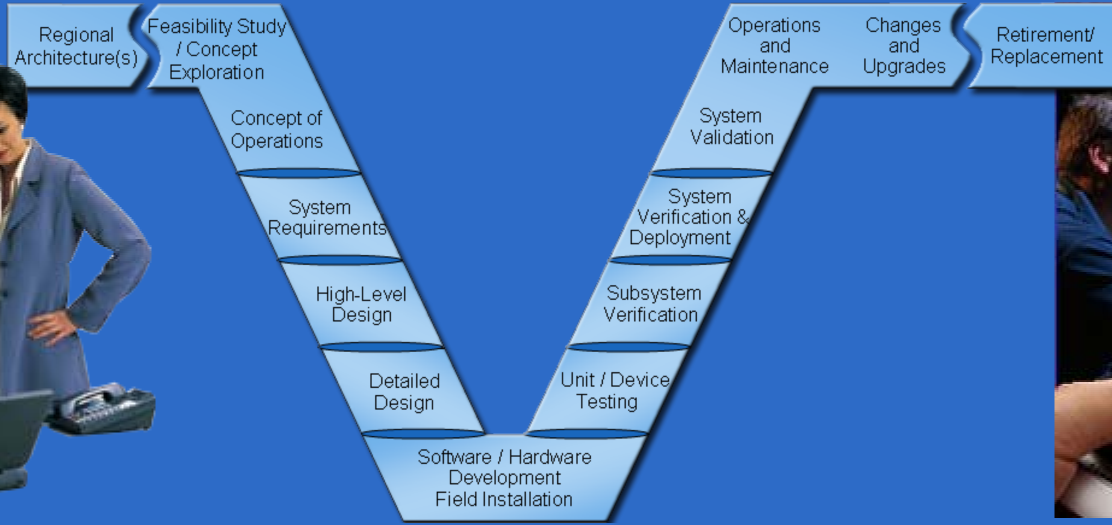


- Welcome and Introductions
- Process Overview
- **Systems Engineering "V"**
- Cross-Cutting Activities
- Applying SE to a Project
- Establishing SE in your Organization
- Process Improvement Discussion
- Wrap Up

Session 3: The Systems Engineering "V"

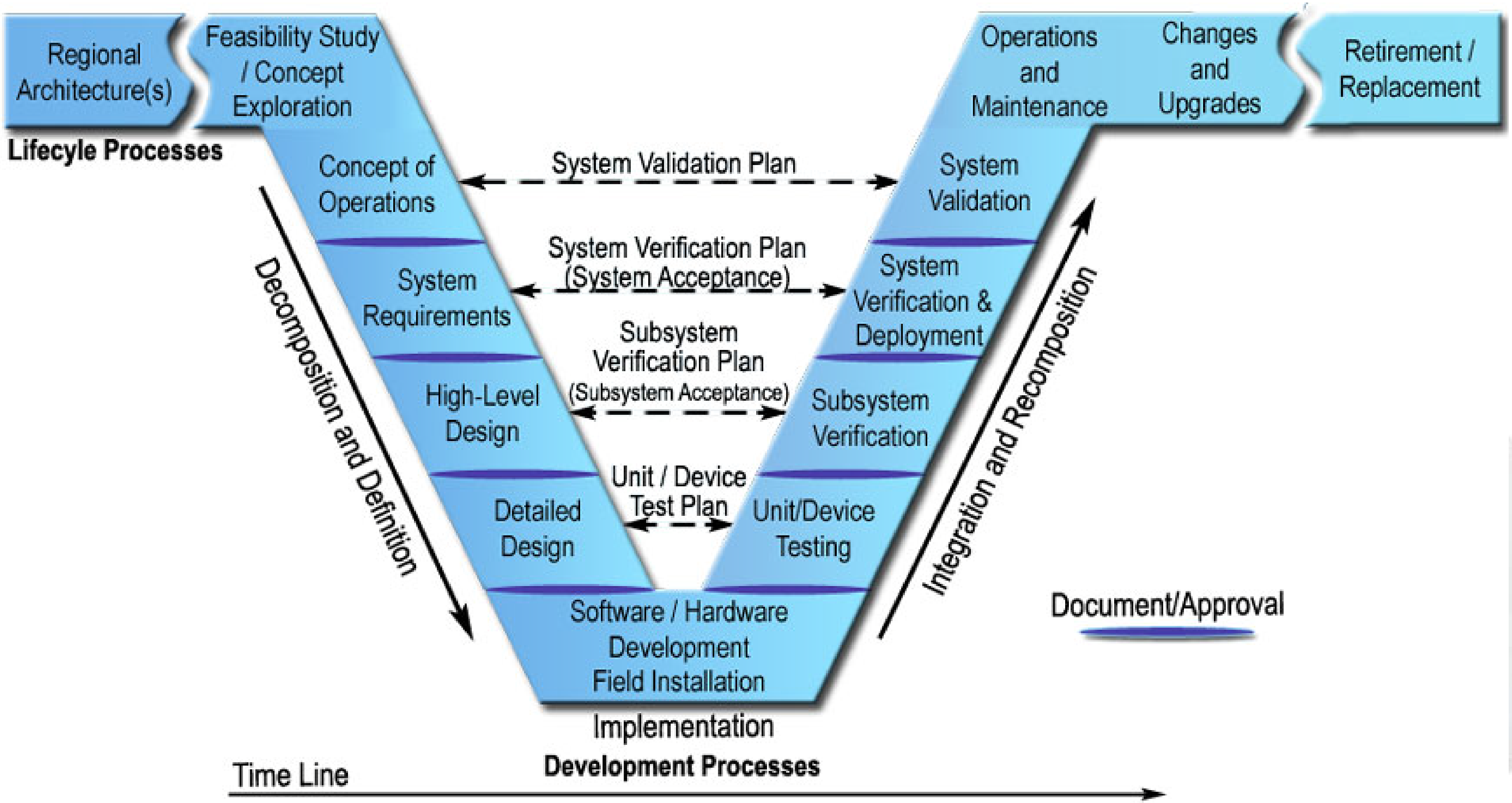
These materials developed under the RITA National ITS Architecture Program

U.S. Department of Transportation
Research and Innovative Technology Administration

Learning Outcome

- Explain the Systems Engineering “V” Process

Systems Engineering Model for ITS: The “V”



Using the Regional ITS Architecture

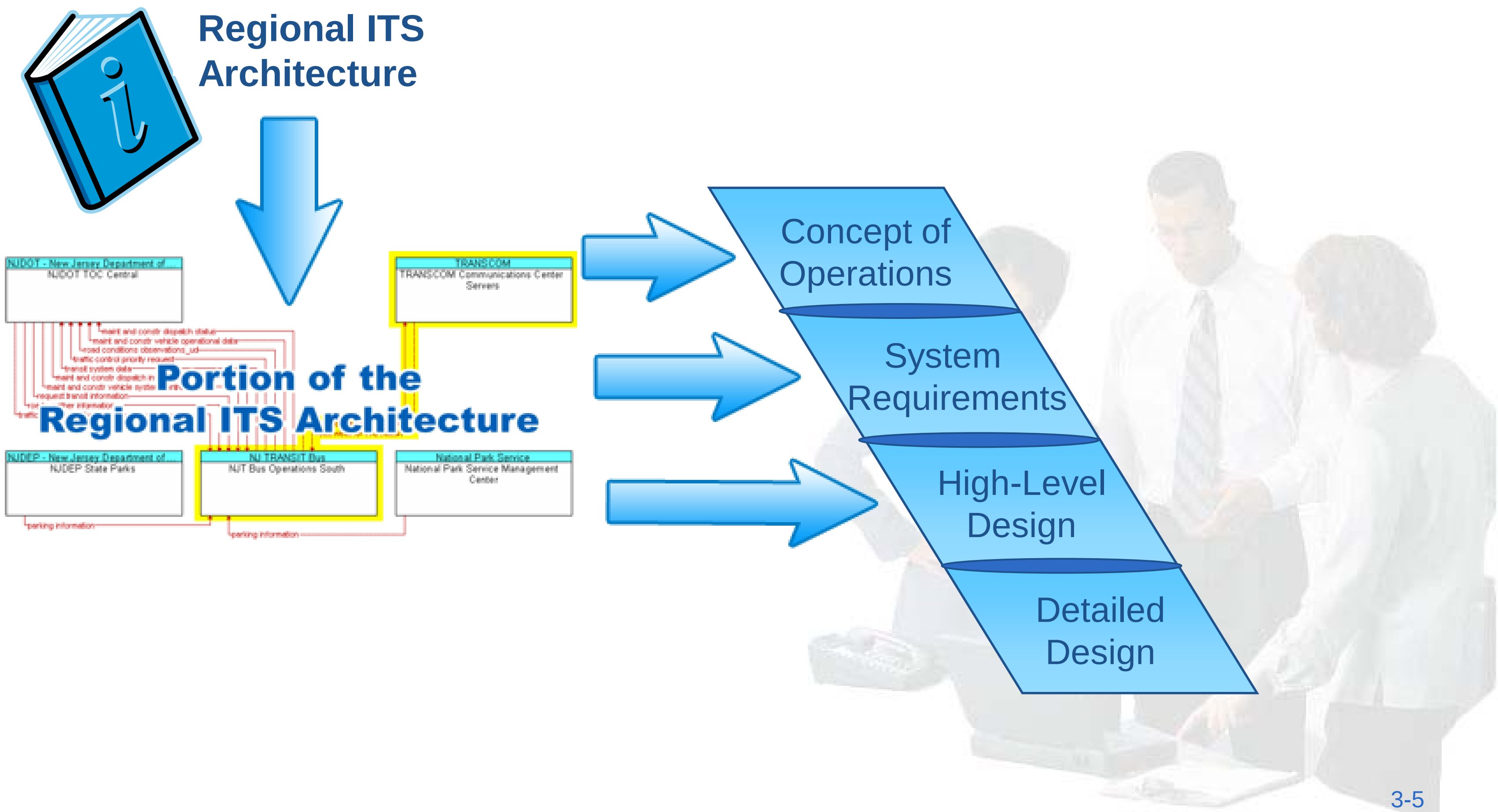
- Key activities:
  - Identify relevant regional ITS architecture(s)
  - Identify portions of regional ITS architecture that the project will implement
  - Verify project is consistent with regional ITS architecture
  - Identify any necessary changes to regional ITS architecture

