This step satisfies 23 CFR 940.11 Requirement 3.

Objectives

- Develop a validated set of system requirements that meet the stakeholders' needs

Input

- Concept of Operations (stakeholder needs)
- Functional requirements, interfaces, and applicable ITS standards from the regional ITS architecture
- Applicable statutes, regulations, and policies
- Constraints (required legacy system interfaces, hardware/software platform, etc.)

Key activities

- Elicit (evoke) requirements from stakeholders
- Analyze requirements
- Document requirements
- Validate requirements
- Manage requirements
- Create a System Verification Plan
- Create a System Acceptance Plan

Output

- System Requirements document
- System Verification Plan
- Traceability Matrix (see Section 5.8.3)

- System Acceptance Plan

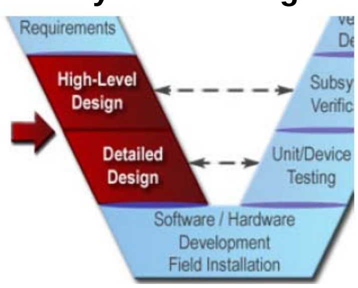
Review

Proceed only if you have:

- Received approval on the System Requirements document from each stakeholder organization, including those that will deploy, test, install, operate, and maintain the new system
- Received approval on the System Verification Plan from the project sponsor, the test team, and other stakeholder organizations
- Received approval on the System Acceptance Plan from the project sponsor, the Operations & Maintenance (O&M) team, and other stakeholder organizations

A template is available at:
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_6.cfm

5.7.5 Systems Design



A system design is created based on the system requirements including a high-level design that defines the overall framework for the system. Subsystems of the system are identified and decomposed further into components. Requirements are allocated to the system components, and interfaces are specified in detail. Detailed specifications are created for the hardware and software components to be developed, and final product selections are made for off-the-shelf components. In the systems engineering approach, we define the problem before we define the solution. The previous steps in the "V" have all focused primarily on defining the problem to be solved. The system design step is the first step where we focus on the solution. This is an important transitional step that links the system requirements that were defined in the previous step with system implementation that will be performed in the next step. This step satisfies 23 CFR 940.11 Requirement 4 and Requirement 5.

Objectives

- Produce a high-level design that meets the system requirements and defines key interfaces, and that facilitates development, integration, and future maintenance and upgrades
- Develop detailed design specifications that support hardware and software development and procurement of off-the-shelf equipment

Input

- Concept of Operations

- System Requirements document
- Off-the-shelf products
- Existing system design documentation
- ITS standards
- Other industry standards

Key activities

- Evaluate off-the-shelf components and procurement options
- Develop and evaluate alternative high-level designs
- Analyze and allocate requirements
- Document interfaces and identify standards
- Create Integration Plan, Subsystem Verification Plans, and Subsystem
- Acceptance Plans
- Develop detailed component-level design specifications

Output

- Off-the-shelf evaluation and alternatives summary reports
- High-level (architectural) design
- Detailed design specifications for hardware/software
- Integration Plans, Subsystem Verification Plans, Subsystem Acceptance Plans, and Unit/Device Test Plans

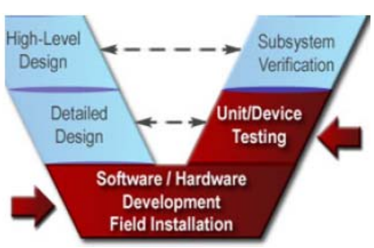
Review

Proceed only if you have:

- Approved high-level design for the project
- Defined all system interfaces
- Traced the system design specifications to the requirements
- Approved detailed specifications for all hardware/software components

A template is available at:
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_7.cfm

5.7.6 Software/Hardware Development and Testing



Hardware and software solutions are created for the components identified in the system design. Part of the solution may require custom hardware and/or software development, and part may be implemented with off-the-shelf items, modified as needed to meet the design specifications. The components are tested and delivered ready for integration and installation. Although hardware and software development may be the first task that comes to mind when thinking about an ITS project, the systems engineering approach focuses on the preceding requirements and design steps and on the integration, verification, and validation steps to follow. This is where the investment in a clear set of requirements and a good system design should begin to pay dividends. The systems engineering process now provides technical oversight as an implementation team of specialists fabricates the hardware and writes the software. This is a highly iterative process, particularly for software, where key features may be incrementally implemented, tested, and incorporated into the baseline over time. Progress is monitored through a planned series of walkthroughs, inspections, and reviews. Although the systems engineering approach does not specify the mechanics of hardware and software development (this is left to the implementation team), the development effort is obviously critical to project success. This is the time to build quality into the hardware/software and to minimize defects. This step partially satisfies 23 CFR 940.11 Requirement 6.

Objectives

- Develop and/or purchase hardware and software components that meet the design specifications and requirements with minimum defects
- Identify any exceptions to the requirements or design specifications that are required

Input

- System and subsystem requirements
- System design
- Off-the-shelf products
- Industry standards
- Unit/Device Test Plans

Key activities

- Plan software/hardware development
- Establish development environment
- Procure off-the-shelf products
- Develop software and hardware
- Perform unit/device testing

Output

- Software/hardware development plans
- Hardware and software components, tested and ready for integration

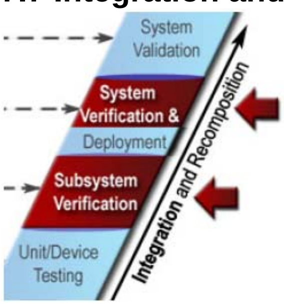
- Supporting documentation (e.g., training materials, user manuals, maintenance manuals, installation and test utilities)

Review

Proceed only if you have:

- Conducted technical reviews of the hardware/software
- Performed configuration/quality checks on the hardware and software
- Received all supporting documentation
- Verified that unit/device testing has been successfully completed

5.7.7 Integration and Verification



The software and hardware components are individually verified and then integrated to produce higher-level assemblies or subsystems. These assemblies are also individually verified before being integrated with others to produce yet larger assemblies, until the complete system has been integrated and verified. In this step, we assemble the system components into a working system and verify that it fulfills all of its requirements. Assembling a puzzle is a nice, simple analogy for this step, but the challenge in an ITS project "puzzle" is that you may find that not all of the pieces are available at the same time, some won't fit together particularly well at first, and there will be pressure to change some of the pieces after you have already assembled them. The systems engineering approach provides a systematic process for integration and verification that addresses the challenges and complexity of assembling an ITS system. Integration and verification are iterative processes in which the software and hardware components that make up the system are progressively combined into subsystems and verified against the requirements. This process continues until the entire system is integrated and verified against all of its requirements. This is the opposite of the decomposition that was performed during the Requirements and Design steps, which is reflected in the symmetry between the left and right sides of the "V". Components that are identified and defined on the left side of the "V" are integrated and verified on the right. In systems engineering, we draw a distinction between verification and validation. *Verification* confirms that a product meets its specified requirements. *Validation* confirms that the product fulfills its intended use. In other words, verification ensures that you "built the product right", whereas validation ensures that you "built the right product". This is an important distinction because there are lots of examples of well-engineered products that met all of their requirements but ultimately failed to serve their intended purpose. This step partially satisfies 23 CFR 940.11 Requirement 6.

