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System of Systems Technology Analysis and Selection Methodology

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Agenda

- Problem Overview
- Challenges of Systems Engineering
- Technology Selection Methodology
- Notional Example

Overview

- System of Systems (SoS) leverage considerable amounts of technology from existing programs of record (POR)
- These SoS need to evolve over time as additional functionality is planned for incorporation into future increments of the SoS
- Over time, this will result in very complex and diverse SoS engineering activities
- In order to support incremental development of a SoS over time, a portfolio of PORs, COTS, and GOTS in various stages of development needs to be compiled that can be allocated to SoS increments
- A methodology is required to select components for incorporation into a future SoS increment and a method to monitor the overall developmental progress of those increments
- The constraining feature of this problem is that any method developed to meet the needs of this type of incremental development must accommodate the unique challenges of SoS engineering

Problem Overview

Problem Overview

- A SoS is defined as “a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities”*

- The development and acquisition of an SoS pose challenges above and beyond those encountered during a traditional system acquisition program

- Traditional systems engineering approaches and tools are often insufficient to address these SoS challenges without adaptation

- One critical SoS engineering challenge that must be addressed is identification, selection, and management of the portfolio of systems that make up an SoS

*Source: Department of Defense (DoD), 2004, Defense Acquisition Guidebook Ch. 4 “System of Systems Engineering," Washington, DC: Pentagon, October 14

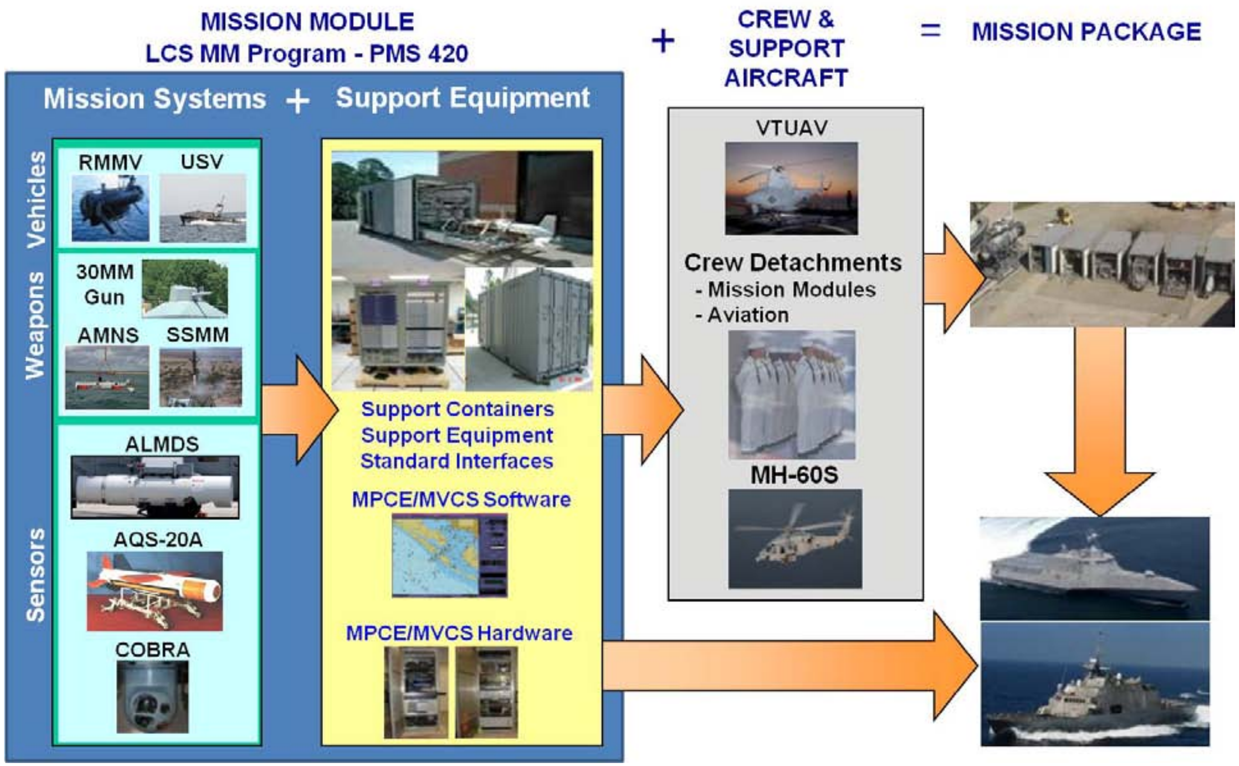
LCS Mission Modules as a SoS

- PEO LMW / PMS 420 is responsible for the development, acquisition, and sustainment of a series of Mission Modules to be used on the Littoral Combat Ship