Rule/Policy

1. Identification of portions of the regional ITS architecture being implemented

Regional Architecture Use in Project Development

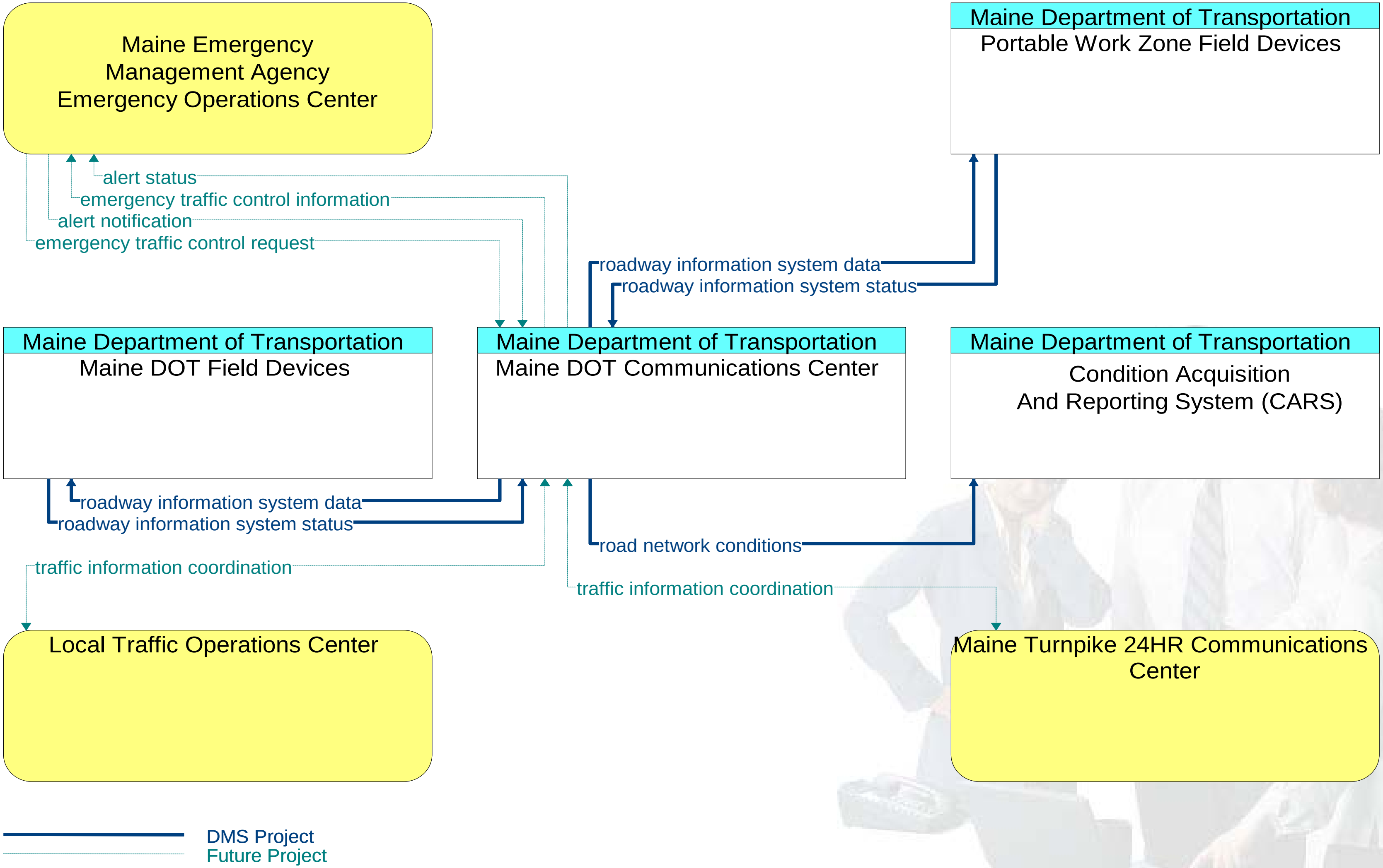
- Step by Step



Mapping an ITS Project to the Regional ITS Architecture

- Before you can use the Regional Architecture, you need to identify the portion that is relevant to your project
  - RA Transportation Services relate to the service(s) that will be provided
  - Inventory Elements relate to the system(s) that will be created or impacted
  - Functional Requirements relate to the functionality that will be implemented
  - Information Flows relate to the interfaces that will be added or updated
- Should be identified early, before project costs are estimated

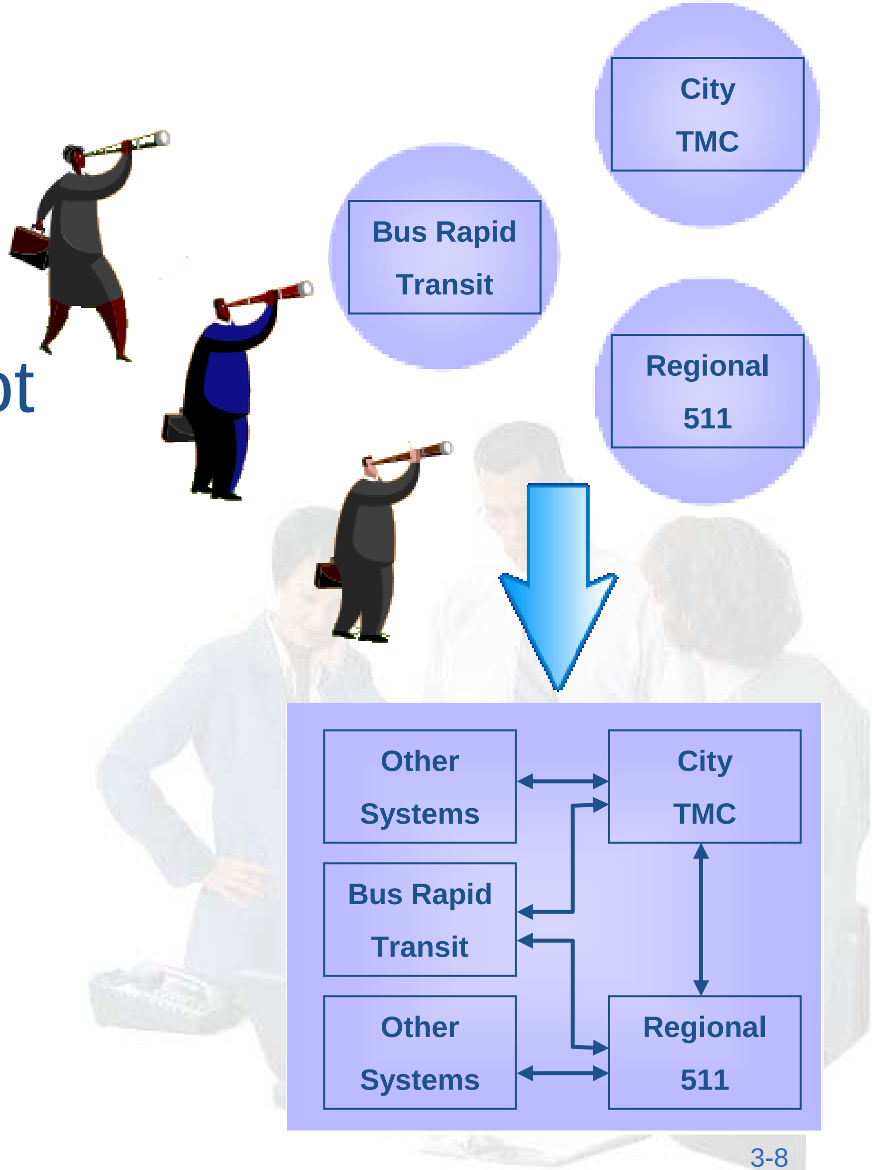
Regional Architecture Example



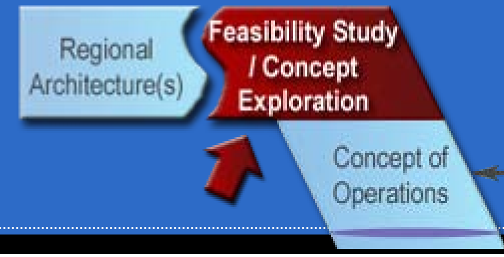
Source: SEHB Fig. 9, p. 19

Benefits of Using the Regional ITS Architecture

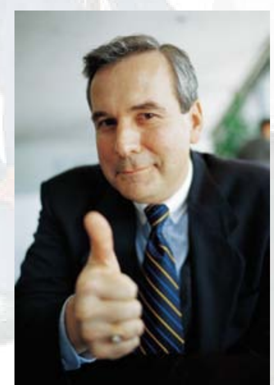
- Project scope considers regional vision
- Helps avoid overlooking capabilities or interfaces not previously considered
- Project consistency with other ITS projects is maximized
- Continuity between planning and project development is maintained



Feasibility Study/ Concept Exploration



- Assess economic, political, and technical feasibility
- Evaluate alternative concepts
- Key activities:
  - Define evaluation criteria
  - Perform initial risk analysis
  - Identify alternative concepts
  - Evaluate alternatives
  - Document results