Objectives

- Integrate and verify the system in accordance with the high-level design, requirements, and verification plans and procedures
- Confirm that all interfaces have been correctly implemented
- Confirm that all requirements and constraints have been satisfied

Input

- System Requirements document
- High-level design specifications
- Detailed design specifications
- Hardware and software components
- Integration plan
- System and Subsystem Verification Plans
- Subsystem Acceptance Plans

Key activities

- Add detail to integration and verification plans
- Establish integration and verification environment
- Perform integration
- Perform verification

Output

- Integration plan (updated)
- Verification plan (updated)
- Testing plan
- Integration test and analysis results
- Verification results, including corrective actions taken

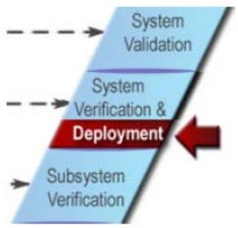
Review

Proceed only if you have:

- Documented evidence that the components, subsystems, and system meet the allocated requirements
- Documented evidence that the external and internal interfaces are working and consistent with the interface specifications

A template is available at:
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_8.cfm

5.7.8 Initial Deployment



The system is installed in the operational environment and transferred from the project development team to the organization that will own and operate it. The transfer also includes support equipment, documentation, operator training, and other enabling products that support ongoing system operation and maintenance. Acceptance tests are conducted to confirm that the system performs as intended in the operational environment. A transition period and warranty ease the transition to full system operation.

Objectives

- Uneventful transition to the new system

Input

- Integrated and verified system, ready for installation
- System Acceptance Plan

Key activities

- Plan for system installation and transition
- Deliver the system
- Prepare the facility
- Install the system
- Perform acceptance tests
- Transition to operation

Output

- Hardware and software inventory
- Final documentation and training materials
- Delivery and installation plan, including shipping notices
- Transition Plan with checklists
- Test issues and resolutions
- Operations and maintenance plan and procedures

Review

Proceed only if you have:

- Formally accepted the system
- Documented acceptance test results, anomalies, and recommendations

5.7.9 System Validation

After the ITS system has passed system verification and is installed in the operational environment, the system owner/operator, whether the state DOT, a regional agency, or another entity, runs its own set of tests to make sure that the deployed system meets the original needs identified in the Concept of Operations. Validation is the responsibility of the agency, and cannot be delegated to the system supplier or vendor.

Objectives

- Confirm that the installed system meets the user's needs and is effective in meeting its intended purpose

Input

- Concept of Operations
- Verified, installed, and operational system
- System Validation Plan

Key activities

- Update Validation Plan as necessary and develop procedures
- Validate system
- Document validation results, including any recommendations or corrective actions

Output

- System Validation Plan (update) and procedures
- Validation results

Review

Proceed only if you have:

- Validated that the system is effectively meeting its intended purpose
- Documented issues/shortcomings
- Established ongoing mechanisms for monitoring performance and collecting recommendations for improvement
- Made modifications to the Concept of Operations to reflect how the system is actually being used

A template is available at:

http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_11.cfm

5.7.10 Operations and Maintenance

Once the customer has accepted the ITS system, the system operates in its typical steady state. System maintenance is routinely performed and performance measures are monitored. As issues, suggested improvements, and technology upgrades are identified, they are documented, considered for addition to the system baseline, and incorporated as funds become available. An abbreviated version of the systems engineering process is used to evaluate and implement each change. This occurs for each change or upgrade until the ITS system reaches the end of its operational life.

Objectives

- Use and maintain the system over the course of its operational life

Input

- System requirements (operations/maintenance requirements)
- Operations and Maintenance Plan and procedures
- Training materials
- Performance data
- Evolving stakeholder needs

Key activities

- Conduct Operations and Maintenance Plan reviews
- Establish and maintain all operations and maintenance procedures
- Provide user support
- Collect system operational data
- Change or upgrade the system
- Maintain configuration control of the system
- Provide maintenance activity support

Output

- System performance reports
- Operations logs
- Maintenance records
- Updated operations and maintenance procedures
- Identified defects and recommended enhancements
- Record of changes and upgrades
- Budget projections and requests

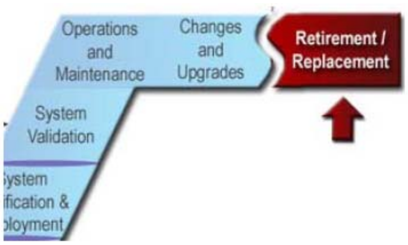
Review

Proceed only if you have:

- Demonstrated that the system has reached the end of its useful life

A template is available at:
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_12.cfm

5.7.11 Retirement/Replacement



Operation of the ITS system is periodically assessed to determine its efficiency. If the cost to operate and maintain the system exceeds the cost to develop a new ITS system, the existing system becomes a candidate for replacement. A system retirement plan will be generated to retire the existing system gracefully.

Objectives

- Remove the system from operation, gracefully terminating or transitioning its service
- Dispose of the retired system properly

Input

- System requirements (retirement/disposal requirements)
- Service life of the system and components
- System performance measures and maintenance records

Key activities

- Plan system retirement
- Deactivate system
- Remove system
- Dispose of system

Output

- System retirement plan
- Archival documentation

Review

Proceed only if you have:

- Planned the system retirement
- Documented lessons learned
- Disposed of the retired system properly

5.8 ITS Project Management Process Guidelines

In addition to the technical process steps identified in the "V" diagram, there are several project management and control activities that are essential in order for an ITS project to be successful. These are also known as cross-cutting activities. Any ITS project can benefit from these project management processes, but larger, more complex ITS projects will benefit the most. Project management, configuration management or change control, traceability and risk management are key cross-cutting activities that support the technical processes of systems engineering.

