Introduction to Systems Engineering 100 course

Part 2 of 2 – Module 2

Welcome

Welcome to the second of two parts of the Florida Department of Transportation's Introduction to Systems Engineering 100 course for Intelligent Transportation Systems, or ITS. This is Module 2.

System Requirements

The next step after the Concept of Operations, or ConOps, is to develop system requirements. The user needs and high-level requirements identified in the ConOps feed into the development of detailed system requirements. In the System Requirements phase, the system engineers create a list of all aspects of the system that are required. Elements of FDOT Design Standards and Standard Plans may be included in the system requirements, along with electronics and software requirements.

At this requirements stage, systems engineering does not specify the technologies that will be used, but rather what the technologies will accomplish – the required features. The requirements need to be hard, not soft, that is verifiable and measurable, and, once applied later in the project, need to be thoroughly tested to ensure all elements of the system do what they are supposed to do. The requirements need to specifically identify what, how well, and under what conditions a product will achieve a given purpose.

System Requirements - Key Activities

There are three key activities to do in system requirements:

1. Develop a Requirements Traceability Verification Test Matrix, or RTVM

2. Create a System Verification Plan

3. Create a System Acceptance Plan.

System Requirements - Key Activity #1

The first of the three key activities to do in system requirements is an RTVM to accompany the requirements document. The RTVM, at minimum, is typically a table with a column containing each detailed requirement and a corresponding column for how that requirement will be tested and verified. Use the FDOT Systems Engineering RTVM Template, which has guidance for filling out the RTVM.

System Requirements - What, not How

The R in RTVM stands for Requirements. User Needs determine the list of requirements. Requirements stipulate the specifications the system will meet but not define how the design will meet those specifications. This allows the developers to use their expertise in designing the system and to use the latest technology.

Systems engineering specifically focuses on requirements and not technologies, at this stage, and thwarts efforts to use particular, pre-chosen technologies in favor of the latest ones available that meet the requirements. Requirements may initially be high-level and tell of generic project functions. Detailed requirements will follow from high-level requirements. The requirements will all be verified individually in the RTVM.

Manage System Requirements

Managing requirements includes key cross-cutting activities with stakeholders, such as:

- Eliciting requirements from stakeholders
- Risk analysis of requirements to get them all
- Documenting requirements for traceability and configuration management
- In-process validation of requirements, so that they are necessary, clear, consistent, accurate, complete, and verifiable.

Good systems engineering practice involves analyzing the requirements to make sure they are achievable, necessary, and independent of technology. The system requirements must be documented in a Systems Requirements Document, and each requirement must be individually referenced for traceability back to the user needs and for traceability forward to the system verification and design. Requirements should be approved by the users and stakeholders of the proposed system. In our example project, high-level requirements will be part of the Project Systems Engineering Management Plan, or PSEMP, and detailed requirements will be in the RTVM.

Delay Technology Decisions

The systems engineering process puts off technology decisions by specifying requirements prior to design. Due to the changing nature of technology, it is important to make technology decisions as close to system implementation as possible. The systems engineering process helps to ensure this by developing the design to meet user needs and system requirements. The systems engineering approach uses general, abstract, functional and high-level language, but with enough detail to bound subsequent desired technology choices to those that will meet user needs and system requirements.

Traceability

The “T” in RTVM stands for Traceability. Traceability, mentioned earlier as a cross-cutting activity, links together the entire systems engineering process. As illustrated here, a chain of common factors links the stages in the V-model. System requirements are derived from the user needs and additional user input. Every requirement must relate back to at least one user need, and there should not be requirements that do not trace back to a user need.

Keep in mind that the systems engineering documents produced at each step of the process must be living documents. In order to have complete traceability, the previous systems engineering documents must be updated to be consistent with the current step’s documentation throughout the system lifecycle. Traceability is documented through consistent configuration management throughout the project lifecycle, another cross-cutting activity. For example, User Needs trace to requirements, which trace to verification methods, which trace to validation and back to user needs.