- The modules leverage considerable amounts of technology from existing POR

- These modules will evolve over time as PMS 420 deploys new increments of the mission modules

- This has resulted in very complex and diverse SoS engineering challenges and procedures



Problem Scope

- PMS 420 is currently developing a methodology that will aid in the evaluation of different candidate technology options and architectures, while focusing to incorporate the relative cost, maturity, schedule, and performance parameters

- Technology or component selection for a system is implemented via a traditional trade study

- Because the LCS Mission Modules constitute several independent SoSs, the challenge is to ensure that the structure of any technology trade methodology captured the unique aspects of SoS engineering

LCS MM SoS Technology Insertion Trade Objectives

- Desire to leverage an existing evaluation method that is adaptable to changes in the warfighter's needs and/or budgetary focus

- Need to account for decision factors that span system maturity, performance, cost, and development time

- Objective to leverage other programmatic tools, metrics, and processes to the extent possible in order to minimize overlap of efforts and reduce duplication of data

- Must allow for the future evolution of semi-automated programmatic tools to implement the methodology

The Challenges of System of System Engineering

Characteristics of an SoS

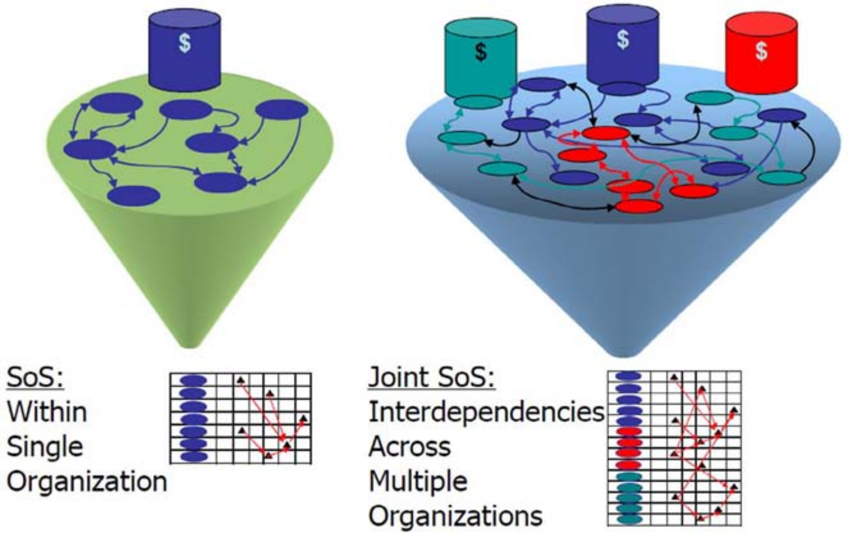
- Maier identified the defining characteristics of a System of Systems*

SoS Characteristic	Mission Module Characteristic
Operational Independence of Elements	Mission Modules are composed of independent mission systems, each of which could be used independently
Managerial Independence of Elements	Many mission systems are independent programs of record
Evolutionary Development	Mission modules will be developed in evolutionary increments
Emergent Behavior	Mission systems work together to provide capability (e.g., sensor mission systems provide targeting data for weapon mission systems)
Geographical Distribution of Elements	Mission Modules contain multiple vehicles that deploy from the LCS

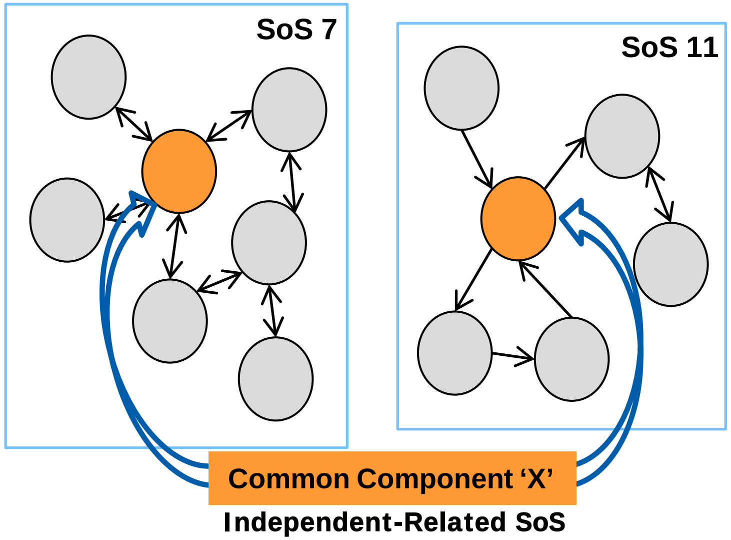
*Source: Maier, M.W., "Architecting Principles for System of Systems," Systems Engineering, Vol. 1, No. 4, 1998, pp. 267-284