5.8.1 Project Management

Project management encompasses *project planning* and *project monitoring and control.*

Project planning lays out the activities, resources, budget, and timeline for the project. TDOT recommends that High Risk projects use two very useful documents for project planning: the Project Plan (PP) and the Systems Engineering Management Plan (SEMP). These documents should be completed early in the project life cycle (usually before the Concept of Operations). Both of these documents should be written in such a way that a newcomer to the project team can understand the type and scope of the project, the responsibilities of the major players, the staffing, the schedule and budget, and the processes that will govern the project. The Project Plan (PP) documents how the project will be managed and controlled from a programmatic standpoint. It identifies the detailed work plans for both administrative and technical tasks.

For each project task, the PP documents what is to be done, by whom, with what funds, when, how (processes to be used), and dependencies. The Systems Engineering Management Plan (SEMP) is the top-level plan for managing the systems engineering effort to produce a final operational system from initial requirements.

Just as the PP defines how the overall project will be executed, the SEMP defines how the engineering portion of the project will be executed and controlled. It describes how the efforts of system designers, test engineers, and other engineering and technical disciplines will be integrated, monitored, and controlled during the complete life cycle. For a small project, the SEMP might be included as part of the PP document, but for any project of greater size or complexity a separate document is recommended.

Project monitoring and control relies on project tracking and project reviews to follow project progress against its plan. Performance measures and metrics are recommended for project tracking. Project reviews are a primary method of communicating progress, monitoring risk, and transferring products and knowledge between project team members. The reviews often occur at the completion of a "V" process step and represent *decision points* that must be passed successfully before moving to the next step in the process.

The following sub-sections will outline particular aspects of project management important to consider in ITS project development, particularly change control, traceability, and risk management. For more detailed information on applying these project management principles to ITS, and for guidelines of developing PPs and SEMPs, the reader is encouraged to access the FHWA/Caltrans Systems Engineering Guidebook for ITS website at:
http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section3/3_9_4.cfm

5.8.2 Configuration Management or Change Control

Change during the ITS project life-cycle is inevitable. Even small changes, if not controlled, can have major effects on the project. Therefore, once the items that will be tracked (software, hardware, documentation, etc.) have been identified, any changes to them must be handled in a controlled fashion. Basically, the change control process [(4)] steps are:

- Submit change request
- Assess impact and prepare recommendation
- Submit report to Configuration Control Board (CCB)
- CCB deliberates and decides
- Document approved changes
- Update traceability matrices

It is important to document changes made during project development, how those changes were accommodated and how change orders will be processed and managed during construction, including necessary approvals.

5.8.3 Traceability

As you move from one step to the next in the systems engineering process, it is important to be able to relate the items in one step with those in another. The relationship between items is called *traceability* [(5)]. For example, you use traceability to relate a requirement to the subsystem that will implement the requirement. Traceability connects many items together. The requirement will be related to a user need as well as to a test that will be used to verify the requirement. Traceability is a powerful concept that allows you to be certain that the system that is implemented at the end of the project is directly connected with the user needs that were identified at the beginning. The traceability matrix may be included in the contract documents for use during construction.

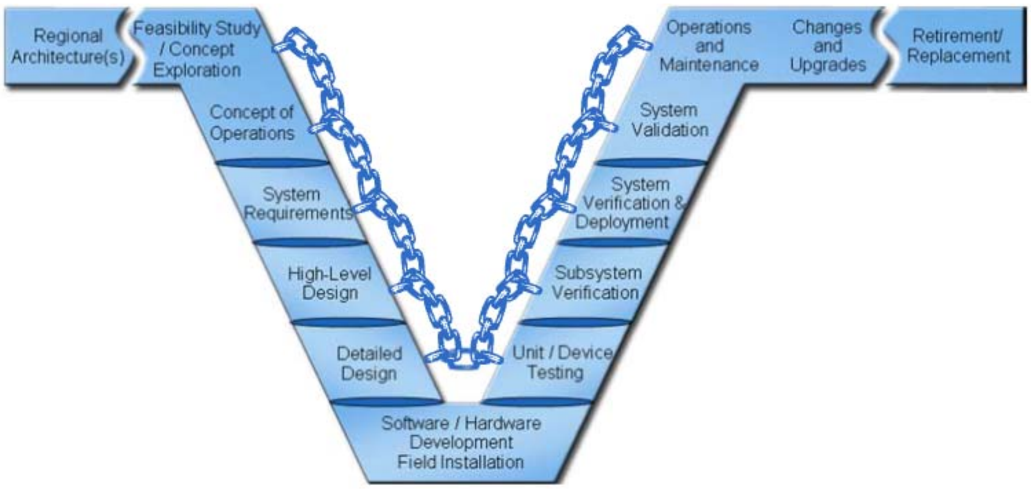


Figure 6 – Traceability

5.8.4 Risk Management

Risk management is the identification and control of risks during all phases of the project life-cycle. The goal of risk management is to identify potential problems before they occur, plan for their occurrence, and monitor the system development so that early action can be taken if the risk occurs.

Risk management is composed of the following general steps:

- Risk identification
- Risk analysis and prioritization
- Risk mitigation
- Risk monitoring

5.9 Special Notes on SEA and Adaptive Signal Control Technology (ASCT)

Many local agencies are now becoming interested in implementing Adaptive Signal Control Technology (ASCT). A Systems Engineering Analysis (SEA) can support the process of exploring the need for ASCT and helps articulate a set of requirements that enable agencies to specify, select, implement and test adaptive signal control technology. In the past, a significant number of adaptive systems have been deactivated well before the end of their useful life due either to a lack of adequate resources or agency capability to support system operation and maintenance, or in some cases a failure to properly align agency and system operations objectives.

The risks associated with ASCT implementation are significant. Therefore, the SEA process will help an agency confirm that its expectations are realistic and achievable before committing to a system.

The SEA documentation for ASCT will provide a structure within which an agency can examine its current operation (or the operation the agency expect to have within the near future), assess whether or not adaptive control is likely to address the agency issues, and then decide what type of adaptive control will be right.

