Proposed Methodology for Performance Prediction and Monitoring for an Acknowledged Systems of Systems

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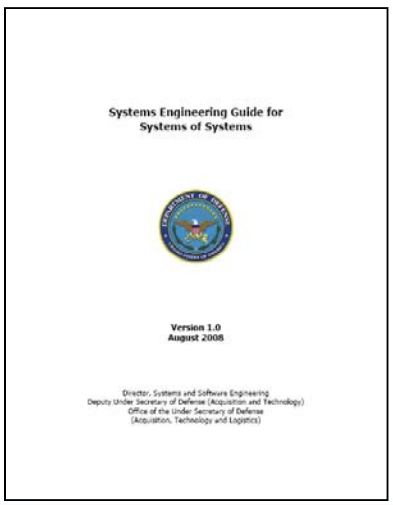
Overview

- Systems of Systems & the Management Challenges
  - Mission Modules Program
- Use of Metrics for Assisting Management
- Challenges in Predicting Performance for a SoS
  - Why TPMs may not work for a SoS
- Criteria for a SoS Performance Measure (SPM)
- Walking through a SPM Example
  - ASW Search Mission
- Conclusion

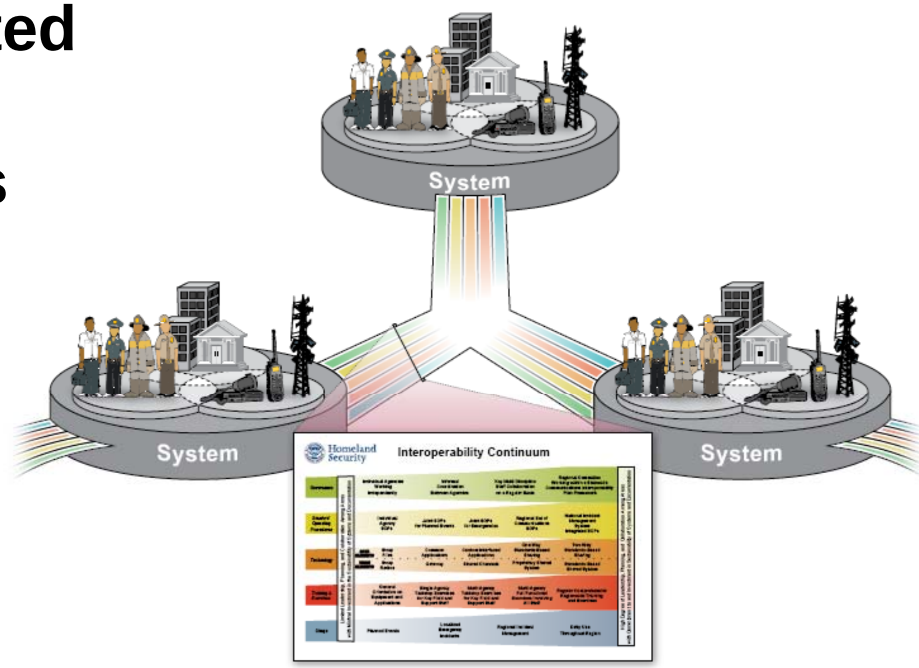
System of Systems Definition

- **An 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 [DoD, 2004(1)].**


Systems Engineering Guide for
Systems of Systems

Version 1.0
August 2008

Director, Systems and Software Engineering
Deputy Under Secretary of Defense (Acquisition and Technology)
Office of the Under Secretary of Defense
(Acquisition, Technology and Logistics)