Types of SoS

- SoS
  - Individual Components or Systems that are integrated into a over-arching system to provide unique capabilities
- Joint SoS
  - Components or Systems, that belong to multiple organizations, which are integrated into an over-arching system
- Independent-Related SoS
  - Independent functionalities, but commonly used components. Potentially within a single organization



Source: DoD Systems Engineering Guide for Systems of Systems, Version 1.0, August 2008



Each of the acknowledged SoS comes with its own set of acquisition and management issues

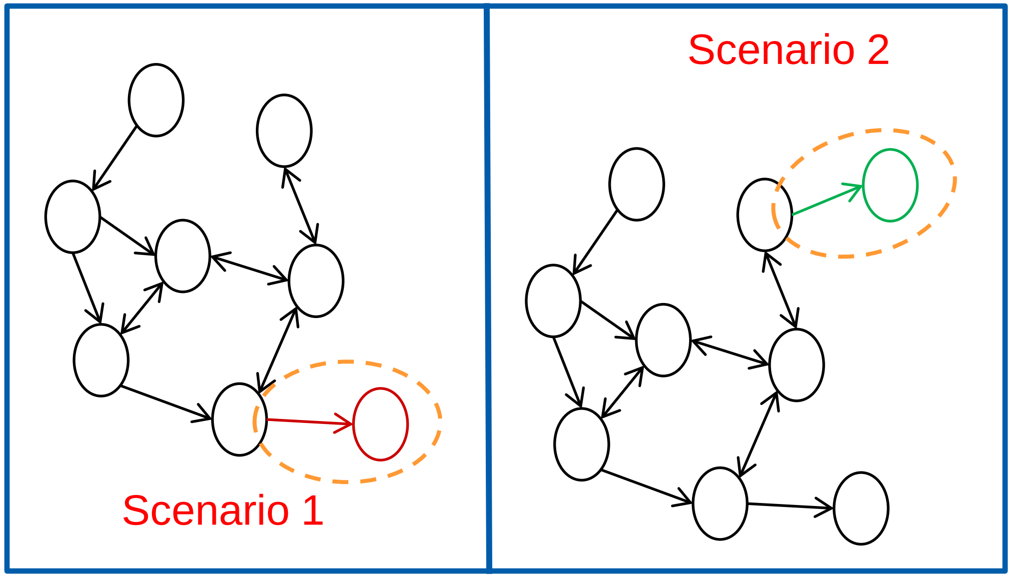
SoS Impacts on Component Evaluation

- Existing systems and components may need modifications to allow integration into the SoS
- Component options may meet a subset of SoS requirements “out of the box”
- Modifications will affect SoS development, cost, performance, and schedule risk
- The SoS may impose additional constraints on the constituent systems

SoS Trade-Off Scenarios

- Two Main SoS Trade-Off Scenarios
  - Replacement of Existing System (Scenario 1)
  - Addition of New System (Scenario 2)

- If a system is used in more than one variation of the SoS, should the system be replaced in some or all of the variations of the SoS?



System Replacement

- There are several instances where a constituent component or system would need to be replaced
  - End of Life-Cycle for the system or component
  - Cancellation of a constituent system's acquisition program
  - A system or component is not meeting desired performance goals
  - A system or component does not have the functionality that is needed
  - Modification of existing program requirements to include new functionality
- System or component selection methods must account for cost, maturity, schedule, & performance
- Insertion considerations for new systems or components must be based not only on the projected impact to a given focus area/capability, but on all of the capabilities/missions of the SoS
  - In some instances it is conceivable that the negative impact on the overall system outweighs the gains in a single area of operation