In our example project, closed-circuit television, or CCTV, cameras will be added. Thus, the User Needs would include "Provide CCTV oversight of roadway and intersections," which would have Requirement(s), such as "Furnish and install cameras at locations in plans" and a Verification Test Method which would be CCTV Construction Engineering Inspection Checklist. This will be further illustrated shortly. Systems requirements trace back to user needs identified in the ConOps and forward to verification methods, also in the RTVM, which are used in the implementation and testing stages later in the testing process.

Verification

The “V” in RTVM stands for verification. Verification in the RTVM is represented by the Verification Test Case ID. The Verification Test Case ID comes from the Systems Verification Plan, which will be done in concert with the RTVM. The System Verification Test Cases and their Activities are developed in the Systems Verification Plan and will be explained shortly.

RTVM Data Fields

The “M” in RTVM stands for Matrix. These are a few lines from an RTVM spreadsheet matrix that is several-hundred lines long. Note the forwards and backwards traceability from the Detailed Requirements Summary in the center, the Verification Test ID to the right, and User Needs to the left. The purpose of the RTVM is to list all the detailed project requirements with a verification method. Later the verifier will perform the test and initial the verification as you can see on the right.

Here the three sections of the RTVM are separated for better viewing. On the left are the User Need and ID. Notice, in the third row, the User Need, taken from our example project's ConOps, says "CCTV system oversight of highway and Interchanges." This accompanies the Detailed Requirement that follows.

Next, in the third row under the Detailed Requirement Summary, the Detailed Requirement ID, DR003, says "Furnish and install CCTV cameras at locations shown in plans." The Source Document is shown as, "FDOT Standard Specs" and Document Section says "682-1." After that, under the Verification Test Case ID, on the right, comes the Verification Method, TC001, and the Compliance, Comments, and sign offs by the reviewer and the FDOT. The Test Case ID comes from the Verification Plan which will be discussed briefly. The portion after the Verification Test ID is filled out during the testing and verification phases, shown later in the V, generally by the contractor along with FDOT oversight.

This further illustrates how the remaining columns might be filled in, where the verifier found full Compliance and affirmed in the Notes/Comments that Approved Product List, or APL, products were used, as expected. APL hardware have been pretested by the FDOT Traffic Engineering Research Laboratory, or TERL. If new technology is needed for the design and it is not on the APL, TERL must first test and approve its use, and the project may be considered high risk just for that reason. The RTVM is used in all the verification stages that follow on the right side of the V-model. As shown, the verifier will perform the verification test and initial the verification.

System Requirements - Key Activity #2

The RTVM accompanies the System Verification Plan, the second systems requirements activity. As the requirements are finalized, create a System Verification Plan to describe Verification Test Cases covering how the requirements will be tested. Verification Test Cases can be used for similar requirements that will be treated or tested in a similar manner. Use the FDOT System Verification Plan Template to complete this plan. The Verification Plan for our example project will be part of the Request for Proposal, or RFP, or other procurement documents, as described in the PSEMP, to ensure the contractor delivers each requirement in the design and implementation.

Verification Test Cases

To define Verification Test Cases the following information will be needed.

- Test Case ID
- Test Method
- Test Case Description
- Test Case Objective
- Data Needed
- Pass/Fail Criteria

- Test Configuration, and
- Assumptions and Constraints.

Most of this information is self-explanatory except for the Test Method.

There are several standard verification test methods, which are:

- Analysis,
- Approved Products List, or APL,
- Construction Engineering and Inspection, or CEI, Checklist,
- Deliverable,
- Demonstration,
- Inspection, and
- Physical Testing

or some combination of these.

The CEI Checklist refers to approved test methodologies already in place for:

- Closed Circuit Television, or CCTV, Inspection
- Dynamic Message Sign, or DMS, Inspection
- Managed Field Ethernet Switch, or MFES, Inspection
- Microwave Vehicle Detection System, or MVDS.
- Road Weather Information System, or RWIS.

