Systems Engineering and Regional ITS Architecture for ITS Projects

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1.0 Preface

The North Dakota Department of Transportation (NDDOT) has established an Intelligent Transportation Systems (ITS) program. To guide the development of this program, NDDOT (along with several local jurisdictions) have developed a regional and statewide ITS architecture to serve as a framework that will guide ITS planning, project development, and implementation to achieve increased integration of the region's transportation system. In addition to the architecture, NDDOT has adapted a comprehensive process for ITS project planning and implementation termed Systems Engineering (SE), including an easy-to-use checklist.

The SE process is a **Federal requirement (23 CFR 940)** for deploying ITS at any project level using Federal funds. All ITS projects using Federal funds must use SE to increase the chances of a successful ITS deployment. The SE requirements are detailed in Section 3.0 of this document.

However, a gap exists between the knowledge of the ITS planning process and its application to ITS project development. This user's guide is intended to address the gap and is primarily intended for three groups of NDDOT employees:

- Planning/Project managers –who plan, design, develop and deploy ITS projects
- Project Engineers/Managers –who are responsible for overall project management
- ITS / Operations planning staff – who are responsible for overall ITS / Operations program direction and deployment

Specifically, this guide identifies what activities need to be performed at different phases of an ITS project and by whom in order to meet SE requirements. While all of the groups of users are expected to be familiar with the ITS concepts and terminology used in this guide, it is strongly suggested that they undergo additional training on the use of NDDOT's Statewide ITS Architecture and the Systems Engineering process. You can visit the most recent versions of North Dakota's ITS architectures online at: http://www.atacenter.org/regional/; while the National ITS Architecture can be found at: http://itsarch.iteris.com/itsarch/
FHWA online training for the ITS architecture and systems engineering can be found at:

https://www.pcb.its.dot.gov/t3/s070313/s070313_guide_a_int.asp

2.0 Federal Requirements for ITS Projects

The Federal requirements can be found in 23 CFR 940 (https://ops.fhwa.dot.gov/its_arch_imp/docs/20010108.pdf). These rules apply to all ITS projects funded with federal dollars, and are recommended for all ITS.
The Rule makes two main points for ITS projects using Federal funds:

1. An ITS Architecture must be developed and maintained for your region
2. A systems engineering approach must be followed for the development of the project

ITS Projects in North Dakota must refer to an ITS Architecture. Currently there are several ITS architecture and planning efforts (NDDOT statewide ITS Architecture and plan, in addition to regional architectures and plans for MPOs of Fargo/Moorhead, Grand Forks/East Grand Forks and Bismarck/Mandan) which have been developed and are actively being maintained. For the

purposes of this guide you should be aware of which architecture corresponds to your project. For the most part, projects outside the boundaries of an MPO would be found in the Statewide ITS Architecture, with supplemental information (including project prioritization) found in the NDDOT ITS Strategic Plan (http://www.ugpti.org/research/projects.php?view=244). Projects along the border of, or between two architectures, should consider both.

In addition to the development of a regional ITS Architecture, the final rule also requires the use of Systems Engineering (SE). This is a systematic approach to defining what you want your system to do, developing a plan to get there, and then as you build, checking to make sure your system meets your needs -solving problems early.

Rule 940 SE Requirements

Rule 940.11 states that the systems engineering analysis shall include at a minimum:

1. Identification of portions of the regional ITS architecture 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
7. Procedures and resources necessary for operations and management of the system

3.0 Definition of an ITS Project

An ITS project is defined as any project that provides or significantly contributes to the provision of one or more ITS user services defined in the National ITS Architecture: http://www.iteris.com/itsarch/

Rule 940 defines an ITS Project as "...any project that in whole or in part funds the acquisition of technologies or systems of technologies that provide or significantly contribute to the provision of one or more ITS user services as defined in the National ITS Architecture."

Simply put, we are talking about any ITS project, (standalone or as part of a larger project) where one transportation-related system communicates electronically as a system or with another system, (now or planned in the future).

