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STRATEGIC HIGHWAY RESEARCH PROGRAM

Accelerating solutions for highway safety, renewal, reliability, and capacity

Regional Operations Forum
Systems Engineering

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What Is Systems Engineering?

From MIT Open Course:

"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem including operations, performance, test, manufacturing, cost, and schedule."

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Why Is Systems Engineering Important?

A tool to help with:

- Reflecting the needs of the users in system development

- Keeping the project on schedule and budget

- Ability to repeat successes / deliver predictable outcomes

- Addressing risks early when system costs are lowest

- Better documentation of the system – no mysteries

- Increasing system reliability and stability

Better Systems Engineering Leads To…

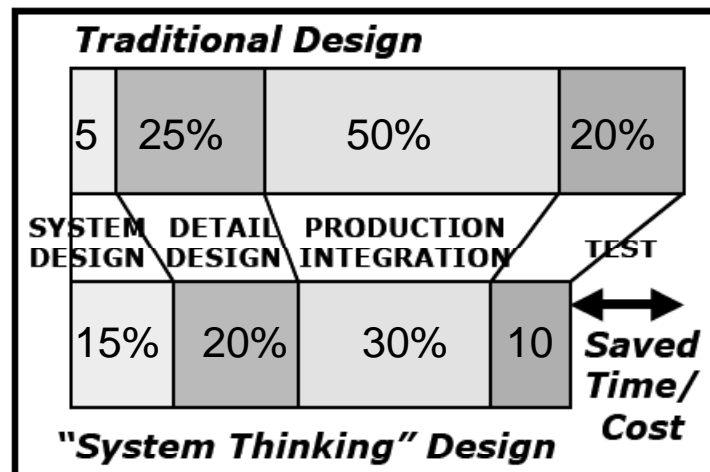## Better System Quality/Value Lower Cost