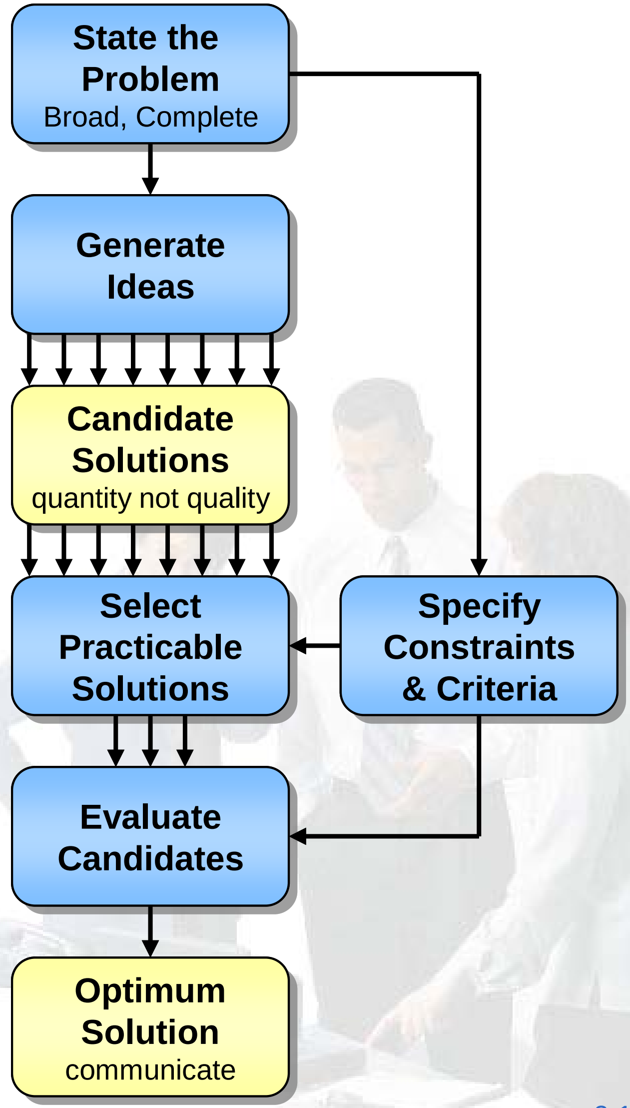
Makes the business case

Feasibility Study/ Concept Exploration (cont'd)

- Alternatives Analysis
  - Use trade study techniques
  - Further analysis of technical, economic, and operational features
    - Considers your resources

4. Analysis of alternative system configurations …

Source: SEHB Fig. 10, p. 21



Alternatives Analysis Example

- Example from Collin, TX Feasibility Study Report

Comparison of Alternatives – Supported Traffic Volumes for 2025

	Alternative#1 (No-Build)	Alternative#2 (Freeway)	Alternative#3 (Tolls east of DNT)	Alternative#4 (Tolls east of Hillcrest	Alternative#5 (Managed Lanes)
DNT to Hillcrest	118,171	161,069	139,565	156,920	149,921
Hillcrest to Custer	61,767	146,283	118,835	121,604	144,736
Custer to Stacy	47,379	120,694	72,280	72,297	115,304
Stacy to US 75	46,607	94,198	58,762	59,369	92,880

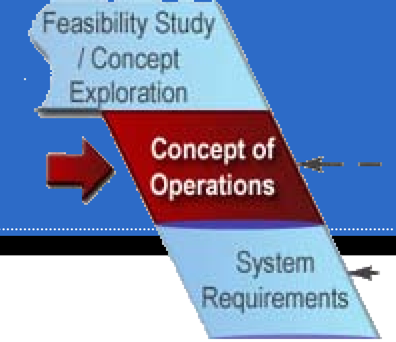
Source: SEHB Table 3, p. 24

Feasibility Study/ Concept Exploration Benefits

- Considers alternatives prior to significant investment
- Reduces risk of cost and schedule overruns
  - Project feasibility is verified
  - Project risks are identified
- Use where

  - Feasibility is in question
  - Fundamentally different alternatives exist

Concept of Operations



- The ConOps defines
  - Who: Stakeholder roles and responsibilities
  - What: Stakeholder needs, system elements and high-level capabilities
  - Where: Geographic and physical extent
  - When: Sequence of activities performed
  - How: Development, operation, and maintenance of system

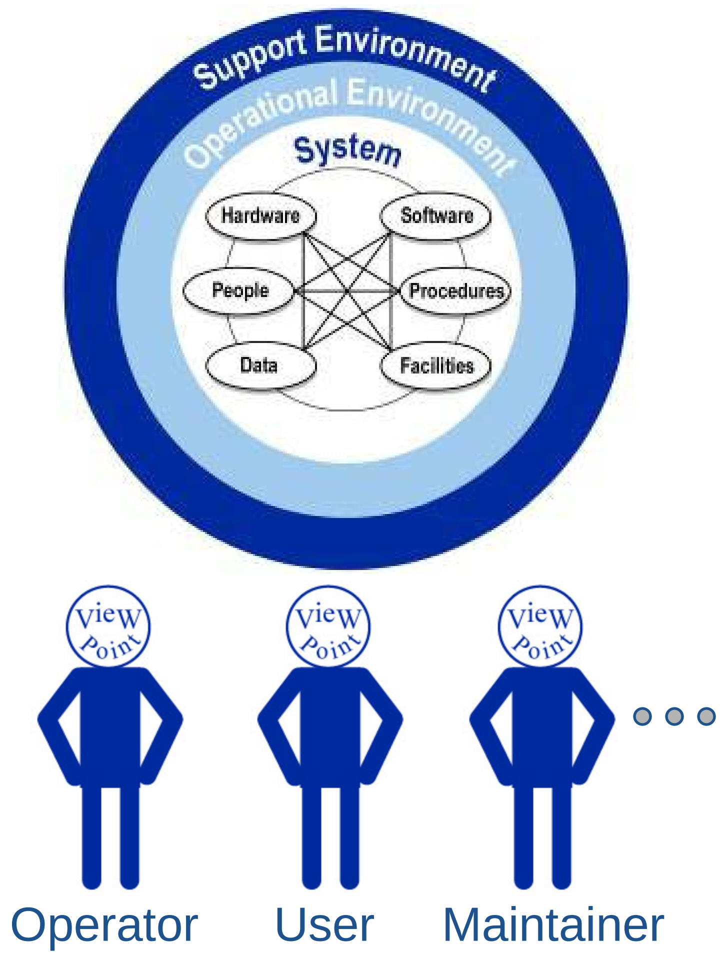
Rule/Policy

2. Identification of participating agencies roles and responsibilities

Concept of Operations (cont'd)

- Key activities
  - Identify stakeholders
  - Define core group responsible for creating ConOps
  - Develop initial ConOps, review with broader stakeholder group and iterate
  - Define stakeholder needs
  - Create a System Validation Plan

Concept of Operations (cont'd)



Adapted from ANSI/AIAA G-043-1992

- Written in the stakeholders' language
- Shows agreement on:
  - Goals, objectives, and expectations
  - Project scope
  - Stakeholder responsibilities
  - Operational Needs
  - How the system will operate
  - Operational and support environment

Concept of Operations Standards

- Suggested industry standards for ConOps outlines

ANSI/AIAA-G-043 Outline

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

Supports New Systems Developments

IEEE 1362 Outline

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

Supports System Upgrades

Source: SEHB Fig. 13, p. 29

Operational Scenario Example

Marcel, a StarTran bus operator, usually begins his work shift with administrative activities. After receiving supervisory direction, he boards the bus and prepares the AVL system. He begins by logging into the system.

The system then prompts Marcel for the route to be followed. He enters the planned route number, and the AVL system retrieves the appropriate route and schedule information from the AVL system server. The bus' AVL system then asks Marcel to verify the appropriate route and schedule information were properly retrieved.

Once he provides verification, the bus' head sign is automatically updated to reflect the appropriate route information. The fare payment schedule is automatically adjusted to reflect the verified route, modified as necessary by the system clock to reflect any applicable time-differential rates.

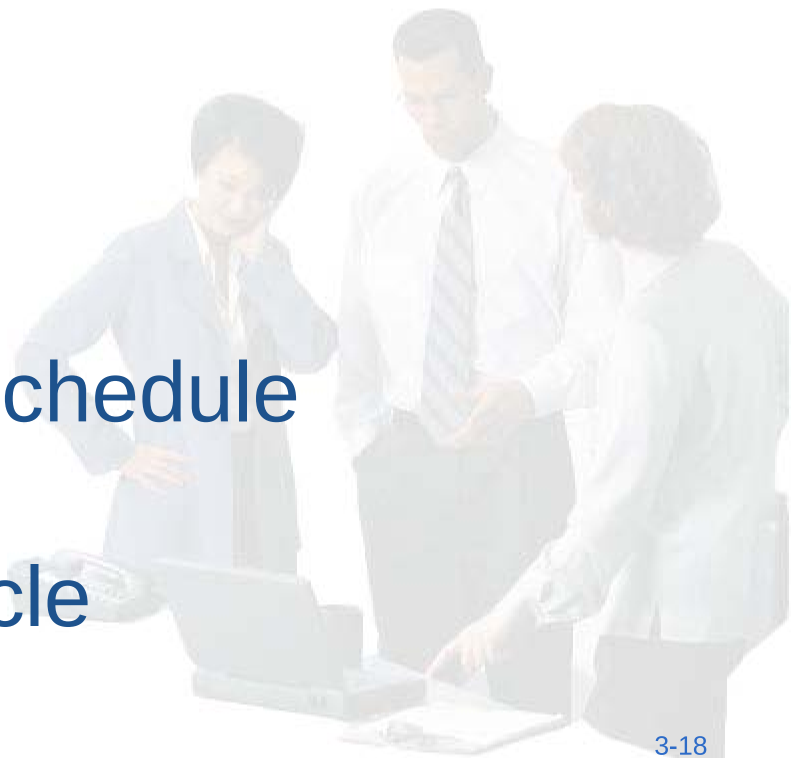
The system then loads the appropriate bus stop announcements for the chosen route. These prerecorded announcements are consistent regardless whether Marcel or another bus operator is driving the route, and have been verified as ADA compliant. These announcements are then broadcast at the appropriate bus stop throughout the route.