PMS 420- Providing Focused Warfighting Capabilities

SoS Acquisition Challenges

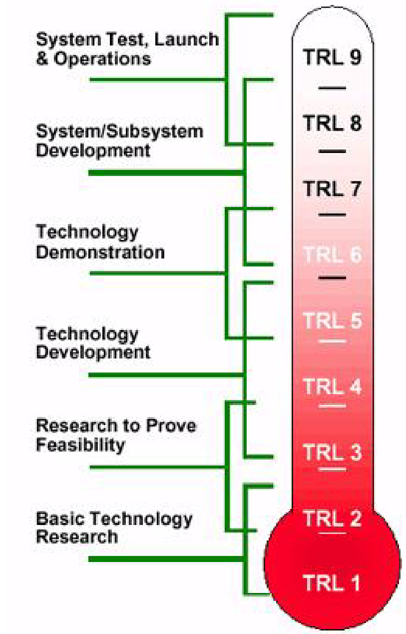
- SoS acquisition management - a significant increase in complexity over traditional system acquisition
- Development requires that significant numbers of technologies be integrated to one another
- Challenges traditional development monitoring tools and cost models
  - need to capture integration complexity
  - level of effort required to connect individual components
- Unintended Consequences - high degree of inter-linkage between components can cause unintended impacts to overall system performance
  - components are modified from original use
  - Technology change: replaced throughout the system life cycle

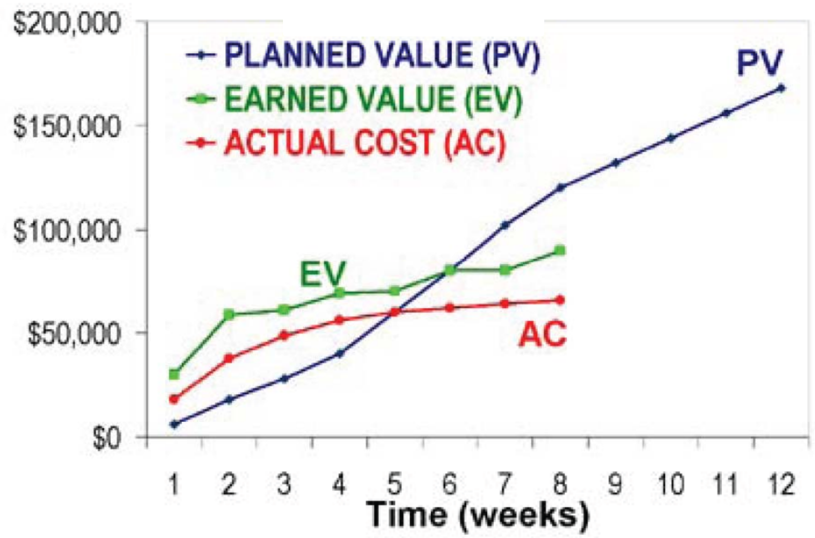
The result of this acquisition management paradigm shift has been significant schedule and cost overruns in SoS programs

What's Done today-
Technical & Financial

Various tools ***and metrics*** are used to monitor the status of system level development/risk:

- Technology Readiness Level
- Earned Value Management
- Manufacturing Readiness Level
- Systems Readiness Levels
- Integration Readiness Levels
- Software Readiness Levels





MRL	Definition
1	Manufacturing Feasibility Assessed
2	Manufacturing Concepts Defined
3	Manufacturing Concepts Developed
4	Capability to produce the technology in a laboratory environment.
5	Capability to produce prototype components in a production relevant environment.
6	Capability to produce a prototype system or subsystem in a production relevant environment.
7	Capability to produce systems, subsystems or components in a production representative environment.
8	Pilot line capability demonstrated. Ready to begin low rate production.
9	Low Rate Production demonstrated. Capability in place to begin Full Rate Production.
10	Full Rate Production demonstrated and lean production practices in place.

What’s Done today – Performance

Mission Needs/Critical Operating Issues

↓

Key System Performance Parameters

↓

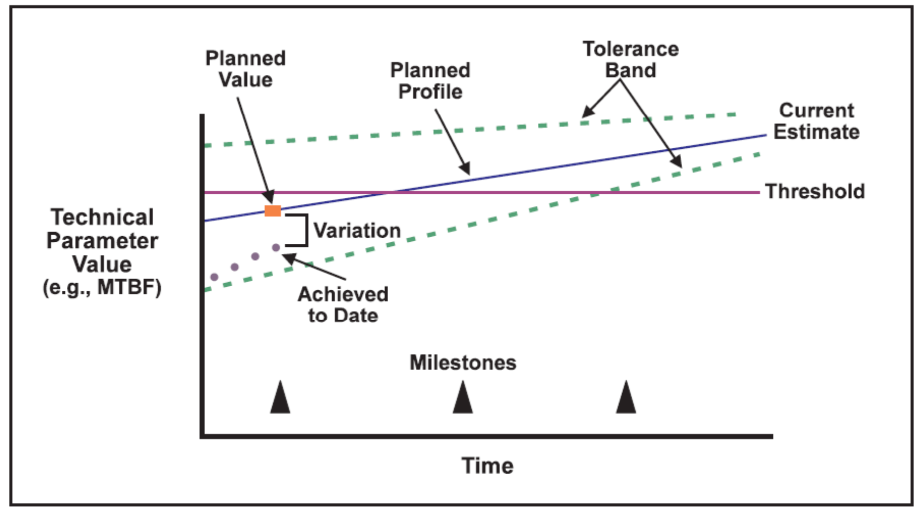
Measures of Performance (MOP’s)