Verification Test Case Data Fields

Each Verification Test Case needs to have the following fields filled in:

- Test Method
- Test Case Description
- Test Case Objective
- Data needed
- Pass/Fail Criteria
- Test Configuration
- Assumptions/Constraints.

Test Case TC001 shows that the CCTV CEI Checklist will be used for the test. The CCTV CEI Checklist is a separate document that has sufficient information to carry out testing of CCTV cameras. The same CEI Checklist approach holds for TC002 and MVDS testing. The remaining test cases show details of testing that are not covered by CEI Checklists.

System Requirements - Key Activity #3

When completing the System Verification Plan Template, the third systems requirements activity is to organize a System Acceptance Plan to describe how to accomplish the acceptance testing of the system or include the system acceptance criteria in the System Verification Plan. System verification and acceptance planning and delivery were shown in the dotted line across the V-model from System Requirements to System Verification. The System Verification Plan and System Acceptance Plan may be one document, especially for a simpler high-risk project. Also, the System Verification Plan and System Acceptance Plan may be developed by the contractor based on the RFP as the project manager determines and explains in the PSEMP.

Knowledge Check #6

Documents developed as part of System Requirements include: Choose all that apply.

a. Operations and Maintenance (O&M) plan

b. Requirements Traceability Verification Matrix (RTVM)

c. System Verification Plan

d. System Acceptance Plan

B, C, and **D** are correct. A is incorrect. The need for or creation of an Operations and Maintenance (O&M) Plan is discussed in the Project Management section of the PSEMP and is not part of the Verification Phase. If a separate O&M Plan is developed, it would be during the Implementation Phase stage of systems engineering and revised as needed during ongoing systems operation. The O&M Plan may be part of or included in TMC or District Standard Operating Procedures, or SOPs. In our example project, the SOP would probably cover the new equipment's O&M in the SOP.

Knowledge Check #7

True or False. In the V-Model, User Needs are verified, and System Requirements are validated.

False! In the V-Model, User Needs are validated, and System Requirements are verified. Requirements undergo validation too by the users as a crosscutting activity to be sure all requirements were all included.

Knowledge Check #8

True or False. Traceability is the ability to copy a design from one project and use it in another.

False. Traceability tracks forward and backward continuity of user needs, requirements, design and testing.

Knowledge Check #9

In the systems engineering process technology choices should:

a. Be decided before the project begins

b. Be put off as long as possible in the systems engineering process

c. Be based on a vendor's sales pitch

d. Be built around user needs and requirements

e. Come from the Approved Products List

B, D, and **E** are correct. In A, technology choices should be put off to meet all the requirements and take advantage of the latest technology. In C, requirements based on FDOT specifications will guide the technology chosen.

Decomposition Phase and Procurement

In our example project, the initial work of the systems engineer to set up the rest of the development process is complete once the PSEMP, Project Architecture, Feasibility Analysis, ConOps and Systems Requirements are done. You will have enough done to complete an RFP, or other procurement documents as described in the PSEMP, to procure the rest. The diagram shows how the process contributes all the necessary work to proceed to the procurement of Design-Build or other service methods with a Request for Proposal. For example, the Design-Build Firm, as described in the RFP, will carry out tasks as prescribed by and tailored by the PSEMP, ConOps, RTVM and Verification Plan and any other documents.

Ensuring Good Consultant SE

Here are some guidelines for hiring a consultant firm to perform your systems engineering tasks. Depending on the phase of the ITS project, you need to include and budget for the necessary systems engineering tasks. You need to make sure you include the necessary systems engineering deliverables when tasking a systems engineering consultant with systems engineering activities. Keep in mind that the hours associated with each systems engineering task will vary by project complexity and, to a lesser extent, by project size.