From StarTran AVL ConOps

Source: SEHB Fig. 15, p. 32

Example Signal System Project Needs

- Improve Traffic Performance
  - Reduce delay
  - Reduce stops
  - Reduce fuel consumption/emissions
  - Increase average speed
  - Reduce travel time
- Improve Traffic Safety
  - Reduce crashes
- Improve Transit Vehicle Schedule Adherence
- Improve Emergency Vehicle Responsiveness



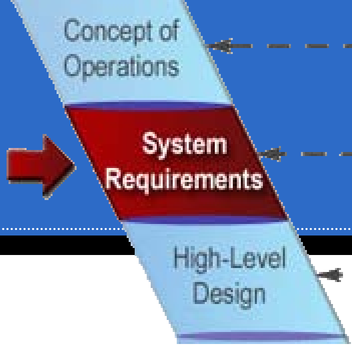
Benefits of Developing a Concept of Operations

- Early stakeholder agreement on:
  - System capabilities
  - Roles and responsibilities
  - Key performance measures and a basic plan for system validation
- Manage stakeholder expectations

Start with Your Eye on the Finish Line

A ConOps helps the project team visualize the final system at the beginning of the project.

System Requirements



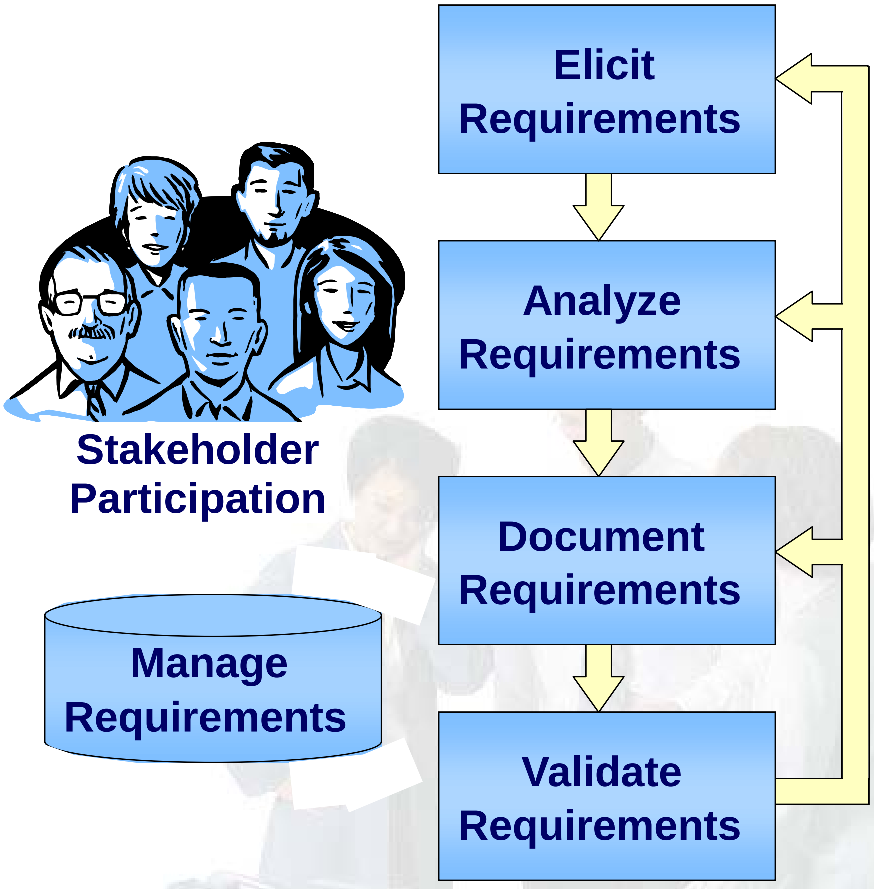
"Something that governs *what*, *how well*, and *under what conditions* a product will achieve a given purpose"

-- EIA-632, Electronics Industry Association Standard "Processes for Engineering a System"

3. Requirements definitions

System Requirements

- Key activities
  - Elicit Requirements
  - Analyze Requirements
  - Document Requirements
  - Validate Requirements
  - Manage Requirements



Source: SEHB Fig. 16, p. 34

System Requirements

- More key activities
  - Create a System Verification Plan that assures testing, demonstration, inspection, and analysis in relation to each requirement
  - Create a System Acceptance Plan that describes the functionality the system must display prior to customer acceptance

Writing Style for Requirements

- Use “shall” rather than “will” or “should”
- One requirement per sentence
- Avoid use of pronouns
- Avoid vague references such as “good workmanship” and “proven technology”

Quality Requirements

Quality Requirements Are

- Necessary
- Unambiguous
- Complete
- Measurable
- Consistent
- Achievable
- Testable
- Technology-independent

Examples of Poor Requirements

- “The system shall use radar detectors for traffic monitoring.”
- “State-of-the-art computers shall be used.”
- “The system shall manage incidents.”
- “All work shall be performed to the satisfaction of the Engineer.”
- “Industry standard designs and components shall be used.”

Requirements Examples (good or bad?):

- "The retrieval of any single status from any field device shall not exceed 2 seconds from the initiation of the request."
- "Congestion shall be reduced."
- "The system user shall be able to verify reversible lane gate status of up, down, locked, and 15^{o} status."
- "People shall feel safer about riding the bus."

System Requirements

- Usually defined in a hierarchy – for example:

Child Requirement

Parent Requirement

- **The system shall read tag data**

- **The system shall read tag ID**
- **The system shall read vehicle type**

Increasing Detail and Specificity →

Source: SEHB Fig. 17, p. 37

Regional Architecture Use in System Requirements

- Maine DMS Architecture Requirements

Element	Functional Area	ID	Requirement
Maine DOT Communications Center	TMC Traffic Information Dissemination	1	The center shall remotely control dynamic messages signs for dissemination of traffic and other information to drivers.

- Maine DMS Project Requirements
  - Parent **requirement: The center shall remotely control dynamic message signs…**
  - **Add detailed** child **requirements to:**
    - **Activate and display a message**
    - **Prioritize messages**
    - **Define a message (pick list, spell check)**
    - **Blank the sign**
    - **Schedule messages for display**

⋮

Typical Requirements from our Example Signal System Project

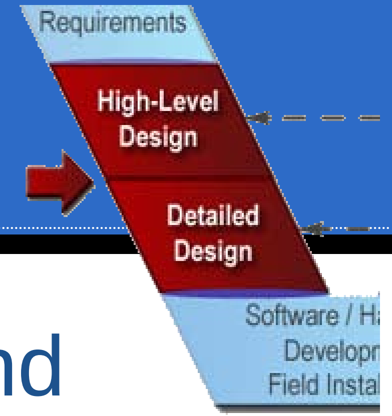
- The system shall provide an intersection display, updated every two seconds.
  - The display shall show current detections
  - The display shall show current phase indications
  - The display shall show current faults
  - The display shall show current time of day
  - The display shall show cycle timers
  - The display shall show current mode (coordination method)
  - The display shall show current transit vehicle priority status
  - Etc.

Benefits of System Requirements

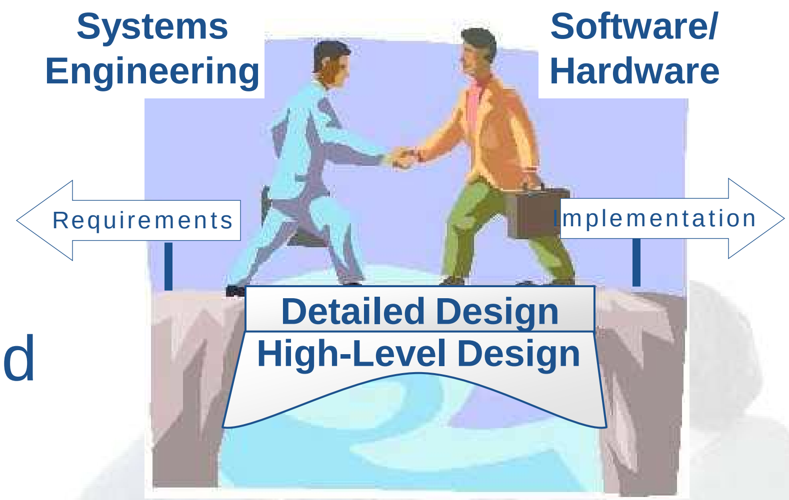
- A clear statement of requirements provides:
  - A shared understanding of the problem to be solved by customer and developer
  - A firm basis for managing project scope
  - The connection between user needs and system design
  - The foundation for system verification/testing

A clear statement of requirements is frequently identified as a key factor in successful IT projects.

