Introduction to Systems Engineering 100 course

Part 1 of 2 – Module 2

Welcome

Welcome to the first of two parts of the Florida Department of Transportation's Introduction to Systems Engineering 100 course for Intelligent Transportation Systems, or ITS. This course introduces the concept of systems engineering and the procedures for applying it to Intelligent Transportation Systems in Florida. This is Module 2.

FHWA ITS Regulations

The Federal Highway Administration, or FHWA, has tailored a systems engineering process to be followed for ITS projects nationally. The FHWA Systems Engineering methodology for ITS is:

- Based on federal law – Title 23 Highways, Code of Federal Regulations, Part 940.11 on ITS Project Implementation
- Required if funding with Highway Trust Funds
- Uses a common National ITS Architecture, and
- V-model is the standard.

While not emphasized in this course, there are other systems engineering approaches besides the V-model, especially used in software design, such as the Agile model, spiral model, and waterfall model. These other approaches still use many of the main concepts we study here, such as user needs, requirements, verification, traceability, configuration management, and so forth.

FDOT Checklist Covers FHWA Requirements

FHWA has seven systems engineering requirements to meet. However, a cost analysis, schedule, and management plans are not required. FDOT covers the seven FHWA requirements with 11 checklist items, and also requires a Project Systems Engineering Management Plan, or PSEMP. Recall that project management is a standard systems engineering cross-cutting activity.

FHWA - 23 CFR 940.11(c) (ppt 40)

The FHWA Rule and Federal Transit Administration, or FTA, Policy, or ITS Final Rule, says that all ITS projects funded with Highway Trust Funds, including transit projects, shall perform a systems engineering analysis, or SEA.

There are seven requirements of systems engineering that need to be satisfied at a minimum.

1. Identification of portions of the Regional ITS Architecture, or RITSA, being implemented

2. Identification of participating agencies roles and responsibilities

3. Requirements definitions

4. Analysis of alternative system configurations and technology options to meet requirements

5. Procurement options

6. Identification of applicable ITS standards and testing procedures, and

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

Although some ITS projects may not directly benefit from Highway Trust Funds, for example Florida's Turnpike Enterprise, or FTE, it is still recommended that the minimum systems engineering analysis requirements are followed since (1) it is good practice, and (2) ITS project funding in the future may wish to include federal Highway Trust Funds.

FDOT Systems Engineering Checklist

The FDOT Checklist of 11 items covers the 7 FHWA requirements. They include:

1. Project Information

2. Project Systems Engineering Management Plan

3. Architecture Assessment

4. Alternative Analysis

5. Concept of Operations
6. Requirements Definitions (High-Level and Detailed)
7. High-Level and Detailed Design
8. Implementation
9. Integration and Verification
10. System Validation and Acceptance, and
11. Operations and Maintenance

Near the end of any high-risk project, the project manager will report once again on these items in the Systems Engineering Project Checklist (FDOT Form 750-040-06) to the:

- District Traffic Engineering and Operations Office, or TSM&O, Program Engineer
- FHWA Florida Division ITS Engineer
- FDOT TSM&O Division
- TSM&O Program State ITS Software Engineer, and
- FDOT District Local Programs Administrator

as needed.

FDOT Coverage of FHWA Requirements

This slide shows, at a glance, coverage of the federal requirements and of the FDOT checklist on the V. The FHWA requirements are on the left of the pairings and the FDOT requirements are on the right. All of the seven federal requirements are matched by one or more of the 11 FDOT checklist items.

Four FDOT checklist items are not federal requirements:

- Project Information,

- Project Systems Engineering Management Plan,
- High-level and Detailed Design, and
- System Validation and Acceptance.

Most notably, the FDOT requires a Project Systems Engineering Management Plan, which is not required by FHWA. The Project Systems Engineering Management Plan is not on the V, and it covers the fifth FHWA requirement, on procurement options, also not on the V.

FHWA's "SE for ITS" Guides

A useful guide to FHWA requirements is the FHWA "Systems Engineering for ITS: An Introduction for Transportation Professionals", available on the FHWA website. The FHWA "Systems Engineering for Intelligent Transportation Systems Guide" is also a useful reference. You can find a link to the FHWA website, as well as to both of these guides, on the resources page.

FDOT SE and ITS Procedure

In Florida, following the FDOT Systems Engineering and ITS Architecture Procedure (February 7, 2020) is your most likely guarantee that your ITS project will comply with federal regulations and the FDOT expectations for a successful ITS project. The document is commonly referred to by shortened forms, such as "The Procedure". Besides describing how to process an ITS project, the ITS Procedure addresses the use of three forms.