↓

Technical Performance Measures (TPM’s)

PSM/INCOSE Technical Report. (2005). *Technical Measurement.* Roedler G.J. and Jones, C.

TPMs track the key indicators of system performance versus planned progress of Key Performance Parameters and other key effectiveness measures



U.S. Department of Defense . (2003). *Extension to: A Guide to the Project Management Body of Knowledge.* Ft. Belvoir, VA: Defense Acquisition University Press

TPMs: Used to Provide PM insight into likelihood of achieving Desired Performance (a metric)

What is a Metric from the PM Viewpoint

Definition of *METRIC*

1 *plural* **:** a part of prosody that deals with metrical structure

2**:** a standard of measurement <no *metric* exists that can be applied directly to happiness — *Scientific Monthly*>

3**:** a mathematical function that associates a real nonnegative number analogous to distance with each pair of elements in a set such that the number is zero only if the two elements are identical, the number is the same regardless of the order in which the two elements are taken, and the number associated with one pair of elements plus that associated with one member of the pair and a third element is equal to or greater than the number associated with the other member of the pair and the third element

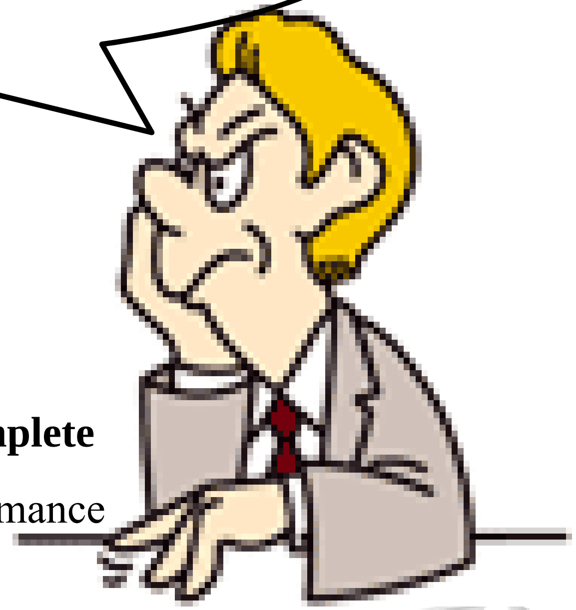
Synonyms: bar, barometer, **benchmark,** criterion, gold standard, grade, mark, measure, standard, par, touchstone, yardstick

Often Program Specific & more useful to gain insight into trends than in use as specific values data points

http://www.merriam-webster.com/dictionary/metric

Need – SoS PM ability to predict performance

How can I rapidly and reliably gain insight into if my program is on track to meet my performance requirements?



Performance Prediction is an issue during SoS Development

Occasionally done by Modeling & Simulation (M&S) of the proposed design

- For High Fidelity Results is **extremely costly**
- Limited ability to verify models **until product development is complete**

Somewhat monitored through the use reported system level Technical Performance Measures (TPMs).

- SoS performance is however not necessarily equal to the sum of system level performance
- Not all data is necessarily provided to the SoS Program Manager (PM), especially in acknowledged SoS's where the PM does not have direct control/authority over the System Level PM's.

Do existing metrics answer this need?

I asked, How can I tell if my program is on track to meet my performance requirements?

No-*TRL's, SRL's, TPM's, etc at the system level provide insight into potential of achieving system level performance but ;*

- *not the impact of their existing performance level or,*
- *how performance is impacted when system capabilities are combined into a SoS or,*
- *understanding of how various combinations and usage rates of the components systems may impact the overall performance results*

So how can we solve the problem of providing the PM with Insight?