System Design



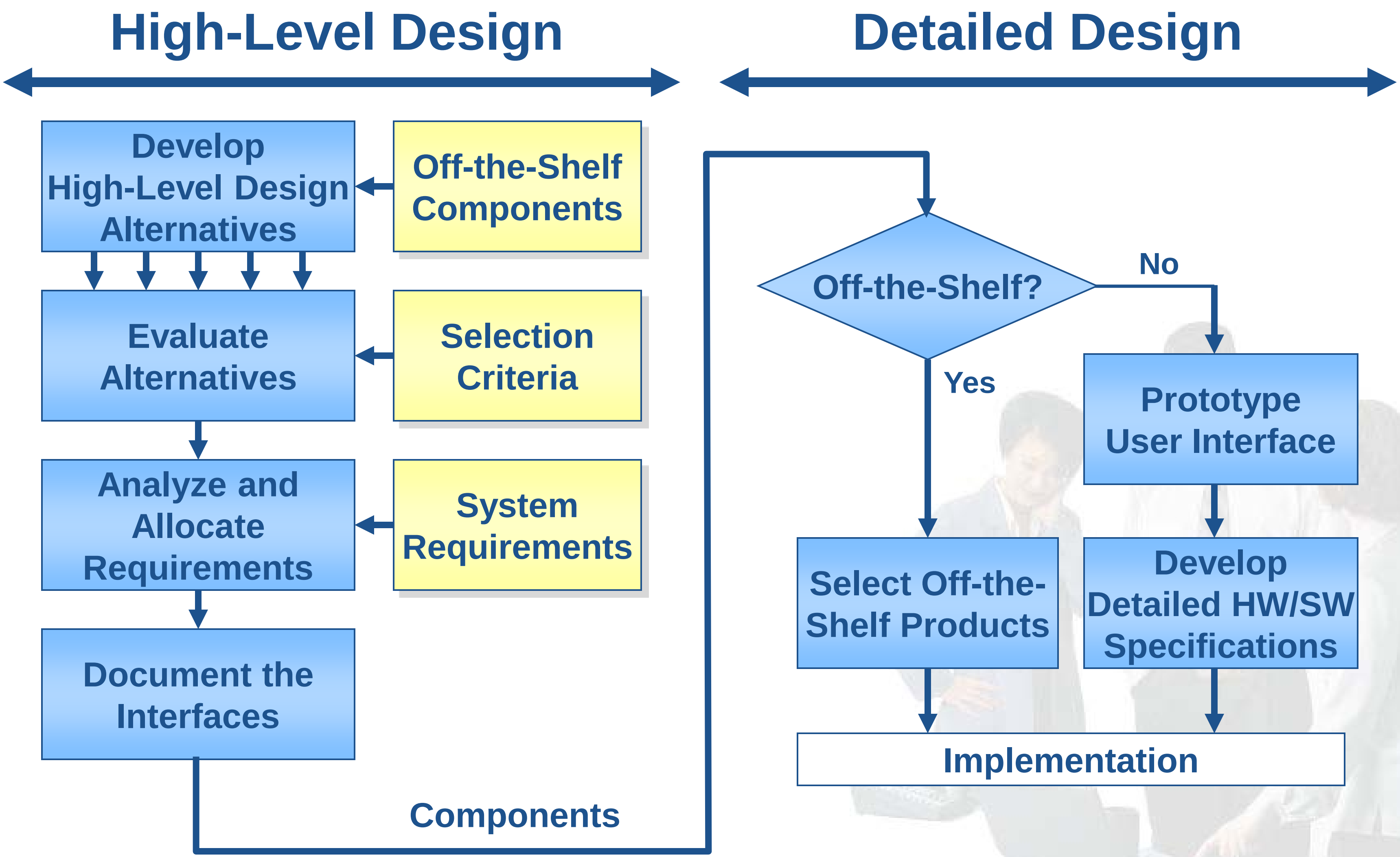
- The bridge between requirements and implementation
- Two distinct levels
  - High-Level Design – Overall structure of the system (subsystems, components, and interfaces)
  - Detailed Design – Complete specification of hardware, software, and communications components



Rule/Policy

4. **Analysis of alternative system configurations and technology options to meet requirements**

System Design Activities

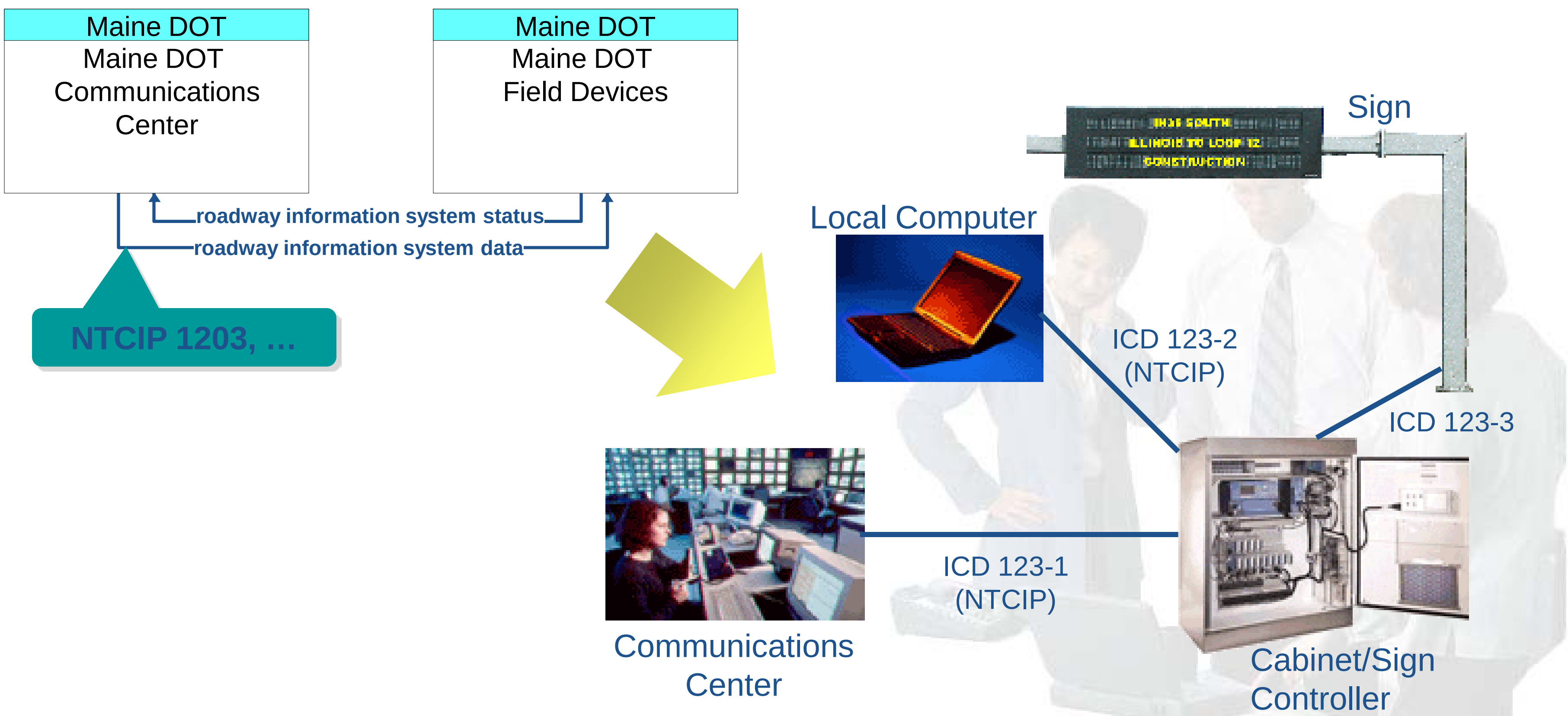


Source: SEHB Fig. 19, p. 45

Source: SEHB Fig. 21, p. 48

Regional Architecture Use in System Design

- Architecture interfaces are starting point for project interface design



Interface Standards in Project Design

- DMS Project ITS Standards

Document ID	Standard Title
NTCIP 1101	Simple Transportation Management Framework (STMF)
NTCIP 1102	Base Standard: Octet Encoding Rules (OER)
NTCIP 1103	Simple Transportation Management Protocol (STMP)
NTCIP 1201	Global Object Definitions
NTCIP 1203	Object Definitions for Dynamic Message Signs
NTCIP 2101	Point to Multi-Point Protocol Using RS-232 Subnetwork Profile
NTCIP 2102	Subnet Profile for PMPP Over FSK modems
NTCIP 2103	Subnet Profile for Point-to-Point Protocol using RS 232
NTCIP 2104	Subnet Profile for Ethernet
NTCIP 2201	Transportation Transport Profile
NTCIP 2202	Internet (TCP/IP and UDP/IP) Transport Profile
⋮	⋮

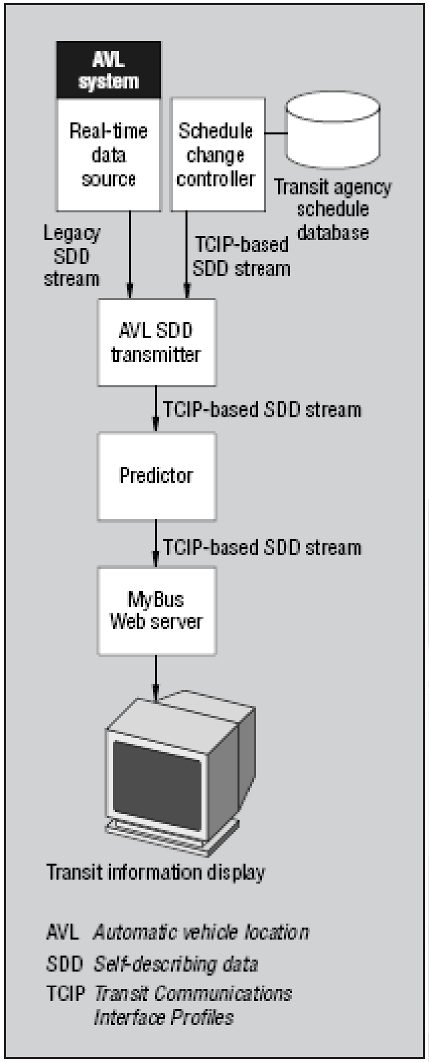
Select and tailor for project

Rule/Policy

6. Identification of applicable ITS standards …

System Design Example

- Metro Transit MyBus System Architecture
  - High-level design with subsystems and major interfaces



Ref: SEHB Fig. 24, p. 51

Benefits of System Design

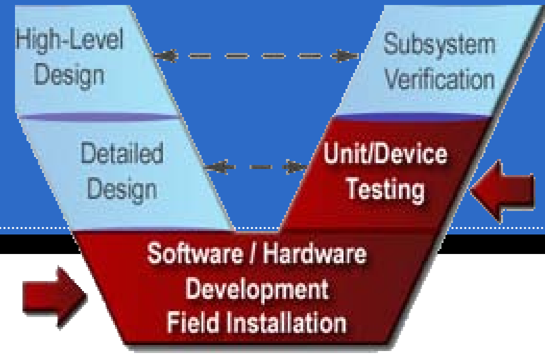
- A good system design:
  - Relates requirements to the system specifications
  - Defines open interfaces that supports different vendor solutions and off-the-shelf products
  - Supports efficient hardware and software development
  - Provides a roadmap for system integration and testing
  - Facilitates maintenance and future expansion and upgrade of the system

A superior system design allows new technologies to be cost-effectively incorporated.

