Intelligent Transportation Systems and Systems Engineering Process Document

Nebraska Department of Roads
Operations Division, ITS Section

Federal Highway Administration
Nebraska Division

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I. Introduction

A. Purpose: The purpose of this process document is to set forth Nebraska Department of Roads (NDOR) policies and procedures for the development and deployment of Intelligent Transportation Systems (ITS) projects in Nebraska. It also provides guidelines on how the ITS program should interface with Federal ITS regulations, the Federal-aid Highway Safety Improvement Program (HSIP) and the National Environmental Policy Act (NEPA) and other environmental regulations. Additionally, the goal is to present it in a manner that is easily understood by NDOR, local public agency (LPA), and Federal Highway Administration, Nebraska Division (FHWA) personnel.

B. Regulatory Basis: Because much of the department's ITS program is funded by Federal-aid Highway program funds, it is based on regulations contained in 23 Code of Federal Regulations (CFR) 940 - ITS.

C. Definitions: Some key definitions from 23 CFR 940 include:

1. *ITS* means electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system.

2. *ITS project* means 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.

3. *National ITS Architecture* means a common framework for ITS interoperability. The National ITS Architecture comprises the logical architecture and physical architecture which satisfy a defined set of user services.

4. *Regional ITS Architecture* means a regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects or groups of projects.

5. *Systems Engineering* is a structured process for arriving at a final design of a system. The final design is selected from a number of alternatives that would accomplish the same objectives and considers the total life-cycle of the system including not only the technical merits of potential solutions but also the costs and relative value of alternatives.

II. ITS Strategic Plan for Statewide Deployments

The ITS Strategic Plan provides a planning-level roadmap for ITS device deployments statewide. It also incorporates by reference the statewide and regional ITS architectures. Additionally, important input was derived from the "NDOR Vision 2032 Long-Range Transportation Plan" goals and objectives, "NDOR Strategic Plan" vision, and "Moving

Ahead for Progress in the 21st Century" (MAP-21) National performance goals. The goals of developing the ITS Strategic Plan are to:

1. Collaborate with stakeholders to establish a vision for ITS deployment throughout NDOR's transportation system.

2. Identify current issues, needs, and objectives that the NDOR should consider in its continued development of the system.

3. Develop a list of currently available ITS applications that could potentially address the identified issues and needs.

4. Use a screening process to identify and prioritize ITS applications appropriate for implementation for the NDOR.

5. Develop an implementation plan to prioritize the allocation of funds for deploying ITS applications statewide.

The planning horizon for the ITS Strategic Plan is ten years and the horizon for the ITS architecture is five years.

III. ITS Architecture

A. FHWA Regulatory Policy: In accordance with 23 CFR 940.5 Policy, ITS projects funded in whole or in part from the highway trust fund shall conform to the National ITS Architecture and applicable standards. Furthermore, in accordance with 23 CFR 940.9 Regional ITS Architecture, a regional ITS architecture shall be on a scale commensurate with the scope of ITS investment in the region.

B. Nebraska ITS Architectures: In addition to the Statewide ITS architecture, Nebraska presently has two regional ITS architectures for the Metropolitan Area Planning Agency (MAPA) and Lincoln Metropolitan Planning Organization (MPO). A regional ITS architecture is also in effect for the Siouxland Interstate Metropolitan Planning Council (SIMPCO) MPO, which includes a portion of Northeast Nebraska and is under the jurisdiction of the State of Iowa.

The Nebraska Statewide and regional ITS architectures were prepared using the Turbo Architecture tool. Turbo Architecture is a high-level, interactive software program to aid in the development of ITS architectures using the National ITS Architecture. The tool is intended to maximize ITS integration opportunities, to facilitate the efficient expansion of ITS, and to reduce the costs and time associated with the preparation and maintenance of ITS architectures.

Key service areas of the Statewide ITS architecture include:

1. Traffic management;

2. Traveler information;
3. Incident management;
4. Maintenance and construction management;
5. Archived data management; and
6. Emergency management.

C. Use and Maintenance of ITS Architectures: The NDOR Operations Division, ITS Section is responsible for the use and maintenance of the Statewide ITS architecture. As the framework for ITS interoperability, the ITS architecture is one of the minimum requirements of the systems engineering analysis process. In conjunction with the systems engineering analysis, the ITS architecture will be referenced and changes to the ITS architecture will be noted for future updates. The policy of NDOR is to update the ITS architecture on an as-needed basis at a minimum of every five years. This can be triggered by a major change or after several smaller changes have been collected. One such major change might be the updating of the Nebraska ITS Strategic Plan.

