Appendix C

A Process Review of the Best Practices and Process Standards for the Deployment of ITS Field Elements

Systems Engineering Process Review:

Best Practices for Field Element Deployment and Operations Summary Report

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October 10, 2002

Document Control Panel	
File Name:	W:\ITS Program\ITS GC\TWO11-SEMP\021010 Final SE Process Rvw (Street Smarts).doc
Created By:	Street Smarts
Date Created:	September 30, 2002
Reviewed By:	Traci Matthews, Pamela Hoke
Modified By:	Pamela Hoke
Date Modified:	October 10, 2002

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List of Acronyms

AIAA .... American Institute of Aeronautics and Astronautics
ATMS .... Advanced Transportation Management System
CCTV .... Closed-Circuit Television
CORSIM
COTS .... Commercial Off-the-Shelf
DMS .... Dynamic Message Sign
DoD .... Department of Defense
ETC .... Electronic Toll Collection
FDOT .... Florida Department of Transportation
FHWA .... Federal Highway Administration
HAR .... Highway Advisory Radio
INCOSE .... International Council on Systems Engineering
ITE .... Institute of Transportation Engineers
ITS .... Intelligent Transportation System
NEMA .... National Electrical Manufacturers' Association
NITSA .... *National ITS Architecture*
NTCIP .... National Transportation Communications for ITS Protocol
SAE .... Society of Automotive Engineers
SECM .... Systems Engineering Capability Model
SEMP .... *Systems Engineering Management Plan*
SITSA .... *Statewide ITS Architecture*
SPMN
USDOT .... United States Department of Transportation
VMS .... Variable Message Signs

1. Introduction

The Florida Department of Transportation's (FDOT) Intelligent Transportation Systems (ITS) Office has proposed a systems engineering approach to fulfill the requirements of the Federal Highways Administration's (FHWA) Final Rule on the *National ITS Architecture* (*NITSA*).[1] The proposed systems engineering approach is based on the Electronic Industries Association Interim Standard (EIA/IS) 731.1, Systems Engineering Capability Model (SECM).[2] The benefits of the systems engineering approach and the basic program areas that make up the proposed approach for ITS deployments in Florida are presented in an issue paper[3] prepared for FDOT.

The issue paper, *Proposed Systems Engineering Approach for ITS Deployments along Florida's Limited-Access Corridors*, identifies the technical/project management program area as the program area that will support the development of ITS projects, including the deployment of ITS field elements. The technical/project management program area is the focus of the *Systems Engineering Management Plan (SEMP)*.

The *SEMP* defines the sub-processes that make up the activities of the technical/project management program area. These activities, as defined in the *Proposed Systems Engineering Approach Issue Paper*, include conceptual design, engineering/design, deployment, operations, central data warehousing, performance evaluation, conflict resolution, and change order management. The systems engineering processes in the technical/project management program[4] area include:

- Stakeholder participation;
- Requirements analysis;
- Analysis of alternate system configurations and technologies;
- Concept designs and master plans;
- Design criteria packages;
- Determination of procurement methods;
- Design;
- Verification;
- Procurement;
- Installation and integration;
- Validation;
- Operations; and
- Management.

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[1] Code of Federal Regulations: *Title 23 Highways, Subchapter K – Intelligent Transportation Systems, Part 940 – Intelligent Transportation System Architecture and Standards*. (April 2002) <http://www.access.gpo.gov/nara/cfr/index.html>

[2] International Council of Systems Engineering (INCOSE), Interim Standard EIA 731, *Standard for Systems Engineering Capability*, (INCOSE, 1998). <www.geia.org/eoc/G47/main.html>

[3] FDOT, ITS Office. *Proposed Systems Engineering Approach for ITS Deployments Along Florida's Limited-Access Corridors*. (August 8, 2001.)

[4] FDOT, 7.