For guidance on the Systems Engineering Analysis (SEA) documentation for Adaptive Signal Control Technology (ASCT), TDOT recommends the guidelines provided by the Federal Highway Administration on FHWA-HOP-11-027 *Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems* [(1)], in addition to the guidelines in this chapter.

6 Procurement Guidelines

6.1 Overview

An analysis of procurement options is a requirement of the Systems Engineering Analysis identified on the Project Implementation section of 23 CFR 940. The successful procurement of ITS projects is a challenging task.

The challenges are especially paramount when procuring ITS projects that involve advanced technologies which require specialized skills and knowledge. Although there are similarities, there are also key differences between the traditional process and the systems engineering approach that should be considered when planning your next ITS project.

[(1)] *The Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems is available at http://www.ops.fhwa.dot.gov/publications/fhwahop11027/mse_asct.pdf*

For example, in the traditional transportation project development process, there is clear contractual separation between the consultant that prepares the PS&E and the contractor that builds the project. This is a risky approach for many ITS projects, in which it is important to have more continuity across the project development life cycle so that the contractor who ultimately implements the ITS system clearly understands the underlying user needs and requirements and has the latitude to implement the most cost-effective solution. For example, the contractor that implements custom software for an ITS project should also participate in the detailed software design. You would not want to impose a contractual barrier between the software designer and the software implementer.

ITS projects vary in scope and typically require collaboration and iteration between the design and implementation phases. Therefore, different procurement approaches are warranted for ITS system acquisitions. The procurement process for an ITS project must be flexible to accommodate the uncertainties of complex system acquisitions, but, at the same time, structured enough to ensure that the responsibilities of the participants are fully defined and their interests protected. This process should also ensure that the most qualified organizations are selected for the system implementation. The project development process is strongly influenced by the selected procurement strategy because it will determine who (agency, consultant, or contractor) takes the lead for each process step. It is important to tailor the procurement strategy based on the scope of ITS project and not to assume that it always has to be done the same way. The definitions of “construction,” ”engineering and design services,” and “non-engineering/non-architectural” form the framework for grouping ITS project requirements in terms of products, systems, and services.

This guidance is not all encompassing as ITS projects can vary significantly in scope, but should provide adequate information to address a majority of situations. It is recommended that State and local agencies consult with the FHWA Division Office when attempting to choose appropriate contracting techniques for their planned ITS projects.

6.2 Scope of ITS Projects and Contracting Requirements

23 USC 101 (G)_[(2)] defines "*Construction*" in terms of "*improvements that directly facilitate and control traffic flow*".

For example, contractor installation of field devices and hardware typically meets the definition of construction. Rehabilitation of an existing physical ITS infrastructure is also generally considered a construction contract.

[(2)] *The text of the United States Code (USC) may be found at: http://uscode.house.gov/*

If an ITS project meets the definition of construction, then the contract should be bid competitively with award to the lowest responsive bidder meeting the specified conditions of responsibility. In this case, the procurement procedures in 23 CFR 635_[(3)] (low-bid, competitive sealed bidding) will apply.

23 USC 112(b) (2) (A) [(2)] and 23 CFR 172[(3)] require the procedures of the Brooks Act (40 USC § 1101-1104) [(2)] to be used for each contract for program management, construction management, feasibility studies, preliminary engineering, design, engineering, surveying, mapping or architectural related services with respect to a construction project performed by or supervised by the State with Federal-aid funds.

These services are typically defined as "*Engineering and design related services"* and perform an identifiable task (see *TDOT Standard Procurement of Engineering and Technical Services* [(4)] *for additional information)*.

The Brooks Act requires agencies to promote open competition by advertising, ranking, selecting, and negotiating contracts based on demonstrated competence and qualifications for the type of engineering and design related services being procured, and at a fair and reasonable price (qualification-based selection).

If an ITS project does not meet the legal definition of "*Construction*" and is not categorized as an "*Engineering and design related services*", then it may be considered to be "*non-engineering/non-architectural*", and may be procured using the State of Tennessee's own procurement procedures [(5)] in accordance with 2 CFR 200 [(3)] and 2 CFR 1201[(3)]. Examples may include research and planning projects, or procurement of commercial off-the-shelf (COTS) hardware or software that requires no customization.
Oftentimes ITS projects do not fit neatly into one category – construction, engineering/architectural, or other. High-risk ITS projects will usually need some sort of engineering/architectural procurement due to the expected degree of hardware or

software customization, integration and testing. However, there may still be a significant amount of roadway construction that is either independent of the ITS portion (such as concurrent road widening that's part of the same project scope) or required for the ITS installation (such as trenching and installing conduit for a communications system). There may also be portions more suited towards a service contract, such as purchase of data or website-hosting services. With such "*hybrid*" projects that have multiple types of work, there should be at least one contract per type of work.

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[3] *The text of the Code of Federal Regulations (CFR) may be found at:* http://www.ecfr.gov/

[4] *TDOT Standard Procurement of Engineering and Technical Services is available at* http://www.tn.gov/assets/entities/tdot/attachments/Policy301-01.pdf

[5] *The Procurement Procedures Manual of the Tennessee Central Procurement Office is available at* http://tn.gov/assets/entities/generalservices/cpo/attachments/Procurement_Manual_approved_7.16.15.pdf

For questions regarding classification of projects by the types listed above, and for questions regarding the State of Tennessee's procedures for "non-engineering/non-architectural" work, please contact the TDOT Traffic Operations Division.

6.3 Sole Source Procurement

23 USC 112(a) [2] requires procurement of ITS systems and components to be competitive. The specification of a particular product may restrict competition as the pool of available products is reduced to the product selected. In some cases, however, the need for a particular product outweighs the need to procure products competitively. Therefore, 23 CFR 635.411 [3] allows the acquisition of proprietary materials with federal funds under Certification, Public Interest Finding or Experimental Products.
Additional information is available at TDOT Guidelines for Submittal of Proprietary Products Certifications, Public Interest Findings and Experimental Products [6].

6.3.1 Certification

A written and signed statement of an appropriate contracting agency official is required, certifying that a particular patented or proprietary product is either:

- Necessary for *synchronization* with existing facilities; or
- A unique product for which there is no equally suitable alternative.