Technology Selection Methodology

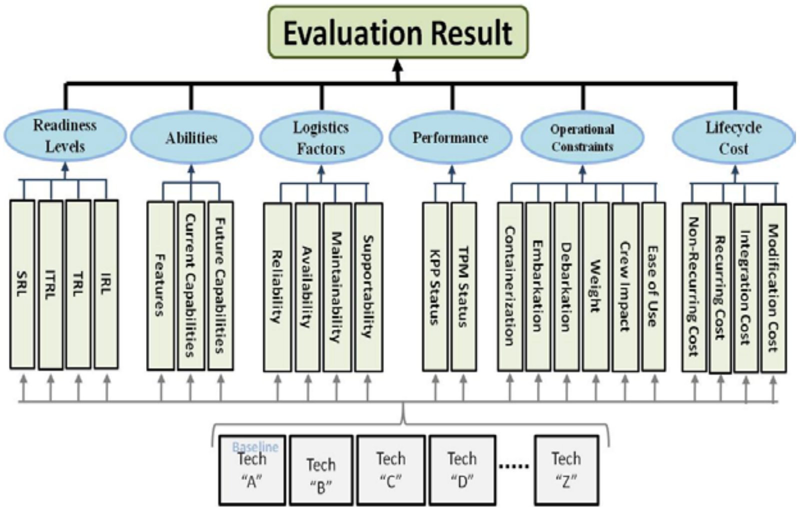
Survey and Analysis of Possible Methods

- A survey of existing trade methodologies was conducted with an emphasis on identifying methods with the following attributes:
  - The method must be flexible enough to easily accommodate changes in decision criteria
  - The method must allow decision makers to adjust criteria weightings in an intuitive manner
  - The method must be implementable in software
  - The method should have a history of demonstrated effectiveness on other programs
- Based on these criteria, four candidate trade methodologies were identified for consideration:
  - Analytic Hierarchy Process (AHP)
  - New Approach to Appraisal (NATA)
  - Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
  - Kepner Tregoe

Our Selection

- The results of our research led us to select the Analytical Hierarchical Process (AHP)
  - Well established methodology
  - Relatively simple to add some modifications
    - To handle the needs of PMS 420
    - To deal with the potential of 'Rank Reversal'

- Methodology is adaptable and can be applied to a wide variety of development efforts
  - Criteria can be adapted based on the SoS
    - Some turned off for certain analysis
  - Weightings can easily be updated by a pair wise comparison
  - The structure of the hierarchy is designed for quick modifications



Some of the Critical Factors that were Considered

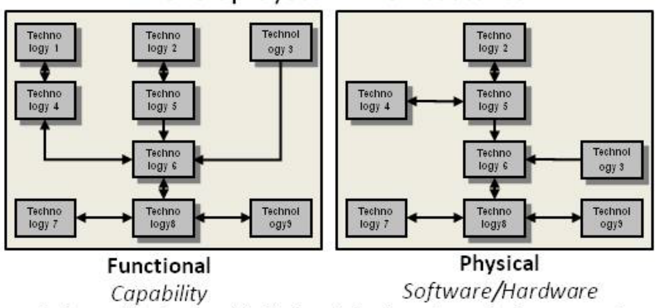
- Number of SoS Variations Affected
- New Inter-system Integrations
- Life-Cycle Costs
  - Recurring
  - Non-recurring
- Performance
  - Technical Performance Measures status
  - Key Performance Parameters status
- Readiness Levels
  - TRL
  - IRL
  - SRL
  - ITRL
- Abilities
- Operational Constraints
- Logistics Factors
  - Reliability
  - Availability

Characteristics of the Trade Approach

- Not all criteria apply to every selection decision
  - E.g., Weight would not be an appropriate criterion when selecting software
- Criteria weights and valuations must be tailored to each decision
  - Different factors are important in different situations
  - E.g., an immature technology may be more acceptable if slated for a future increment as opposed to the current increment
- Emphasis on evaluation against the entire SoS
  - Consider the impact on the entire SoS architecture
  - Impact on over-arching KPPs and TPMs
  - Just because a system is an outstanding individual performer does not mean that it will work well within the SoS