The first task in developing this plan is to prepare an appraisal of systems engineering processes and standards and their application to ITS deployment projects and programs. This report is one element of the appraisal and focuses on the systems engineering practices currently in use in government and industry in the United States that can be related to ITS field element deployments and operations. In the overall view of the ITS program and project development for FDOT, the field elements are the subsystems/components of the larger ITS. The systems engineering processes are applied to all levels of the system and its development.

The task focuses on the systems engineering processes applied to ITS field elements and the effort includes:

- Research of systems engineering practices;
- Acquisition of resource documents;
- Examination and analyzation of the potential process standards and best practices; and
- Summarization findings in this report.

This report expands on the work prepared in the *Proposed Systems Engineering Approach Issue Paper* and provides a review of systems engineering processes as applied to field element deployments and operations. The processes and practices have been evaluated for selection and inclusion in FDOT's systems engineering process for ITS. This is the first task in the development of the *Systems Engineering Management Plan* for the deployment of ITS along Florida's five (5) principal FIHS limited-access corridors. This report is organized into three (3) sections: Research, Process Standards, and Best Practices and Recommendations.

2. Research

ITS field elements are, for the purposes of this task, defined as the equipment packages that comprise the roadway subsystem within the framework of the *NITSA*, Florida's regional ITS architectures, the *Statewide ITS Architecture* (*SITSA*), and the infrastructures necessary to support the equipment packages. Field elements include ITS devices such as closed-circuit television (CCTV) cameras, dynamic message signs (DMSs), communications hubs, regional weather stations, loop detectors, highway advisory radio (HAR), remote traffic microwave sensors, radio towers, ramp metering, dynamic trail blazers, motorist aid call boxes, electronic toll collection (ETC) equipment and other roadside equipment, and infrastructures that support transportation management systems.

The first step in identifying best practices is to research current systems engineering practices both in general industry and in the ITS field. Within the general industry, much of the information on systems engineering standards and best practices targets United States Department of Defense (DoD) projects. Within the transportation industry, systems engineering methods have long been used on traffic signal systems. The successful implementation of traffic signal systems has generally resulted from the use of sound systems engineering processes in the development and implementation of the systems. Currently, the FHWA is developing tools and training courses to help promote the use of systems engineering processes in the deployment of ITS projects.

An extensive literature search on systems engineering practices used by both the government and industry was conducted. In particular, the research was focused on the systems engineering practices as they apply to the deployment and operations of ITS field devices. This research started with the International Council on Systems Engineering (INCOSE) website, the United States Department of Transportation's (USDOT) ITS Joint Program Office's website, and other related websites. Additional resources include reference books, text books, and training materials from a number of sources. An annotated bibliography of the systems engineering reference material most applicable to ITS field device deployment is provided at the end of this document.

It was noted early in the research effort that there are numerous references for systems engineering processes and standards as applied to general industry and in particular as applied to aerospace and defense systems; however, there are few documents on the application of systems engineering processes and practices as they apply specifically to ITS services or to the field element subsystems.

3. Process Standards and Best Practices

Usually, a field device comprises one subsystem or component of a larger system. Currently, FDOT has a number of ITS field devices deployed throughout the state. It is anticipated that the deployment of ITS field devices might include the following for new ITS projects:

- Integration of new ITS field devices into existing systems;
- Integration of new ITS field devices into new systems; and/or
- Integration of existing ITS field devices into new systems.

The *SEMP* recognizes that different projects need to implement systems engineering processes in different ways. The systems engineering methods should match the project needs. New and complex projects will typically require a robust systems engineering approach, while an established project may only require occasional monitoring[5].

The *Proposed Systems Engineering Approach Issue Paper* identified systems engineering processes for the technical/project program management area for ITS deployments on the FIHS limited-access corridors. The process standards and best practices identified during the research phase of this task are discussed for each of the systems engineering processes.