For example: a traffic signal that communicates to a central operating center would be an ITS project. An isolated traffic signal which is not planned to be coordinated, or linked back to an operations center or other signals is not an ITS project.

The communication between the systems is what makes an ITS project. The Architecture is the framework (or plan) to guide the integration of different systems, and SE is the process we follow when developing the projects to ensure what we put in the field will be able to communicate with existing and future infrastructure.

Is it an ITS Project?

1. New office Computers for transportation employees

No –Does not directly address a specific transportation problem

2. Truck safety information.
Yes –If the data is collected electronically and transmitted to a permitting/inspection system

3. Real-time traveler information system
Yes –Information from an operations center is sent out to message boards in the field (Other examples; 511 and Internet travel information)

4. Data Management software to assist payroll
No –Does not address a transportation problem

5. Maintenance management software
Possibly –If it involves technologies to track assets, vehicle maintenance, operations…

6. Isolated traffic signal
Possibly –If there is a plan to link the signal with other signals or an operations center in the future

7. Buying new snowplow trucks
Yes –If the vehicle procurement includes communication technologies for data collection

8. Adding lanes/ widening of the Interstate
Yes –If the widening involves new ITS conduit/fiber and/or roadside equipment along the right of way

4.0 ITS Project Development Process

NDDOT is in the process of integrating the use of its statewide ITS Architecture and the systems engineering requirements into the NDDOT project development process. NDDOT's ITS project development process identifies the additional steps that ITS projects must take throughout the project lifecycle.

You can refer to the NDDOT Design Manual for the NDDOT project development process. This applies to typical projects to certify projects in R-O-W, Utilities, and PS&E. The ITS project development process is supplemental information needed to comply with federal regulations and processes.

1) Identification of ITS Projects.
An ITS project is a project that acquires technologies or systems of technologies that contribute to one or more ITS user service. A major ITS project typically includes systems that cross jurisdictional boundaries (such as municipal, state, and federal jurisdictional boundaries), is multi modal (includes different modes of transportation such as highways, airports, and ferry terminals), or that includes systems that affect the existing regional combination of ITS elements (this may include actions like combining or adding to existing elements to form a region-wide system, removing elements from systems, or breaking systems apart to form separate systems,

etc.).

Table 1 Appendix A lists ITS elements, the associated ITS program areas, and system manager. If a project is federally funded and contains any of the elements listed in Table 1, it must be developed as an ITS project. You are encouraged to develop non-federally funded projects that contain any of the elements listed in Table 1 as ITS projects also.

Contact the NDDOT ITS Engineer if any part of a project may be an ITS element (as presented in the regional ITS architecture) and it is not included in the elements listed in table 1.

Identify all ITS projects as such in the scope portion of the Categorical Exclusion by Definition, Programmatic Categorical Exclusion, or Documented Categorical Exclusion report.

2) Regional Architecture

Develop ITS projects in accordance with the regional architecture that applies at the project location. NOTE: Some projects may fall within more than one architecture (i.e. MPO, neighboring state, etc.)

3) Systems Engineering Analysis

Complete a systems engineering analysis for all ITS projects beginning in the scoping phase and two weeks prior to PS&E. The systems engineering analysis includes items one through seven listed below and are detailed by completing the Systems Engineering Checklist.

As projects are developed, they will include normal systems engineering analysis associated with each ITS program area for items two through seven.

1. Identify the ITS elements (and associated program areas) to be installed or improved as part of the proposed project and provide a brief description of the work to be accomplished to complete installation or improvement of those elements.

2. Identify roles, responsibilities, and positions of agencies that will participate in designing, purchasing, installing, operating, maintaining, expanding, or removing the system and what their responsibility will be.

3. Note: If items three through seven are not provided in the online table for an element, contact the system manager for that element and request that the system manager develop those items and provide them to the State ITS Engineer to add to the table.