The Project Risk Assessment and Regulatory Compliance Checklist (FDOT Form 750-040-05) is used to:

a. assess if the project is low risk or high risk, and

b. address all regulatory systems engineering items in the Federal Final Rule.

We'll look at assessing whether a project is low- or high-risk in Part 2.

Projects that change the Regional ITS Architecture need to request that change through the Architecture Change Request form (FDOT Form 750-040-04), so that the RITSA can be updated. Federally funded high-risk projects shall produce the Systems Engineering Project Checklist (FDOT Form 750-040-06), which covers the 11 required systems engineering steps mentioned earlier. The FDOT Systems Engineering and ITS Architecture Procedure and the three forms are available through the FDOT Forms Management website. A link is available on the resources page.

Project Planning

The FDOT Systems Engineering and ITS Architecture Procedure outlines a process for ITS project development.

(1) After initial project planning,

(2) Agency managers, FDOT districts or local agencies, shall conduct an initial project risk assessment early in the project planning cycle.

The initial project risk assessment will use the Project Risk Assessment and Regulatory Compliance Checklist (FDOT Form 750-040-05) to determine the level of risk associated with the project.

(3) The results of the initial project risk assessment will provide input into the project prioritization process.

(4) If the project is selected for implementation through the project prioritization process, the project will be recommended for inclusion in FDOT's Five-Year Work Program.

Depending on the risk assessment results, the project budget shall be adjusted, as needed, to ensure adequate funding for systems engineering activities through preliminary design, final design, implementation, and verification. Note that project-level risk assessment discussed as part of FDOT's ITS Procedures is not the same as cross-cutting systems engineering risk analysis and management that is treated in the systems engineering documents, such as the ConOps and PSEMP.

Project Advertisement

Agency managers, while producing the project scope documents for the procurement package, shall repeat the risk assessment as the scope is more clearly defined at the stage of project advertisement (or it may have changed since the project planning phase). Most often, the design, installation, and testing parts of the systems engineering will be procured from contractors by the agency. Agency managers shall ensure that the systems engineering analysis requirements, from the Systems Requirements stage, are included in the procurement scope and that the remaining systems engineering process tasks and documents are also included, as needed.

In addition to making sure that the project scope advertises systems engineering activities to be done by consultants and contractors, it is important to ensure that stakeholders have project budgets to allocate staff or consultant time for their participation in in-process validation activities and verification reviews. Procurement will be treated in more detail later in the course.

Local Agency Projects

For local agency projects with FDOT-delegated oversight, the District Local Programs Administrator shall coordinate the review of the systems engineering documentation submitted for FDOT review and approval with the District TSM&O Program Engineer. This is to ensure that (a) federally funded projects initiated at the local agency are compliant with the RITSA, and (b) the systems engineering process is used, if justified, employing the risk-assessment tools discussed in this procedure. Submit forms and documents to the District Local Programs Administrator. If scope changes while underway, the project needs to be reassessed for risk.

Low-Risk and High-Risk Examples

Let's take a look at what's meant by Low-risk and high-risk projects.

Low Risk: Expansion or upgrading of existing ITS (e.g., closed-circuit television cameras, or CCTV, and dynamic message signs, or DMS) where the RITSA elements, system requirements and agency agreements already exist.

High Risk: New RITSA elements, multi-jurisdictional, multi-modal, software development, connected vehicle and adaptive signal systems.

Tailoring Systems Engineering

Recall that the correct amount of tailoring of the systems engineering process occurs when the cost of risks balances the cost of doing more systems engineering. The federal Final Rule states that the systems engineering process shall be tailored to the project’s scale and complexity. The FDOT Systems Engineering and ITS Architecture Procedure has a Tailoring Guide to determine the systems engineering to be performed for low- and high-risk, federally and non-federally funded projects.

Very straightforward, low-risk projects only need to fill out the Risk Assessment and Regulatory Compliance form – no other forms or documents. The District TSM&O Program Engineer makes the decision as to how much documentation will be done for a low-risk project. In federally compliant, high-risk projects, tailoring is to be described in the Project Systems Engineering Management Plan. In non-federally funded, high-risk projects, the District TSM&O Program Engineer makes the decision as to how much system engineering documentation will be done and whether it should meet federal compliance.

Low-Risk or High-Risk Project?

As discussed earlier, there are three forms referred to in the FDOT Systems Engineering and ITS Architecture Procedure. The first is to determine if it will be a low- or high-risk project. Use the form

Project Risk Assessment and Regulatory Compliance Checklist (FDOT Form 750-040-05) (Part 1.6) to answer the following questions:

a. Only your agency, not multiagency?

b. Uses only existing software or none?

c. Uses only proven hardware and communications? Must be from the FDOT Approved Products List, or APL.

d. Uses only existing interfaces? All interfaces are shown in the Regional ITS Architecture.

e. Uses only existing system requirements? All requirements are established in earlier documents.

f. Uses only existing operating procedures?

g. Uses only technologies with service life longer than 2-4 years? No use of technologies near the end of service-life expectancy.