Figure 1. Intuitive Value of SE

Mar, Houour; Value of Systems Engineering
2002 INCOSE Symposium
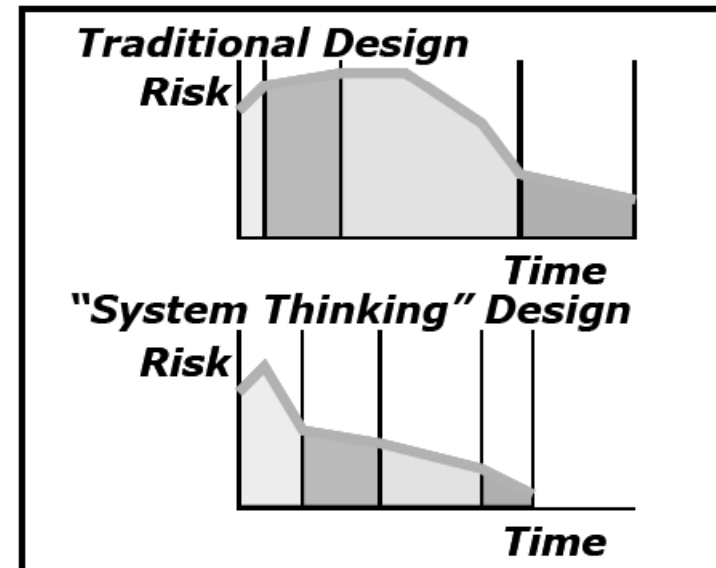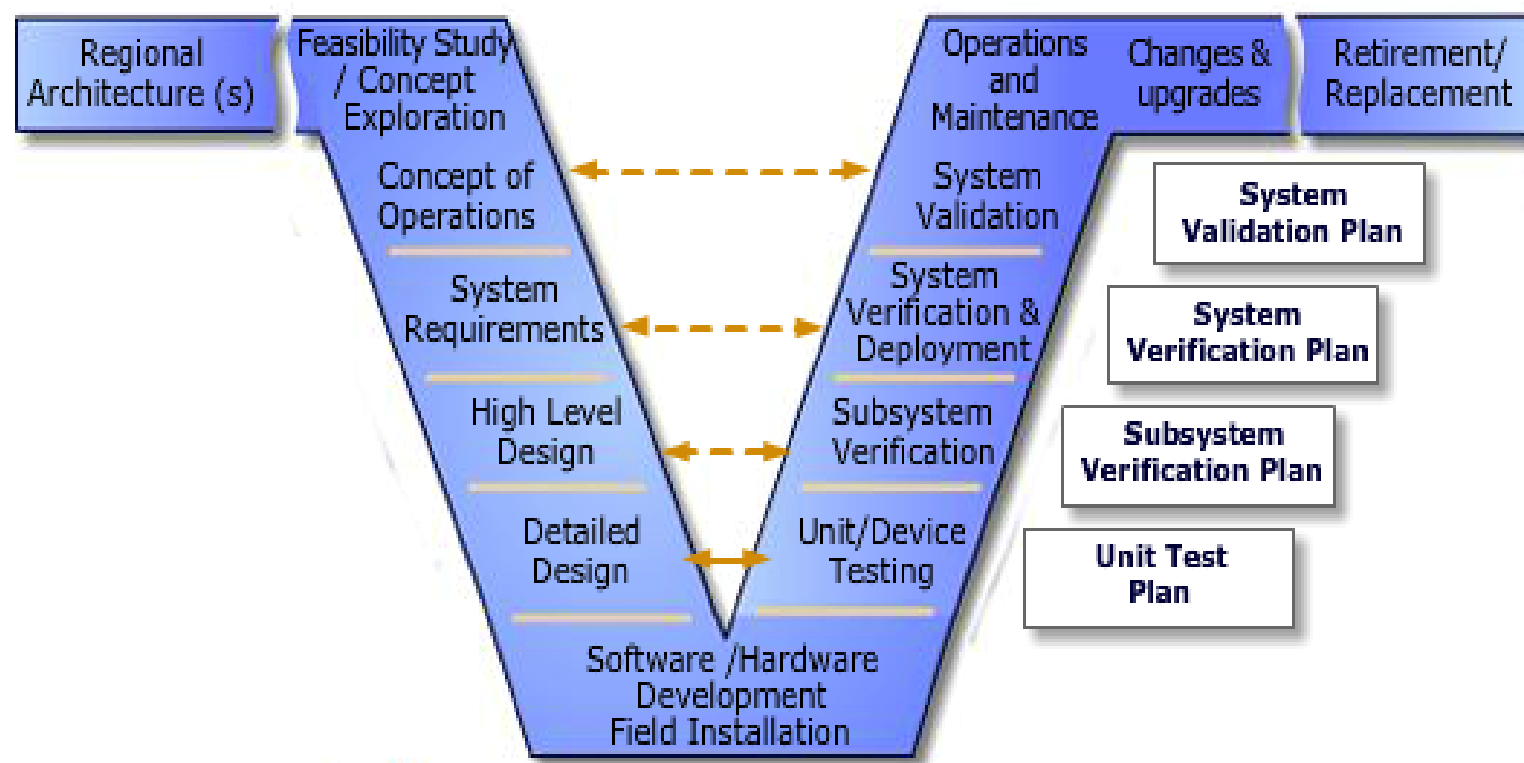
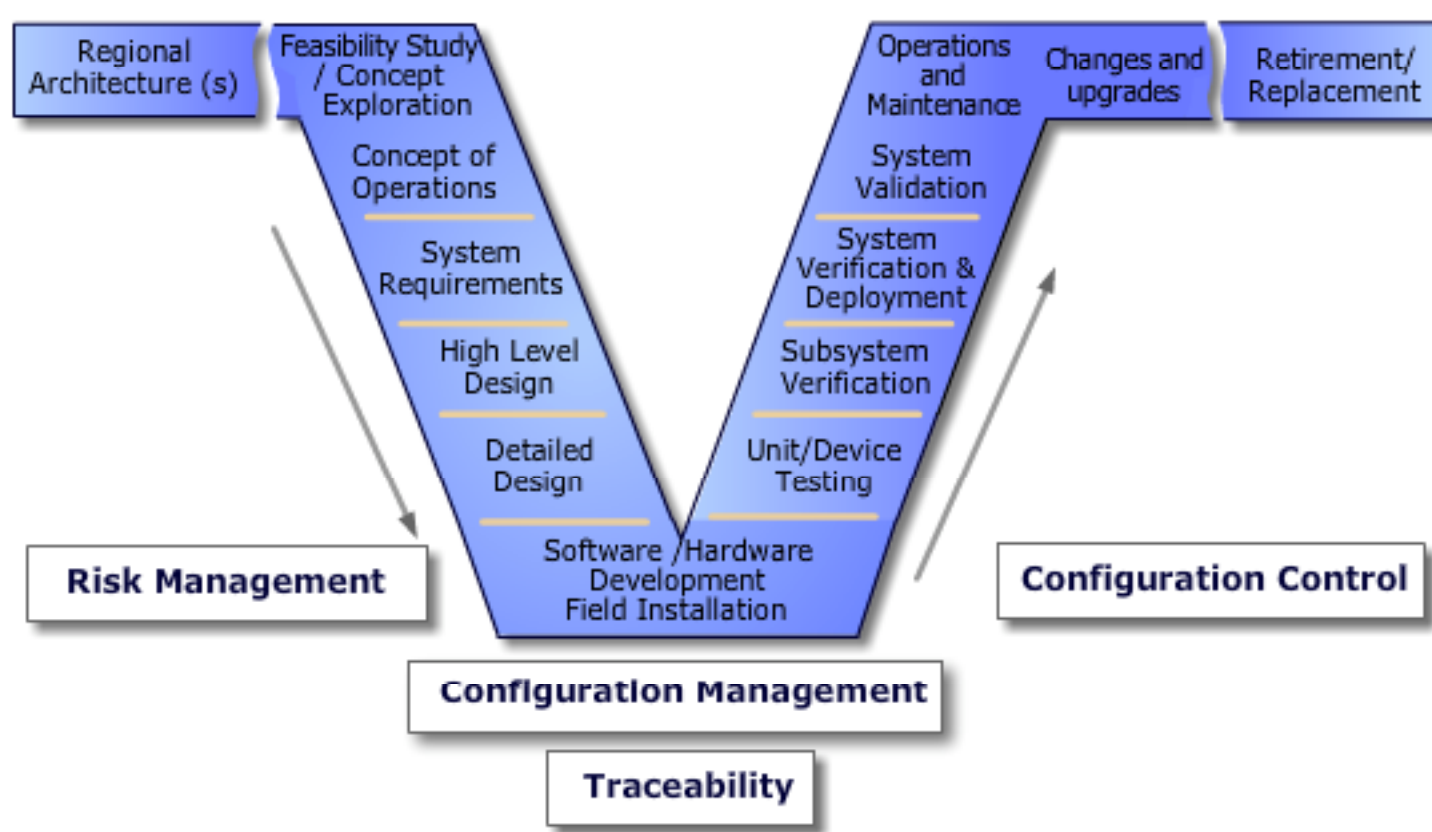## Shorter Schedule Reduced Risk

