Introduction to Systems Engineering 100 course

Part 1 of 2 – Module 1

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 1.

Overview

This introduction to systems engineering course is in two parts. We start with basic ideas about systems and systems engineering and move on to elements of systems engineering for ITS and project deliverables. We answer basic questions and examine what systems, systems engineering, and ITS are, and why we do systems engineering for ITS. Part 1 also covers FDOT and Federal requirements and deliverables for systems engineering for ITS projects.

The second part of the course shows how to use the systems engineering process covered in Part 1. We go into developing the various documents needed, such as for project management, operations, and requirements, and explore the systems engineering steps to develop an ITS project and procure it. Also, we will introduce the use of the Regional ITS Architecture, or RITSA, in project development.

We will explore the use of systems engineering in the procurement of contract services and how systems engineering can help you get the solution users need. The primary intent of systems engineering is to engineer project success. Meeting the users' needs on schedule and within budget is project success!

Part 1 Objectives

The course objectives for part 1 are:

- Explain basic Systems Engineering concepts
- Explain the intent and use of the Systems Engineering process and V-model
- Understand the driving force of user needs in Systems Engineering
- Understand how FDOT processes ITS projects

- Be familiar with resources available to process ITS projects, and
- Become familiar with FDOT deliverables for ITS projects

Part 2 Objectives

The course objectives for part 2 are:

- Describe the process to follow for local ITS projects
- Introduce the use of the Regional ITS Architecture, or RITSA, in project development
- Understand use of Systems Engineering in Procurement of contract services in an ITS project
- Overall, improve the use of Systems Engineering and instances of ITS project success

Some Initial Questions

This course is about systems engineering for ITS. But before we jump into how to do systems engineering for ITS we should answer the following questions:

- What is a System?
- What is an Intelligent Transportation System?
- What is Systems Engineering?
- Why do Systems Engineering for ITS?

What is a System?

The “S” in ITS is for Systems. But what is a system? We all have an intuitive sense of a system.

The dictionary has a brief, generic definition of a system: a set of things working together as parts of a mechanism or an interconnecting network.

More briefly, even, a system is a set of things working together. There are many things that fit this definition. In transportation, there are many ways to identify systems because there are many things that work together. Defining and identifying the system users need in an ITS project is an important first step.

What is an Intelligent Transportation System?

What is an Intelligent Transportation System? Using our original dictionary definition as a model, ITS is a set of technologies working together as parts of an interconnecting communications network … that provides information to stakeholders to manage and operate the transportation system.

ITS can apply to roadways with auto, freight, transit and pedestrian traffic, etc. ITS involves multiple disciplines, a broad range of stakeholders, and the transportation needs of many users.

Intelligent Transportation Systems

Intelligent Transportation Systems offer safety and mobility advantages when information is shared. Information sharing is what gives the intelligence to Intelligent Transportation Systems. Sharing information is the operation that brings all the technology elements together to make a complete Intelligent Transportation System.

With ITS, the whole is more than the sum of its parts. The parts are the technologies – hardware and software – and users. The whole is the shared information that can be put to use to add safety and mobility to the roadway infrastructure. The Traffic Management Center, or TMC, illustrates just some of the information sharing that ITS can accomplish.

ITS Involves Information Sharing

This slide illustrates how multiple agents can coordinate and cooperate by sharing information in an Intelligent Transportation System. The Traffic Management Center can communicate with the different system users – for instance, travelers, emergency services, and the transit agency - and that they can share information with each other and the Traffic Management Center. The various stakeholders may use dynamic message signs, or DMS, closed circuit television, or CCTV, cellular phones, radios, and other equipment to identify problems and reach people in their various types of vehicles.

To develop an ITS project all the stakeholders and all the communications and equipment must help in some way to meet the users' needs. A primary, initial job of the project manager is to determine the needs of each agent using the system. Coordination and cooperation between system users by information sharing can reduce the delay to get aid to motorists in crashes and in the clearance of vehicles and debris.

The Florida Highway Patrol, or FHP, and other emergency services benefit from early crash identification and coordination through the Traffic Management Center. Drivers can rely on trip planning and rerouting information as data is shared across the fiber optic, radio, and cellular communications network.

Information Sharing in an ITS

While technology enables information sharing between stakeholders, an important point is that technology, in itself, is not ITS. All the complex technology – fiber optics, radio, cellular, closed circuit television, vehicle detectors, dynamic message signs, computers and software – are only there to share information on roadway conditions between users and to satisfy user needs for information on events taking place on the roadway.

The intelligence in ITS is human intelligence gained from electronic measurement and connectivity. As engineers, planners and technicians, we may tend to focus on technology, but it’s in the value added as information that ITS improves travel and Transportation Systems Management & Operations, or TSM&O.

What is Systems Engineering (SE)?