If all are Yes, then it is a low-risk project.

The rest of the Project Risk Assessment and Regulatory Compliance Checklist (FDOT Form 750-040-05) (Part 2) needs the following completed:

1. Parts of the Regional ITS Architecture to be used

2. Participating agencies, roles, responsibilities

3. Resources needed for Operations and Maintenance

4. Requirements definitions

5. Applicable ITS standards and testing procedures

6. Alternative systems configurations, and

7. Procurement options

These are the 7 requirements in the Federal Final Rule, as discussed earlier.

Project Checklist Form

The second form that the FDOT ITS Procedure calls for is a Project Checklist Form (750-040-006) for projects that are to be federally compliant. The form addresses the 11 FDOT checklist points that have been presented earlier.

Architecture Form

The third form referred to in the FDOT ITS Procedure calls for use of an Architecture Modification Form for high-risk projects whenever there is a RITSA change, whether federally or non-federally funded. The ITS Architecture Request Form (750-040-04) is used to change the RITSA. It is not needed for low-risk projects, since, for a project to be low-risk, it can't involve a change to the RITSA. Present the rationale and description of the RITSA changes. You may need to use graphics from the RITSA which will be discussed in Part 2.

Summary of Systems Engineering Tailoring

The primary systems engineering advantage of a low-risk determination is that

(1) some or even all project documents may not need to be produced, and

(2) some of the project documents may be more easily combined or will be relatively brief.

Portions of similar, earlier projects can be used, as well.

High-risk, federally compliant projects follow the full systems engineering process, but are also scaled according to project scope, risk and complexity. Use portions of earlier systems engineering documents and combine documents, as applicable. The District TSM&O Program Engineer makes the decision as to how much documentation will be done for high-risk, non-federally funded projects and whether they should be done to meet federal compliance.

Whether the project is low-risk or high-risk, it is scaled according to project scope, risk and complexity. Some low-risk project systems engineering can be managed using only the Risk Assessment form. Determination of Low-Risk documentation needs to be made by District TSM&O Program Engineer. Use portions of earlier systems engineering documents and combine documents, as applicable to the tailoring.

FDOT ITS Documents

As we have discussed, systems engineering documents are needed to reduce risk in complex projects. See the FDOT Systems Engineering website to access the ITS systems engineering

templates. The templates are pre-formatted and include instructions for filling them out. A link to the FDOT Systems Engineering website is available on the Resources page.

In addition to the forms described, the FDOT Systems Engineering and ITS Architecture Procedure calls for creation of documentation for:

1. Project Systems Engineering Management Plan, or PSEMP.

   Parts of the PSEMP may be separate reports in complex, high-risk projects, including:

   a. Procurement

   b. High-Level Systems Requirements

   c. ITS Standards, and

   d. Operations and Maintenance Plan treatment

2. Concept of Operations, or ConOps.

   a. Alternative Systems Analysis

   b. System validation is introduced in the ConOps, but may be its own report in more complex, high-risk projects.

3. Requirements Traceability Verification Matrix, or RTVM, and the System Verification Plan are separate documents, but produced in tandem (i.e., alongside one another).

In Part 2, we will look at use of some of these documents more closely.

In larger projects the other templates come into play. For example, the Risk Analysis, usually covered in the PSEMP, may have its own report. These all address stages in the V-diagram, except for the Project Systems Engineering Management Plan, which establishes the project management, a cross-cutting activity, and includes the Procurement method. For low-risk projects, especially when one is used, some documentation may be combined.

The systems engineer should check with the project manager before combining reports. To help produce these required systems engineering reports, FDOT has document templates on its systems engineering website. Some of the templates on the website apply to only high-risk, high complexity projects and are not examined in this introductory course. In high-risk, high complexity projects,

besides the standard documents, sometimes additional reports are used to assist in project management, such as risk management and test plan reports.

Adaptive Signal Control Technology (ATSC) Projects

For Adaptive Signal Control Technology, or ASCT, projects, use FDOT's systems engineering process and templates as directed by the District TSM&O Program Engineer. For further guidance on ConOps, requirements, validation plan, and verification plan for ASCT projects, see FHWA's "Model Systems Engineering Documents for Adaptive Signal Control (ASCT) Systems." To mainstream the use of Adaptive Signal Control Technology, FHWA has developed guidance that promotes a Systems Engineering Process commensurate with the scale of the project and that reduces effort and risk.

