# Colorado ITS Systems Engineering Analysis Guidelines

## Revision History

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<tr>
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<td>• Removed inconsistencies both within this document and between this document, the project sheet and the sample templates.</td>
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<td>• Updated references to current version of Turbo Architecture.</td>
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<td>• Revised the project documentation requirements for Medium and High Risk projects.</td>
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<td>• Updated the method for maintaining the Regional Architecture in Turbo Architecture.</td>
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1.0 INTRODUCTION

Intelligent Transportation Systems (ITS), which is defined by 23 CFR 940.3 as ITS means electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system has brought about a new concept within the area of deployment as it pertains to transportation infrastructure. Unlike traditional road and bridge construction, which can be replicated many times using common specifications and standardized plans, ITS is an amalgamation of diverse electronic, telecommunications, network systems, and computer hardware—and software—that may vary widely from location to location.

To ensure the optimal design and implementation of ITS, a different approach is needed than that used for highway infrastructure deployment. The approach used is that of Systems Engineering (SE). SE as defined by 23 CFR 940.3 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 other words to simplify it, SE is “an approach to building systems that enhances the quality of the end result.”

This “Systems Engineering Analysis Guidelines” identifies the applicability of using the SE Process to promote successful implementation of ITS projects, and to develop necessary project related information in accordance with Federal Rules. The SE Process will also help to ensure project traceability from requirements, through implementation, to operations and maintenance.

2.0 PURPOSE AND APPLICATION

The purpose of these Guidelines is to describe the CDOT Systems Engineering Analysis (SEA) in a step-by-step roadmap that allows the user to understand how the SEA interfaces with the Regional ITS Architecture and how to use Turbo Architecture to obtain ITS project information that is required within the SEA. This will also ensure that CDOT is compliant with 23 CFR 940.11, which states:

All ITS projects funded with highway trust funds shall be based on a systems engineering analysis, the analysis should be on a scale commensurate with the project scope, and the systems engineering analysis shall include, at a minimum:

- Identification of portions of the regional ITS architecture being implemented (or if a regional ITS architecture does not exist, the applicable portions of the National ITS Architecture);
- Identification of participating agencies roles and responsibilities;
- Requirements definitions;
• Analysis of alternative system configurations and technology options to meet requirements;
• Procurement options;
• Identification of applicable ITS standards and testing procedures; and
• Procedures and resources necessary for operations and management of the system.

3.0 OVERVIEW OF ITS PLANNING DOCUMENTS IN COLORADO

This Section identifies and provides a brief description of the ITS planning documents that are both helpful and necessary to complete the SEA process.

Statewide ITS Strategic Plan - The Colorado Department of Transportation (CDOT) has done considerable work planning, implementing and operating ITS in Colorado beginning with the Colorado Incident Management Coalition, the Denver Early Deployment Study, the Model Deployment Initiative, and the Colorado Transportation Management System. In 2002, the CDOT ITS Branch, in consultation with the ITS Steering Group, developed an ITS Strategic Plan setting forth the vision and strategic goals for ITS investments statewide, describing organizational roles and responsibilities, and establishing strategies and implementation actions to achieve the CDOT goals for ITS investment. This plan also incorporated performance measures metrics as part of investment decisions for ITS.

National ITS Architecture - Developed by the U.S. DOT, the National ITS Architecture is a common framework for planning, defining, and integrating intelligent transportation systems. User services are the part of the National ITS Architecture that document what ITS should do from the user’s perspective. A broad range of users are considered, including the traveling public as well as many different types of system operators. New or updated user services have been, and will continue to be addressed, by the National ITS Architecture over time. An ITS architecture is a framework within which a system (or project) can be built.

Regional ITS Architectures - CDOT used the National ITS Architecture as a basis to develop the Regional ITS Architectures. The Architectures are required by 23 CFR 940.9 as a condition of receiving and using federal funds on ITS applications. The Architecture establishes a framework to facilitate regional deployment of ITS projects and ensure institutional agreement and technical integration for the implementation of ITS projects as identified in the ITS strategic plan. The Architecture provides a formalized description of all the elements of a fully functioning intelligent transportation system, including which entities are responsible for the individual elements and how those entities and elements interface with each other. The Architecture defines what the pieces of the system are and the information that is exchanged between them. The Architecture is functionally and logically oriented and not technology-specific, which
allows the architecture to remain effective over time. It defines “what must be done,” not “how it will be done”. FHWA requires that the “region” address specific elements within the Architecture that foster integration between existing systems and ensure that subsequent systems will be integrated into existing systems.

CDOT ITS Branch also worked with the CDOT Regions and other stakeholders to develop the following Regional ITS Architectures and Regional ITS Strategic Plans.