So how can I tell if my program is on track to meet my performance requirements?

Proposed 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.
3. Identify and document the constraints on the non-linear model that would be required for a linear approximation model to be valid.

So how can we look at the factors determining SoS Performance?

Lets assume that SoS Performance can be defined as:

ƒ(SoS capability, operational employment)

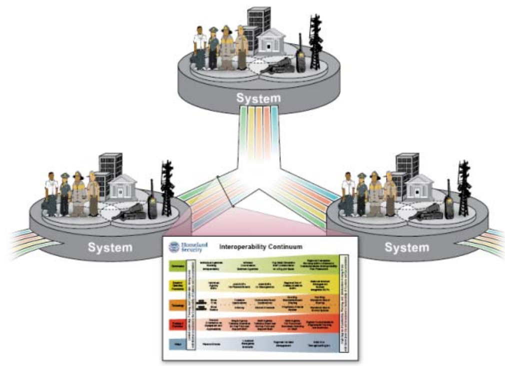
Where:

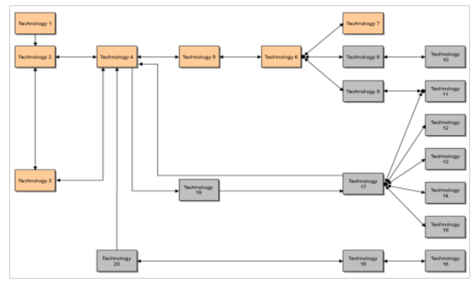
SoS capability = *ƒ(SoS technical maturity, SoS integration, SoS support, & System Performance)* where the individual systems contribution/impact to the SoS can be determined and,

Operational Employment = *ƒ(usage options (can a system in the SoS help meet a performance goal), usage rate (how much will it be used))*

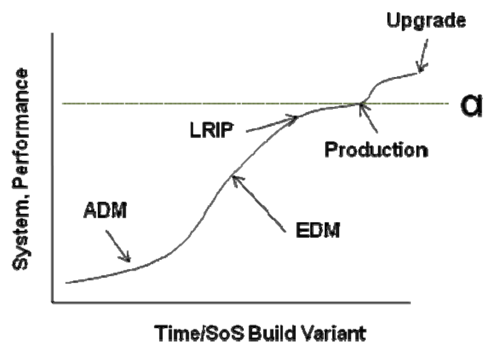
A Ten Step Plan for predicting SoS Performance

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





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



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

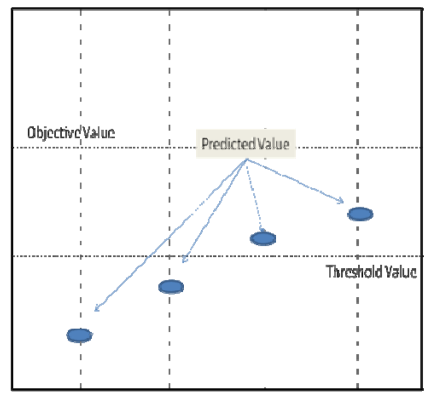
$$Pm_{(x,y,..)n} = \omega_n * \alpha_{(x,y,...)}$$