IV. ITS Project Implementation

A. Project Scoping and Approval: As is the case for all Federal and State-funded highway projects, it is very important that any ITS elements be included in the initial project scoping.
For any ITS devices to be included in projects, they must reflect priorities in the ITS Strategic Plan and be approved by the NDOR ITS Policy and Program Team. This team is chaired by the NDOR Deputy Director – Operations and includes representatives from the NDOR Operations, Traffic Engineering, Business Technology Support, Program Management, , and a District Engineer. An FHWA, Nebraska Division representative also attends the meetings to observe and to address any Federal-aid Highway Program issues on the agenda.

B. Highway Safety Improvement Program (HSIP) Funded ITS Projects: Many ITS countermeasures have safety benefits (e.g., anti-icing system, adaptive signal control technology, etc.). If an ITS project is to be funded by HSIP funds, it must address at least one of the critical emphasis areas (CEAs) of the Nebraska Strategic Highway Safety Plan (SHSP). The CEAs in the current SHSP include:

1. Increasing Safety Belt Usage;
2. Keeping Vehicles on the Roadway, Minimizing the Consequences of Leaving the Road, and Reducing Head-On and Across-Median Crashes;
3. Reducing Alcohol-Impaired Driving;
4. Improving the Design and Operation of Highway Intersections; and
5. Addressing the Over-Involvement of Young Drivers.

In developing such a project, the project justification must be crash data-driven and show the ITS devices to be safety beneficial. The project must also be approved by one of the NDOR Safety Committees.

Although many alternatives may be considered during Safety Committee discussion, the committee will generally recommend a single countermeasure with which to proceed as a project. However, the final selected alternative will be determined during the environmental review process. In this regard, the Safety Committees will rely on the Environmental Section of the Project Development and Planning Division to guide a proposed project through the environmental process and to ensure that the project complies with the National Environmental Policy Act (NEPA) and other environmental regulations (e.g., Endangered Species Act, Section 106, Clean Water Act, etc.). This also applies to non-safety funded ITS projects.

Proposed alternatives may be simple or comprehensive, incorporating several types of improvements into one project. The ITS Section may also be asked to prepare a cost estimate for the selected improvements and to work with the Highway Safety/Accident Records Section on a benefit-cost study.

C. Project Programming: After a project is approved by the ITS Policy and Program Team, and a Safety Committee if safety funds are involved, a Highway Improvement Programming Request (DR-73 for State and DR-530 for local projects) is prepared and signed by the appropriate official.

The project would then be placed into the NDOR pre-construction project scheduling system which is in the Clarity software. This complex, computerized system monitors the progress of all projects planned by the department. All work tasks necessary for the completion of the project are defined, any interdependencies between tasks are established, and a critical path is determined for project completion. Using the critical path network, time estimates for each activity, and the proposed completion date for the project, the system computes work schedules. Reports on work accomplishment are received from activity managers so that the progress of the project can be monitored. The time needed to complete a project varies with the complexity of the project.

D. Project Prioritization: The ITS projects must also be included on the Statewide Transportation Improvement Program (STIP) and Transportation Improvement Programs (TIPs). According to 23 CFR 450.104, "*STIP* is a statewide prioritized listing/program of transportation projects covering a period of four years that is consistent with the long-range statewide transportation plan, metropolitan transportation plans, and TIPs, and required for projects to be eligible for funding under title 23 U.S.C. and title 49 U.S.C. Chapter 53." Additionally, this section of the CFR defines a TIP as "a prioritized listing/program of transportation projects covering a period of four years that is developed and formally adopted by an MPO as part of the metropolitan transportation planning process, and required for projects to be eligible for funding under title 23 U.S.C. and title 49 U.S.C. Chapter 53."

To meet the planning requirements, the major or regionally significant safety and ITS projects, as defined in 23 CFR 450.104, are listed separately on the STIP and applicable TIPs. Listings of minor or non-regionally significant safety and ITS projects, respectively, are included in the safety and ITS group listings in the STIP. Minor safety

and ITS projects in the metropolitan planning areas are listed separately on the TIPs and referenced in the STIP.

