



Performance Prediction and Methodology for Monitoring PARMs in a SoS development

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Session: System of Systems



Overview

- Mission Module Definition, History, & Status
- SoS Acquisition Approach
- Challenges in Monitoring SoS Performance
- System Performance Measure Methodology
- Summary



PMS 420 LCS Mission Modules

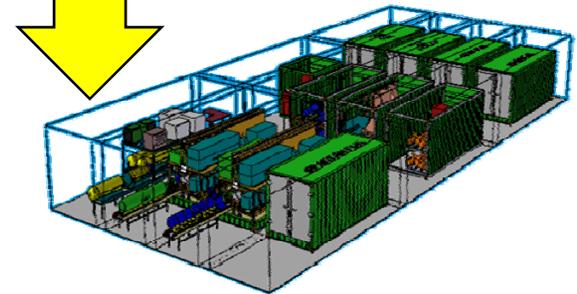
Littoral Combat Ship (LCS)

- **Optimized for warfighting in the littorals**
 - Unique designs for unique environment
 - Fast, maneuverable, shallow draft
- **Targeted at critical capability gaps**
 - Reconfigurable single-mission focus
 - Mines; small fast surface craft; diesel submarines
- **Modular Open Systems Architecture approach**
 - Flexible system for dynamic battlespace
 - Advanced unmanned air, surface, and underwater vehicles
 - Onboard sensors, weapons, command and control
- **Naval and Joint Force multiplier**
 - Operational flexibility for sea superiority and assured access
 - Integral member of future surface combatant family of ships
 - Fully netted with the battle force