A Ten Step Plan for predicting SoS Performance

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

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

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

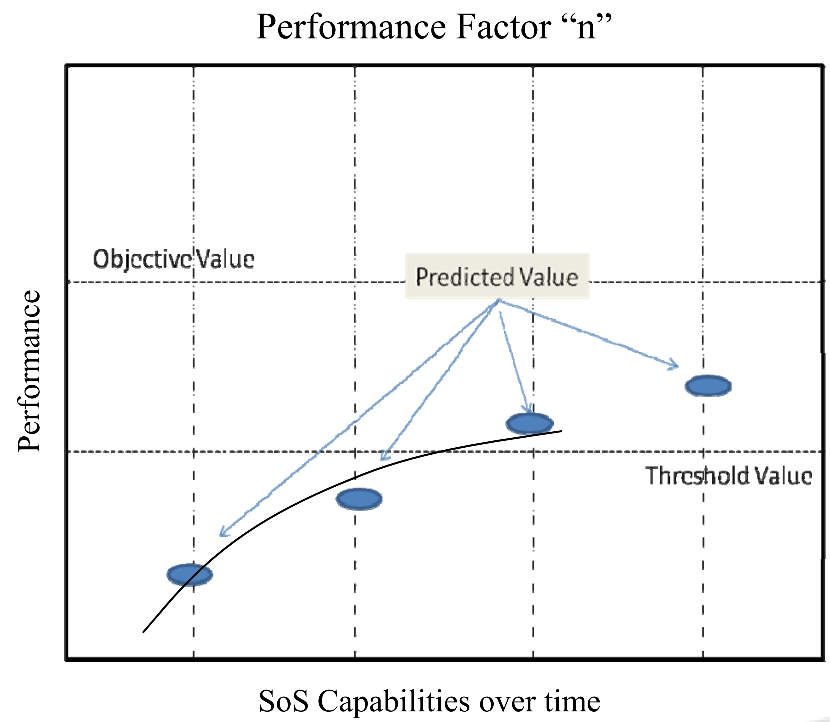


Performance Factor "n"

$$= [\text{CONOP}_A, \text{CONOP}_B, \text{CONOP}_C]$$

$$= \text{AVG}(\text{CONOP}_A + \text{CONOP}_B + \text{CONOP}_C)$$

Beginning tool for gaining insight on SoS Performance for use in Prediction & Monitoring

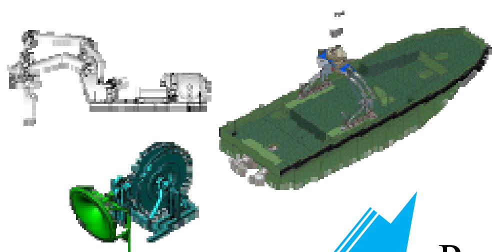


Sample Case – ASW Search Mission for a Notional ASW SoS

N=5 SoS

Table 1: Notional ASW SoS				
	KPP Impacted			
Capability/MS	Search	Detect	Classify	Engage
System 1 (USV-Towed Array)	x	x		
System 2 (USV-Dipper)	x	x	x	
System 3 (60R-Dipper)	x	x	x	x
System 4				x
System 5 (USV)	x	x	x	

Search functional tread identifies N=4 technologies of which two sets are integrated



Maturation pathways are developed

	Table 2: Notional ASW SoS Maturity Growth Plan			
	Developmental status (n state)			
Capability (ω)	Present (n=1)	Test Event 1 (n=2)	OPEVAL (n=3)	Production (n=4)
System 1	0.7	0.8	0.9	1.0
System 2	0.8	0.9	1.0	1.0
System 3	1.0	1.0	1.0	1.0
System 5	0.5	0.7	0.9	1.0

Performance Equations developed

USV/TA = $Pm_{(1,5)n} = \omega_n * \alpha_{(x,y,\ldots)} = Pm_{(1,5)n} = \omega_{5n} * \alpha_{(1)}$

USV/Dipper= $Pm_{(2,5.)n} = \omega_n * \alpha_{(x,y,\ldots)} = Pm_{(2,5)n} = \omega_{5n} * \alpha_{(2)}$

MH60R Dipper= $P_3 = \omega_n * \alpha = \omega_{3n} * \alpha_3$

Use of technologies within various CONOPS determined

Table 3: Mapping CONOPS to Capabilities Usage			
KPP/Capability -Search	CONOP A	CONOP B	CONOP C
Integrated System 1 – USV with Towed Array	100%	50%	50%
Integrated System 2- USV with Dipping Sonar		50%	25%
System 3 –MH-60R with Dipping Sonar			25%

CONOPS Equations developed

$CONOPS_A = 1.0(\omega_{5n} * \alpha_{(1)})$;

$CONOPS_B = 0.5(\omega_{5n} * \alpha_{(1)}) + 0.5(\omega_{5n} * \alpha_{(2)})$; and

$CONOPS_B = 0.5(\omega_{5n} * \alpha_{(1)}) + 0.25(\omega_{5n} * \alpha_{(2)}) + 0.25(\omega_{3n} * \alpha_3)$