E. FHWA Project Oversight: FHWA oversight of Federal-aid Highway Program projects is governed by a Stewardship and Oversight Agreement between NDOR and FHWA, Nebraska Division. In this regard, FHWA designates Projects of Division Interest (PoDI), formerly known as full-oversight. These are projects that have an elevated risk, contain elements of higher risk, or present meaningful opportunity for FHWA involvement to enhance meeting program or project objectives. Because of the degree of FHWA efforts expended on systems engineering on some ITS projects, FHWA may designate a certain level of involvement to monitor the implementation of the systems engineering.

V. Systems Engineering Analysis

A. FHWA Regulatory Policy: As defined in 23 CFR 940.3, "Systems engineering is a structured process for arriving at a final design of a system. The final design is selected from a number of alternatives that would accomplish the same objectives and considers the total life-cycle of the project including not only the technical merits of potential solutions but also the costs and relative value of alternatives."

In accordance with 23 CFR 940.11 Project Implementation, "All ITS projects funded with highway trust funds shall be based on a systems engineering analysis." Furthermore, "The analysis should be on a scale commensurate with the project scope." At a minimum, the systems engineering analysis shall include:

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

B. Systems Engineering Resources: There are two systems engineering resources that are referenced in this process document. One is the "Systems Engineering Guidebook" at http://www.fhwa.dot.gov/cadiv/segb/, which is co-sponsored by the FHWA, California Division and the California Department of Transportation. The other is the FHWA publication, "Systems Engineering for ITS – An Introduction for Transportation Professionals" at http://ops.fhwa.dot.gov/publications/seitsguide/.

C. Systems Engineering Purpose: The purpose of systems engineering is to reduce project risks. Technology projects in particular have had a high rate of failure. To illustrate, data

from the "Extreme Chaos" study (The Standish Group International, Inc., 2000) show the following statistics for such projects:

- Average cost overruns of 45%;
- Average time overruns of 63%; and
- Average functionality delivered of 67%.

In contrast to these statistics, systems engineering practices have been shown to improve the success rate of technology projects. More specifically, the implementation of systems engineering on ITS projects or projects with ITS elements provides the following primary benefits:

- Reduced risk of schedule and cost overruns;
- Increased likelihood the project will meet user functional needs; and
- Reduced risk of vendor selection liability.

D. Systems Engineering Basics: As stated in the "Systems Engineering Guidebook," systems engineering "focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design..." In other words, first define *what* needs to be done and then determine *how* it is to be done.

The systems engineering process is usually depicted through the use of one or more versions of the V Diagram. Figure 1 shows how the systems engineering process correlates with the traditional design process.

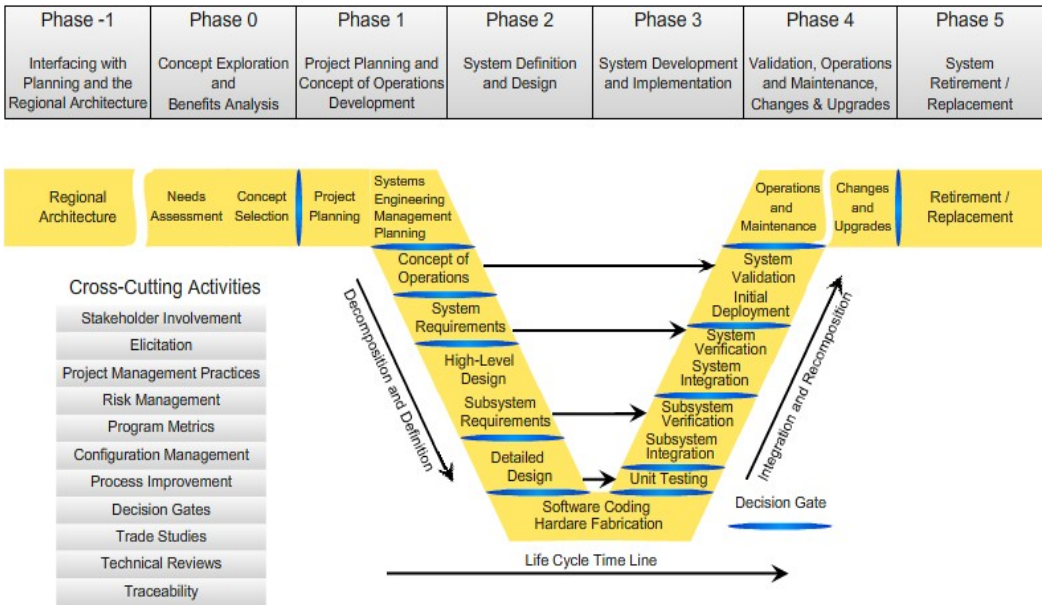

Figure 1 – Systems Engineering V Diagram
(Source: Systems Engineering Guidebook)

For ease of understanding, Figure 2 shows a simplified version of the V Diagram.