Navy Need: small, fast delivery vehicle with integrated focused mission package



**Littoral Combat Ship
Interface Control Document**





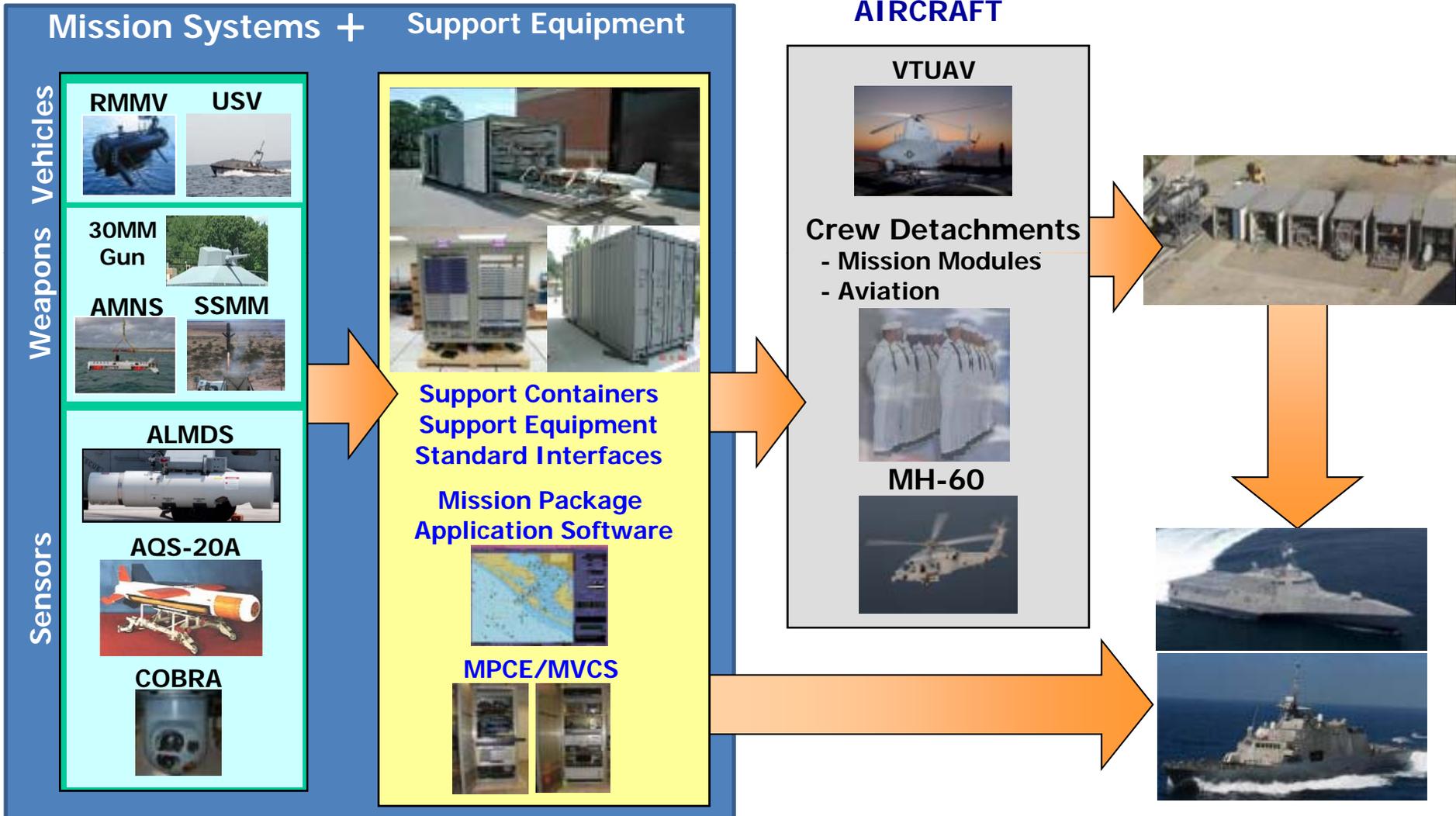
PMS 420 LCS Mission Modules

Mission Packages Defined

MISSION MODULE
LCS MM Program - PMS 420

+ CREW & SUPPORT AIRCRAFT

= MISSION PACKAGE



MPAS – Mission Package Application Software MPCE – Mission Package Computing Environment MVCS – Multi Vehicle Communication System



Overall LCS MM Program Status

- MCM Mission Module program is executing per plan (schedule & funding)
 - MCM DT on track to begin in JUN 2011
 - MCM OT on track to begin Q4 FY12
 - MCM MP IOC FY13
- Surface Warfare (SUW) Mission Package executing to revised plan due to congressional marks
 - SUW DT on track to begin in APR 2012
 - SUW OT on track to begin Q4 FY12
 - Awaiting Rapid Deployment Capability / POM 13 guidance for Surface-to-Surface Missile Module way forward
 - SUW MP IOC FY13
- Anti-Submarine Warfare (ASW) Mission Package
 - ASW Increment I development suspended with MP #1
 - IWS-5 leading risk reduction with at-sea demo in FY12
 - ASW Increment II planning begins in FY12 and development begins in FY13
 - ASW MP IOC FY16



Acknowledged SoS Challenges

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Acknowledged System of Systems Challenges

- **Management and Oversight:** SoS systems engineers (SE) must be able to function in an environment where the SoS manager does not control all of the systems that impact the SoS capabilities and stakeholders have interests beyond the SoS objectives.
- **Management and Oversight:** SoS SE must balance SoS needs with individual system needs.
- **Implementation:** SoS SE planning and implementation must consider and leverage the development plans of the individual systems.
- **Implementation:** SoS SE must address the end-to-end behavior of the ensemble of systems, addressing the key issues which affect that behavior.

"The problems that need to be addressed are large and complex and are not amenable to solution by better systems engineering alone. Without a solid governance and management approach for an SoS, independent authorities who oversee the multiple governance processes of the DoD are unlikely to accept guidance from a systems engineer they do not control"

Ref: DoD System Engineering Guide for Systems of Systems, V1.0, Aug 2008 21

"Acknowledged" SoS have recognized objectives, a designated manager, and resources, but the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. It is one of four SoS types identified in *DoD System Engineering Guide for SoS, V1.0, Aug 2008*.

→ *Successful development and implementation of an "Acknowledged" SoS is dependent on collaboration between the SoS' and the constituent systems' SE and PM teams.*

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How is the LCS Mission Module Program Addressing Acknowledged SoS Issues?