- ITS Architecture and ITS Strategic Plan for the Denver Regional Area (Region 6). November and December 2007. [Maintainer: DRCOG]

Regional ITS Strategic Plans - Although the strategic plan it not required by Federal Rule, it is a valuable road map for implementing a system of strategies over a period of time. It provides a regional policy framework and presents an unconstrained regional vision for investment in ITS applications in the region. It also provides a starting point for bringing ITS projects and systems together into an integrated plan, and identifying transportation related needs that can be addressed by ITS applications within the context of a systematic approach. Both the Statewide ITS Strategic Plan and the Regional ITS Strategic Plans have been collaborative efforts involving CDOT, other federal, state, and local agencies, along with other stakeholders to develop a framework for deploying ITS. This framework addresses the institutional and operational elements required for effective, integral statewide and regional transportation systems. The strategic plan identifies a package of ITS applications to be implemented and integrated over time. It also addresses specific transportation goals and needs in coordination with regional and statewide planning activities. This strategic plan will be the framework to assure that all the pieces will ultimately fit together, not only with each other, but also with other potential transportation improvements.

Turbo Architecture – In conjunction with each Regional ITS Architecture a database has been created using Turbo Architecture version 5.0. Turbo Architecture is a software tool that allows users to catalogue and organize project and/or regional architectures in a database format. The software also provides users with enhanced functionality in working with architecture stakeholders, elements, market packages, operational concepts, functional requirements, interfaces, standards and agreements. The software defines the architecture, relationships and interconnects
between stakeholders and elements and gives the user the ability to access physical and logical diagrams at multiple levels. Use of the software will facilitate FHWA Systems Engineering Analysis (SEA) project requirements, consistency, version control, maintenance and subsequent updating of the Regional ITS Architecture.

### 4.0 FEDERAL REQUIREMENTS FOR ITS PROJECTS

As stated in Section 2.0, systems engineering is not just a set of tools, but is a process that occurs throughout the project lifecycle. Typical steps in the systems engineering approach range from conception, requirements analysis, design, testing, acceptance, and operations and maintenance. While the use of the architecture and the SEA is mandatory for federally funded projects, project developers are encouraged to use this approach for any ITS project using state or local funds, especially for projects that integrate with other systems in the region. The rule requirements are applicable for all ITS projects funded with Highway Trust Funds. Thus, conformity with the rule requirements is required for both routine and non-routine projects. However, with routine projects, the effort and the scope of systems engineering analysis should be minimal. For non-routine projects, the scale of the systems engineering analysis depends on the scope of the project.

Also, 23 CFR 940.11 states: Upon completion of the regional ITS architecture, the final design of all ITS projects funded with highway trust funds shall accommodate the interface requirements and information exchanges as specified in the regional ITS architecture. If the final design of the ITS project is inconsistent with the regional ITS architecture, then the regional ITS architecture shall be updated as provided in the process defined in 940.9(f) to reflect the changes. The regional ITS architecture is a specific application of the framework specified in the National ITS Architecture, tailored to the needs of the transportation stakeholders in the region. Compliance with the rule needs to be demonstrated prior to authorization of Highway Trust Funds for construction or implementation of ITS projects.

### 4.1 DEFINITION OF AN ITS PROJECT

As stated in 23 CFR 940.3, an ITS project is defined 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.”

A “Major ITS project” is defined as:

“… any ITS project that implements part of a regional ITS initiative that is multi-jurisdictional, multi-modal, or otherwise affects regional integration of ITS systems.”

Given the broad definition of ITS projects and the wide range of transportation technology projects covered under National ITS Architecture User Services, many, if not
most, transportation technology projects are considered ITS projects. The scope of a project determines whether a project can be termed an ITS project or not. Generally, a project can be classified as an ITS project if it:

- addresses a user service in the National ITS Architecture; and,
- uses technology to solve the transportation problem.

With ITS applications becoming a common part of traffic operations, it is important to distinguish between routine projects and non-routine projects from an ITS planning standpoint in order to invest the appropriate level of effort in the systems engineering analysis.

Routine projects are typically replacement or maintenance projects or the expansion of existing systems which involve little to no interaction with other external agencies. Examples of such projects could be camera or DMS replacement, expansion of system equipment along a corridor, installation of sensors, traffic signal optimization, etc. For such projects, CDOT’s project managers are familiar with the requirements, the design, and the implementation strategy and can follow a simplified systems engineering analysis.

Non-routine projects, on the other hand, typically involve integration and expansion type projects with several external agencies and stakeholders. For such projects, development of a concept of operations, requirements identification, detailed design, and implementation are often major tasks. Many times, these projects also have regional implications requiring collaboration across multiple jurisdictions and agencies. For these projects, systems engineering analysis is a vital and resource-intensive activity that should occur throughout the project lifecycle in order for the project to succeed. Examples of such projects include new software for advanced traffic management systems, Computer Aided Dispatch (CAD) integration, archived data management systems, etc.