Now that we have a sense of what a system is and what an Intelligent Transportation System is, let's look at what systems engineering is. Systems engineering, or SE, is an engineering approach that addresses the system as a whole, emphasizing the total operation. It examines the system from all users' perspectives and is concerned with the interactions between systems, system interfaces, and the systems operating environment.

The systems engineering development process has continuity, or traceability, from beginning to end of the project’s development to help manage complexity. Systems engineering also refers to the principles and procedures according to which complex, holistic project development is done. Even relatively simple ITS projects are complex enough for a systems engineering approach. The systems engineering approach has systemic checks to identify risks, and balance competing needs and constraints.

Why do Systems Engineering for ITS?

The systems engineering process must begin by discovering the highest-risk problems that need to be resolved and by identifying the most probable or highest impact failures that can occur. Systems engineering involves finding solutions to these problems. Systems engineering is used in many industries where complex electronics and software are used to solve problems. This makes it a good fit for ITS project development with its use of complex electronics and numerous user interfaces that require a holistic approach, looking at the whole system from every angle over the entire project lifecycle.

Systems Engineering Benefits

Systems engineering project management process benefits include:

- Meeting user needs for project success
- Treating the entire project lifecycle
- Improved stakeholder participation
- Reduced risk of schedule and cost overruns
- Risk management of all system activities
- Adaptable and resilient systems development
- Consistent methodology and terminology
- Verified functionality and fewer defects
- Use of the latest technology available
- Better documentation
- Better understanding of the system as the systems engineering progresses.

Why do Systems Engineering?

The foundation of systems engineering is based on the needs of the system users through the entire project lifecycle, from inception to retirement. Systems engineering management aims to reduce cost and improve schedule controls. Ultimately, we do systems engineering to improve the prospect of project success. Project success is delivering the system:

- that meets user needs
- on schedule
- and within budget.

Why do Systems Engineering for ITS?

Systems engineering focuses on eliciting the user needs of multiple stakeholders, using the many disciplines involved in TSM&O, and integrating the complex electronics and software into a manageable system.

Stakeholders

ITS uses complex electronics and software to pass information to multiple Stakeholders, such as:

- FDOT
- Local DOTs
- Metropolitan Planning Organizations, or MPOs
- Transit Agencies
- Traffic Management Center, or TMC, Operators
- Florida Highway Patrol
- Road Ranger Service Patrols
- Drivers
- Towing Services
- Emergency Services
- System Maintenance
- Contractors

Systems engineering provides opportunities to elicit and address all the stakeholder needs by requesting their feedback throughout the development process.

Multiple Disciplines

Also, ITS is interdisciplinary:

- Traffic
- Electronics
- Software
- Communications
- TMC Operations
- Enforcement
- Rescue
- Public Information
- Vehicle Design – especially new vehicles with connected vehicle features and equipment.

ITS involves integrating multiple disciplines, a broad range of stakeholders, and the transportation needs of many users.

Equipment

ITS passes information to stakeholders with complex electronics and software, such as:

- Traffic Management Center computers and software
- Closed Circuit Television monitors and CCTV Cameras
- Dynamic Message Signs
- Lane Change Signs
- Toll equipment

- Traffic Signals
- Vehicle Detectors
- Connected Vehicle technology
- Radio, cellular, and fiber optic cable
- Support equipment – cabinets, poles, gantries, etc.

Systems engineering provides a way to address all the system interconnectivity and stakeholder uses of equipment.

Delivering the System Users Want

In standard roadway infrastructure projects, user needs are well-established, and their requirements are standardized. But, in sharing information using ITS, user needs are regionally specific to the agencies involved, protocols followed, and the equipment used in the field and in the Traffic Management Center. Meeting user needs is the most fundamental goal when applying systems engineering to an ITS project. User needs are often not obvious and are found in the details that agencies bring to the table. Determining user needs requires stakeholder input from the beginning and throughout the project.

A Failure to Communicate User Needs

Here's an amusing comic that depicts how different user perceptions, expectations, and understandings of a project can make a project fail. Using a tree swing as an example, we see:

- How the Customer explained it
- How the Project Leader understood it
- How the Analyst designed it
- How the Programmer wrote it
- The Business Consultant's description
- How the project was documented

- What Operations installed
- How the Customer was billed
- How it was supported, and
- What the Customer really needed

What's at the root is a failure to communicate user needs. The project management process clearly missed conveying important information. The graphic contains different understandings of what the customer wanted by the various project developers. Because the customer did not convey clearly what was really wanted, the systems engineering team could not fully identify and deliver the desired product.

The intermediate steps then only grossly approximated what was needed. If user needs are not sufficiently identified, chances for project success are greatly reduced. By building communication between stakeholders into the systems engineering process, communications failure is less likely or less serious when it occurs. Costs are reduced when user needs identify potential problems early in the development process.