4. Identify what is needed to complete each system and how each element must function within the system. This includes all items necessary to complete a fully operational system including hardware, software, installation, training, etc.

5. Evaluate alternatives that will meet systems configuration and technology requirements and determine preferred alternatives.

6. Identify and evaluate procurement options (contractor fabricate and install, purchase proprietary system and contractor install, purchase proprietary system and install with State forces, etc). Identify the preferred option.

7. Identify the applicable standards and testing procedures from the regional ITS architecture standards section that apply to the project's ITS elements.

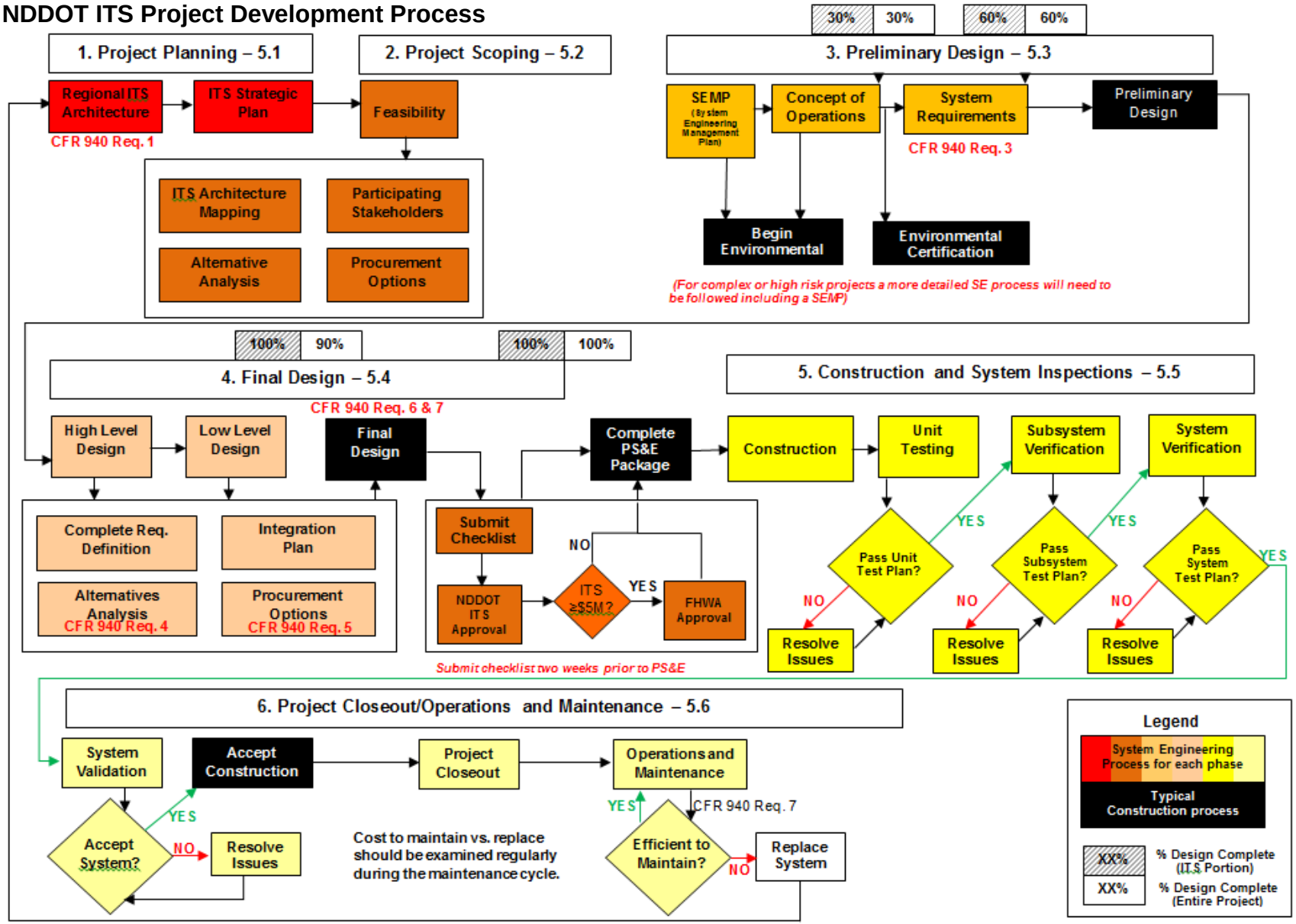
8. Identify all procedures and resources that are needed to manage, operate, and maintain the project's ITS elements.