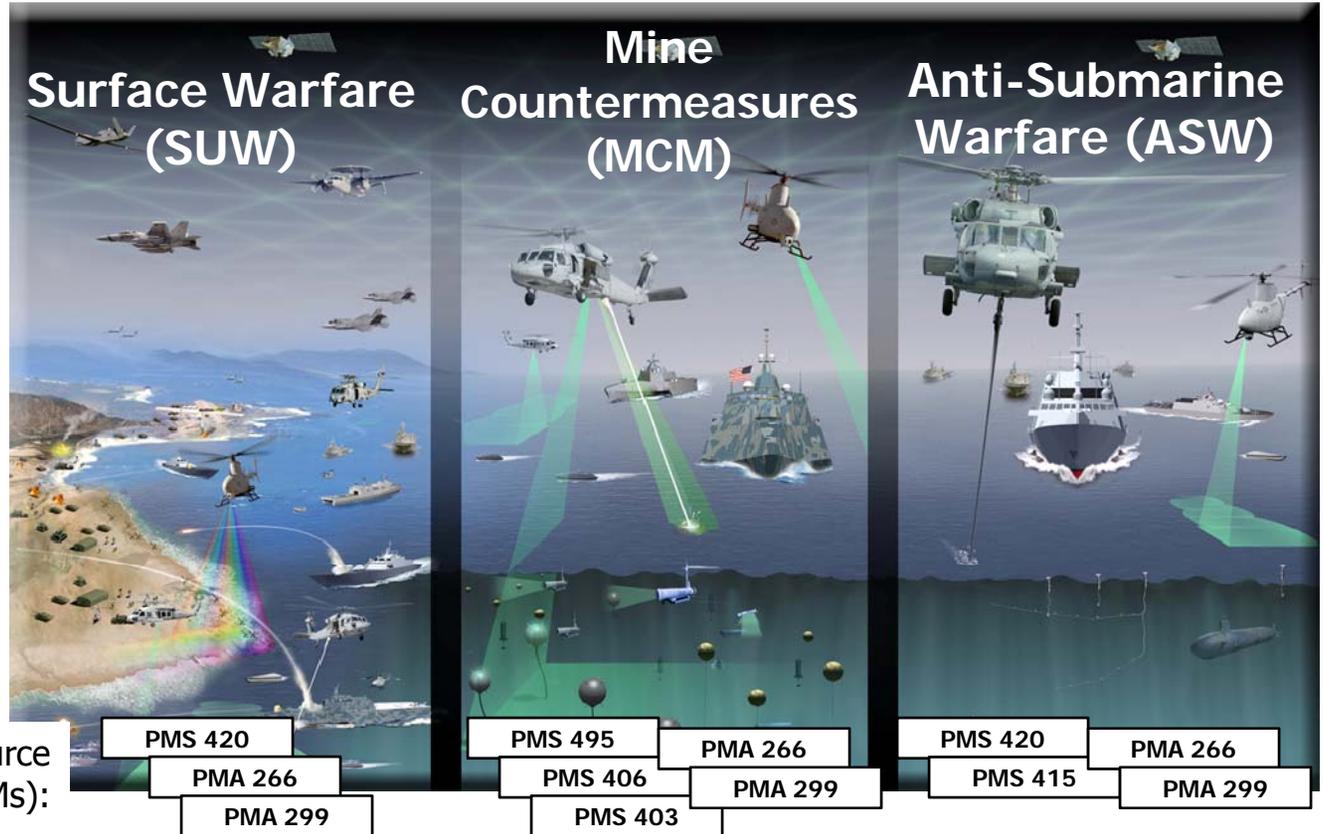
- **Ensuring System Maturity**
 - Monitoring the readiness of all technologies and integrations within the SoS environment
- **Enforcing Commonality**
 - Developing solutions which can work across the program to save time and money while increasing flexibility
- **Estimating SoS Availability**
 - SoS RMA defined: Am, Ao, Mission Availability, LCS MM perspective
- **Estimating SoS Performance**
 - Monitoring performance through KPPs/TPMs from a SoS perspective

PMS 420 is working at the forefront of SoS acquisition developing novel methodologies that provide SoS technical and management insight.



PMS 420 LCS Mission Modules

PMS 420 Acquisition Approach Relies Heavily on using Navy Warfare Centers as Lead System Integrators (LSIs)



Participating Acquisition Resource Managers (PARMs):

Warfare Centers are MP Lead System Integrators, and will assume TDA roles post MP development:



Production and integration is handed off to Northrop Grumman for LRIP:

NORTHROP GRUMMAN



TPMs are Used as Leading Indicators Through System Development

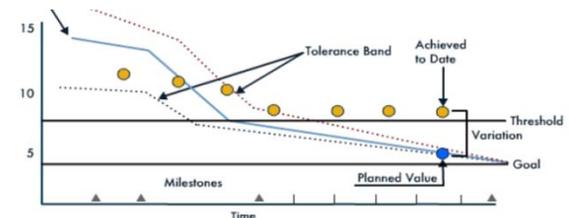
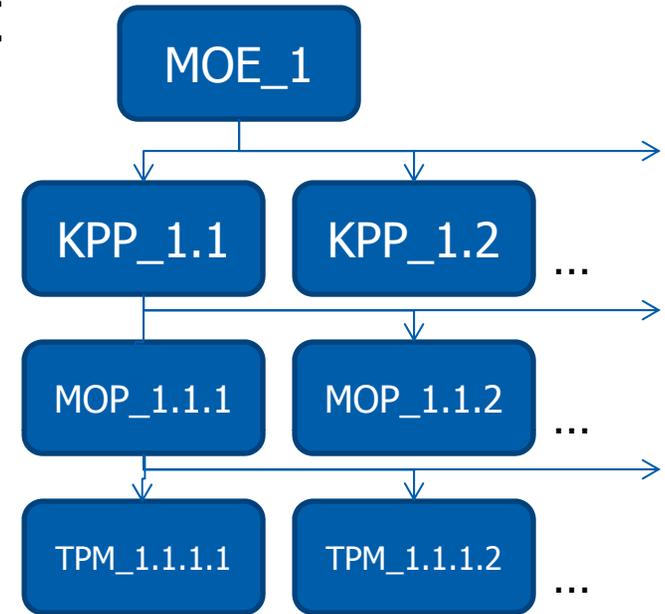
- **Measures of Effectiveness (MOEs):** generally used to define the level of operational success desired wrt to the mission environment.
- **Key Performance Parameter (KPP):** Key Performance Parameter required to meet operational success.
- **Technical Performance Measures (TPMs):** selected physical and functional characteristics that can be measured during testing/operations
- **Technical Performance Measures examples:**

System Specific:

- Fuel Efficiency
- Vehicle Weight
- Reliability (MTTR)
- Drag forces at speed
- Power train friction
- Etc.

SoS TPM:

- Time on Station
- System Weight (Veh + LH&R + spares)
- Reliability (MLDT)
- Integration Maturity
- Form Factor



TPM Recap, SYS 202 Intermediate Systems Engineering, Defense Acquisition University (DAU).