Systems Engineering for Project Success

Why do we go through the trouble of doing systems engineering? The simple answer is to improve the prospect of project success, which means meeting user needs within the allotted cost and schedule. Not delivering the correct system on time and in budget is a waste of resources.

Work done by the Standish Group followed information technology and software projects over 15 years. They examined performance measures for successful, challenged, and unsuccessful projects. Their research has consistently shown only about a 30 percent full success rate. This points out why information technology and software projects are considered high-risk ITS projects.

The biggest problems were cost and time overruns, leading one to suspect that original estimates were overoptimistic to begin with and possibly engineered to get approval to proceed, rather than a problem with project management per se. Doing too much or too little systems engineering is a problem. Another failure is not properly addressing user needs by focusing overly on technology instead of the project goals. Also, smaller projects have a much higher likelihood of success than larger ones. By applying systems engineering effectively, the intention is to provide a framework to reduce risk and to help ensure that projects deliver full functionality on time and within budget.

Project Risk

How much systems engineering is necessary? The graph shows, in the center, the minimum cost for projects that use systems engineering. In the center, there is neither too little systems engineering, as on the left, nor too much, as on the right. At equilibrium, schedule and cost overruns on the left side are offset by the amount of formal systems engineering processes followed on the right side. Typically, 7-15 percent of the total project cost should be budgeted for completing systems engineering, but the actual amount depends on the project risks and the systems engineering activities selected to manage those specific risks.

Knowledge Check #1

Choose all that apply. Intelligence in ITS comes from information sharing because:

A. **Multiple stakeholders have a means to respond to incidents**

B. **Agents can coordinate and cooperate**

C. **Technology allows networked communication between people**

D. Technology is the only thing to consider

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

D, Technology may be a powerful tool of ITS, but it isn’t enough by itself. People operate the technology and benefit from the ways they use it.

Knowledge Check #2

True or False: The correct amount of tailoring of the systems engineering process occurs when the cost of risks balances the cost of doing more SE.

True. The correct amount of tailoring of the systems engineering process occurs when the cost of risks balances the cost of doing more SE. Typically, 15 percent of the total project cost should be budgeted for completing SE, but the actual amount depends on the project risks and the systems engineering activities selected to manage those specific risks.

V-model Use in Systems Engineering

Now that we have examined what systems, systems engineering, and ITS are, and why we do systems engineering for ITS, we can look into how we do systems engineering for ITS. We next consider that systems engineering can be done various ways. We'll compare how the systems engineering V-model differs from the traditional highway development process and why. We'll take a tour of the V-model, what systems engineering the Federal Highway Administration, or FHWA, requires for funding of ITS projects, and how FDOT complies with FHWA's requirements.

Systems Engineering "V" Process for ITS

There are several systems engineering approaches used for complex electronics and software development. In ITS we use the V-model. However, there may be exceptions for:

- Very large or highly complex and high-risk projects, and
- New software development

The systems engineering V-model addresses the entire project lifecycle. It also has some alignment with traditional project development process.

Traditional Project Development is a Success

By following a traditional project development process, many infrastructure projects have been successful. Standardized, documented, proven designs, few stakeholders and experience over many years create a low-risk environment for traditional transportation projects. Even though some official FDOT documents, such as the FDOT Design Manual, FDOT Standard Plans, and FDOT Design Standards, do not officially refer to a "Systems Engineering Process" they are related to the systems engineering process. Project design and standards plans manifest elements of systems engineering as part of the traditional FDOT delivery process.

Systems Engineering "V" and Traditional Project Development

The systems engineering process, represented in the V-shape, is related to the traditional project development process, across the top, which is typically used by transportation agencies for infrastructure projects. There are correspondences between similar activities. In the traditional process, three steps – Preliminary Engineering, Plans, Specifications, and Estimates, or PS&E, and construction – are divided into ten steps in the V. How the steps on the left and right sides of the V relate to one another make the V shape necessary.

Systems Engineering Model for ITS

This diagram is an overview of the entire systems engineering process. This is the model typically used for systems engineering management of ITS projects and is called the “V-model” due to its V-shape. A key difference from the traditional development process is the horizontal double-headed arrows in the V-process that make the V-shape necessary, otherwise it could just be laid out more linearly like the traditional process. These horizontal arrows show the relationship of activities between the opposing sides of the V. There is a testing stage on the right for each development stage on the left.

Let's take a quick tour of the V. Note that the project lifecycle timeline goes from left to right. Also note that there are document approvals between most of the stages in the development process, as shown by the blue disks between stages. These are sometimes called gateway documents, because completion of the document at each stage is the gateway to starting the next stage in the V-diagram.