For *synchronization* it is understood that the product matches specific current or desired characteristics of a project. Synchronization may be based on:

- Function (the proprietary product is necessary for the satisfactory operation of the existing facility),
- Aesthetics (the proprietary product is necessary to match the visual appearance of existing facilities),

- Logistics (the proprietary product is interchangeable with products in an agency's maintenance inventory),
- Or any combination thereof.

In addition, it may be advisable to evaluate the following factors as they relate to synchronization:

- Lifecycle (the relative age of existing systems that will be expanded and the remaining projected life of the proposed proprietary element in relation to the remaining life of the existing elements);

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(6) *TDOT Guidelines for Submittal of Proprietary Products Certifications, Public Interest Findings and Experimental Products is available at http://www.tdot.state.tn.us/materials/reseval/products.htm*

- Size/extent of products and systems to be synchronized to/with, and the relative cost of the proprietary elements compared with replacing the elements requiring synchronization.

"*Engineering and design related services" cannot be selected by* Certification.

6.3.2 Public Interest Finding (PIF)

An approval by the FHWA Division Administrator is required, based on a request from a contracting agency that it is in the public interest to allow the contracting agency to require the use of a specific material, product, or service even though other equally acceptable materials or products are available. For guidance on completing and submitting PIFs for ITS projects, please contact the TDOT Traffic Operations Division.

6.3.3 Experimental Products

If a contracting agency requests to use a proprietary product for research or for a distinctive type of construction on a relatively short section of road for experimental purposes, it must, submit an experimental product work plan [(7)] for review and approval.

The work plan should provide for the evaluation of the proprietary product, and where appropriate, a comparison with current technology. For guidance on requesting use for experimental products on ITS projects, please contact the TDOT Traffic Operations Division.

6.4 Contracting Techniques

The selection of appropriate contracting options for designing and constructing an ITS project depends on many variables. These variables include:

- Type and complexity of the required products, systems, and services;
- Interdependence of project components and subsystems;

- Inclusion of ITS systems components with roadway construction projects;
- Use of varied and rapidly changing advanced technologies;
- Need to prequalify consultants and/or contractors;
- Constrained deployment schedule;
- Magnitude of construction impacts on road users;
- Risk management factors associated with capital investments in transportation systems.

The following identifies some of the contracting techniques that have been used for ITS projects and highlights a few of the considerations for their use in your next project.

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[7] *Additional information regarding Experimental Products is available at http://www.fhwa.dot.gov/programadmin/contracts/expermnt.cfm*

6.4.1 Design-Bid-Build

The design-bid-build technique has historically been used by transportation agencies for designing and constructing construction projects. It is an effective procurement vehicle only for ITS projects that meet the definition of "*Construction*" (see Section 6.2).

Design-bid-build is a project delivery system in which a transportation agency utilizes the services of an engineering consulting firm (or in-house staff) to design a project (design step), invites contractors to submit bids (bid step), and subsequently constructs the project using the services of a contractor (build step). The technique utilizes two independent but sequential contracts - engineering and design services and construction. These projects typically incorporate physical installations of field hardware, devices, cables, foundations, pull boxes, conduit system, poles, or other definable physical components such as traffic management buildings. However, the design-bid-build technique may not be best suited for ITS projects that contain rapidly-changing technologies, unknown factors and specifications, software, computer hardware, communications, and system integration.

6.4.2 Design-Build

The design-build technique [8] is a project delivery system in which a single entity provides design services and constructs the project - all under one contract. Design-build may be effectively leveraged to overcome some of the challenges of the traditional contracting techniques when designing and constructing technologically complex ITS projects.

The design-build contracting technique is best suited for:

- Projects that can best be defined by functional or performance based specifications;
- Projects that have the propensity to benefit significantly from innovative design and construction solutions;
- Projects containing complex systems and subsystems that require major integration efforts and involve many unknown and indefinable factors and rapidly changing advanced technologies.

(8) Guidelines for design-build contracts in Tennessee are available at http://www.tdot.state.tn.us/construction/Design_Build.htm

Here are some important considerations when using the design-build technique:

- Requirements/high-level design prepared prior to selection;
- All requirements must be identified and must be strong;
- Places burden of verification and validation on agency;
- Significant quality control required.

6.4.3 System Manager and System Integrator

The systems manager technique is a project delivery strategy in which all project design and interface functions are performed by a consultant under engineering and design services contracts, and all construction activities are performed by various contractors under different construction contracts.

> ***Alternative Contracting Approaches:*** FHWA has allowed the State DOTs to evaluate non-traditional contracting techniques under a program titled "Special Experimental Project No. 14 - Innovative Contracting". SEP-14 is a functional experimental program that may be used to evaluate promising non-traditional contracting techniques. Guidance on SEP-14 is available at: http://www.fhwa.dot.gov/programadmin/contracts/sep_a.cfm

The responsibilities of a systems manager overlap both design and construction phases of the project and typically includes development of project sequencing and coordination of the various subsystems, design, preparation of PS&Es, inspection, testing, and integration of the various subsystems into a total operating system. The agency maintains direct management, administration, and control authority over the contractors.

The system integrator technique is similar to the system manager technique except that the integrator is not involved in the planning and design stages.

6.5 Use of System Requirements on the Procurement Process

Regardless of the procurement approach selected, systems engineering support is always useful for an ITS project, most importantly its System Requirements. Here are some considerations regarding the use of requirements on the procurement process:

- Good requirements reduce the most risk when developed and used right from the start;
- Good requirements allow agencies to control the procurement process leading to successful project implementation;
- Requirements should be used on the selection of technology;
- Make technology decisions as late as possible in the process;
- The burden of clarity is on the agency writing the documentation;
- Avoid ambiguity on requirements;
- It is good practice to ask vendors to document how their system/product will satisfy the requirements.

6.5.1 Request for Information (RFI) – (Optional)

Once your requirements have been drafted, there may be some that you are not sure can be met by any, or a sufficient number, of the available systems. This is a point at which you need to consider whether it will be appropriate to purchase a commercially available system (with or without some customization) or develop a unique system. When this occurs, it is appropriate, and perhaps desirable, to release to vendors a formal request for information (RFI) focused on the specific requirements about which you are uncertain. Response to an RFI should not be a condition of future participation by a vendor in the procurement process. Use of the RFI will allow you to decide whether or not your requirements can be satisfied by a commercially available system. If not, you can then decide whether to modify your requirements or develop a much more detailed set of requirements and a specification that would be appropriate for development of a unique system.