TPM provide insight to:

- Defining test objectives through engineering development phases,
- Monitoring and tracking technical risk through as a system progresses through engineering development phases

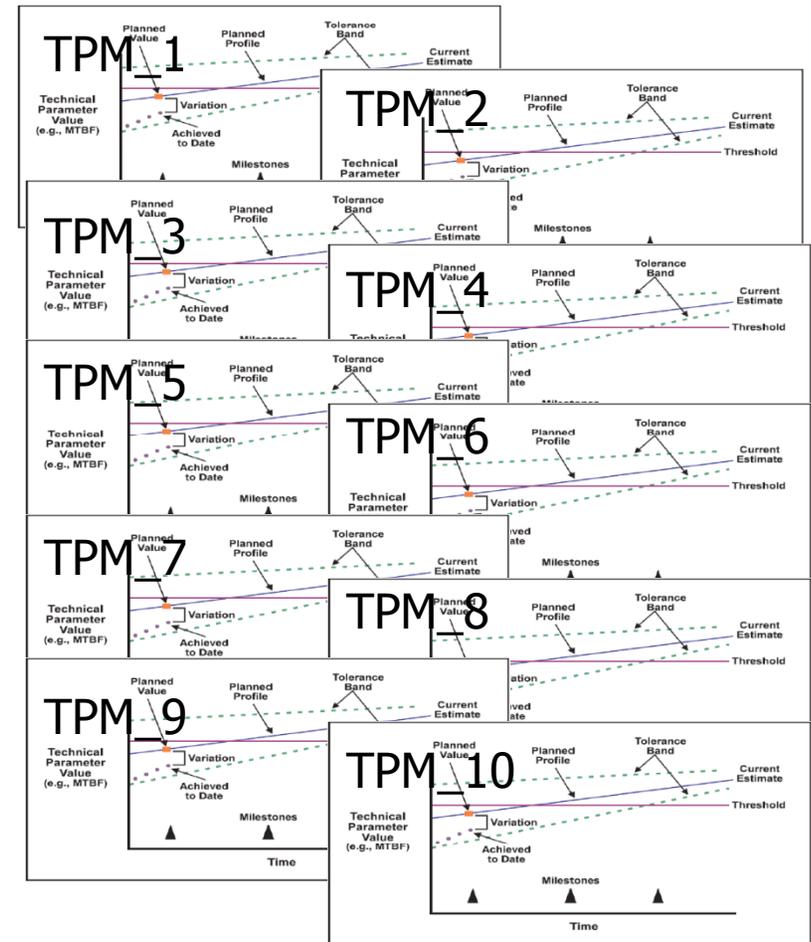
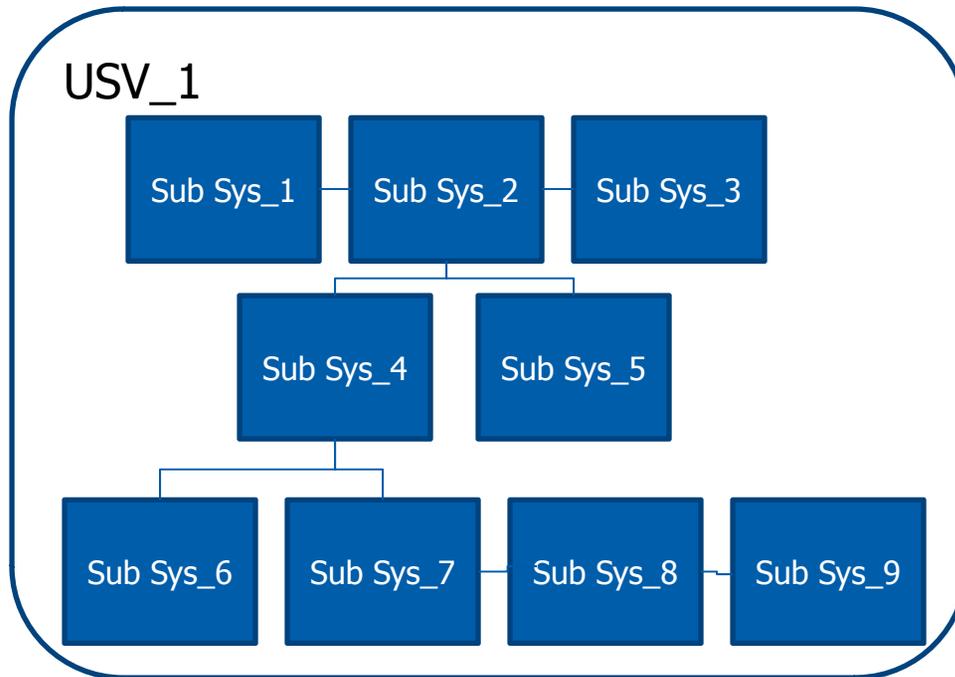
...but what makes a good SoS TPM that is measurable during development?