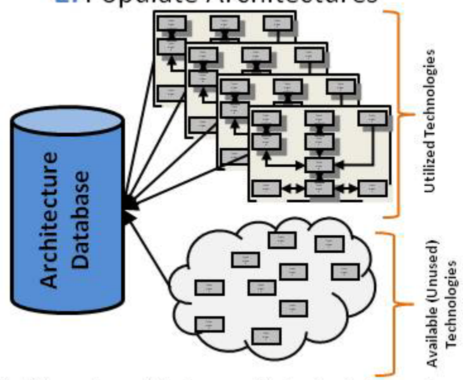
Tailored Methodology

1. Develop System Architectures



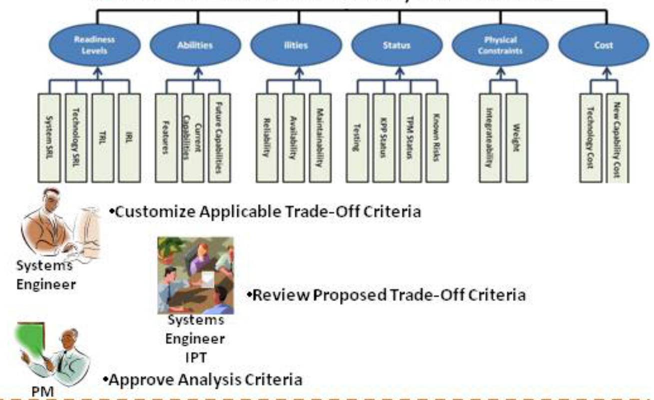
System architecture provides the foundation for system maturity assessments (SRL, CRL, etc.)

2. Populate Architectures

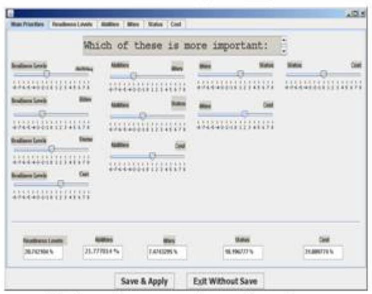


Details of the system architectures and the technologies are stored in the Architecture Database

3. Define Trade-Off Analysis Criteria

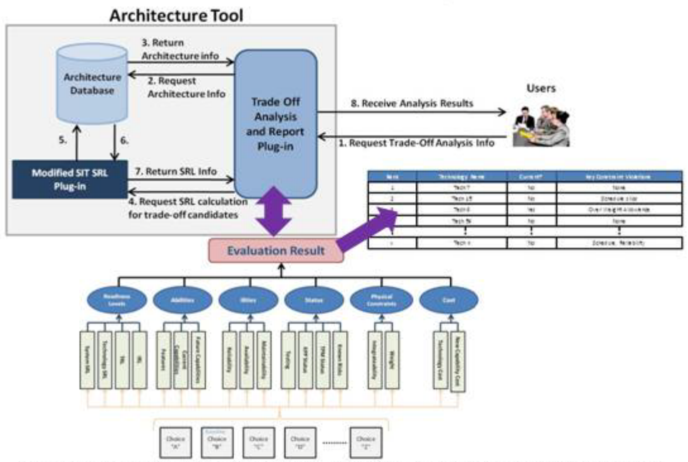


4. Define Analysis Criteria Weightings



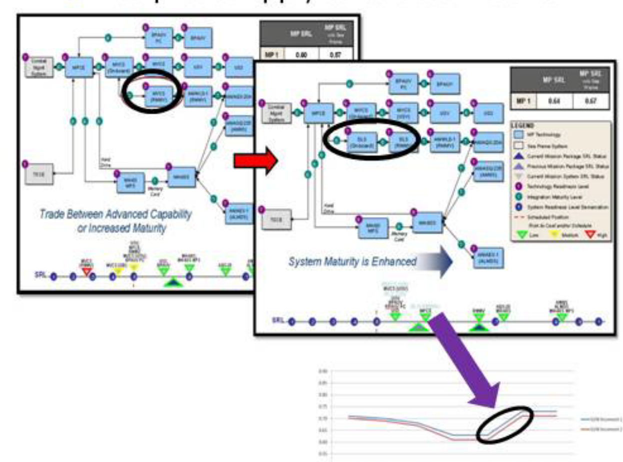
Weighting values are selected based on the programs current focus and direction

5. Calculate Trade-Off Analysis

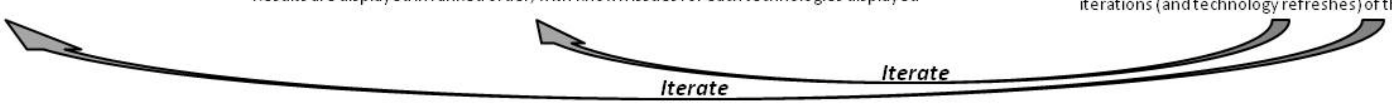


Data of the currently utilized and available technologies are compared in the analysis
Results are displayed in ranked order, with known issues for each technologies displayed