3.1 Stakeholder Participation

Stakeholders are a critical element to the process. Multiple agencies and multiple disciplines will be involved in the project, including planners, managers, engineers (discipline and systems), users, and maintenance staff. The stakeholders will:

- Identify representatives for each major stakeholder at three (3) levels: policy, management, and technical.

  Identify policy-level representatives for top-level steering committees or program management. The management and technical representatives need to participate at the regional planning level and should be given decision-making authority for technical decisions.

- Identify an ITS advocate in every key agency as a means to facilitate inter-agency cooperation.

- Accurately define and address stakeholder roles, responsibilities, and needs by involving the operations and maintenance personnel in all phases of ITS project planning and deployment.

[5] INCOSE and American Institute of Aeronautics and Astronautics (AIAA) Systems Engineering Technical Committee, S*ystems Engineering: A Way of Thinking, A Way of Doing Business, Enabling Organized Transition from Need to Product*, (INCOSE and AIAA, August 1997) 4. <www.incose.org/lib/aiaa/aiaainco.pdf>

- Address information sharing issues up front. Stakeholders' roles and responsibilities need to be clearly defined early in the planning stage.

- Stakeholders will be an integral part of the systems engineering process and must work well together. Consideration should be given to team building techniques to build the basis for fostering the team relationship and maintaining open lines of communications throughout the project.

3.2 Requirements Analysis

The analysis of requirements is used to develop functional and performance requirements for the system and its components. Requirements can and will change over the life cycle of the system. The systems engineering process is an iterative process and, through each iteration of the requirements analysis, the requirements will become more detailed.

- Often times, the stakeholder requirements are conflicting. Where possible, these requirements should be ranked from the most important to the least important.

- Establish and maintain a decision database as a means to maintain requirements traceability. This database will also become the baseline for documenting the requirements and specifications for the system and elements as part of the change management and configuration management processes.

- Develop a plan to analyze the requirements.[6] This plan may include the following tasks:
  - Define and quantify stakeholder expectations;
  - Identify and define constraints impacting design solutions [i.e., National Transportation Communications for ITS Protocol (NTCIP) standards' maturity, costs, legacy devices);
  - Identify external constraints (i.e., regulations and laws, capability of interfacing systems);
  - Identify operational scenarios;
  - Identify and define systems effectiveness measures;
  - Identify system boundaries (i.e., what falls outside the control of the system such as an arterial management system);
  - Identify functional and physical interfaces to external or higher-level interacting systems;
  - Define environments for each operational scenario (i.e., weather, topology, time, road vibration);

[6] *Systems Engineering Fundamentals,* (Fort Belvoir, Virginia: Defense Acquisition University Press, 2000) 41-44. <http://clc.dau.mil/kc/no_login/portal.asp?strRedirect=LC_CIA>

  - Define functional requirements;
  - Define performance requirements;
  - Define modes of operations;
  - Define technical performance measures;
  - Define physical characteristics; and
  - Define human factors.

- The requirements and needs define the technology. Do not select an ITS technology and then define the requirements to meet the technology.

- Well-written requirements are clear, complete, measurable, consistent, achievable, testable, verifiable, and in line with the expectations and needs of the stakeholders.

- Analyze the requirements for ambiguities, conflicts, and omissions so that there is a single, validated set of requirements.

- Ensure requirements traceabilility by numbering the components of every step.
  - Numbering should be hierarchical and sequential.
  - Reference requirements both forwards and backwards within the processes. (As the requirements become more technical and detailed through iterations of the systems engineering process, ensure that they can be mapped to the original stakeholder requirements.
  - Depending on the complexity of the requirements, it may be helpful to use third party traceability software to support the process.

- Determine the ITS standards, in particular the NTCIP standards that may apply to the field device. Develop a thorough understanding of the meaning and implementation of those standards. If staff resources do not include experts in these areas, hire a consultant that is an expert with the applicable standards.

  The FHWA will be distributing a software tool, SpecWizard, to help users create accurate and unambiguous NTCIP specifications for ITS field elements. This tool should be available in the near future.