One of the best ways to determine rough hours of magnitude is to find a similar project and see how many hours it took to develop the systems engineering documentation. Wherever possible, and especially for low-risk and simple projects, the project manager may choose to combine systems engineering activities, such as the ConOps and Systems Validation Plan, the Systems Verification Plan and Acceptance Testing Plan or develop a combined Systems Requirements Requirements Traceability Verification Matrix document. Complex, High-Risk projects, of course, require more time and expertise.

SE Deliverables

Many Florida systems engineering document templates are available on the Resources page. We have gone over several of these during the course for our example project:

- PSEMP
- RITSA
- ConOps and Validation Plan, and
- RTVM, Systems Verification and Acceptance Plan.

If you are developing a Request for Proposal for purchasing contracted Design-Build Services, you need to make sure that you require the remaining documents from the V-model as part of the ITS project deliverables. Besides implementation, systems integration and testing, the Design-Build deliverables need to include:

- Design Documents
- Implementation Documents
- Operations and Maintenance Plan
- Test Plans and updated RTVM
- Validation Report.

SE and Procurement

Systems engineering is critical to a successful ITS project procurement. The traditional approach of putting plans and specifications out and awarding the contract to the low-bid contractor works well for projects with well-understood requirements. However, ITS projects have more complex requirements and technologies as well as requirements that change with the users and stakeholders. For any high-risk project, you will need to do enough systems engineering up front to make sure you are procuring what the users want.

FDOT does not do system construction. So, the later phases of the project of design, implementation, and testing are often done by contractors who are solicited with an RFP. When preparing an RFP or equivalent to procure an ITS system, it is critical that the RFP contain the system concept and requirements. These need to be defined in sufficient detail to adequately determine the best solution that can be obtained from the prospective bidders.

The initial systems engineering will determine what to specify for delivery. The RFP scope must include obtaining the proper systems engineering documentation for each phase of the project's lifecycle, as depicted on the V-model, beyond what was done preliminary to preparing the RFP. As mentioned in the RTVM discussion, ITS hardware is procured based on the FDOT Approved Products List as determined by the FDOT Traffic Engineering Research Laboratory. The Requirements Traceability Verification Matrix will be used in system procurement. Procurement includes test and acceptance criteria for the system based on verifying the requirements and validating the user needs.

Implementation Phase

Next, we will go over the inputs, processes, and documentation needed to complete the work. The Design-Build firm may be contracted to do any or all of this work based on the project management and systems engineering done up to this point and written up in the PSEMP. Documents produced include Plans, Specifications, Test Reports and an updated RTVM. Also, the equipment and systems are installed and integrated. The RTVM is updated in this stage and in the next to account for verifications that take place.

In the implementation stage, shown at the bottom of the V the agency typically conducts technical reviews, configuration management activities, and product reviews based on the requirements defined in the RFP. The agency systems engineer assists the agency's project manager with systems integrator evaluation, product evaluation, detailed design, risk management, and technical plans review. The systems integrator, that is, the contractor that develops the technical plans, conducts configuration management, and performs activities described in the scope, including unit tests as part of the development activities.

Recomposition Phase

In the Recomposition stage of the V-model, the agency reviews, participates in, and approves the integration and testing plan, training documentation, and test plans/procedures. Documents produced include Subsystem and System Verification Test Reports, updates to the RTVM at each stage, and a Validation Report of the validation procedure and results.

The RTVM is updated at several stages to show verification progress. The tests are documented, and the validation data collected and analyzed as the System Validation Plan prescribed early on in the ConOps document. The dotted lines back across the V help to explain how the V shape helps to define the process. Also, an operations and maintenance plan may be produced.

The systems engineer supports, participates in, and monitors integration reviews, training, test procedures, tests, and risk management. Various tests and reviews are explained in Florida's Statewide Systems Engineering Management Plan. The systems integrator performs, documents, and implements integration tests, and resolves defects. Additionally, the systems integrator confirms that system requirements are met, performs configuration management, and conducts risk management tests.