Figure 2. Risk Reduction by SE

Module I: Systems Engineering for
Transportation Projects in a Nutshell

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The Systems Engineering Process – The "V Model"

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Cross-Cutting Systems Engineering Activities

Concept of Operations

- Describes the problem to be solved, and how the stakeholders will solve the problem using the system

- Facilitates understanding of goals

- Forms the basis for long range planning

- Presents an integrated view of the stakeholder organization and mission

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Systems Engineering Exercise

- The State of Lincoln and Jefferson are planning to implement a new ramp metering system
  - Lincoln DOT currently meters the I-450 corridor in the Monroe metropolitan area
  - Lincoln DOT will use this project to implement metering on I-450
  - Jefferson DOT currently does not meter any ramps
    - They propose to meter both I-50 and I-450
    - The first phase will add meters on I-50 inside the I-450 interchange approaching Buchanan

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Exercise - System Description

- Both agencies agree that there should be one central system
  - Both agree that it should be operated out of LDOT's TMC
  - There will be a satellite system in the JDOT TMC

- The new/expanded metering system will include new software and hardware
  - A new algorithm will be implemented

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Team Exercise

- Would you consider this to be a complex project?
  - Should consideration be given to simplifying the SE process?
  - If so, in what way?
- How would you define the "system" that will be covered by the project and the concept of operations?
- What stakeholders should be involved in developing the Concept of Operations?

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SE Experiences by State

- How are you applying Systems Engineering in your organization?

- What benefits did you experience?