System of Systems (SoS) are inherently Complex – TPM Compounding Example

Guidance is to track between 6-10 TPMs:

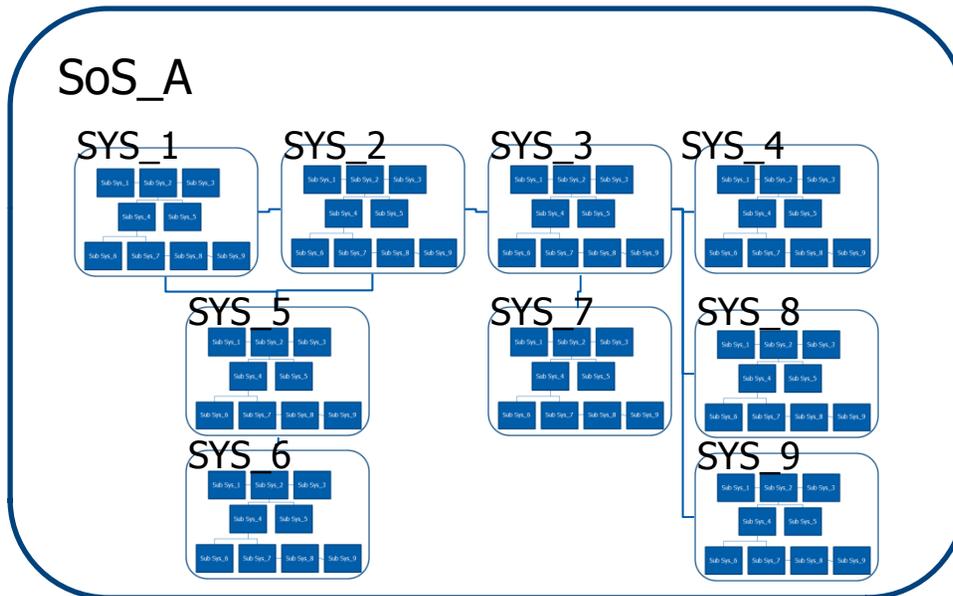
Consider "System A" with 9 Sub-Systems:





System of Systems (SoS) are inherently Complex – TPM Compounding Example

Now, Consider a System of Systems with 9 Sub-Systems (81 Sub-Systems):



Approx 90 TPMs are “inherited”:

- *Tracking all 90 TPMs increases the PM burden on the SoS Integrator*
- *Some TPMs may be NA to the SoS mission*
- *Others become less critical to the SoS mission because multiple systems are available to perform a required function*

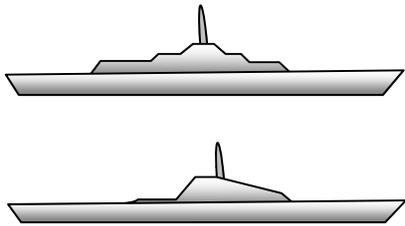
New Methodologies are necessary to allow the Systems Engineer to effectively track and understand TPMs in the Complex SoS Construct



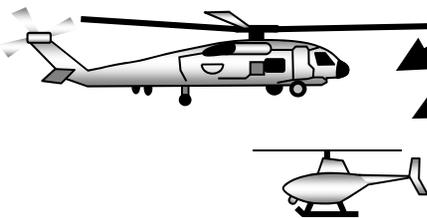
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LCS and its MPs are a Complex System of Systems

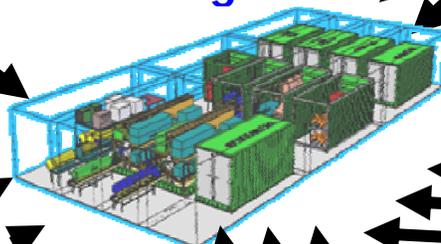
Seaframe:



Aviation:



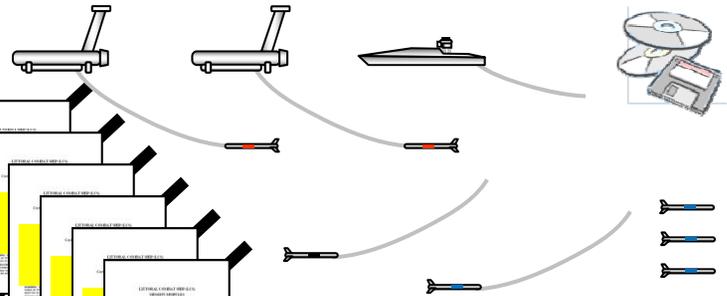
Notional LCS Mission Package



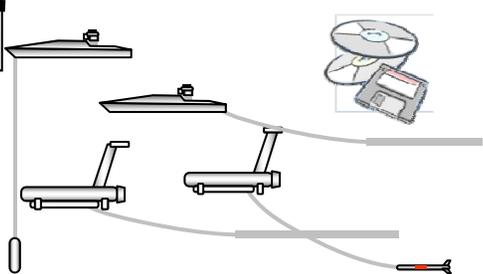
Surface Warfare Mission Module:



Mine Countermeasures Mission Module:



Anti-Submarine Warfare Mission Module:



LCS and its MPs are Challenged with the Integration of 15+ Systems Primarily Managed by Participating Acquisition Program Managers (PARMs)



Factors Impacting SoS Performance

Lets assume that SoS Performance can be defined as:

$$f(\textit{SoS capability, operational employment})$$

Where:

SoS capability = $f(\textit{SoS technical maturity, SoS integration, SoS support, \& System Performance})$ where the individual systems contribution/impact to the SoS can be determined and,

Operational Employment = $f(\textit{usage options (can a system in the SoS help meet a performance goal), usage rate (how much will it be used)})$

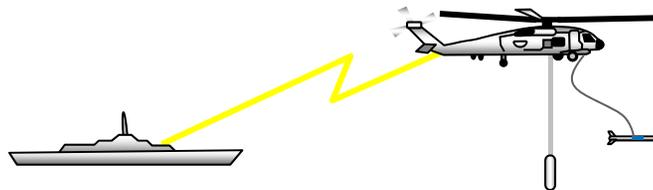
Proposed SPM Methodology:

- 1 - Identify the key factors related to SoS Performance
- 2 - Develop a non-linear formulation that will support the prediction of a notional SoS's Performance over time under various operational usage concepts and technology mixes.



Notional Detect to Engage Mission Thread

Single-System Employed:

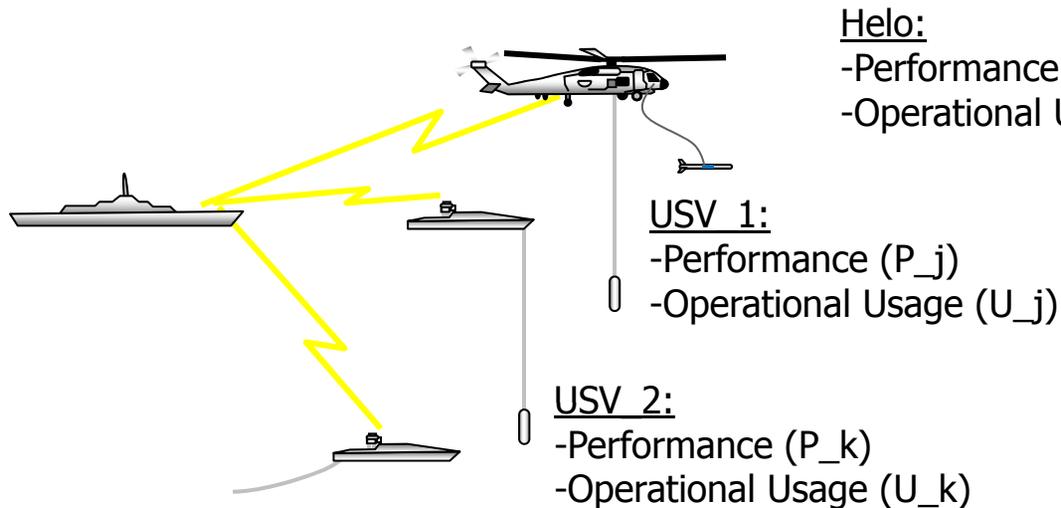


Limited to Helo:

- Performance (P_i)
- Operational Usage (U_i)

$$\text{CONOPS}_{x_n} = \beta P_{1n}$$

System of Systems Employment:



Helo:

- Performance (P_i)
- Operational Usage (U_i)

USV 1:

- Performance (P_j)
- Operational Usage (U_j)

USV 2:

- Performance (P_k)
- Operational Usage (U_k)

$$\text{CONOPS}_{x_n} = \beta P_{1n} + \eta P_{2n} + \delta P_{3n}$$

SoS construct allows:

- Multiple systems of various performance capability to contribute to the mission
- Reduce TOC with unmanned systems and established PORs!!
- However, effective SoS technical monitoring techniques are still evolving.

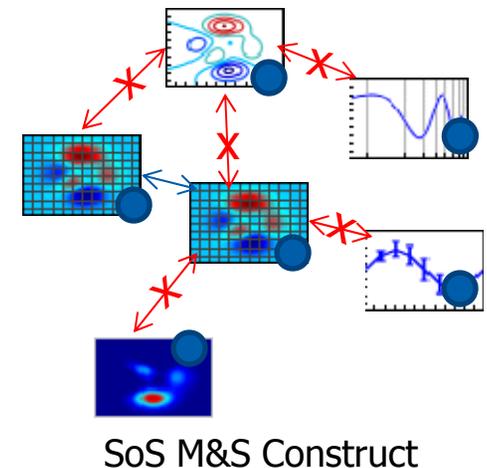
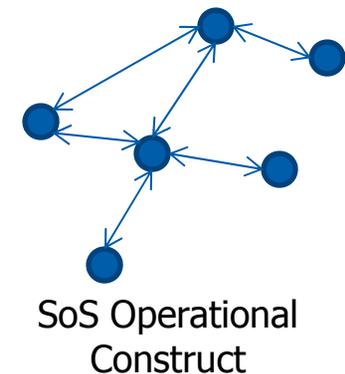


System Performance Measure (SPM)

"The SoS Systems Engineer must establish metrics and methods for establishing performance of the SoS capabilities... to identify the most important mission threads and focus the assessment on end-to-end performance."