An example system engineering analysis form (Systems Engineering Checklist), usable for both major and minor ITS projects, is provided online at:

Intranet: http://mydot.nd.gov/divdist/maintenance/its.htm or
Internet: http://www.dot.nd.gov/divisions/maintenance/its.htm

Place the completed ITS Systems Engineering Analysis in filenet once completed prior to PS&E.

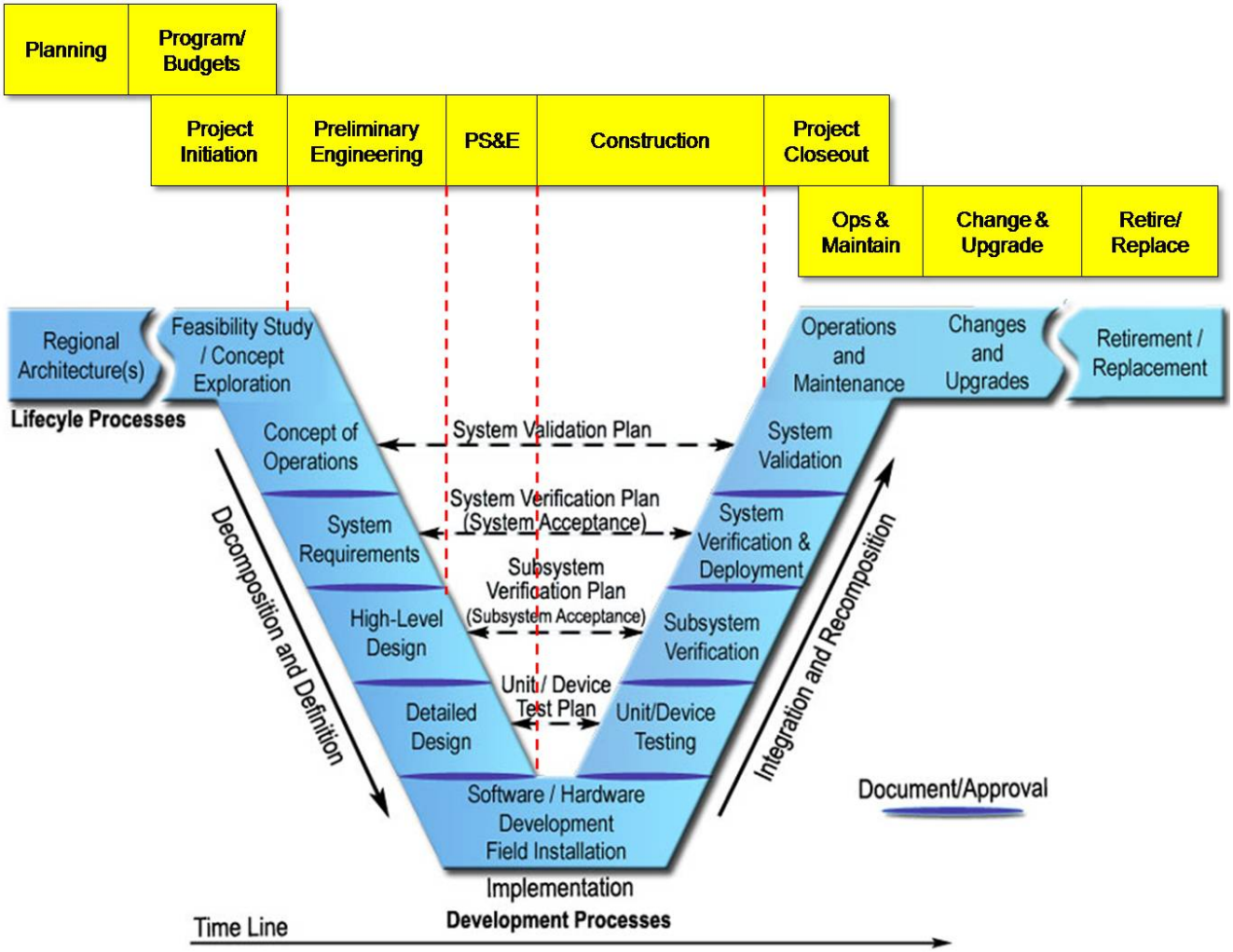
NDDOT ITS Project Development Process



Overview of the Systems Engineering V Model

The V Model (or sometimes called the V Diagram) is the recommended development model for ITS projects. In the figure below, the V Model represents the ITS project life cycle. The V Model has been used in many different industries to ensure projects are completed as designed and budgeted. The V Model has been modified slightly to show how project development fits within the broader ITS project life cycle.

The left wing shows the regional ITS architecture, feasibility studies, and concept exploration that support initial identification and scoping of an ITS project based on regional needs. A gap follows the regional architecture(s) step because the regional architecture is a broader product of the planning process that covers all ITS projects in the region. The following steps in the "V" are for a specific ITS project. The central core of the "V" shows the project definition, implementation, and verification processes. The right wing shows the operations and maintenance, changes and upgrades, and ultimate retirement of the system. The wings are a key addition to the model since it is important to consider the entire life cycle during project development.



4.1 Project Planning

The first step in the development of an ITS project is the development of an ITS Architecture. For most ITS projects you should only have to refer and utilize the ITS Architecture (not develop or modify). The NDDOT Maintenance Division, ITS section currently maintains the Statewide ITS Architecture.

ITS Architecture