3.3 Analysis of Alternate System Configurations and Technologies

The selection of a system configuration or ITS field element technology should include a trade-off analysis between performance, cost, and operational effectiveness of the element. Often simple and off-the-shelf solutions provide the best results. The selection criteria should be weighted according to the preference of the customer. The selection criteria should be unbiased and the evaluation method documented.

- Identify alternative systems or technologies (i.e., technology surveys, brainstorming, review of similar systems, requests for information from vendors).
- Use trade studies, a formal decision-making methodology, to analyze alternative system configurations.
- Evaluate comparison costs and benefits using a utility-cost analysis or benefit-cost analysis. Evaluate vendor responses based on the weighted selection criteria previously developed. Document analysis results.

3.4 Concept Designs and Master Plans

Document the concept of operations. This document should include the stakeholder goals and objectives, how the system or field element will be deployed, practices and procedures, expectations, utilization environments, measures of effectiveness, and life cycles.

- The operational concept should be an accurate reflection of stakeholder needs.
- Use block diagrams in a text or graphical format to define and depict system concepts.
- Define and depict the ITS field element components and their relationships to the system.

3.5 Design Criteria Packages

The design specifications for the ITS field elements should be detailed and traceable to the requirements.

- The specifications are derived from the requirements.
- There should be at least one specification for each requirement.

3.6 Determine Method of Procurement

The procurement of the field device subsystems can be included in a system project or can be procured separately. Low bid, task order, and design-build are successful with field devices if no software or system integration is involved. Recommended considerations include:

- Agency procurement and contracting early in the process;
- ITS field equipment vendors and/or suppliers prequalification; and
- Pool agencies and organizations and use indefinite quantity procurements to obtain pricing breaks and quantity discounts for field equipment.

3.7 Design

The design process selects the components and their interconnections so as to meet the system requirements. The plans, specifications, and engineer's estimates are the results of a traditional transportation design project.

- During the design process, revisit the functional architecture and specifications to verify that the physical design can perform the requirements at the expected performance level.
- In terms of field elements, consider the following in the design:
  - Reliability;
  - Maintainability;
  - Availability; and
  - Affordability.

3.8 Verification

The verification process ensures that the system and elements have been designed and installed correctly. In other words, does the system and elements meet the requirements? The process begins in the design activity.

- The derived requirements and design specifications must be testable. As noted in Section 3.2, Requirements Analysis, the requirements must be single statements that are unambiguous, understandable, and verifiable.
- Develop a systems test plan that will verify that the system and elements meet the requirements. Elements of the plan should include:
  - Review of documentation during implementation and integration;
  - Field inspection during implementation;

- o Factory tests;
- o Unit tests;
- o System tests; and
- o Acceptance tests.

3.9 Procurement

Managing the installation requires good project management skills. This includes planning the schedule, estimating the resource requirements (contractor and agency), and tracking the cost and schedule.

A risk assessment should be performed to determine the likelihood of an occurrence, the potential impact, and the mitigation cost. Some of the risks most frequently encountered are personnel shortfalls, unrealistic schedules and budgets, incorrect user interface, incorrect functions, scope creep, field device shortcomings, external dependencies (i.e., devices that are not available on time, subcontractors, etc.), and unrealistic technical requirements.

- Develop a work breakdown structure for the deployment contract.

- Develop a risk management plan. Define each risk, its likelihood of occurrence, and the potential impact. Define the mitigation methods to be used if the risk occurs. Define the monitoring and control measures.

- For competitive procurements, define the evaluation process to be used in making a selection.

3.10 Installation and Integration

During the implementation there should be intervals where field devices are tested on a limited basis to make sure that it is on the right track. It is better to catch problems early than it is to install all of the devices and then find out that the devices do not meet the requirements or perform as intended.

- Testing should be performed at the unit level for each field device (i.e., controllers, detectors, signs, etc.) to determine that all the equipment meets the functional and environmental tests.