6. Interpret & Apply Calculated Results



Outputs of the analysis are used to make decisions that will impact the future iterations (and technology refreshes) of the Mission Packages



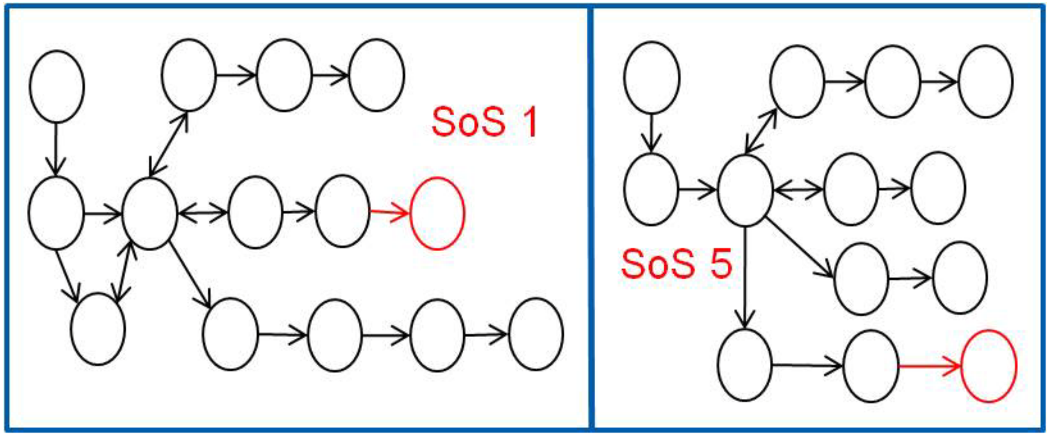
Approach to Implementation

- Details of Architecture Development
  - The formulation of several views of system architecture for the SoS
  - This is a key step in enhancing the overall SE efforts
- Populate architecture tools
  - Enter system architecture data
  - Design architecture database for both utilized and non-utilized components
  - Ensure database schema is optimized for SoS levels of detail
- Detail Trade-Off Criteria
  - Setup a hierarchical structure of Criteria and associated Sub-Criteria
  - Initial set should include as much detail as possible
    - List can later be reduced, depending on components to be analyzed
- Select the Criteria weights
  - Perform a Par wise comparison to determine the percentages

Notional Example

Trade-Off Example

- We created a scenario in which there are 2 variations of an SoS with a common component that needs to be replaced



- There are three replacement options available

- Utilized a DAU classroom example to provide criteria values

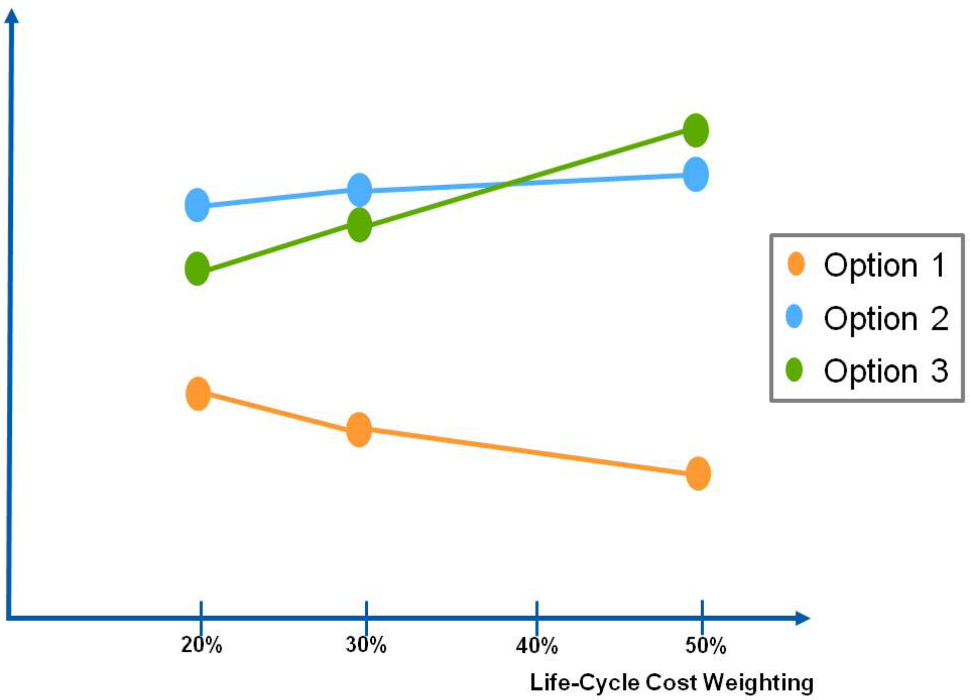
- Our current trade-off calculator was adapted to this example
  - Removed programmatic detail
  - Adapted DAU framework to correlate with our structure