The ITS Architecture is a planning document which documents the flow of information between ITS. During the development of the Architecture stakeholders met and discussed their ITS needs, and how the various ITS would be integrated together.

The NDDOT Statewide ITS Architecture was developed under a contract with Advanced Traffic Analysis Center (ATAC) of the Upper Great Plains Transportation Institute. The most current version of the North Dakota Statewide ITS Architecture, including other ITS Architectures developed for North Dakota by ATAC can be accessed at: http://www.atacenter.org/regional/

If your ITS project differs from the ITS Architecture, the Architecture will need to be updated. The ITS Section of the Maintenance Division currently has the responsibility for updating the Statewide Architecture and for tracking any changes. For requested changes to any of the North Dakota Architectures, please refer to the corresponding Architecture for current instructions and forms, Section 5.6 has general guidelines on Architecture maintenance.

ITS Strategic Plan

The ITS strategic plan is a supplemental document to the ITS Architecture which prioritizes the projects in the ITS Architecture.

The NDDOT ITS Statewide Plan can be found at:
http://www.ugpti.org/research/projects.php?view=244

4.2 Project Scoping

The next step in project development is Project Scoping (or Concept Exploration), where a project is selected from the ITS Strategic plan for implementation. In this phase, project documents are required by FHWA for ITS projects to ensure the use of Systems Engineering.

The level of complexity or risk of the ITS project, will determine the documentation required. The ITS Engineer can assist in the determination of whether the ITS project is high risk or complex. It is important to ensure these requirements are being met, not only for stand-alone ITS projects, but also for any NDDOT project which contains ITS elements to ensure large capital improvements are not delayed by ITS Systems Engineering requirements. Typically most ITS deployments utilize “off the shelf” components, and are considered low risk.