6.5.2 Industry Review of Requirements – (Optional)

More comprehensive feedback from vendors can be obtained by distributing a draft version of your requirements to vendors. This is appropriate when you have developed requirements that will involve some customization or may include assumptions about appropriate technology. Provided you have included a Concept of Operations and clear statements of need, this provides the opportunity for vendors to contribute in two effective ways.

Vendors will recognize requirements that assume a design that is different from theirs and this gives them the opportunity to redefine the requirement in a manner that does not preclude their system simply because of the wording or structure of the requirement. Vendors will also recognize high cost customization or new development that would be necessary to satisfy a requirement, and this also gives them the opportunity to suggest alternatives that would substantially reduce the procurement cost or streamline the development.

Responses from vendors should be treated as confidential and not shared with other vendors. If a vendor expects a response to be shared, he is less likely to offer advice that he considers proprietary and part of his competitive advantage.

6.5.3 Request for Qualification (RFQ) – (Optional)

A request for qualifications (RFQ) is appropriate when there are mandatory requirements placed on the capabilities and experience of the vendor. This is a means of reducing the agency’s risk. It provides the opportunity to assess a vendor’s financial stability, their track record in providing support and training, and proof that an advertised system is fully operational and successful. It should NOT be used simply to reduce the workload of the agency in evaluating responses to an RFP by limiting the number of vendors permitted to respond to a detailed specification or RFP. It should be used after requirements have been prepared and the agency is certain that vendors who show satisfactory qualifications will be able to also satisfy the technical requirements.

6.5.4 Request for Proposals (RFP)

A request for proposal (RFP) is the key vehicle for assessing the extent to which an engineering service for ITS implementation will satisfy the agency’s requirements. For Federal-aid (Highway Trust Fund/FHWA) projects, RFPs are the common contracting mechanism for fulfilling the Brooks Act requirements for engineering or architectural related services. Response proposals are used to determine the most qualified firm that will fulfill the system requirements. As illustrated in Figure 7, the requirements are referenced at every step in the process to help guide the selection.

While it may contain mandatory, desirable and optional requirements, the vendor should be required to explain how their system fulfills each requirement, and not simply be permitted to provide a Yes/No or Pass/Fail response. There are often different ways in which different systems may claim to satisfy a requirement, and not all methods will be equally suitable (or acceptable to an agency) in all situations. Each answer should be evaluated to determine firstly whether or not the answer is accurate, secondly the extent to which it satisfies the requirement, and thirdly as to whether the method of satisfaction is acceptable to the agency.

In addition, the method by which a vendor satisfies a requirement may have other implications, such as the effect on work practices, staff efficiency or requiring additional equipment or software to be efficiently implemented. The method used to compare responses to an RFP should include a means of accommodating the assessment of compliance.

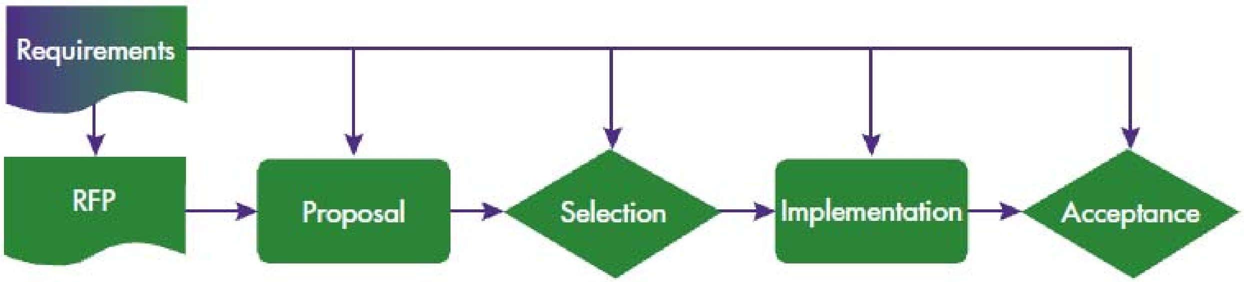

Figure 7 - Engineering/architectural services contracting approach supported by Systems Engineering Analysis

7 ITS Architecture

7.1 Overview

An Intelligent Transportation System (ITS) Architecture is a high level plan for how ITS can be used to address transportation needs in a State or region. In Tennessee, a Statewide and eleven regional ITS architectures have been developed and are currently in use (See Sections 7.2 and 7.3).

According to 23 CFR 940, the regional ITS architecture shall include, at a minimum:

- A description of the region;
- Identification of participating agencies and other stakeholders;
- 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;
- 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;
- System functional requirements;
- 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);
- Identification of ITS standards supporting regional and national interoperability; and
- The sequence of projects required for implementation.

7.2 Tennessee Statewide ITS Architecture

The development of the Tennessee Statewide ITS Architecture was led by the Tennessee Department of Transportation (TDOT) and involved representatives from each of the four TDOT Regions as well as from planning, design, incident management, wireless communications, and public transportation at the statewide level. The Tennessee Division of the Federal Highway Administration, the Tennessee Highway Patrol, the Tennessee Emergency Management Agency, and numerous other agencies were also active in the process.

The geographic scope of the Tennessee Statewide ITS Architecture (9) covers all rural areas of the state that are outside the eleven Metropolitan Planning Organization (MPO) areas that were designated as needing regional ITS architectures.

7.3 Tennessee Regional ITS Architectures

Tennessee has eleven regional ITS architectures (10) currently developed: Bristol, Chattanooga, Clarksville, Cleveland, Jackson, Johnson City, Kingsport, Knoxville, Lakeway, Memphis and Nashville.

7.4 Tennessee Turbo Architecture Databases

The Turbo Architecture™ tool (11) is a high-level, interactive software program that assists transportation planners and system integrators, both in the public and private sectors in the development and maintenance of regional architectures using the National ITS Architecture as a reference. Turbo Architecture allows a user to generate a variety of architecture reports, diagrams, and tables used to supplement the Systems Engineering Analysis documentation necessary for ITS Compliance (See Section 4).

Figure 8 shows a Turbo Architecture™ output of the Tennessee Statewide ITS Architecture Disaster Traveler Information – Tennessee 511 Service Package (12).