Example Details

Criteria	Sub-Criteria	Source	Option 1	Option 2	Option 3
Performance					
	TPM Status	Speed Rating	3 mph	40 mph	32 mph
	KPP Status	Capability Performance	80 %	65 %	72 %
Operational Constraints					
	Weight	Weight	1600 kg	575 kg	500 kg
	User Impact	Training	40 hr	20 hr	25 hr
Life-Cycle Costs					
	Recurring Costs	Maintenance, O&S, Disposal	$ 1820	$ 1680	$ 1450
	Non-Recurring Costs	Development, Procurement	$ 1300	$ 1100	$ 1400
⋮	⋮	⋮	⋮	⋮	⋮

Example Results and Implications

- Recommended options do change with the shifting of the Criteria weights
- While the recommendations do change, the shift that they experience is restrained
- The example indicates that for the 2 SoS, Option 2 or Option 3 would be beneficial choices
  - The customer could feel confident with either of those choices



Summary

- It has been established that SoS engineering is notably more complex and intricate than regular Systems engineering
- These challenges will be amplified by the need to add or remove portions of the SoS
- The early design of an architecture, and preparation of a trade-off methodology will reduce the impacts of the required component replacement
- Once established, this comparison methodology is simple to maintain, easy to use, and produces actionable results

Questions?

Backup Slides

Abstract

NORTHROP GRUMMAN

One issue that affects development of both systems and system of systems (SoS) is the need to remove and replace one or more components, with minimal impact to risk, schedule, and cost of the program. Usually, this has been performed on a case-by-case basis when major problems or funding challenges have arisen. Rather than continue to be perceived as a “Reactionary Only Approach”, programs are beginning to research and seek out methodologies and processes that are forward thinking, while attempting to be precognitive. In order to accomplish this direction, a uniform process must be developed that will allow for the program managers to make accurate and consistent appraisals of all of the component options for their program. The US Navy (PMS 420 / SSC Pacific), the Northrop Grumman Corporation, and the Stevens Institute of Technology have been collaborating to develop such a trade-off methodology for systems and SoS. The concept will leverage the previously created System Readiness Level as a measure of system and SoS development from a maturity / milestone perspective. Added to this will be a system performance monitoring approach that provides insight into both current and anticipated performance. By taking into account the maturity and development status of various components, the method defines a range of projected performance growth and yields insight into the degree to which a given option is or could meet requirements. This allows for a true trade-off analysis capability that can be used to examine the extent to which a set of component options either meet budget constraints or maximize performance. This paper will define the trade-off and selection methodology and demonstrate its value through implementation on a relevant example. With this application, the methodology will provide the program manager with the knowledge to make more informed decisions.