Project Initiation

For many ITS projects, much of the required systems engineering may already be done, and the lead agency/district/division may only need to point to (and utilize) existing documentation. For

ITS projects that are new, or for ITS projects that have communications-related changes to past projects, the following documentation (including documentation in the next sections) will be required for approval.

ITS Architecture Mapping
Document the portions of the ITS Architecture you are implementing. This would typically consist of output of the corresponding service packages using the regional architecture Turbo website (http://atacenter.org/regional) or Turbo Architecture© software, which describes the information flows of the system. This information should be provided in Section 3 of the SE Checklist. The service package flow diagrams are also available in Appendix A of the statewide architecture report, or in the Service Package chapter in the MPO regional architecture reports.

Participating Agencies
A list of participating agencies can be obtained from the stakeholder list from the regional architecture Turbo website. This information should be provided in Section 3 of the SE Checklist. A table of stakeholders is also available in the architecture report for the statewide and MPO regional architectures.

Alternatives Analysis
The ITS Architecture is technology independent, meaning it describes the flow of information between systems, but not the technology used to transfer the information. This document should describe the various technologies which were looked at for the project. (i.e. wireless communication vs. fiber / LED vs. Fiber Optic Signs / Digital Highway Advisory Radio vs. Analog / permanent HAR vs. portable / etc…). This information should be referenced in Section 3 of the SE Checklist.

Procurement Options
Depending on how well your ITS project is defined, there are a variety of procurement options. For some ITS projects that are well defined, low bid may work well. However for other more complex projects, particularly ones with software development, a system manager using the RFP process may be more appropriate. This information should be provided in Section 4 of the SE Checklist.

For more information on ITS Procurement, The Guide to Contracting ITS Projects and its companion web-based tool are available at: http://www.citeconsortium.org/Model/index.htm

FHWA Project Approval

If the ITS component in a project or if the ITS Project exceeds $5M, and before proceeding to preliminary design, you will need to get approval from FHWA for the ITS portions of your project. To do this you will need to fill out the *ITS Checklist*, which is attached at the end of this users guide. Not all of the requirements listed on the checklist need to be completed at this stage, however for most projects, (ITS Architecture Mapping, Participating Agencies, Alternatives Analysis, and Procurement Options) must be identified or developed, and noted in or attached to the checklist. Once this is accomplished, the checklist will be sent to FHWA for review and if approved, preliminary design may start. During the following phases,

the ITS Checklist should be updated as you complete the requirements and then submitted to the ITS Engineer for approval.

For ITS components or ITS Projects less than $5M, no FHWA approval is required, however, the ITS Checklist along with any other pertinent documentation will need to be approved by the NDDOT ITS Engineer prior to PS&E.

4.3 Preliminary Design

Concept of Operations

A Concept of Operations (ConOps) is different than the Operational Concept found in the Architecture which defines the roles and responsibilities of the stakeholders. The ConOps is the initial definition of the system. In this process, the project stakeholders reach a shared understanding of the system to be developed and how it will be operated and maintained. The Con Ops is documented to provide a foundation for more detailed analyses that will follow. It will be the basis for the system requirements that are developed in the next step.

For complex or high risk ITS projects, the completion of the Concept of Operations marks the 30% Design of the ITS project, and should coincide with the 30% Design of any non-ITS related portions of the project in order to finish the environmental process. It should be noted that the environmental process should be started well before 30% design is complete.

System Requirements

Once the environmental clearance (if needed) is obtained from FHWA, the project can move past 30% design. In this process the "stakeholder needs" identified in the ConOps are reviewed, analyzed, and transformed into verifiable requirements that define *what* the system will do but not *how* the system will do it. Working closely with stakeholders, the requirements are developed and verified.

System Requirements Document

Describe the requirements as listed above based on the needs of the stakeholders in the ConOps. For continuing deployments of ITS, this document may already be complete; show the document name and date on the Checklist. From this document, the specification is developed.

System Verification Plan

This plan describes how you will test and accept the various system(s) of the ITS project based on system requirements. The plan will be used to verify if the design and specifications are met.

