A Methodology for Assessing Systems Engineering Practices

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Agenda

- Purpose for Devising a Systems Engineering Assessment Methodology
- Systems Engineering Assessment Methodology Overview
- Systems Engineering Case Study
- Systems Engineering Assessment Methodology – Potential Applications
- Summary

Purpose for Devising a Systems Engineering (SE) Assessment Methodology

- To assess the effectiveness of systems engineering activities and to show how this knowledge can assist with planning for activities on current and future programs.

SE Assessment Methodology Overview – Systems Engineering Method

- Logical set of activities to be accomplished in every System Life Cycle phase

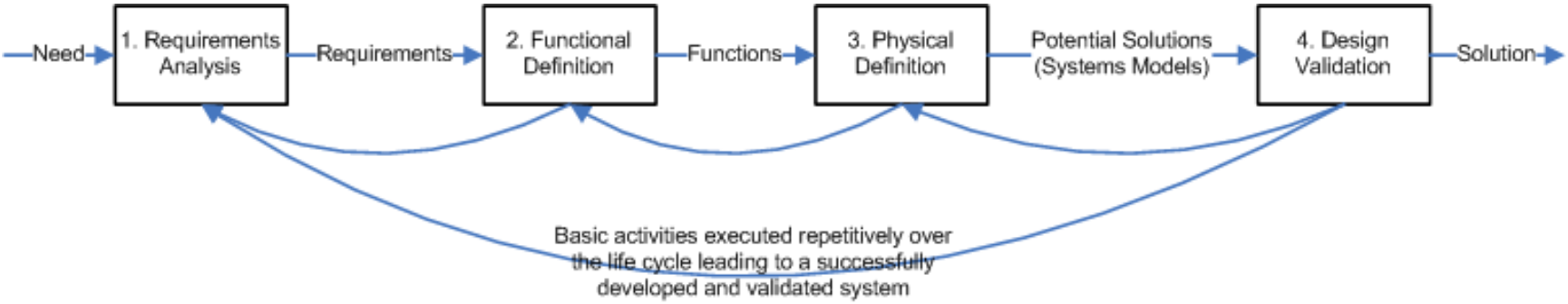

Figure adapted from "Systems Engineering Principles and Practice", Kossiakoff and Sweet, 2003

Requirements Analysis – Assemble and organize input conditions and clarify, correct, and quantify what the system must do

Functional Definition – Translate requirements into functions and define interactions among functional elements

Physical Definition – Translate functional design into hardware and software components and select preferred approach to best balance performance, risk, cost, and schedule

Design Validation – Design models and the system test environment then simulates or test/analyze system with the models

SE Assessment Methodology Overview – System Life Cycle

- System Life Cycle: divides complex system development process into phases

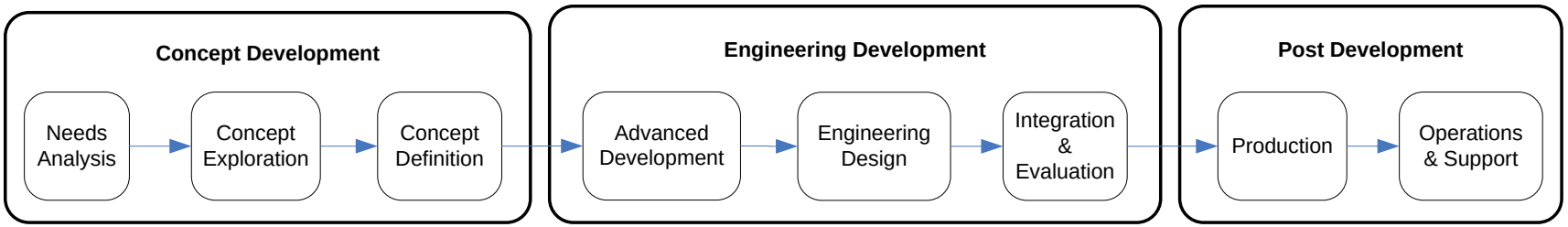

Figure adapted from "Systems Engineering Principles and Practice", Kossiakoff and Sweet, 2003

- **Needs Analysis** – Defines the need for a new system and determines if there is a practical approach to satisfying such a need
- **Concept Exploration** – Examines potential system concepts and identifies required performance and feasibility of possible approaches
- **Concept Definition** – Analyzes a number of alternative concepts in order to select a preferred concept that will be developed

SE Assessment Methodology Overview – Phase Sequence

- The Systems Engineering Method is applied iteratively to each phase of the System Life Cycle
  - This example shows the Concept Development phase:

Systems Engineering Method Step	Concept Development Life Cycle Phase		
	Needs Analysis	**Concept Exploration**	**Concept Definition**
Requirements Analysis	A: Analyze needs	E: Analyze operational requirements	I: Analyze performance requirements
Functional Definition	B: Define system functions	F: Define subsystem functions	J: Define component functions
Physical Definition	C: Visualize subsystem technology	G: Visualize components, architectures	K: Select components, architecture
Design Validation	D: Validate needs, feasibility	H: Validate performance requirements	L: Simulate, validate system effectiveness

Figure adapted from "Systems Engineering Principles and Practice," Kossiakoff and Sweet, 2003

SE Assessment Methodology Overview – Activity Context

- Need knowledge from the prior steps for current step
  - May be done by same people/organization or others
  - Accumulated steps provide the whole picture
- Information does not need to be complete to start next activity steps
  - Should be sufficient level to support initiating the next activities

SE Assessment Methodology Overview – Terminology

- Impact refers to the level of influence on the program
  - Impact ≠ Effort : Impact does not necessarily reflect amount of effort by contractor and program office
- Assessed impact to the project/program
  - Three levels of impact (High, Medium, and Low) as determined by Sponsor and Subject Matter Experts
- "Actual" vs. "Ideal" Impact
  - "Ideal" impact assumes prior steps were done sufficiently to support informational needs for this step and effort progresses exactly as originally planned
    - "Ideal" varies depending on intended application of SE Method
  - "Actual" impact is the assessed program impact of the systems engineering effort

Systems Engineering Case Study – Assessment Goals

- Understand the impact of APL SE actions and activities on the program and their relationship to the whole
  - Devise a way to look back at how tasking evolved from baseline plan and its impact on the effectiveness of the program
  - Conduct assessment of activities to understand why unanticipated activities occurred
  - Provide considerations and guidance to be used for planning and organizing future activities

Systems Engineering Case Study – Case Study Description

- Sponsor: Air Force Space Command - Space and Missile Systems Center (SMC)
- Initial Tasking
  - Systems Engineering - Requirements generation and integration of pilot program
  - Intended scope - Concept Exploration Phase within Concept Development
- Evolution: as tasks progressed, information gaps were identified and activities shifted (with sponsor concurrence) to address these needs
  - Evolution within a program is anticipated, to a certain extent, with the discovery and realization of key system concepts
  - In this case study, tasking and activity changes differed from what was expected with standard SE program evolution
  - It is important to understand why unanticipated activities occur to help learn and improve for the future

Systems Engineering Case Study – Major Activities

- Requirements Generation
  - Requirements Definition
  - Mission Analysis
  - Technology and User Studies
  - Modeling
- Prototyping
  - Concept Demonstrator
  - Concept Development Testing Environment

Systems Engineering Case Study – Requirements Definition: Ideal

Systems Engineering Method Step	Concept Development Life Cycle Phase		
	Needs Analysis	Concept Exploration	Concept Definition
Requirements Analysis	A	E	I
Functional Definition	B	F	J
Physical Definition	C	G	K
Design Validation	D	H	L
Key:	High Impact	Medium Impact	Low Impact

- Anticipated requirements activity: create a Technical Requirements Document

Systems Engineering Case Study – Requirements Definition: Actual

Systems Engineering Method Step	Concept Development Life Cycle Phase		
	Needs Analysis	Concept Exploration	Concept Definition
Requirements Analysis	A	E	I
Functional Definition	B	F	J
Physical Definition	C	G	K
Design Validation	D	H	L
Key:	High Impact	Medium Impact	Low Impact

- Tasked to develop Technical Requirements Document (TRD)
  - Found guidance documents lacked needed detail
  - Added Process Flow documents to supplement Needs Analysis information and provide common understanding of system functions

Systems Engineering Case Study – Requirements Definition: Comparison

Ideal	Concept Development Life Cycle Phase		
	Needs Analysis	Concept Exploration	Concept Definition
Requirements Analysis	A	E	I
Functional Definition	B	F	J
Physical Definition	C	G	K
Design Validation	D	H	L
Key:	High Impact	Medium Impact	Low Impact

Actual	Concept Development Life Cycle Phase		
	Needs Analysis	Concept Exploration	Concept Definition
Requirements Analysis	A	E	I
Functional Definition	B	F	J
Physical Definition	C	G	K
Design Validation	D	H	L
Key:	High Impact	Medium Impact	Low Impact