- Unit level tests can be performed at the factory and in the field prior to device integration into the system or subsystem.

- Acceptance testing should be a formal, step-by-step process that tests the actual operations of the device.

  - o Each of the device requirements should be tested by pre-defined test procedures and the results documented in a test report.
  - o Define the criteria for the passing or failure of each requirement.
  - o Once the field device has passed each of the tests, an observation period should be required for a predetermined amount of time.
  - o During the observation period, the requirements for failures that require a restart of the observation period should be clearly defined and included in the appropriate test report.

- Acceptance tests should be based on a matrix that is a function of the requirements, specifications, implementations, and the test procedures to ensure that all requirements are tested.

3.11 Validation

The validation process determines whether the end product, or the component or field element, matches the needs of the stakeholders as defined in the concept of operations. The entire systems engineering process is an iterative process. If it is determined that the field element does not match the requirements during the validation process, a review of the requirements should be reinitiated.

- Establish validation of stakeholder needs and the operational concept at the outset of the design process.

- Validate the requirements by establishing that the requirements have not introduced new issues or left issues unresolved in the system as designed.

- Validation activities can include complex mathematical modeling and/or simulations (i.e., CORSIM analysis of DMS to show reduction in congestion), visual inspections (to verify the physical design features), demonstrations, or testing. The method should match the complexity of the subsystem or component and should consider the potential risks.

- The validation process includes the verification that the design solution integrates with other systems or field elements.

- As part of the acceptance testing of the system and elements, an operational validation should be performed to confirm that the capabilities of the designed system and elements meet the operational needs.

3.12 Operations

Systems engineering processes can be used as tools for operations and maintenance activities to improve the systems and components. Systems engineering can be used to manage change, including design modifications to the ITS field elements and to develop operator procedures and training for ITS services.

- Over time, the system should be reevaluated from an operations and maintenance point of view and the needs and requirements should be redefined.
- Maintain documentation for each ITS field element, including as-built drawings, operations and maintenance manuals, and warranty and maintenance information.
- Follow operations, maintenance, and configuration management procedures for operations and maintenance.
- Maintain records for all modifications and maintenance activities.

3.13 Management

In order to successfully operate and maintain the field devices, management needs to ensure that there are adequate resources available, including skilled and trained staff and an adequate budget. In addition, relationships with the stakeholders and participating agencies need to be maintained.

- If agency staffing is not available, outsourcing should be considered.
- Continue to maintain strong and effective working relationships with the shareholders after the ITS project has been deployed.
- Conduct regular operations and maintenance briefings with agency personnel.
- Monitor, measure, evaluate, and report system performance and benefits.
- Establish performance requirements and criteria to manage and operate ITS services.
- Develop staff training programs.
- Provide necessary maintenance and operations resources.

4. Recommendations

The *SEMP* recognizes that different projects need to implement systems engineering in different ways. The systems engineering processes should match the project needs. New and complex projects will typically require a robust systems engineering approach, while an established project may only require occasional monitoring.

The systems engineering processes must be adapted to the project needs. In the case of the deployment and operations of ITS field elements, the project needs will vary by the type of implementation and integration, including:

- Integration of new ITS field devices into existing systems;
- Integration of new ITS field devices into new systems; and
- Integration of existing ITS field devices into new systems.

The *SEMP* must be able to provide an overall direction for processes and be flexible in the application.

Technical reviews and audits should be included at various points in the systems engineering processes to ensure that the development stages have been satisfactorily completed.

Annotated Bibliography

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A case study on the implementation of NTCIP standards and VMS by the Washington Department of Transportation. They had several delays in their project and it ended up taking twice as long as originally planned. They did not follow the systems engineering process. There were no formal requirements and what requirements they did have were developed with the vendor after the proposal process. The process was unstructured, which in turn lead to several problems. This is an example of how not to implement ITS devices.