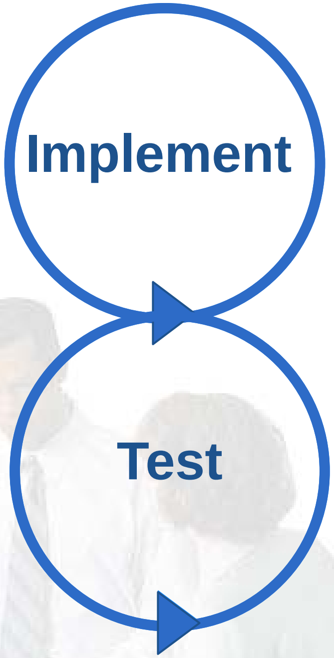
Measures of Success

- The right needs and requirements are captured
- System satisfies all of the needs and requirements
- But how do we make sure it does?

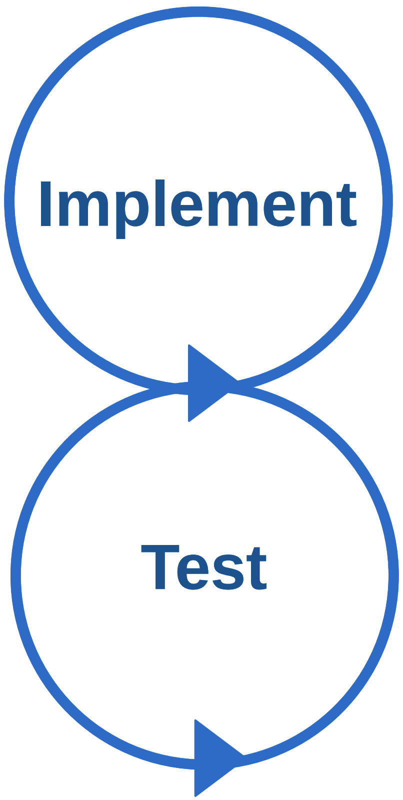
Software/Hardware Development and Testing

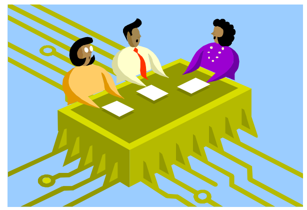


- Key activities
  - Plan software/hardware development
  - Establish development environment
  - Procure off-the-shelf products
  - Develop software and hardware
  - Perform unit/device testing
- Performed by technical specialists
  - Developers & Testers should be independent, particularly for higher risk efforts
- Systems engineering plays a monitoring role



Monitoring Software/Hardware Development and Testing





Walkthroughs

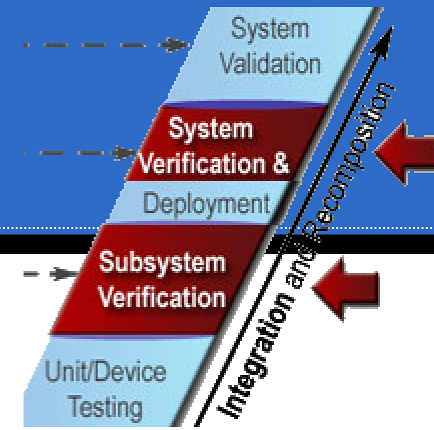
Inspections

Reviews

Source: SEHB Fig. 26, p. 55

- Check software quality
  - Structure
  - Documentation
  - Standards and conventions

Integration and Verification

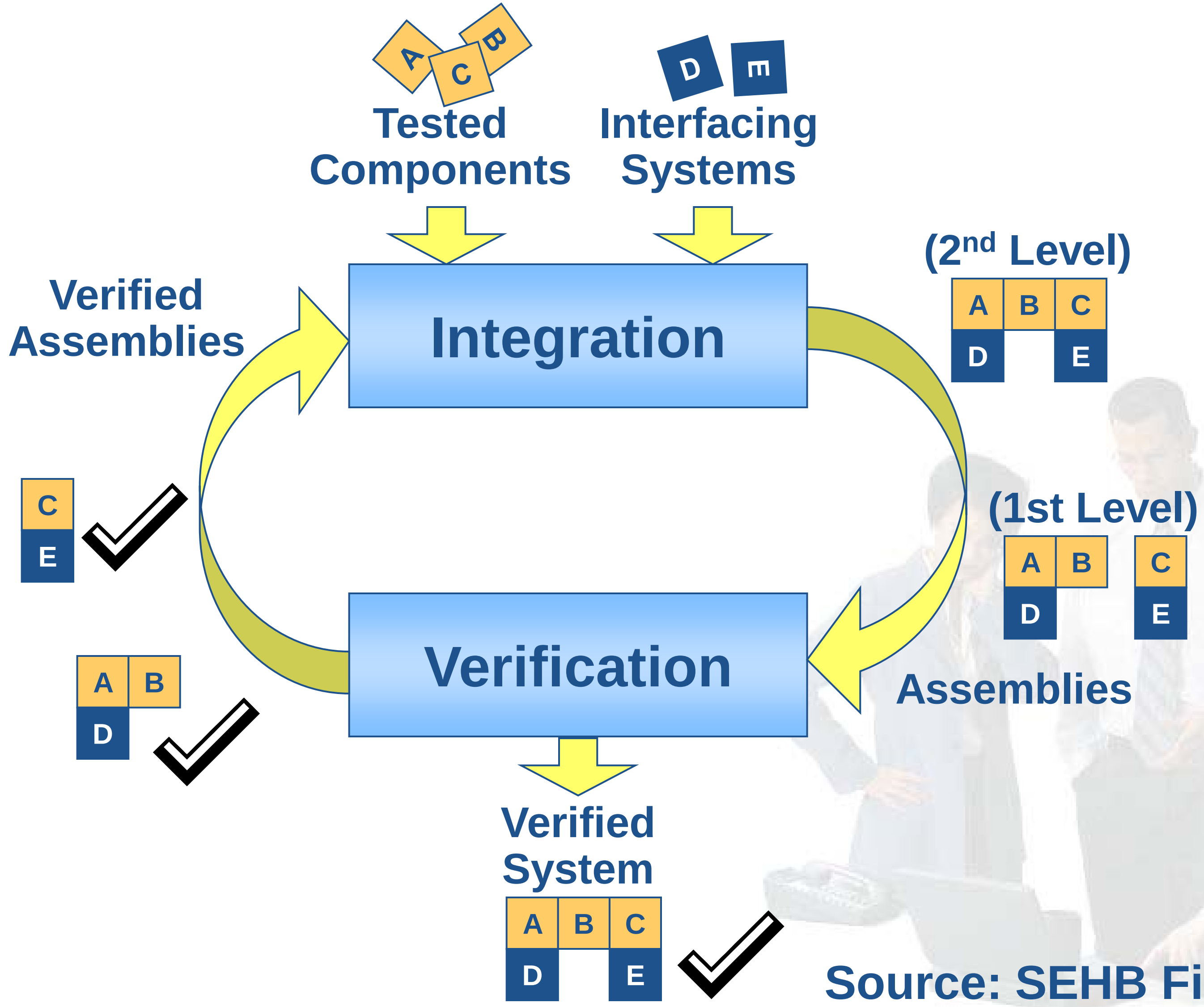


- Key activities
  - Add detail to integration and verification plans
  - Establish integration and verification environment
  - Perform integration
  - Perform verification
  - Confirm system meets requirements
- Verification – was system built right?