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(9) The current Tennessee Statewide ITS Architecture documentation is available at http://www.tdot.state.tn.us/trafficoperations/its/statewide.htm

(10) The Tennessee Regional ITS Architecture documentation is available at http://www.tdot.state.tn.us/trafficoperations/its/regions.htm

(11) Current information on the Turbo Architecture™ tool is available at

http://www.iteris.com/itsarch/html/turbo/turbomain.htm

(12) The Tennessee Statewide and Regional ITS Architectures Turbo Architecture databases are available at http://www.kimleyhorn.com/projects/tennesseeITSarchitecture/statewide.html

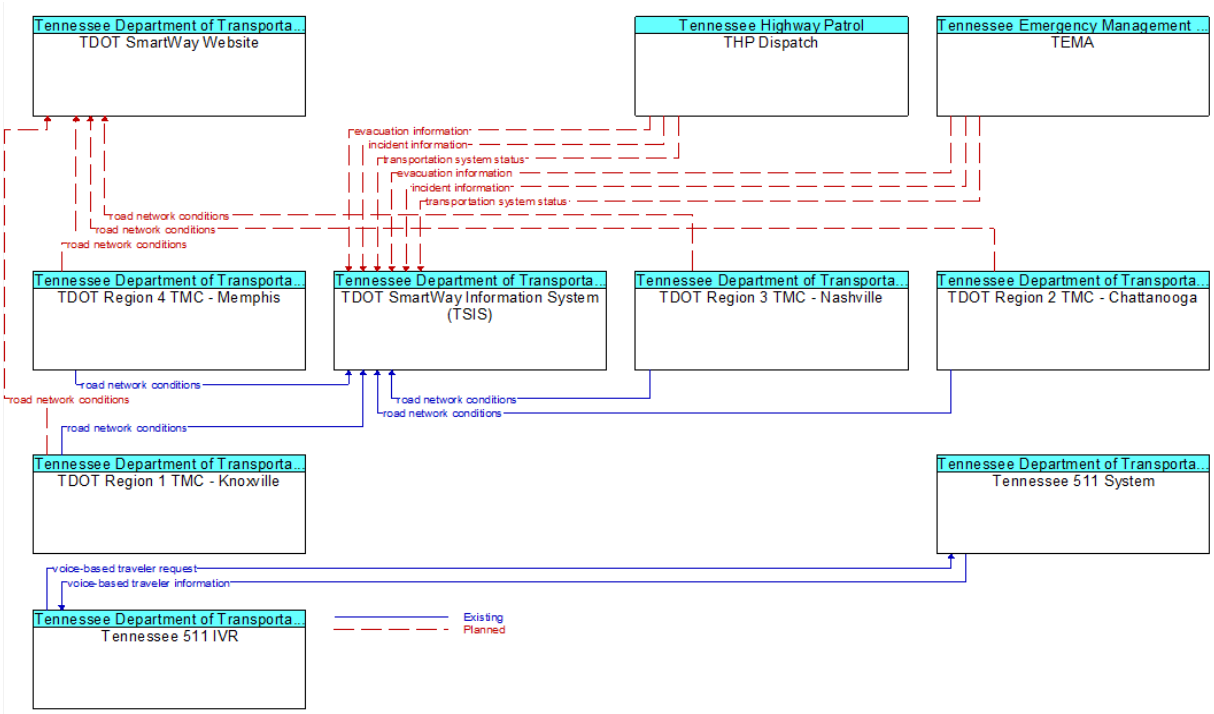

Figure 8 - Turbo Architecture™ output

7.5 ITS Architecture Update Guidelines

According to 23 CFR 940, agencies and other stakeholders participating in the development of an ITS architecture shall develop and implement procedures and responsibilities for maintaining it, as needs evolve within the region. The 23 CFR 940, also mentions that the final design of all ITS projects shall accommodate the interface requirements and information exchanges as specified in the Regional or Statewide ITS Architecture. If the final design of the ITS project is inconsistent with the Regional or Statewide ITS Architecture, then the discrepancies shall be reconciled and the ITS Architecture or the project shall be modified as appropriate by the local or state agency.

Therefore, there are several factors or events that influence the need and decision to update an ITS architecture. The following should be considered:

- Changes in ITS priorities or objectives;
- New stakeholders;
- Updates to the National ITS Architecture;
- Changes in Federal Policy or Legislation;
- Changes in State Policies or Legislation; and

- ITS Deployment and Integration.

As each ITS project is implemented, the regional ITS architecture will need to be updated to account for any expansion in ITS scope, and to allow for the evolution and incorporation of new ideas. When actually defined or implemented, a project may add, subtract or modify elements, interfaces, or information flows from the regional ITS architecture. Because the regional ITS architecture is meant to describe the current (as well as future) regional implementation of ITS, it must be updated to correctly reflect how the developed projects integrate into the region. Update requests will be submitted by the local agency project manager.

The Tennessee Statewide and Regional ITS Architectures as well as the ITS deployment recommendations reflect the needs and priorities of stakeholders at the time it was developed. In order for the ITS architecture to remain a valuable ITS planning and project programming tool for TDOT, it is important that both the architecture and deployment plan be periodically reviewed and updated to reflect changes in priorities, policies or needs in Tennessee.

The procedures for maintaining the Statewide and the Regional ITS Architectures have been determined in the documentation mentioned in Sections 7.2 and 7.3. TDOT Traffic Operations Division Office has been designated as the entity responsible for updating and maintaining the Statewide ITS Architecture. The responsibility to lead the maintenance process in the Regional ITS Architectures is delegated to each individual Planning Organization. Major updates to the Regional ITS Architectures shall be approved by TDOT Traffic Operations Division Office and the FHWA Division Office.
It is recommended that full updates of the Regional ITS Architecture and Deployment Plan occur in the year preceding the Long Range Transportation Plan (LRTP) update so that stakeholders will be able to determine, document and submit for consideration the ITS needs and projects that are most important to the Region. Minor changes to the Regional ITS Architecture should occur as needed between full updates of the plan, particularly if a project is being deployed and requires a change to the Regional ITS Architecture in order to establish conformity.

7.6 Using the Regional ITS Architecture

The Regional ITS Architecture is a tool that can be used to support planning processes, programming and budgeting activities and project implementation activities. Planning processes are used to identify projects whose implementation will respond to regional needs. These projects are placed in programming documents such as the Transportation Improvement Program (TIP) in order to secure funding. Once funded, the projects are implemented. Use of the Regional ITS Architecture throughout the project lifecycle (Figure 9) improves continuity between the transportation planning process and the projects that are ultimately implemented.