By following this ASCT Guidance Document, an agency can expect to produce the following systems engineering documents:

• Concept of Operation

• System Requirements

• Verification Plan

• Validation Plan

In addition, it is expected that an agency would prepare a procurement plan to provide an appropriate framework for the ASCT acquisition. FHWA strongly recommends that ASCT systems not be procured using traditional low-bid process, because experience has shown that ASCT systems are complex and require sufficient integration and customization. Also, they should not be treated as commercial-off-the-shelf, or COTS, purchases.

Where is the Engineering in SE?

Much has been said about the systems engineering process. But where is the engineering in systems engineering? The answer is that systems engineering takes place over the entire lifecycle of the project. Several gateway engineering documents are produced and revised as configuration management requires.

Systems engineering coordinates and combines many engineering efforts and disciplines. Over the project lifecycle, multi-discipline engineering efforts take place in every phase of the project, as shown in the table.

1. The project architecture involves arranging communications interfaces and component networking, which are planned in the ConOps built in the Design and Implementation phase and tested in the Verification phase.

2. Alternative plans and feasibility studies use traffic engineering, simulation, and benefit-cost analysis to identify the problem and choose the preferred approach.

3. In the Concept of Operations document, we build high-level functional requirements, operational modes, and scenarios to meet user needs.

4. Scheduling in the Project Systems Engineering Management Plan requires use of Critical Path Method, or CPM, or Program Evaluation Review Technique, or PERT.

5. Risk analysis is undertaken in the ConOps and PSEMP and carried out at every succeeding stage using probability/likelihood estimation and estimation of degree of failure and repair.

6. Systems requirements involves identifying the needed previously developed FDOT design standards and practices.

7. System design is engineering of the hardware, software, connectivity choices and failsafe design, among others, which could include sign and closed-circuit television structures, for example.

8. System verification uses design-based tests for units, subsystems and fault identification and remediation.

9. System validation uses traffic and system performance measurement and analysis, based on the ConOps document and the final design.

10. In Operations and Maintenance, Operations uses maintenance of traffic, or MOT, traffic flow optimization, dynamic routing, decision trees, emergency management and safety engineering.

Maintenance requires failsafe maintenance procedures, so operations are only safely interrupted during planned shutdowns and unplanned system failures. These are among the many engineering tasks performed as part of systems engineering for ITS. Systems engineering brings all these tasks together, so the entire system is developed as a unified whole.

Knowledge Check #4

Systems Engineering is performed: Choose all that apply.

a. **To improve possibility of project success**

b. To completely burn the project budget

c. To ensure user needs are met

d. Only for low-risk projects

e. To improve stakeholder participation

A, C, and E are correct.

Knowledge Check #5

Which is not a requirement for the federal Systems Engineering Analysis (SEA)?

a. Analysis of alternative system configurations and technology options to meet requirements

b. Identification of project cost and schedule

c. Identification of applicable ITS standards

d. Procurement options

B is the correct answer. Cost and schedule are not federal requirements. They do appear in the FDOT Project Systems Engineering Management Plan though.

Knowledge Check #6

What document is the best source for performing Systems Engineering Analysis and Systems Engineering in Florida?

a. Florida State ITS Architecture

b. FDOT Systems engineering and Intelligent Transportation Systems (ITS) Architecture Procedure

c. Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT)

d. Project Systems Engineering Management Plan (PSEMP)

B is the correct answer, the FDOT Systems Engineering and Intelligent Transportation Systems (ITS) Architecture Procedure or, simply, the FDOT ITS Procedure.

Knowledge Check #7

Why should you perform Risk Assessment early in the planning phase and prior to procurement?

a. To determine if the project is high-risk or low-risk

b. To adjust project funding to include systems engineering requirements, if needed

c. To document perceived risks and to select systems engineering activities to manage the perceived risks

d. All of the above

D is the correct answer. All of the above.

Knowledge Check #8

Which of the following statements are true about FDOT ITS Procedure? Choose all that apply.

a. Is the source document for all FDOT ITS projects

b. Includes 11 checklist items to meet FHWA's seven systems engineering requirements

c. Includes a guide for tailoring systems engineering of low-risk and high-risk projects

d. Requires use of ITS Architecture Change Request Form (750-040-04) for both low-risk and high-risk projects

A, B and **C** are correct.

D is incorrect. ITS Architecture Change Request Form (750-040-04) is not applicable to low-risk projects.

Knowledge Check #9

True or False? The FDOT has a website with systems engineering document templates to use with ITS projects?

True! The FDOT systems engineering document templates must be used to produce the required system engineering reports.

Conclusion

You have completed part 1 of the Florida Department of Transportation's Introduction to Systems Engineering 100 course for Intelligent Transportation Systems, or ITS. Please continue to part 2.

Thank you for your time and attention.