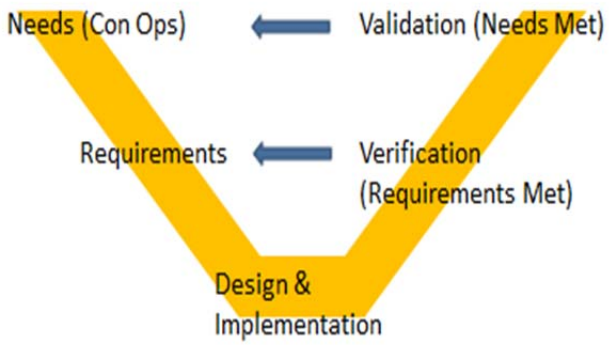

Figure 2 – Simplified V Diagram

As illustrated by the left side of the V diagram, it is very important that any ITS devices be included in the initial scoping of the project. The needs and requirements should be determined prior to the design phase at the bottom of the V. After the design is completed and the project is implemented, a verification process ensures that the project requirements are met and validation demonstrates that the agencies operational needs are met. This is illustrated by the right side of the V diagram.

E. Project Scope and Risk: As stated in 23 CFR 940.11, the systems engineering analysis should be on a scale commensurate with the project scope. If only one ITS device is to be installed as part of a large roadway reconstruction project, for example, the level of systems engineering required would likely be very limited. In cases where an agency has experience with a particular ITS device and there is little uncertainty in the cost, schedule and implementation, a reduced level of systems engineering might only be necessary. Even in situations where there is broad experience with a technology, however, recent advances in the technology could merit a full systems engineering analysis. The degree of risk and the level of systems engineering to be performed on a specific project will be determined through consultation between NDOR and FHWA.

F. Systems Engineering Deliverables: For the purpose of consistency, NDOR requires four systems engineering deliverables for ITS projects. The documents are considered living and could be updated/revisited throughout the evaluation even after approval. These include:

1. Project Plan: The project plan is a relatively brief document that lays out the associated tasks that need to be performed to accomplish the project. It typically includes the project purpose, goals, task descriptions, budget, resources and schedule.

2. Systems Engineering Management Plan (SEMP): The SEMP is an extension of the project plan that focuses on the technical tasks in more detail and manages the overall systems engineering. It identifies what items are to be developed,

delivered, integrated, installed, verified and supported. Also, when these tasks will be done, who will do them, and how the ITS infrastructure, devices or software will be procured.

3. Concept of Operations Plan: The concept of operations is the stakeholder view of the operation of the system, including roles and responsibilities, needs assessment, and operational scenarios. It presents the functional needs from the perspective of the stakeholders instead of the product vendors.

   There are two standard outlines for the concept of operations. These include the following (Source: Systems Engineering Guidebook):

ANSI/AIAA-G-043 Outline	IEEE 1362 Outline
1. Scope	1. Scope
2. Referenced Documents	2. Referenced Documents
3. User-Oriented Operational Description	3. The Current System or Situation
4. Operational Needs	4. Justification for and Nature of Changes
5. System Overview	5. Concepts for the Proposed System
6. Operational Environment	6. Operational Scenarios
7. Support Environment	7. Summary of Impacts
8. Operational Scenarios	8. Analysis of the Proposed System

   While these outlines are only to be used as guides and are subject to change, the ANSI outline is intended for new systems and the IEEE outline is intended for system upgrades.

4. Requirements and Verification Plan: This document determines the requirements for the system and sub-systems. The requirements must be complete, tie back to the needs in the concept of operations, and be verifiable. Requirements should drive specifications included in contract documents for ITS deployment. The verification plan should be represented in deployments as a part of system acceptance.

G. Model Systems Engineering Documents: The NDOR Safety Committees have funded several Adaptive Signal Control Technology (ASCT) projects. In an effort to facilitate the implementation of this technology, the FHWA developed "Model Systems Engineering Documents for ASCT," FHWA-HOP-11-027, August 2012. This publication is available at http://ops.fhwa.dot.gov/publications/fhwahop11027/index.htm.