Systems Engineering Guide for SoS, V1.0, ODUSD(A&T)SSE, 2008.

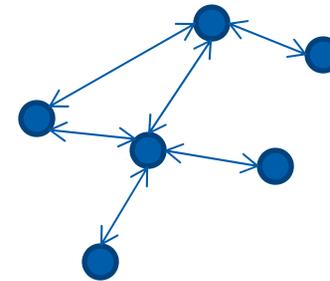
- TPMs are generally based on Models and Simulations (M&S).
- Developing and maintaining a M&S for a System of System (SoS) is expensive and often must be re-developed and re-compiled when systems are switched out, operational parameters change, etc.
 - *Using M&S to answer frequent data calls is an expensive and time consuming option*
 - *M&S are data intensive, which the SoS PM doesn't always have access to.*
 - *M&S for each system are fundamentally funded and managed by each PARM according to different time lines and are often domain specific.*
- Interoperable M&S frameworks are being developed, but we're not there yet...
- *System Performance Measure (SPM) (a la "TPM") is proposed to provide the SoS Program Manager with insight in to technical progress through development phases.*



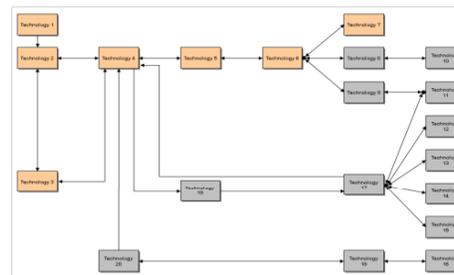


The Ten Step Plan Toward System Performance Measures (SPMs)

- 1) Define the notional SoS composed of "n" systems
- 2) Develop the notional mission strings
- 3) Map system level contributions towards the desired SoS performance
- 4) Define the notional system maturity growth paths in terms of a expected developmental capability/ performance
- 5) Account for where individual systems/technologies must be integrated to support the functional thread
- 6) Develop a performance corollary to reflect where multiple technologies work together to provide a unified capability

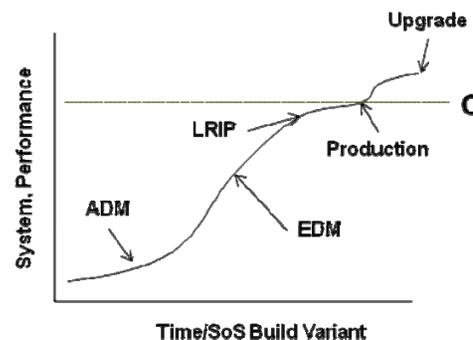


SoS Operational Construct



Mission Thread Analysis

Notional System of Systems				
Capability/ System	Key Performance Factor Impacted			
	Factor 1	Factor 2	Factor 3	Factor n
Technology 1	X	X	X	
Technology 2		x	X	
Technology 3	X	x	X	X
Technology 4				X
Technology 5	X	x		



$$P_{1n} = \omega_n * \alpha$$

$$P_{m(x,y,...)_n} = \omega_n * \alpha_{(x,y,...)}$$



The Ten Step Plan Toward System Performance Measures (SPMs) (cont'd)

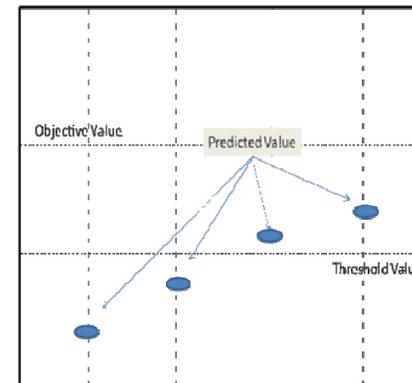
7) Define the methodology for mapping the performance factors and their associated technologies to potential CONOPS

$$\text{CONOPS}_{X_n} = \beta P_{1n} + \eta P_{2n} + \delta P_{3n} + \varepsilon P_{4n} + \gamma P_{5n}$$

8) Combine and normalize the outcomes from the CONOPS analysis to provide a single point metric indicating the performance expectation of the defined SoS state

$$\text{SPM}_{\text{search}n} = \{ \text{CONOPS}_{A(n)}, \text{CONOPS}_{B(n)}, \text{CONOPS}_{C(n)} \} = \begin{bmatrix} \omega_{5n} & 0 & 0 \\ 0.5 \omega_{5n} & 0.5 \omega_{5n} & 0 \\ 0.5 \omega_{5n} & 0.25 \omega_{5n} & 0.25 \omega_{5n} \end{bmatrix} \times \begin{bmatrix} \alpha_{(1)} \\ \alpha_{(2)} \\ \alpha_{(3)} \end{bmatrix}$$

9) Use the predicted system maturation paths and their anticipated insertion points into the SoS to predict the probability that the production SoS will be able to satisfy its performance metrics