Sample Case – ASW Search Mission for a Notional ASW SoS

Now assuming the predicted performance in production of each of the systems was $\alpha(1)$ = 600 nm2/hr, $\alpha(2)$ = 100 nm2/hr, and $\alpha_3 = 300\ nm^2/hr$

$$SPM_{searchn} = \{ CONOPS_{A(n)}, CONOPS_{B(n)}, CONOPS_{C(n)} \} = \begin{bmatrix} \omega_{5n} & 0 & 0 \\ 0.5\ \omega_{5n} & 0.5\ \omega_{5n} & 0 \\ 0.5\ \omega_{5n} & 0.25\ \omega_{5n} & 0.25\ \omega_{5n} \end{bmatrix} \times \begin{bmatrix} \alpha_{(1)} \\ \alpha_{(2)} \\ \alpha_3 \end{bmatrix}$$

Table 4: Notional ASW SoS PML over time

Capability (nm2/hr)	Present (n=1)	Test Event 1 (n=2)	OPEVAL (n=3)	Production (n=4)
CONOPS A	300	420	540	600
CONOPS B	175	245	315	350
CONOPS C	200	280	360	400
Normalized Average	225	315	405	450

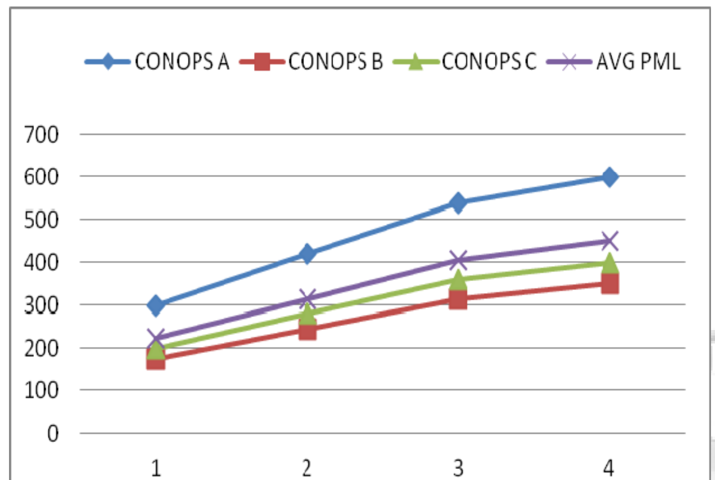
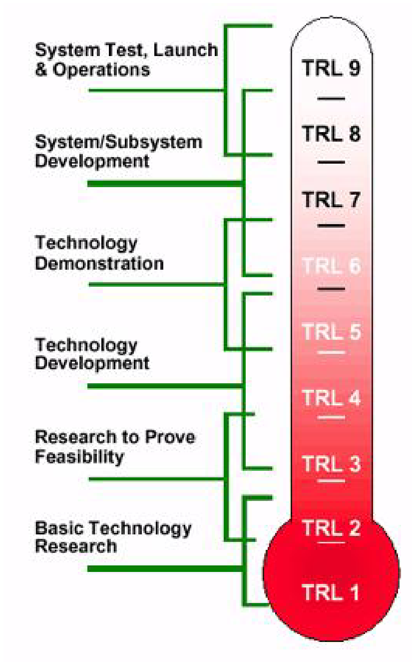


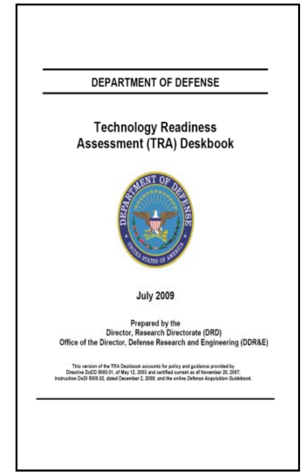
Figure 3: SPM of the Search KPP as a Function of CONOPS and SoS Maturity

A word of Caution: Any Metric is Fallible



TRL 6. System/subsystem model or prototype demonstration in a relevant environment

But a fuller definition is: **Representative model** or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a **relevant environment**. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment**.**



A *relevant environment* is a set of stressing conditions, representative of the full spectrum of intended operational employments, which are applied to a CTE as part of a component (TRL 5) or system/subsystem (TRL 6) to identify whether any design changes to support the required (threshold) functionality are needed.

A functional form of a system, generally reduced in scale, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and

Supporting Information

Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?

Metric should be used as an indicator of "is further research into this area needed?"