The ITS portion of the project should be at 60% design, which should correspond with the 60% design of the overall project so that the preliminary design inspection can take place.

4.4 Final Design

The final design phase consists of a description of how the systems will perform the required activities on a system level, and then on a lower component level.

High Level and Low Level Design

A system design is created based on the "System Requirements" which is the high-level design that defines the overall framework for the system. Subsystems of the system are identified and decomposed further into components. Requirements are allocated to the system components, and interfaces are specified in detail. Detailed specifications are created for the hardware and software components to be developed, and final product selections are made for Commercial Off-The-Shelf (COTS) components.

High-Level Design

Define the overall structure of the ITS project; i.e. project level architecture. System level requirements are further defined and allocated/assigned to the sub-systems of the hardware, software, database, and people.

Detailed Design

The complete specification of the hardware and software, and communications components, defining how the components will be developed to meet the system requirements (detailed enough to write the software).

Integration Plans

Detail how the system will be built or put together. The components (hardware, software, database elements, firmware and/or processes) are designed by the component specialists to create specifications which will be used to procure or build the components. This is where any COTS hardware and/or software are also specified.

Verification Plans

Detail how the subsystems and individual components will be tested and accepted. (Not required for COTS unless COTS is customized/modified. However, other testing may be required for COTS to ensure compatibility for integration; i.e. NTCIP Testing.)

These designs and plans must be completed and incorporated into the final design inspection, and before the PS&E package is delivered.

5.5 Construction and Inspections

Once the PS&E package is complete, the project shall follow the normal procedures for letting and awarding of a project. Then, construction of the project will commence. Compared with traditional construction projects, ITS projects have additional steps designed to catch problems early in the construction phase. Components are tested before they are assembled into sub-systems; subsystems are tested before assembling full systems.

Unit Testing, Subsystem, and System Verification

Hardware and software solutions are created for the components identified in the system design. Part of the solution may require custom hardware and/or software development, and part may be implemented with COTS items, customized/modified as needed to meet the design specifications. The components are tested and delivered ready for integration and installation.

The software and hardware components are individually verified and then integrated to produce higher-level assemblies or subsystems. These assemblies are also individually verified before being integrated with others to produce yet larger assemblies, until the complete system has been integrated and verified. The Verification Plan developed during the Requirements/Detailed Design processes is used for verification of the system.

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

4.6 Project Closeout / O&M

It is important that the NDDOT ITS Architecture remain accurate and current as ITS projects are planned, designed and implemented. The following activities ensure that the NDDOT ITS Architecture is updated periodically.

System Validation

After the ITS system has passed system verification and is installed in the operational environment, the system owner/operator (whether the state DOT, a local agency, or another entity), runs its own set of tests to make sure that the deployed system meets the original needs identified in the Concept of Operations. System Validation must be completed and documented before you Accept Construction for the project.

Operations & Maintenance

After the initial deployment and system acceptance, the system moves into Operations & Maintenance (O & M) phase, where the system will carry out the intended operations for which it was designed. During the O & M, routine maintenance is performed as well as staff training. O & M is the longest phase (may continue for decades) of the system engineering process, extending through the evolution of the system and ends when the system is retired or replaced.

It is important that there are adequate resources to carry out the needed O & M activities; otherwise, the life of the system could be significantly shortened due to neglect. This is covered during the ConOps phase of the Systems Engineering process.