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The FHWA Final Rule on Architecture and Standards Conformity (23 CFR 940)

- Issued on January 8, 2001
- Ensures that projects are developed according to pre-defined criteria and comply with the National ITS Architecture and applicable ITS standards
- SE should be commensurate with project scope: Enough so that it supports good outcomes meaningfully
- Requires a Systems Engineering Analysis:
  - Identification of the portion of the regional architecture being implemented
  - Identification of participating agencies
  - Definition of requirements
  - Analysis of alternatives
  - Identification or selection of procurement options
  - Selection and definition of applicable standards and testing procedures
  - Identification of resources for operations and maintenance of the system

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Developing the Concept of Operations

Identify Stakeholders → Develop a Vision how you will use the system →

- Procedures
- Deployment
- Performance
- Utilization
- Effectiveness
- Life cycle
- Environment
- Maintenance

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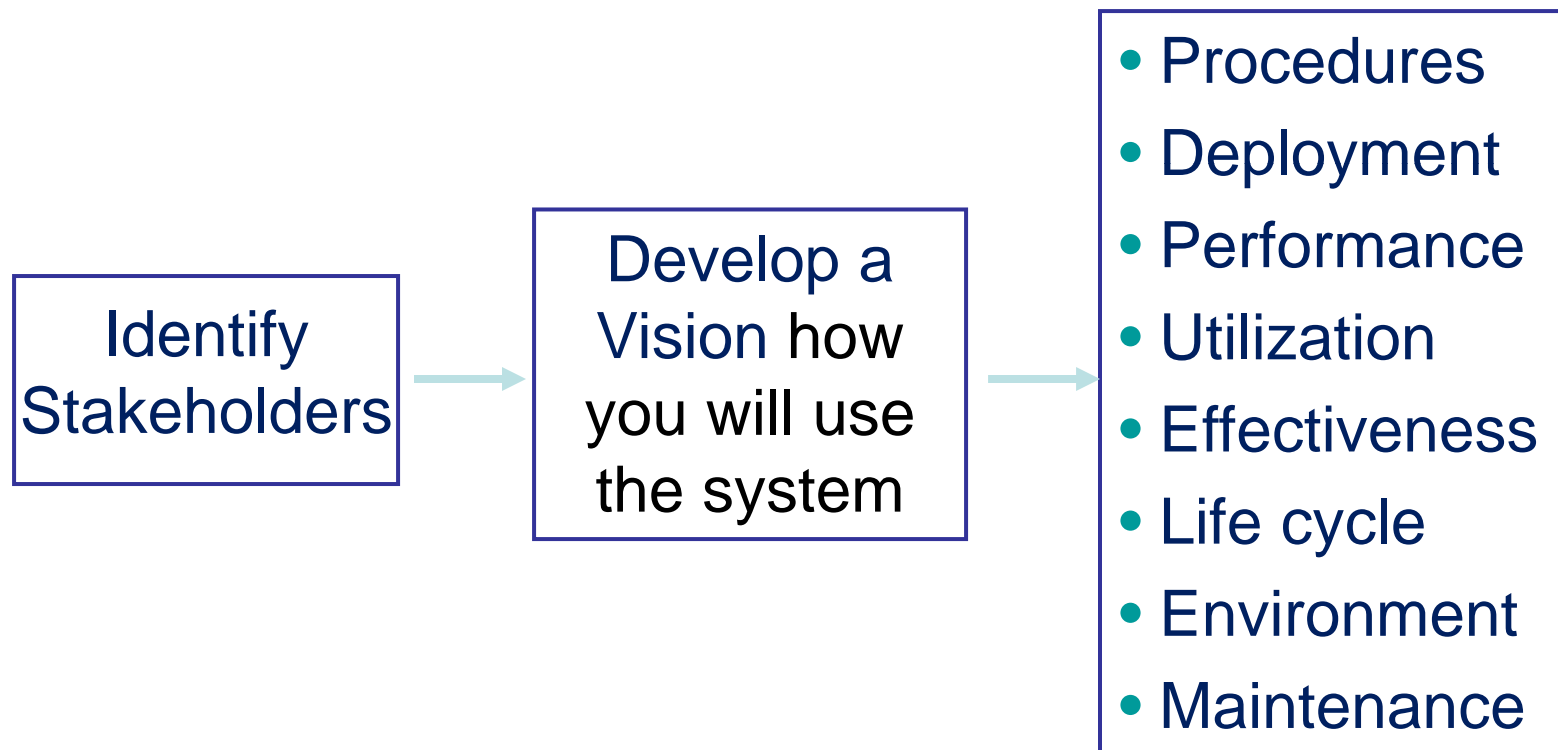
A Concept of Operations

Two different industry standards provide suggested outlines for Concepts of Operations are shown below.

ANSI/AIAA-G-043 Outline (1992)

1. Scope
2. Referenced Documents
3. User-Oriented Operational Description
4. Operational Needs
5. System Overview
6. Operational Environment
7. Support Environment
8. Operational Scenarios

IEEE Std 1362 (1998)

1. Scope
2. Referenced Documents
3. The Current System or Situation
4. Justification for and Nature of the Changes
5. Concepts for the Proposed System
6. Operational Scenarios
7. Summary of Impacts
8. Analysis of the Proposed System

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Requirements

"Something that governs what, how well and under what conditions a product will achieve a given purpose."