Concluding Thoughts

- System of Systems (SoS) management is an exceptional challenge for today's complex & integrated systems.
  - SoS use however is increasing across DoD
  - Metrics exist in many areas but for predicting performance, short of extensive M&S, are still in development
- The presented SoS Performance Methodology may offer a way to assist the SoS PM in gaining insight into this area
  - Understanding of SoS architectures and how technologies interact is key element
  - All metrics are potentially fallible if used beyond their limitations

QUESTIONS?

Abstract

Program Managers (PMs) are expected to quantifiably justify that their program will result in the delivery of a system with the required performance through development.

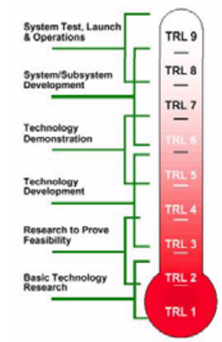
Traditionally, the PM has several technical management tools at their disposal, including TPMs, Modeling and Simulation, etc. that provide insight and predictive capability in system performance. When the program matures to a point where actual test data can be gathered, it is compared against expected system performance.

The increasing use of the System of Systems (SoS) model for the rapid fielding of warfighting capabilities poses new systems engineering challenges for the DoD. Due to the complex nature of SoS interdependencies, PMs are especially challenged when asked to quantifiably predict progress made toward full-capability SoS performance in an incremental development. To support the PM in making technical trades and tracking performance progress for an acknowledged SoS, the US Navy (PMS 420 and SSC Pacific) have been collaborating on the development and verification of a SoS Performance Measure (SPM) tool set.

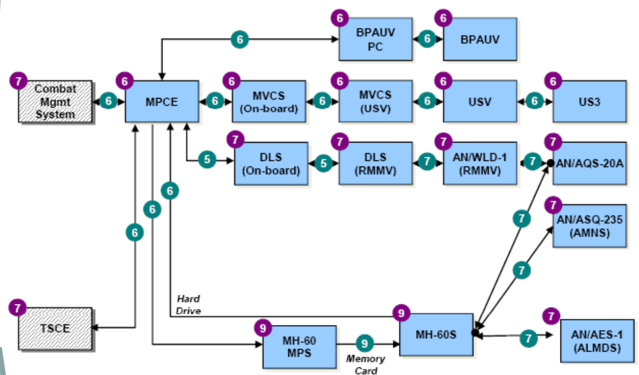
The SPM tool applies a modified Technical Performance Measure (TPM) type approach to a SoS construct. However, instead of focusing on a single measurable technical value that can be monitored during development of a Individual system, the SPM links the SoS Key Performance Parameters (KPPs) to individual component capabilities, their maturity, and their potential usage rates. The System Maturity Model (SMM), Concept of Operations (CONOPS), and usage rate variance analyses are all considered in the SPM calculation. The SPM tool will be reviewed and valuable lessons learned to date within the Mission Modules Program will be discussed.

What is being developed for a SoS
what metrics/ methods presently exist?

STEVENS Institute of Technology Has Developed a Maturity based analysis methodology called: System Readiness Level (SRL)



IRL	Definition
9	Integration is **Mission Proven** through successful mission operations.
8	Actual integration completed and **Mission Qualified** through test and demonstration, in the system environment.
7	The integration of technologies has been **Verified and Validated** with sufficient detail to be actionable.
6	The integrating technologies can **Accept, Translate, and Structure Information** for its intended application.
5	There is sufficient **Control** between technologies necessary to establish, manage, and terminate the integration.
4	There is sufficient detail in the **Quality and Assurance** of the integration between technologies.
3	There is **Compatibility** (i.e., common language) between technologies to orderly and efficiently integrate and interact.
2	There is some level of specificity to characterize the **Interaction** (i.e., ability to influence) between technologies through their interface.
1	An **Interface** between technologies has been identified with sufficient detail to allow characterization of the relationship.



SRL = IRL x TRL

(Normalized)

Provides a **system-level** view of development maturity with opportunities to drill down to element-level contributions

Sauser, B., J. Ramirez-Marquez, D. Henry and D. DiMarzio. (2007). “A System Maturity Index for the Systems Engineering Life Cycle.” *International Journal of Industrial and Systems Engineering*. 3(6). (forthcoming)