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

Appendix A: ITS Elements Table

ITS ELEMENT	ITS PROGRAM AREA	ITS SYSTEM MANAGER
Animal/Vehicle Warning System	Crash Prevention & Safety	District Traffic Manager
Archived Data Management	Information Management	CO Traffic Data Manager
	Internal Operations	
Automated Anti-Icing System	Road Weather Management	District Maintenance Coordinator/Supervisor
Automated Pedestrian Detection System	Crash Prevention & Safety	District Traffic Manager
Automated Work Zone Safety System	Crash Prevention & Safety	District Construction
	Roadway Operations & Maintenance	
Automated Vehicle Location (AVL)	Internal Operations	District Maintenance Coordinator/Supervisor CO Maintenance Operations MV Coordinator & NDHP CVO
	Road Weather Management	
	Commercial Vehicle Operations	
Bridge Scour Detection System	Internal Operations	Hydraulics Engineer (Bridge)
CCTV & Video Imaging	Freeway Management	District Traffic Manager District Maintenance Coordinator/Supervisor
	Arterial Management	
	Road Weather Management	
	Traffic Incident Management	
Crash Data Reporting	Internal Operations	CO Traffic Data Manager
Credentials Administration System	Commercial Vehicle Operations	MV Coordinator & NDHP CVO
Dynamic Message Signs	Freeway Management	CO Maintenance Operations District Traffic Manager State Traffic Manager
	Arterial Management	
	Roadway Operations & Maintenance	
	Road Weather Management	
	Traveler Information	
Electronic Screening	Commercial Vehicle Operations	MV Coordinator & NDHP CVO
Emergency/Incident Mgt. System	Traffic Incident Management	District and State Traffic Manager
Environmental Sensors	Road Weather Management	District Maintenance Coordinator/Supervisor CO Maintenance Operations
	Traveler Information	
	Internal Operations	
Freight Management System	Commercial Vehicle Operations	MV Coordinator & NDHP CVO
Fleet Management System	Internal Operations	State Fleet Coordinator CO Maintenance Operations

ITS ELEMENT	ITS PROGRAM AREA	ITS SYSTEM MANAGER
Grade Crossing Warning System	Crash Prevention & Safety	District Traffic Manager
Highway Advisory Radio (HAR)	Traveler Information	District Traffic Manager State Traffic Manager
	Freeway Management	
	Arterial Management	
Infrared Inspection System	Commercial Vehicle Operations	MV Coordinator & NDHP CVO
Intelligent Specialty Vehicle System	Road Weather Management	District Maintenance Coordinator/Supervisor
Interconnecting Traffic Signals	Crash Prevention & Safety	District Traffic Manager
Land Mobile Radio System	Internal Operations	IT & State ITD District Maintenance Coordinator/Supervisor District Construction
	Road Weather Management	
	Roadway Operations & Maintenance	
Low Power FM Radio	Traveler Information	District Traffic Manager
Maintenance Decision Support System	Internal Operations	District Maintenance Coordinator/Supervisor CO Maintenance Operations
	Road Weather Management	
Maintenance Management System	Internal Operations	CO Maintenance Operations
Major Communications Projects (DSL, Fiber, Satellite, etc.)	*Most ITS Program Areas*	State ITD Director
Onboard Safety and Security System	Commercial Vehicle Operations	MV Coordinator & NDHP CVO
Over Height Warning System	Crash Prevention & Safety	District Traffic Manager MV Coordinator & NDHP CVO
	Commercial Vehicle Operations	
Roadway Signal Priority	Crash Prevention & Safety	District Traffic Manager
Safety Information Exchange	Commercial Vehicle Operations	MV Coordinator & NDHP CVO
Signal Control System	Crash Prevention & Safety	District Traffic Manager
Signal Pre-emption System	Crash Prevention & Safety	District Traffic Manager State Traffic Manager
Temperature Data Probe	Road Weather Management	District Maintenance Coordinator/Supervisor CO Maintenance Operations
Traffic Detectors/Sensors	Crash Prevention & Safety	District Traffic Manager State Traffic Manager
	Freeway Management	
	Arterial Management	

ITS ELEMENT	ITS PROGRAM AREA	ITS SYSTEM MANAGER
Traffic Management System	Crash Prevention & Safety	District Traffic Manager
Travel Reporting System	Traveler Information	CO Maintenance Operations
Weigh In Motion	Internal Operations	CO HPMS Coordinator MV Coordinator & NDHP CVO
	Commercial Vehicle Operations	