Rule/Policy

6. **Identification of applicable ITS standards and *testing procedures*.**

Iterative Integration and Verification



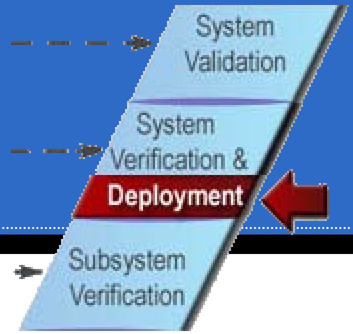
Source: SEHB Fig. 27, p. 60

Verification Procedure Example

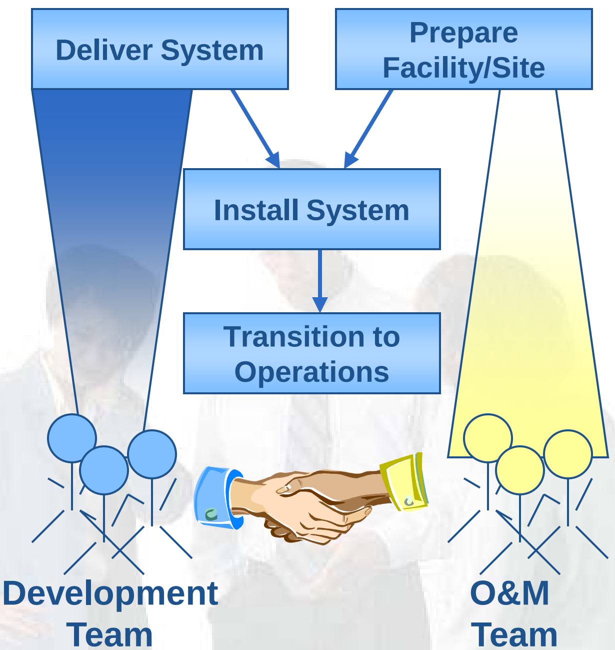
Test ID: General 1				
Purpose: To show that a valid username/password is accepted for logging in to CHART II within 15 seconds, and that an invalid combination is rejected. In addition, this test case also demonstrates that the system returns control to the user and the user is not prevented from performing activities in other windows on the desktop. CHART-27, CHART-10, CHART-21, CHART-275, CHART-276, CHART-29, CHART-26			Test Start Date:	
Test Pre-Conditions: This test assumes a valid username and password of a user in the CHART2 system is known.			Test End Date:	
Test Step No.	Test Steps	Expected Behavior	Results As Expected (Y/N)	Comments
1	Click on the Login button on the GUI toolbar.	An hourglass should display immediately, within 5 seconds, till the login window is displayed. Then, you should be prompted for a UserID and password.		
2	Attempt to login with an invalid username or password.	The system should popup an error message indicating that an invalid user ID or password was specified.		
3	Attempt to login with the valid UserID and password.	The system should indicate that the user is logged in by showing Operations Center:Username on the GUI toolbar window.		
4	Click on Navigator	Navigator window is opened.		
5	Click on DMS node	List of DMSs is displayed on the right hand side of the Navigator.		

CHART II Integration (excerpt) **Source: SEHB Table 14, p. 64**

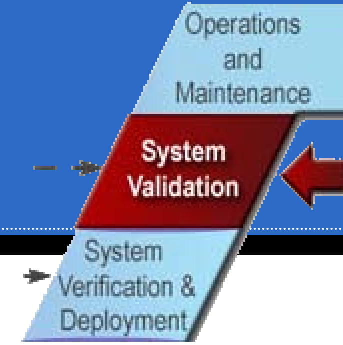
Initial Deployment



- Key activities
  - Plan for system installation and transition
  - Prepare the facility
  - Deliver the system
  - Install the system
  - Perform acceptance tests
  - Review/accept documentation
  - Conduct training
  - Transition to operation
- Facilitates smooth transition to operations



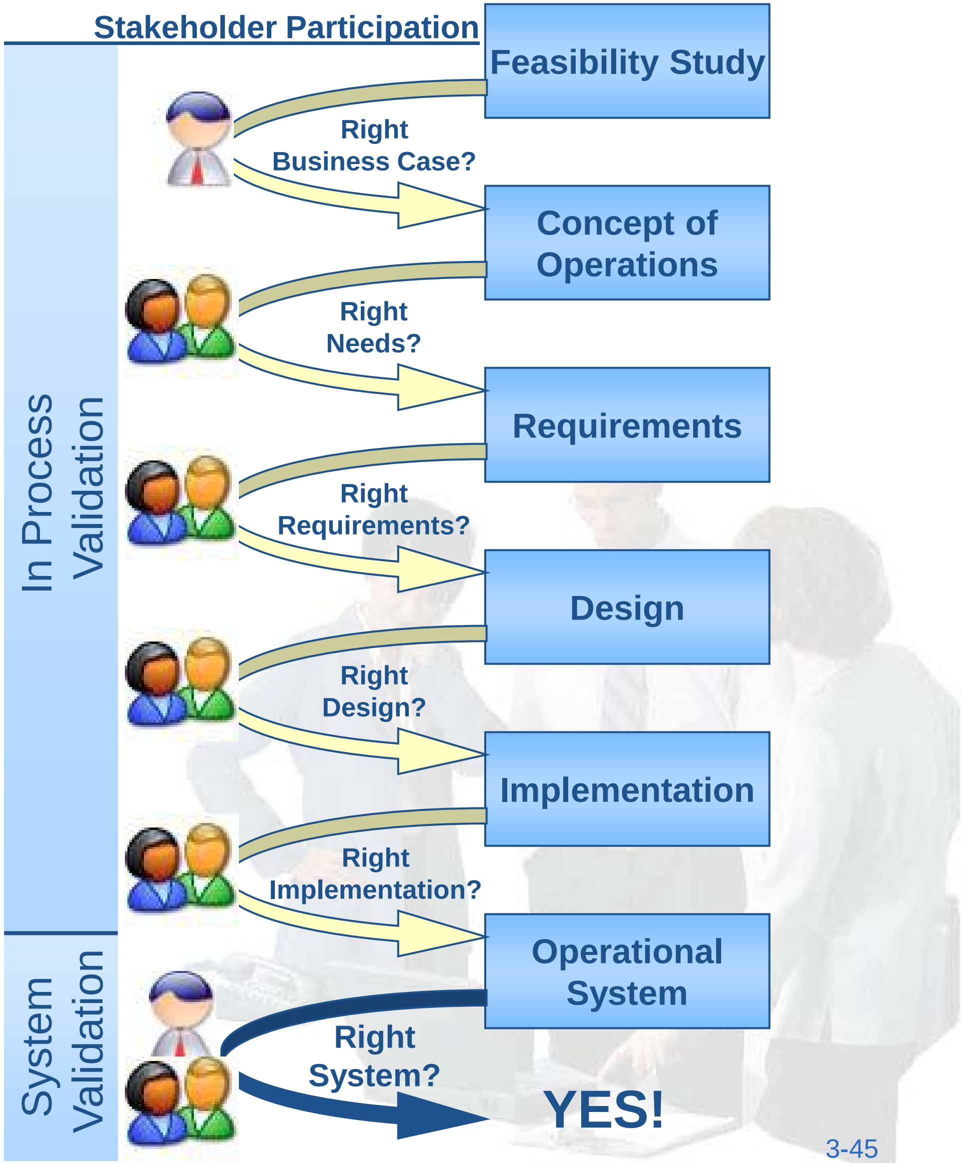
System Validation



- Validation – was the right system built?
- Confirm that user needs are met by the installed system
- Key activities
  - Update Validation Plan as necessary and develop procedures
  - Validate system
  - Document validation results including any recommendations or corrective actions

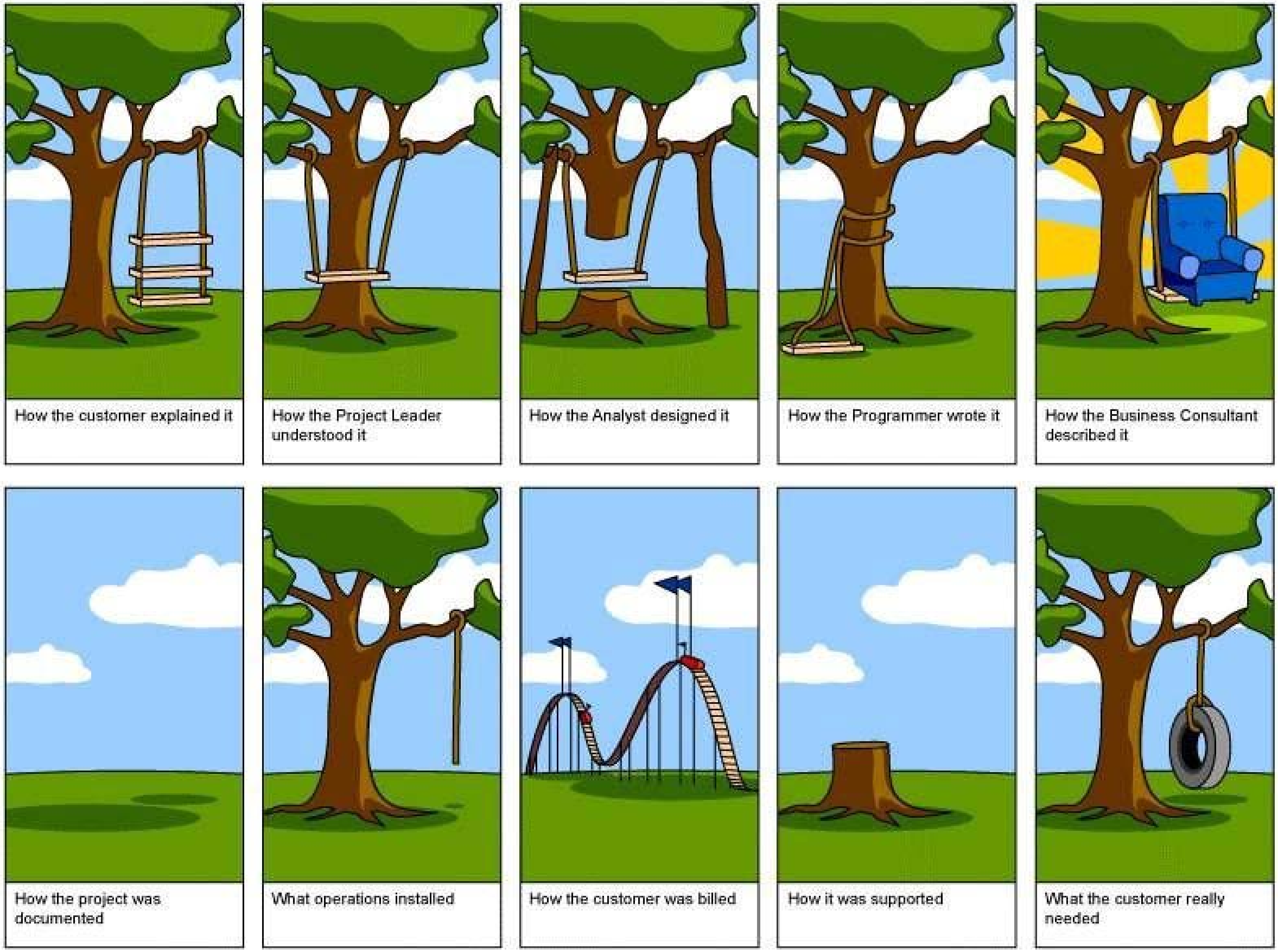
System Validation

- Validation takes place throughout the Systems Engineering process



Source: SEHB Fig. 30, p. 71

In-Process Validation was Clearly Lacking on this Project



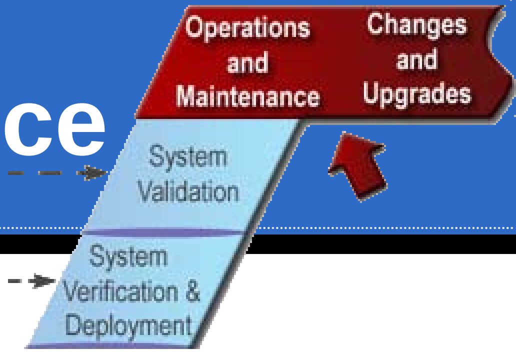
System Validation Example

ORANGES Evaluation Goals and Performance Measures (excerpt)