### 4.2 OVERVIEW OF SYSTEMS ENGINEERING

These Guidelines are not intended to be a textbook on the SE process. Systems engineering has been developed over the last 20 to 30 years to the point that many of the processes have been standardized. The predominant standards development organization (SDO) for Systems Engineering is the Institute of Electrical and Electronics Engineers (IEEE). In order to provide guidance in the application of these SE standards and process to the planning and implementation of ITS projects, FHWA has prepared *Systems Engineering for Intelligent Transportation Systems* and maintains a website ([http://wwwcf.fhwa.dot.gov/cadiv/segb/index.htm](http://wwwcf.fhwa.dot.gov/cadiv/segb/index.htm)) providing descriptions and examples for each step of the process.

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The basic steps in the Systems Engineering process are the following:

1. Concept of Operations,
2. High-Level Requirements,
3. Detailed Requirements,
4. High-Level Design,
5. Detailed Design,
6. Implementation/Construction,
7. Integration,
8. Verification/Validation, and

The SE process may be depicted graphically with the steps in the process laid out in the shape of a “V.” The basic “V” diagram is shown in Figure 1 and represents the SE steps for a typical project laid out over time. The left, or downward sloping, side of the “V” describes the process of decomposing the Concept of Operations and high level requirements into more detailed requirements leading to design specifications. The bottom of the “V” represents the implementation or construction phase of the project. The right, or upward sloping, side of the “V” represents the integration, testing and verification phase of the project. The commissioning and/or operation of the project is the final phase and should validate that the project meets the objectives stated in the Concept of Operations.
As stated in Section 2.0, 23 CFR 940.11 requires that ITS projects receiving federal funding must undertake and document the following activities that relate to the Systems Engineering Process:

- Identify the portion of the Regional ITS Architecture being implemented;
- Identification of participating agencies (stakeholders);
- Definition of requirements;
- Analysis of alternatives;
- Procurement options;
- Standards and testing procedures; and,
- Resources for operations and maintenance.

23 CFR 940 covers several additional aspects of the ITS project development process, including requirements for Regional- and Project-level ITS architecture. For most ITS projects, compliance with 23 CFR 940 will be all but assured if the SE process is followed. Figure 2 relates the systems engineering process “V” with the activities listed in 23 CFR 940.

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**Figure 1: The Systems Engineering Process**

4.3 SYSTEMS ENGINEERING RELATIONSHIP TO SEA

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- Identification of participating agencies (stakeholders);
- Definition of requirements;
- Analysis of alternatives;
- Procurement options;
- Standards and testing procedures; and,
- Resources for operations and maintenance.

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- Regional ITS Architecture
- Participating agencies
- Procurement options

- Requirements definition

- Alternatives analysis

- Standards and testing *
- Operations and maintenance *

* Initial planning for these activities occurs during Concept of Operations

Figure 2: Mapping of 23 CFR 940 to the SE Process
5.0 PROJECT INITIATION AND IMPLEMENTATION

The following is a description of the CDOT Systems Engineering Analysis process:

1. Complete *CDOT Systems Engineering Project Sheet* and *CDOT ITS Project Risk Assessment Form*

2. Based on the assessed risk level, submit the following items to CDOT or the MPO responsible for maintaining the applicable Regional ITS Architecture:

| Low          | • Completed CDOT Systems Engineering Project Sheet¹  
|             | • Completed CDOT ITS Project Risk Assessment Form¹ |
| Medium       | • Completed CDOT Systems Engineering Project Sheet¹  
|             | • Completed CDOT ITS Project Risk Assessment Form¹  
|             | • Concept of Operations¹  
|             | • Project Turbo Architecture File²  
|             | • Detailed Design³ (if applicable) |
| High         | • Completed CDOT Systems Engineering Project Sheet¹  
|             | • Completed CDOT ITS Project Risk Assessment Form¹  
|             | • Concept of Operations¹  
|             | • Project Plan¹  
|             | • Project Turbo Architecture File²  
|             | • System Functional Requirements³  
|             | • Detailed Design³  
|             | • Testing and Evaluation Plan³  
|             | • Operations & Maintenance Plan³  |

¹ These documents MUST be complete and logged before the FHWA will authorize any federal funds.
² The Project Turbo Architecture File will be compiled by the Architecture Maintainer using the latest version of Turbo Architecture based on the information provided by the sponsor.
³ These documents are prepared as part of the project development and submitted for the project record.

3. CDOT or the MPO responsible for maintaining the applicable Regional ITS Architecture will confirm and log the initial submittal. The documentation will allow FHWA to authorize any federal funds during the development and execution of a funding IGA.