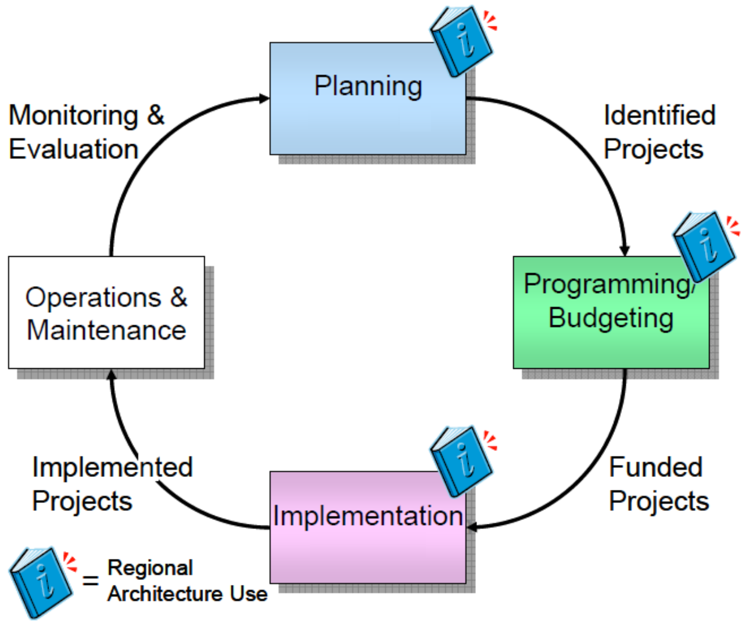

Figure 9 – Regional ITS Architecture and project lifecycle

7.6.1 Planning

The goal of the planning process is to make quality, informed decisions pertaining to the investment of public funds for regional transportation systems and services. Using the regional ITS architecture to support these planning activities is an important step in the mainstreaming of ITS into the traditional decision-making of planners and other transportation professionals.

The long range plan is the expression of a state or metropolitan area's long range approach to constructing, operating, and maintaining the multimodal transportation system. It is the policy forum for balancing transportation investments among modes, geographic areas, and institutions. A regional ITS architecture is related to both the statewide transportation plan, the metropolitan transportation plan, and agency long range plans.

The regional ITS architecture can provide decision-making tools to evaluate and prioritize the various strategies for transportation improvement. This can be accomplished by analyzing performance measures data providing the planning organization the ability to measure non-recurring congestion, travel times and travel time reliability, and other aspects of system performance and service reliability across all modes.

Regional ITS architecture outputs, specifically the project sequencing output may also be useful to planning staff as an aid to evaluation and prioritization of strategies. The architecture provides a short-term and long-term, multimodal view of the ITS systems in the region, what is very important for planning. It provides the details of the transportation services and functions that can be provided by the stakeholders via ITS projects. The regional ITS architecture also illustrates the interfaces necessary between transportation systems to meet the transportation needs of the region. It facilitates development and integration of ITS projects by housing applicable national ITS Standards and/or the local agency own ITS Standards. Finally it translates these details to the definition of a set of projects to be implemented.

A regional ITS architecture serves as a visible demonstration of the institutional dependencies that exist in a region, how agencies can benefit from each other's activities and presents a significant opportunity to support the needs for effective planning for operations [(13)].

Several other planning activities can also be supported by outputs of the regional ITS architecture, like Congestion Management Process, Safety Planning and Freight Planning.

7.6.2 Programming and Budgeting

Using a Regional ITS Architecture to define an ITS project links the objectives and needs of the region identified in the architecture with the ITS deployed in the field. In a region, ITS projects are deployed by many organizations including State DOTs, transit agencies and many local agencies and authorities. If projects of the various organizations are defined from the same reference point, the Regional ITS Architecture, then coordination begins in the initial planning and funding phase. ITS projects in a region may be funded by a variety of sources. ITS projects that are funded with federal funds are programmed by Metropolitan Planning Organizations (MPOs) and State DOTs with input from transportation agencies in the region.

7.6.3 Project Implementation

Once an ITS project has been funded and implementation begins, there is a natural tendency to focus on the programmatic and technical details of the project to be implemented and lose sight of the broader regional context for the project. Using the regional ITS Architecture as a basis for project implementation provides this regional context. It provides each project sponsor the opportunity to view their project in the context of surrounding systems. It prompts the sponsor to think about how their project fits within the overall transportation vision for the region. It identifies the integration opportunities that should be considered and provides a head start for the systems engineering analysis that is required for ITS projects.

[(13)] *Applying a Regional ITS Architecture to Support Planning for Operations is available at http://www.ops.fhwa.dot.gov/publications/fhwahop12001/fhwahop12001.pdf*

8 ITS References

The following ITS references are useful resources supplementing this TDOT ITS Project Development Guidelines:

Regional ITS Architecture Guidance – Developing, Using and Maintaining an ITS Architecture for Your Region - http://www.ops.fhwa.dot.gov/publications/regitsarchguide/raguide.pdf

Systems Engineering for Intelligent Transportation Systems – An Introduction to Transportation Professionals - http://ops.fhwa.dot.gov/publications/seitsguide/seguide.pdf

Systems Engineering Guidebook for Intelligent Transportation Systems - https://www.fhwa.dot.gov/cadiv/segb/files/segbversion3.pdf

FHWA California Division website on ITS (Process, Deliverables, Checklists, Examples, etc.) - https://www.fhwa.dot.gov/cadiv/segb/views/index.cfm

The Model Systems Engineering Documents for Adaptive Signal Control Technology (ASCT) Systems - *http://www.ops.fhwa.dot.gov/publications/fhwahop11027/mse_asct.pdf*

NCHRP 560 Guide to Contracting ITS Projects - http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_560.pdf

The Road to Successful ITS Software Acquisition - http://www.fhwa.dot.gov/publications/research/operations/its/98036/rdsuccessvol2.pdf

Using Systems Engineering and Regional ITS Architecture for ITS Projects - http://www.virginiadot.org/travel/resources/userguideReprint4-7.pdf

Applying a Regional ITS Architecture to Support Planning for Operations - *http://www.ops.fhwa.dot.gov/publications/fhwahop12001/fhwahop12001.pdf*