Notice that the Requirements Traceability Verification Matrix is continually updated as part of its verification function during testing. The system evaluator conducts validation studies and reports results to the project stakeholders. As the last step, the Regional ITS Architecture is updated to change the status of the example project from planned to existing, edit any details, and capture any changes to operational concepts, stakeholders, operating agreements, and so forth.

Knowledge Check #10

Which of the following has the correct order of steps in the systems engineering process?

a. Requirements, System Validation, Design, O&M

b. Feasibility Study, Regional ITS Architecture, Design, Requirements

c. Requirements, Design, Testing, ConOps

d. ConOps, Requirements, Design, Changes and Upgrades

The correct answer is **D**: ConOps (or Concept of Operations), Requirements, Design, followed by Changes and Upgrades.

Knowledge Check #11

Producing an RFP needs systems engineering up front from:

a. Requirements Traceability Verification Matrix

b. Implementation Documents

c. Project Systems Engineering Management Plan

d. Concept of Operations

A, C, and **D** are the correct answers. B, Implementation Documents, are a product of RFP contracted services.

Conclusion

This completes the introductory course. You should now have a better understanding of the course's learning objectives. The primary intent of systems engineering is to take the necessary steps for project success. This training aims to ensure better understanding and use of systems engineering and a greater success rate for FDOT ITS projects.

You have been introduced to why we do systems engineering for ITS and the use of the systems engineering V-model. You can better understand why the V-model works better for ITS projects than the traditional process. We have discussed identifying and addressing user needs as an essential part of systems engineering. You must understand what problems the regional users want to solve to

deliver an effective ITS project. You have been introduced to the federal and FDOT requirements for the systems engineering process.

You are now aware of the FDOT Systems Engineering ITS Architecture Procedure Number 750-040-003, which ensures compliance with federal regulations and explains how the systems engineering process and V-model should be applied in Florida. You have had an overview of developing the PSEMP, Project Architecture, ConOps, Systems Requirements and RTVM and their role in producing a Request for Proposal to complete the ITS procedure. We have introduced the Regional ITS Architecture use in project development. We explored the procurement process and how systems engineering can help you deploy equipment that meets the expressed user needs and system requirements.

Systems engineering helps you improve the prospects of success in deploying complex Intelligent Transportation Systems. You identify what users want and follow the systems engineering process to deliver the system, while managing schedule and costs. That is project success!

Resources

The governing Florida Systems Engineering and ITS Architecture Procedure (750-040-003, February 7, 2020) provides the basis for ITS project analysis, use of the Regional ITS Architecture and tailoring the level of systems engineering required. This is required reading if you are doing an ITS project in Florida. Much of this course is based on the FDOT Systems Engineering and ITS Architecture Procedure.

The Florida Statewide and Regional ITS Architectures are found at the website shown. (https://teo.fdot.gov/architecture/)

The ARC-IT website has all the ITS and Connected Vehicle service packages and physical diagrams along with hypertext definitions and all the views and methodologies.

Systems Engineering Guidebook for ITS (FHWA), provided by the Federal Highway Administration can be found on the FHWA website.

Another reference provided by FHWA, *Systems Engineering for ITS – An Introduction for Transportation Professionals (FHWA)* can also be found on the FHWA website.

The FHWA Rule/FTA Policy can be found at the website shown. (https://ops.fhwa.dot.gov/its_arch_imp/policy.htm)

The Systems Engineering Body of Knowledge, or SEBoK, Guide is a valuable resource written in generic systems engineering terms.

USDOT has an ITS Professional Capacity Building Program that offers free, ongoing webinars that can be viewed at any time.

Conclusion

You have completed the Florida Department of Transportation's Introduction to Systems Engineering 100 course for Intelligent Transportation Systems.

Thank you for your time and attention.