Functional Requirements

Interface Requirements

Performance Requirements

Data Requirements

Characteristics of Good Requirements

Requirements must be:

- Necessary
- Clear (unambiguous)
- Complete
- Driven by needs in the ConOps
- Achievable (feasible)
- Testable and measurable (quantifiable)
- Technology independent

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Characteristics of Bad Requirements

Requirements must NOT be:

- Vague
- Compound
- A mix of interim goals and final output
- Dependent on a technology
- Poorly linked to customer expectations
- Subjective
- Qualitative
- Design prescriptive

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Managing Requirements

- Requirements are the basis for acquisition, design, and acceptance
  - Traceability is critical
- Requirements should be included in configuration management
- Should we freeze requirements?
  - Why?
  - Under what conditions?
  - If so, when?
- Should we ever relax requirements once they are established?
  - Before we make a build vs buy decision?
  - After we have selected a contractor
  - Under what conditions?

Scaling SE Process: Complex Projects

High-Risk Indicators

The presence of one or more of these factors indicates a higher risk situation:

1. Multi-jurisdictional and/or multimodal
2. New software creation
3. New hardware integration
4. New interfaces – especially if to external systems
5. System requirements not well understood and *written down*
6. New technology applications, likely technology changes

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Scaling SE Process: Complex Project Example

The Project: Share control of existing CCTV cameras between State DOT and adjoining city.

Let's see how the high-risk factors apply:

- Multi-jurisdictional and/or multi-modal
- New software creation
- New hardware integration
- New interfaces
- System requirements not well understood
- New technology applications, likely technology changes

This is a high-risk application. ***Follow the "V" with no shortcuts!***

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Scaling SE Process: Simpler Projects

Low-Risk Indicators

A low-risk ITS project should have all of these characteristics:

1. Single jurisdiction and/or single mode
2. No software creation
3. Proven hardware and communication
4. No new interfaces
5. System requirements/operating procedures well defined and documented
6. Only stable technologies used

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Scaling SE Process: Simpler Projects

Low-Risk Project Example

The Project: Add 4 CCTV Cameras to a surveillance system currently including 10 cameras

Let's see how the low-risk factors apply:

- Single jurisdiction and/or single mode
- No software creation
- Proven hardware and communication
- No external interfaces; duplication of existing ones
- System requirements well defined/documented
- Only stable technologies used

This project is a good example of a low-risk application. All low-risk factors apply.

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So, What Can I Do to Simplify the SE Process on Simpler Projects?

You still have to follow the "V"

However, there are ways to make it easier

- Use existing resources
  - Existing ConOps
  - Existing requirements (even if they have to be modified)
  - Adapt existing test scripts
  - Determine where manufacturer certifications or results from tests elsewhere can be used
- Scale the ConOps to the project
- Look to buy instead of build
  - Use high level requirements to compare existing systems

You still have the cross-cutting activities. **Follow the "V"!**

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Take Aways - Applying Systems Engineering in Your Organization

- Communicate the value of systems engineering

    - Better documentation, more stakeholder participation, reflect user needs, address risks, increased system reliability and stability, repeat successes

- Applying it to projects – use of the V Model and FHWA Final Rule

- Improving internal capabilities – e.g., project, risk and configuration management

- Marking it part of the Organization culture – establishing policies and documenting processes

- Implementing across the Organization

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Resources

ITS Professional Capacity Building (PCB) Program -
   http://www.pcb.its.dot.gov/

(Comprehensive, accessible, and flexible ITS learning for the transportation industry)

ITS Peer-to-Peer Program - http://www.its.dot.gov/peer/index.htm

(Provides public sector transportation stakeholders with a convenient method to tap into the growing knowledge base of ITS experience and receive short-term assistance)

Systems Engineering Web Page -
http://www.ops.fhwa.dot.gov/int_its_deployment/sys_eng.htm

(Comprehensive, accessible, and flexible ITS learning for the transportation industry)

Talking Transportation and Technology (T3) Webinars
- *Live webinars on cutting-edge topics*: http://www.pcb.its.dot.gov/t3_webinars.aspx
- *Archived webinar sessions*: http://www.pcb.its.dot.gov/t3_archives.aspx

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