10) Combine and normalize the calculated values to arrive at a single point prediction on can the SoS provide the required performance related to the specified KPP

$$\begin{aligned} &\text{Performance Factor "n"} \\ &= [\text{CONOP}_A, \text{CONOP}_B, \text{CONOP}_C] \\ &= \text{AVG}(\text{CONOP}_A + \text{CONOP}_B + \text{CONOP}_C) \end{aligned}$$



Summary: Lessons Learned

- PARMs monitor the developmental status of individual systems by defining and measuring TPMs, which are a predictive tool to estimate anticipated performance through engineering development phases.
- The TPMs methodology does not apply well to the SoS construct for several reasons, including the:
 - Inherent complexity of the SoS
 - Inherent operational flexibility of the SoS
 - Constituent systems are often modified or utilized in different ways than specified in the systems original requirement set.
- A System Performance Measure (SPM) has been developed to provide the SoS Program Manager with insight into technical progress through development and/or incremental fielding of a SoS.
 - A non-linear SPM formulation that supports the prediction of a notional SoS's Performance over time under various operational usage concepts and technology mixes has been proposed.



PMS 420 LCS Mission Modules

Questions?



PMS 420 LCS Mission Modules

Title: Performance Prediction and methodology for monitoring PARMs in a SoS development

Authors: R. Volkert (SSC P), C. Jackson (SSC P)

Abstract: Today's acquisition environment is cost constrained and extremely dynamic. The System of Systems (SoS) construct is attractive as it leverages multiple Participating Acquisition Program Managers (PARMs) efforts and reduces technical risk as COTS/GOTS technologies can easily be integrated and removed from the SoS framework when technologies become obsolete. However, the traditional performance prediction and monitoring tools (TPMs, MOEs, MOPs, etc.) were developed to monitor independent system development. We find that these technical monitoring tools are insufficient as systems become increasing intertwined and intended to operate as a system within a SoS. The Littoral Combat Ship (LCS) Mission Modules (MM) is classified as an 'acknowledged' SoS, which has recognized objectives, a designated manager, and resources for the SoS. However, the constituent mission systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the constituent systems are based on collaboration between PMS 420 (the SoS manager) and the PARM (the constituent system manager). This complicates the task of a SoS manager who must navigate the evolving plans and development priorities of the SoS constituent systems, along with their asynchronous development schedules, to plan and orchestrate evolution of the SoS toward ultimately meeting the SoS performance objectives. The process that the LCS MM program office (PEO LCS/ PMS 420) has developed to monitor the technical performance of its constituent PARMs will be reviewed. Additionally lessons learned from applying these tools and processes within the context of an acknowledged SoS will be presented.



From a System to an Acknowledged System of Systems

Table 2-1. Comparing Systems and Acknowledged Systems of Systems

Aspect of Environment	System	Acknowledged System of Systems
Management & Oversight		
Stakeholder Involvement	Clearer set of stakeholders	Stakeholders at both system level and SoS levels (including the system owners), with competing interests and priorities; in some cases, the system stakeholder has no vested interest in the SoS; all stakeholders may not be recognized
Governance	Aligned PM and funding	Added levels of complexity due to management and funding for both the SoS and individual systems; SoS does not have authority over all the systems
Operational Environment		
Operational Focus	Designed and developed to meet operational objectives	Called upon to meet a set of operational objectives using systems whose objectives may or may not align with the SoS objectives
Implementation		
Acquisition	Aligned to ACAT Milestones, documented requirements, SE with a Systems Engineering Plan (SEP)	Added complexity due to multiple system lifecycles across acquisition programs, involving legacy systems, systems under development, new developments, and technology insertion; Typically have stated capability objectives upfront which may need to be translated into formal requirements
Test & Evaluation	Test and evaluation of the system is generally possible	Testing is more challenging due to the difficulty of synchronizing across multiple systems' life cycles; given the complexity of all the moving parts and potential for unintended consequences
Engineering & Design Considerations		
Boundaries and Interfaces	Focuses on boundaries and interfaces for the single system	Focus on identifying the systems that contribute to the SoS objectives and enabling the flow of data, control and functionality across the SoS while balancing needs of the systems
Performance & Behavior	Performance of the system to meet specified objectives	Performance across the SoS that satisfies SoS user capability needs while balancing needs of the systems

Ref: DoD System Engineering Guide for Systems of Systems, V1.0, Aug 2008



System of Systems Challenges

SoS increases the complexity, scope, and cost of both the planning process and systems engineering, and introduces the need to coordinate inter-program activities and manage agreements among multiple program managers (PMs) as stakeholders who may not have a vested interest in the SoS. The problems that need to be addressed are large and complex and are not amenable to solution by better systems engineering alone. Without a solid governance and management approach for an SoS, independent authorities who oversee the multiple governance processes of DOD are unlikely to accept guidance from a systems engineer they do not control, placing the systems engineer in an untenable position in attempting to support an SoS. An administrative/governance structure that addresses these realities will enable SoS SE to be more effective in all phases of the processes as outlined in this document. This document acknowledges these issues but does not make any recommendations for changes to existing management and control structures to resolve inter-system issues,