The Systems Engineering Process begins, in the upper left, with examination of the Regional ITS Architecture, followed by a Feasibility Study/Concept Exploration, which may be undertaken to examine alternatives and the costs and benefits of instrumenting them. Next comes a Concept of Operations document, or ConOps, which identifies the stakeholders and determines their needs as users of the system. It also lays out high-level requirements for the system to accomplish for the users. With the top horizontal arrow, the ConOps connects across the V to the System Validation phase. We will explore this linkage later in the course.

The diagram shows, after the ConOps, the development of the Systems Requirements. Notice in the V that there is a double-headed arrow across the V from the Systems Requirements phase to the System Verification step later in the deployment. Based on the System Requirements and ConOps, a Request for Proposals, or RFP, is often developed to hire a Design-Build Contractor to carry out most of the remaining parts of the V:

- High-level Design,
- Detailed Design,
- Procurement of Hardware,
- Field Installation,
- Testing,
- Verification, and

- Validation.

At the upper right of the V, in the stage of System Validation, the project is handed off from the development team to the operations team. Note that the Systems Engineering Process and the lifecycle do not end with operations and maintenance (on the upper right) but continues with changes and upgrades until the final replacement/retirement of the system. In the second part of this course we will walk through more details of essential first steps in the V diagram and their role in procurement of the system.

Verification and Validation Terminology

We mentioned system verification and validation. Though they sound alike, in systems engineering, verification and validation refer to two very different things and need to be used appropriately to avoid confusion. Verification is used to verify that a system works or that a task was done. Verification confirms that a system meets its specified requirements. Verification asks the question: Was the system built right? Requirements, Testing and Verification steps are shown on the V.

Validation is used to validate that the right system was built or that the task was the right task to do. Validation confirms that the system or task meets its user needs. Validation asks the question: Was the right activity undertaken, or the right system built? Validation occurs in every step, but only final System Validation is shown on the V.

In-Process Validation

In-process validation is another use of the term validation and takes place throughout the Systems Engineering process. In-process validations come with success in meeting approval criteria at each stage in the V-diagram. As noted earlier, Final System Validation answers the question: Was the right system built? The in-process validations ask if, at the stage in development, were the right business case, user needs, requirements, design and implementation found. Only the final systems validation is shown on the V.

Validation is not automatic but requires revisions in the in-process activities until they meet approval criteria. Final system validation can only occur once the system is operational. Stakeholder or user participation is key to a successful validation of the system. In-process validation is also a cross-cutting activity.

Crosscutting Activities in the "V"

We have briefly looked at the major stages of systems engineering, documentation, and the horizonal arrows across the V and have seen how in-process validation is done. Note now that there are several activities that occur at every stage within the V on a continuing basis, besides in-process validation. These are called “cross-cutting activities.” Cross-cutting activities, such as project management, configuration management, traceability, risk management, stakeholder inputs, and in-process validation occur throughout the systems engineering lifecycle.

As cross-cutting activities, they do not appear in the V because they apply to many of the steps in the V. With the systems engineering stages of the V, arrows crossing the V and cross-cutting activities, we now have a generic overview of the systems engineering analysis process. Now that we have looked at why we do systems engineering for ITS and how we do systems engineering, let’s look at how systems engineering is used in Florida to meet federal requirements for systems engineering of ITS projects.

Here are brief definitions of the cross-cutting activities.

- Systems engineering project management crosscuts all phases of the systems engineering process, as project management normally does.

- Configuration management keeps the system particulars consistent throughout the project. It is important to manage changes to the system as it develops. Configuration management synchronizes changes to the system by keeping its various documents in sync with one another as the project progresses. This pays off in implementation with fewer errors.

- Traceability is essential to systems engineering activities. User needs, requirements, and verification methods carry through the project lifecycle, and their relationships can be traced forwards and backwards from any stage.

- Risk management is used throughout the project lifecycle. As the various systems engineering documents are developed, areas of risk can be defined where user consensus is not fully understood or where system tradeoffs need to be made.

- Stakeholder input is elicited throughout the project to help the project meet user needs. These activities include project oversight, elicitation of inputs, and technical reviews which occur in every phase of the V.

- As we examined earlier, in-process validation examines that the right activities were undertaken in each step of the V.

There is a formal system validation at the end of the project which answers the question: Was the right system built to accomplish the user needs expressed in the ConOps? As noted in the previous slide, verification and validation are different. Verification tasks are shown on the V. Only the final system validation task is shown on the V, though validation is done in-process at every stage of the V to check that the right activity was undertaken.

Knowledge Check #3

Which of the following does not appear in the systems engineering “V” diagram?

A. System Requirements

B. Concept of Operations (ConOps)

C. Risk Management

D. System Validation

E. Field Installation

C is the correct answer. Risk Management does not appear in the systems engineering “V” diagram. Risk Management is a crosscutting activity, which occurs throughout the systems engineering process.

Conclusion

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

Thank you for your time and attention.