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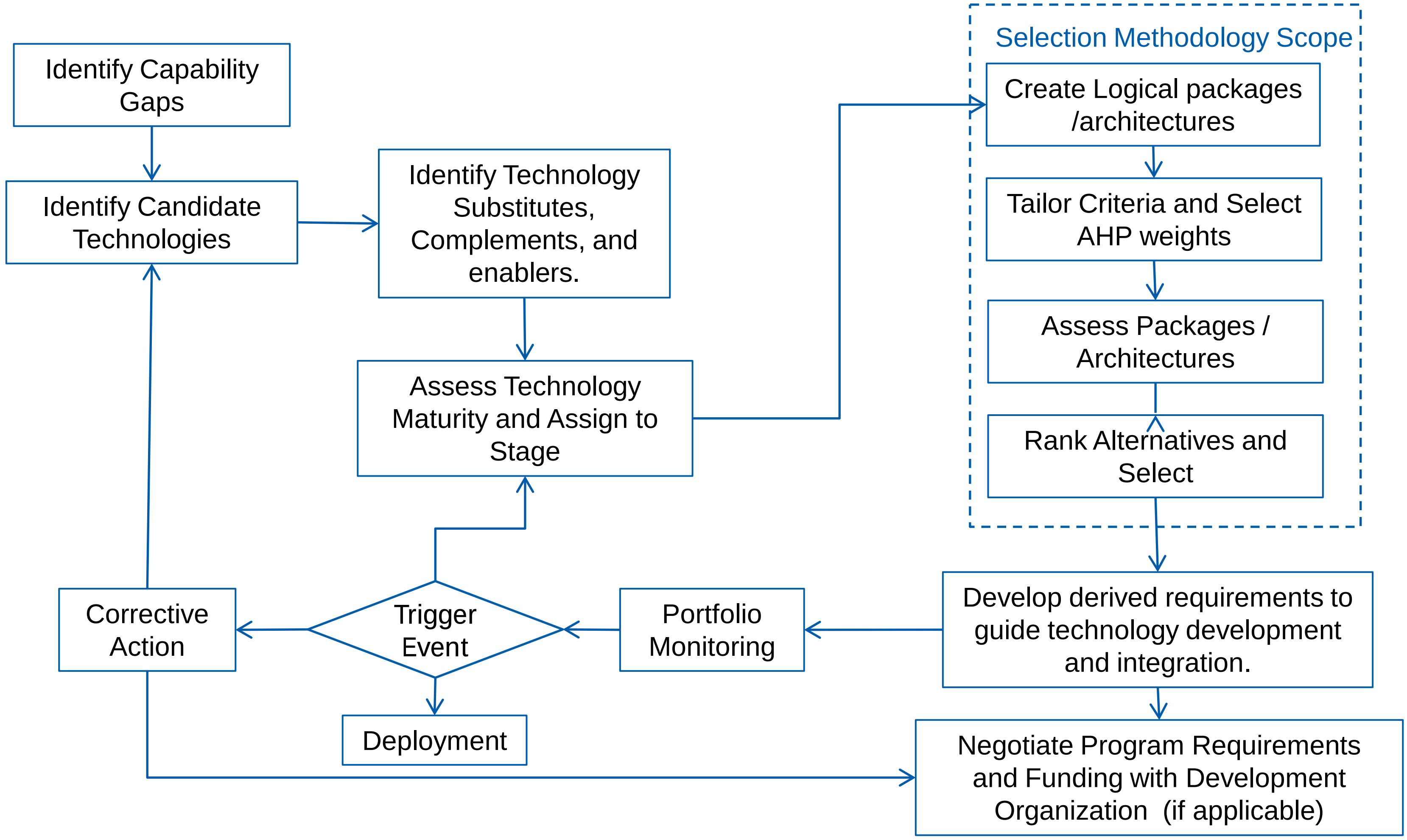
Technology Selection and Management Process



Assessment of SRL Criticisms

- The SRL issues raised by Dr. Kujawski are valid
- The very limited way that PMS 420 is using SRL is an acceptable deviation from theory because it compensates for the some of these issues
- That is not the case for some of the SRL derivative methods that have been developed. These exacerbate the issues with SRL rather than mitigate them
- PMS 420 does not use these SRL derivative methods
- SRL is a starting point for assessing system maturity, but it is not the end point
- There are opportunities to further mitigate the issues raised by Dr. Kujawski and improve the assessment of system maturity

SRL Calculation

- The SRL is not user defined, but is instead based on the outcomes of the documented TRL and IRL evaluations

- Through mathematically combining these two separate readiness levels, a better picture of overall complex system readiness is obtained by examining all technologies in concert with all of their required integrations

SRL = IRL x TRL

$$\begin{bmatrix} SRL_1 & SRL_2 & SRL_3 \end{bmatrix} = \begin{pmatrix} IRL_{11} & IRL_{12} & IRL_{13} \\ IRL_{12} & IRL_{22} & IRL_{23} \\ IRL_{13} & IRL_{23} & IRL_{33} \end{pmatrix} \times \begin{pmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{pmatrix}$$

$$\text{Composite SRL} = 1/n\left(SRL_1/n + SRL_2/n + SRL_3/n\right)$$

$$= 1/n^2\left(SRL_1 + SRL_2 + SRL_3\right)$$

- These values serve as a decision-making tool as they provide a prioritization guide of the system's technologies and integrations and point out deficiencies in the maturation process

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