- Early Needs Analysis information was not mature
  - Shift in focus needed to earlier steps
  - Resources and information unavailable to properly address later steps
- Level of resulting information insufficient to support follow-on Concept Definition activities

Systems Engineering Case Study – Mission Analysis: Ideal

Systems Engineering Method Step	Concept Development Life Cycle Phase		
	Needs Analysis	Concept Exploration	Concept Definition
Requirements Analysis	A	E	I
Functional Definition	B	F	J
Physical Definition	C	G	K
Design Validation	D	H	L
Key:	High Impact	Medium Impact	Low Impact

- Analyses conducted to support requirements effort

Systems Engineering Case Study – Mission Analysis: Actual

Systems Engineering Method Step	Concept Development Life Cycle Phase		
	Needs Analysis	Concept Exploration	Concept Definition
Requirements Analysis	A	E	I
Functional Definition	B	F	J
Physical Definition	C	G	K
Design Validation	D	H	L
Key:	High Impact	Medium Impact	Low Impact

- Provided important knowledge to support requirements activities
- Helped to supplement incomplete Needs Analysis information

Systems Engineering Case Study – Mission Analysis: Comparison

Ideal	Concept Development Life Cycle Phase		
	Needs Analysis	Concept Exploration	Concept Definition
Requirements Analysis	A	E	I
Functional Definition	B	F	J
Physical Definition	C	G	K
Design Validation	D	H	L
Key:	High Impact	Medium Impact	Low Impact

Actual	Concept Development Life Cycle Phase		
	Needs Analysis	Concept Exploration	Concept Definition
Requirements Analysis	A	E	I
Functional Definition	B	F	J
Physical Definition	C	G	K
Design Validation	D	H	L
Key:	High Impact	Medium Impact	Low Impact

- Actual impact in Concept Exploration was relatively close the ideal impact
- Mission needs were unclear, thus analysis had to address earlier steps in Needs Analysis than initially intended
  - Resulted in diminished ability to address Physical Definition and Design Validation steps

Systems Engineering Case Study – Summary Tables

Ideal Summary

LC Phase	1 Needs Analysis				2 Concept Exploration				3 Concept Definition			
SE Step	1 RA	2 FD	3 PD	4 DV	1 RA	2 FD	3 PD	4 DV	1 RA	2 FD	3 PD	4 DV
Cell	A	B	C	D	E	F	G	H	I	J	K	L
Requirements					H	H	H	L	M	M		
Mission Analysis			M	H	H	H	M	L				
Tech /User Studies					M	M	H	L	L	M		
Modeling				L	L	L	M	H	H	M		
Concept Demo					L	M	M	H		L	L	M
Concept Testing			L	L			H	H			M	M

Actual Summary

LC Phase	1 Needs Analysis				2 Concept Exploration				3 Concept Definition			
SE Step	1 RA	2 FD	3 PD	4 DV	1 RA	2 FD	3 PD	4 DV	1 RA	2 FD	3 PD	4 DV
Cell	A	B	C	D	E	F	G	H	I	J	K	L
Requirements	M	H			H	H			L			
Mission Analysis	H	M		L	H	H	L	L				
Tech/User Studies	M	L	L	L	M							
Modeling						L	M	L				
Concept Demo					L	M	M	L		L		
Concept Testing						L	L	M				

Systems Engineering Case Study – Summary Assessment

- Relative to Ideal impact, Actual impact overall was
  - Less than anticipated
    - Especially in Physical Definition and Design Validation steps
  - Earlier in the life cycle than anticipated
    - Provided higher impact in Needs Analysis
    - Identified some needed information
    - Uncovered additional questions to be addressed by sponsor organizations

- Impact to Concept Exploration and Concept Definition phases was lessened due to Needs Analysis phase deficiencies
  - Information was insufficient to support CE and CD activities
  - Efforts diverted to the Needs Analysis phase

Systems Engineering Assessment Methodology – Potential Applications

- Program Office planning and tasking
  - Help to identify information needs and potential gaps
  - Help to visualize activities and what makes them successful
    - Map each activity to appropriate step(s) and identify information that precedes it as well as what steps it supports in turn
- Coordination of efforts
  - Can be a common means of coordination between organizations
  - Set expectations for inputs and outputs for task activities
    - Clarify deliverables impact and stakeholders

Summary

- This Methodology was useful to visualize the effectiveness of real-world systems engineering activities.
- Expect this Methodology to be useful in assessing the effectiveness of other programs so that additional lessons can be learned towards future improvements.
- Anticipate this Methodology may provide additional insight to sponsors and to internal SE teams in assessing what is required to support a given effort.