4. Upon FHWA approval, allocation of funding, and execution of a funding IGA, continue with project development, submitting supplemental documents to CDOT
or the MPO responsible for maintaining the applicable Regional ITS Architecture as per the Project Plan (High risk projects only).

5. Project implementation.

6. Project testing and evaluation.

7. Once the project is complete, submit the Project Summary Documents to CDOT or the MPO responsible for maintaining the applicable Regional ITS Architecture. Depending on the assessed risk level, submit the following summary documentation:

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<th>Risk Level</th>
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| Low        | • Confirmation e-mail confirming successful project completion and testing.  
• Completed benefits assessment. |
| Medium     | • Revised Concept of Operations (if applicable)  
• System Functional Requirements  
• Testing and Evaluation Plan  
• Operations & Maintenance Plan (copies of any applicable IGAs/MOUs may substitute)  
• Lessons learned |
| High       | • Revised Concept of Operations (if applicable)  
• Revised System Functional Requirements (if applicable)  
• Testing and Evaluation Plan  
• Revised Operations & Maintenance Plan (including copies of IGAs/MOUs, if applicable)  
• Lessons learned |

The Testing and Evaluation Plan will document both the completed testing results and the assessment of the relevant project benefits.

5.1 CDOT SYSTEMS ENGINEERING PROJECT SHEET AND RISK ASSESSMENT FORM

It will be helpful to complete the Risk Assessment Form first. Complete all sections of the checklist. The instructions are contained on the checklist itself.

Both the checklist and the assessment form must be complete and submitted before FHWA will authorize a federally-funded ITS project.

5.2 CONCEPT OF OPERATIONS

The purpose of the Concept of Operations is a key document that describes the intended system development and operations. This includes a scope of the project, a description of the system procedures and operations under different conditions as well as a description of the project stakeholders’ roles and responsibilities. The Concept of Operations also
provides a preliminary description of the intended operations and maintenance plan and the intended testing and evaluation plan.

A sample Concept of Operations template has been adapted from FHWA Systems Engineering Guidebook website as a suggested format for use. This template will assist in the preparation of a concept of operations that is commensurate with the size of the project.

5.3 PROJECT PLAN

The purpose of the Project Plan is to introduce and describe the project. This will include the project purpose, tasks, expected results and schedule. A sample Project Plan template has been adapted from FHWA Systems Engineering Guidebook website as a suggested format for use.

For project sponsors of High risk projects, this template will assist in the preparation of a project plan that is commensurate with the size of the project.

5.4 USING TURBO ARCHITECTURE TO OBTAIN SEA INFORMATION

The purpose of the Regional ITS Architecture is to define a technical and institutional framework of the implementation and integration of transportation technology projects that meet the regional transportation needs.

The Regional ITS Architectures in Colorado are defined with the current version of the Turbo Architecture software,, which is an interactive software application that can assist planners and system integrators in the maintenance and definition of both regional ITS architecture and project ITS architectures. Turbo Architecture is based completely on the National ITS Architecture.

As part of the project definition, the sponsor must identify how the project fits within the appropriate regional ITS architecture. The sponsor will provide a text description with reference to the appropriate regional ITS architecture plan document.

CDOT or the MPO responsible for maintaining the applicable regional ITS architecture will use this information to develop a project architecture file using the latest version of Turbo Architecture. This file will be maintained with the rest of the project documents.

5.5 SYSTEM FUNCTIONAL REQUIREMENTS

The purpose of the System Functional Requirements report is to describe what the system is to do [functional requirements], how well it is to perform [performance requirements], and under what conditions [non-functional and performance requirements]. A sample System Functional Requirements template has been adapted from FHWA Systems Engineering Guidebook website as a suggested format for use.

For project sponsors of Medium and High risk projects, the template will assist in the preparation of the set of functional requirements that is commensurate with the size of the project.
5.6 **DETAILED DESIGN**
The detailed design will be conducted as per federal and state rules and regulations.

5.7 **TESTING AND EVALUATION PLAN**
The purpose of the *Testing and Evaluation Plan* is to describe the intended process to verify that the project design and implementation meets the functional requirements and the concept of operations. A sample *Testing and Evaluation Plan* template has been adapted from FHWA Systems Engineering Guidebook website as a suggested format for use.

For project sponsors of Medium and High risk projects, this template will assist in the preparation of a testing and evaluation plan that is commensurate with the size of the project. The testing and evaluation plan should embody both the plan and the results.

5.8 **OPERATIONS & MAINTENANCE PLAN**
The purpose of the *Operations & Maintenance Plan* is to describe how the project will be operated and maintained. A sample *Operations & Maintenance Plan* template has been adapted from FHWA Systems Engineering Guidebook website as a suggested format for use.

For project sponsors of Medium and High risk projects, this template will assist in the preparation of an operations and maintenance plan that is commensurate with the size of the project.