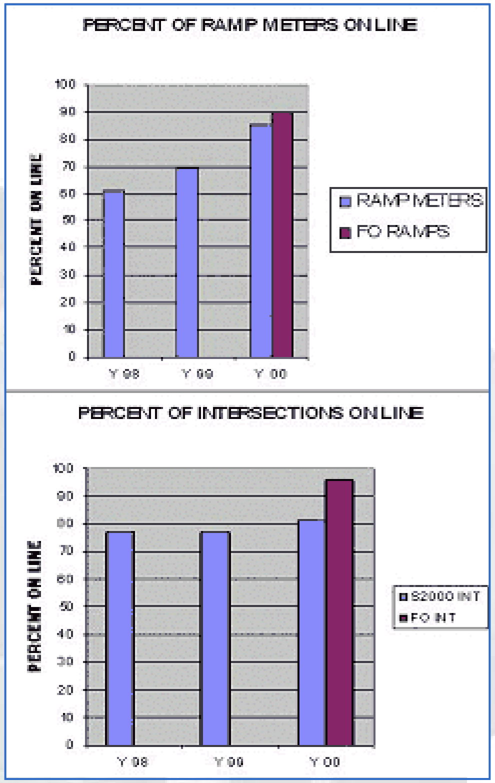
FOT Evaluation Goal	Measure
1. Increase parking revenue	• Revenue received
2. Increase transponder market penetration	• Number of smart card users that newly acquire a transponder
3. Reduce transaction times	• Average transaction times
4. Increase prepaid revenue share	• % revenue prepaid
5. Reduce monthly pass distribution costs	• Procurement, inventory, delivery, commissions for any conventional passes made available on smart cards

Source: SEHB Table 16, p. 74

Operations & Maintenance



- Key activities
  - Conduct Operations and Maintenance Plan Reviews
  - Maintain operations and maintenance procedures
  - Provide user support
  - Collect system operational data
  - Change or upgrade system
    - Another pass through the “V”
  - Maintain configuration control of system
  - Provide maintenance activity support

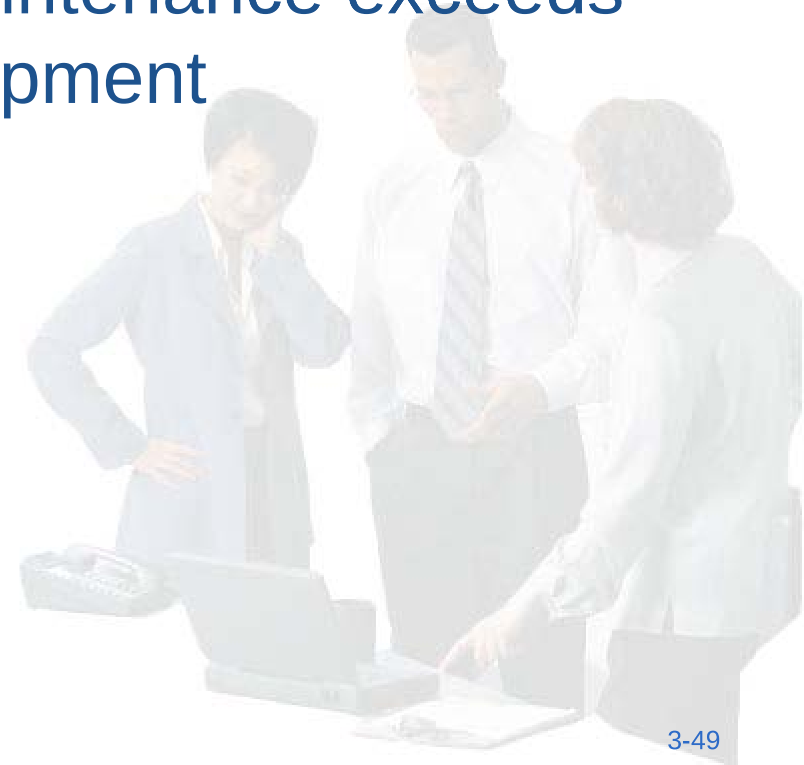


Rule/Policy

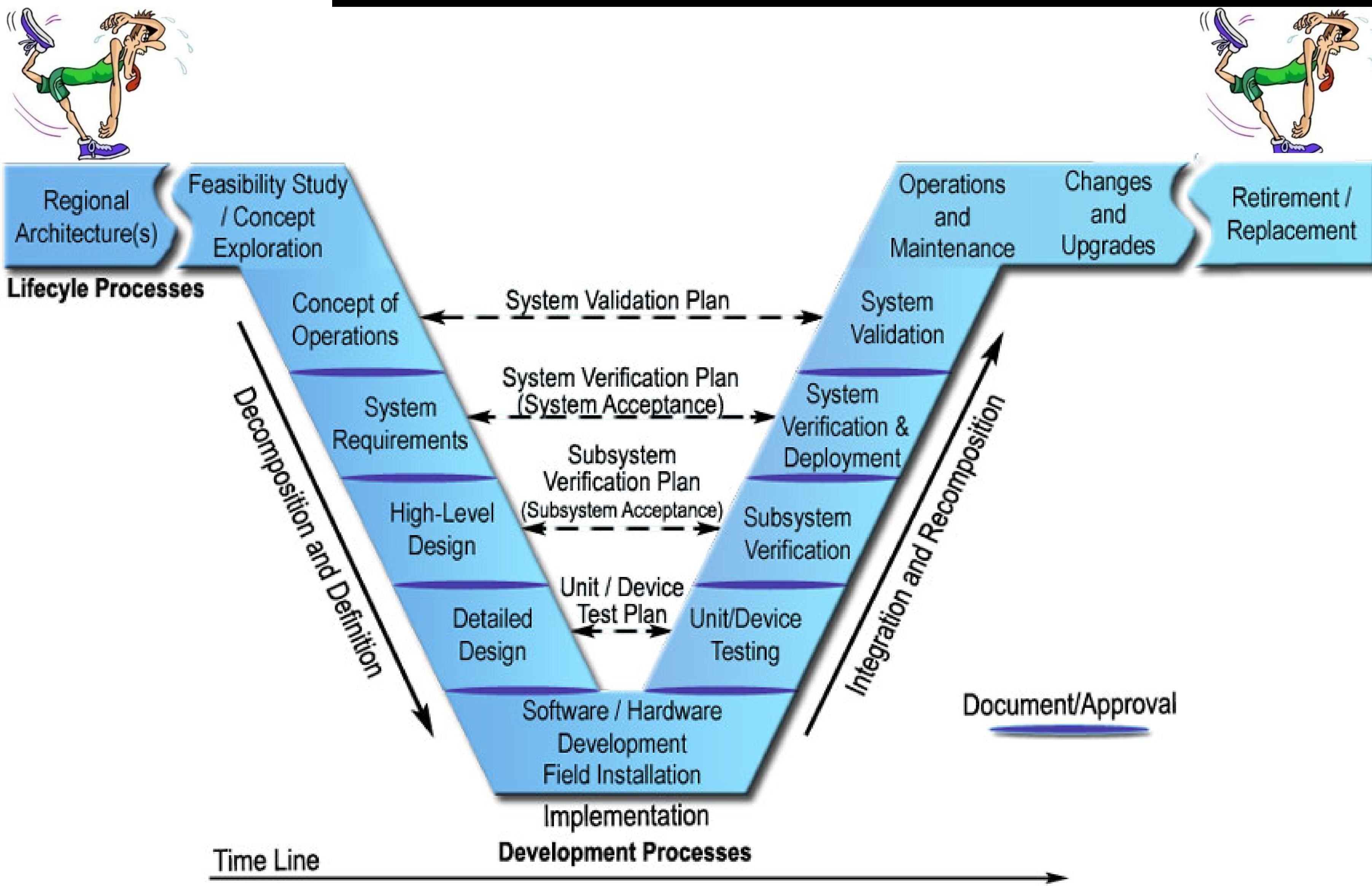
7. Procedures and resources necessary for operations and management of the system

Retirement/Replacement

- The end of the system lifecycle
  - Stakeholder needs change or are met in an alternative manner
  - Cost of operations and maintenance exceeds cost of new system development
- Key activities
  - Plan system retirement
  - Deactivate system
  - Remove system
  - Dispose of system



That completes the tour of the "V"



Learning Outcome

- Explain the "V" Process