   The Model Documents are intended to provide guidance in developing systems engineering documents covering the evaluation, selection and implementation of ASCT systems. According to the Executive Summary, "These documents will assist agencies to apply the systems engineering process in a manner that is commensurate with the scale of the project, in order to substantially reduce the level of effort and address many of the risks associated with procurement of ASCT. The process will also help an agency confirm that its expectations are realistic and achievable before committing to a system."

Nebraska ASCT projects that use Federal-aid Highway Program funds will use the Model Documents to meet the systems engineering requirements.

VI. ITS Procurement Procedures

A. Best Value Procurement Supported by Systems Engineering Analysis: Because ITS projects have many complexities and uncertainties, the traditional low-bid process can in some cases be inappropriate for such projects. An example is a complex software system such as ASCT. As stated in the Model Documents for ASCT, "The requirement for competitive procurement is satisfied through an RFP or similar process that allows for careful evaluation of the extent to which each requirement is met and the suitability of the method used to satisfy the requirement. The evaluation process may also include consideration of costs to determine best value for money." In any case, the procurement approaches should be considered during the systems engineering analysis through the SEMP document. The systems engineering documentation will provide the justification for the selected procurement method.

One alternative form of procurement is design-build contracting. ITS projects can be considered a form of design-build for determining best value. The aim of this approach is to facilitate meeting schedule, cost and quality goals. Based on current Nebraska statutes, NDOR has determined that State agencies are prohibited from using the design-build approach on projects. However, this prohibition has been determined not to apply to local public agencies. Federal regulations on design-build may be found at 23 CFR 636 – Design-Build Contracting.

B. Low-Bid Procurement: When it is feasible and necessary to use a low-bid contracting approach, it is important that the systems engineering requirements and verification plan components are included as part of the contract special provisions. Submittals of ITS devices should be required at an early stage of the contract to demonstrate compliance with the requirements. Furthermore, the verification plan should include an acceptance test plan.

A variation of the low-bid contracting approach is to select the ITS device using an RFP process for purchasing the devices through a State contract administered by the Nebraska Department of Administrative Services. The installation of the devices would be done through a low-bid contract. NDOR has used this approach with dynamic message signs.

C. Sole Source Procurement: Federal-aid Highway Program funds shall not participate in the cost of any project except as allowed in 23 CFR 635.411 – Material or product selection. Generally it is desirable for a minimum of three options to be provided for competitive bidding. If this is not feasible, 23 CFR 635.411(a) provides the following exceptions for patented or proprietary material:

1. Such patented or proprietary item is purchased or obtained through competitive bidding with equally suitable unpatented items;

2. The State transportation department certifies either that such patented or proprietary item is essential for synchronization with existing highway facilities, or that no equally suitable alternate exists; or
3. Such patented or proprietary item is used for research or for a distinctive type of construction on relatively shorts sections of road for experimental purposes.

For projects with ITS elements, any sole sourcing of patented or proprietary ITS software or devices must be justified and documented through a systems engineering analysis. The analysis should determine the functional needs, evaluate various alternatives to meet the needs, assess the compatibility of software and devices from different manufacturers, and verify vendor claims. From a long-term perspective, the replacement of existing devices that reach the end of their useful life should also be considered.

Requests for sole sourcing are processed using a public interest finding (PIF) letter. PIF letters require approval by the NDOR Director's Office and the FHWA, Nebraska Division. Due to innovations in technology, new PIF requests for the same software or devices need to be reanalyzed on at least a yearly basis.

D. Value Engineering: Following procurement, some large projects containing ITS elements are subject to value engineering (VE). It should be cautioned that ITS is not entirely cost-driven, is based on a systems engineering analysis, and thus should be exempted from VE. It should be noted that ITS software and devices also have long-term operational and safety impacts that are not considered in VE analyses.

VII. Evaluation

Evaluations of the effectiveness of completed ITS projects are very important toward improving the ability of the agencies to make future decisions. For some complex projects, this might involve validating that the intended need of the system is being met after it has been in operation for a period of time. For HSIP-funded project, a crash data-based evaluation will be conducted if such data is available. Three years before-and-after study periods are normally chosen for safety project evaluations. As with the project development process, benefit-cost analysis is used for economic analysis.