Systems of Systems Measurement

Progress and Plans

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2016 PSM Workshop on SoS Measurement

Participants

Mike Yokell	Lockheed Martin
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February, 2016 PSM User's Group in Arlington, Virginia

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Topics

- Background and motivation
- Systems of Systems
  - Systems of Systems Engineering SoSE defined
  - An Implementers View of SoSE
- Workshop description
- Questions driving measurement at each step of SoSE implementation
- Results of workshop

SoS Background and Motivation

- Growth in Systems of Systems (SoS)
  - SoS are prevalent in military and non-military domains in today's networked environment
  - Most military capabilities depend on multiple systems working together effectively to meet user mission needs
  - However, current defense acquisition is based on the development and engineering of individual systems, often without a clear understanding of the SoS context(s) in which systems will be deployed
- Need for SoS engineering is recognized
  - Increased attention is being paid to application of SE across the SoS supporting missions
  - SoS pose challenges for current SE practice resulting in development of approaches to SoSE

To date, there has been little attention to SoS measurement

System of Systems

A set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities

Systems of Systems Engineering

The process of planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a system-of-systems capability that is greater than the sum of the capabilities of the constituent parts

Maier (1998) five key characteristics of SoS

- Operational independence of component systems
- Managerial independence of component systems
- Geographical distribution
- Evolutionary development processes
- Emergent behavior

Energy

Water

Air
Transportation

Missile Defense
SENSORS
BOOST / ASCENT
MIDCOURSE
TERMINAL
Command, Control, Battle Management, and Communications (C2BMC)
Primary Radar Function
Surveillance and Track
Precision Discrimination
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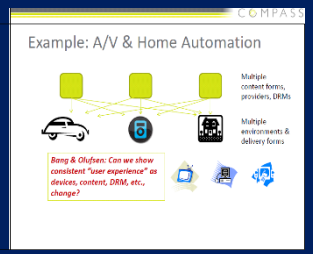
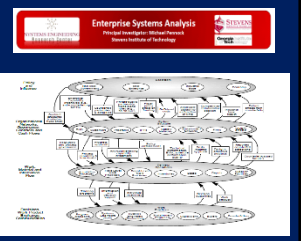
Maier SoS Characterization

- Maier (1998) postulated five key characteristics of SoS:
  - Operational independence of component systems
  - Managerial independence of component systems
  - Geographical distribution
  - Evolutionary development processes
  - Emergent behavior

Scale and Scope of SoS





Technical ----- Socio -Technical ----- Enterprise

SoS Types

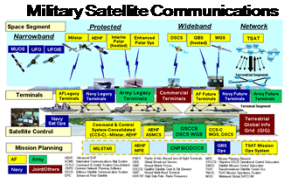
- **Directed**
  - SoS objectives, management, funding and authority; systems are subordinated to SoS
- **Acknowledged**
  - SoS objectives, management, funding and authority; however systems retain their own management, funding and authority in parallel with the SoS
- **Collaborative**
  - No top down objectives, management, authority, responsibility, or funding at the SoS level; Systems voluntarily work together to address shared or common interest
- **Virtual**
  - Like collaborative, but systems don't know about each other

- Many SoS exist but are not recognized and develop and evolve without benefit of SE
- Types apply when the SoS is recognized and treated as an SoS
- In reality, most actual SoS are a combination of these types

SoS Domain

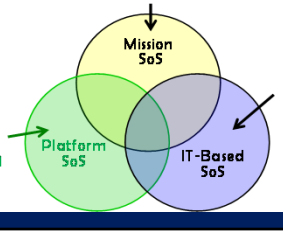
Platforms

A military platform (e.g. ship, aircraft, satellite, ground vehicle) equipped with independent systems (e.g. sensor, weapons, communications) needed to meet platform objectives



Missions

Sets of systems working together to provide a broader capability or mission



Information Technology

Networked information systems to support operations within or across platforms or systems to meet mission or capability objectives

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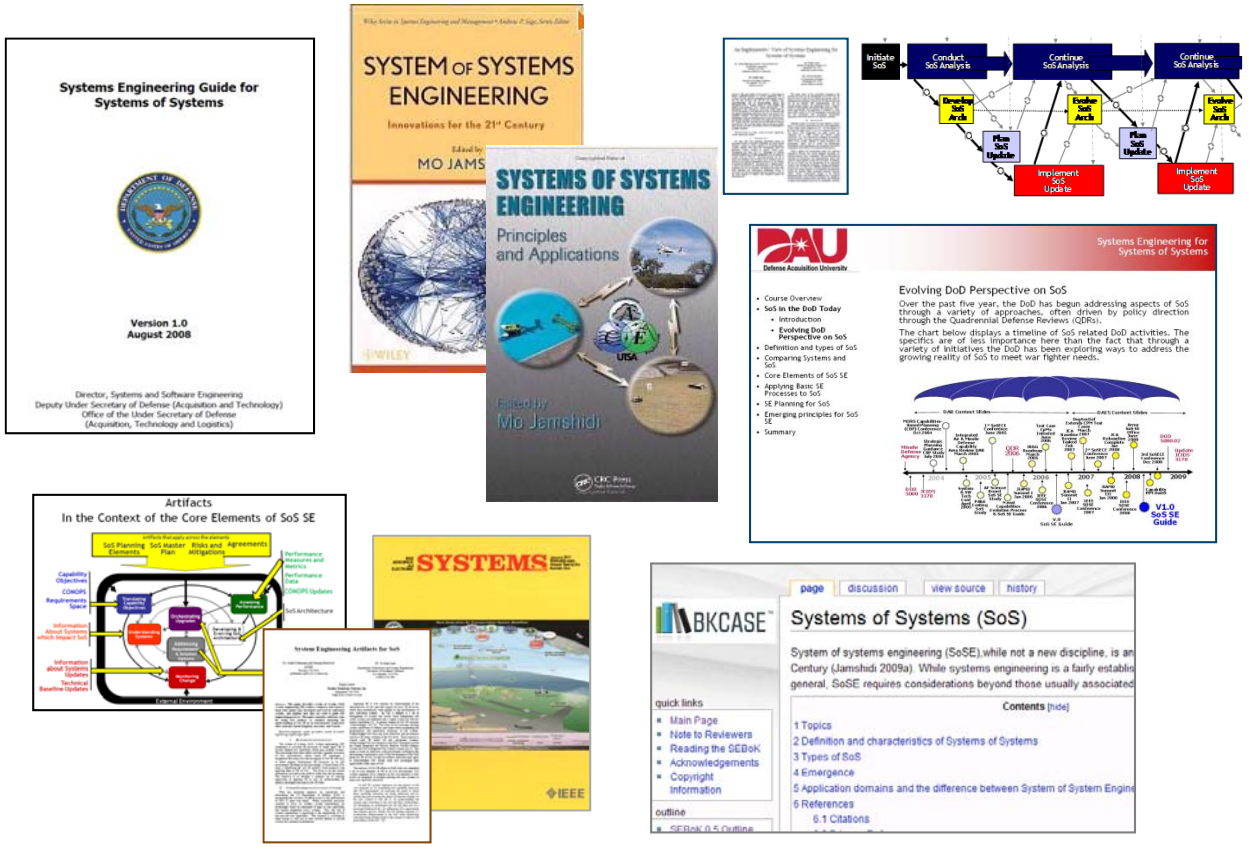
Investigations Into SoS SE for Defense & Beyond



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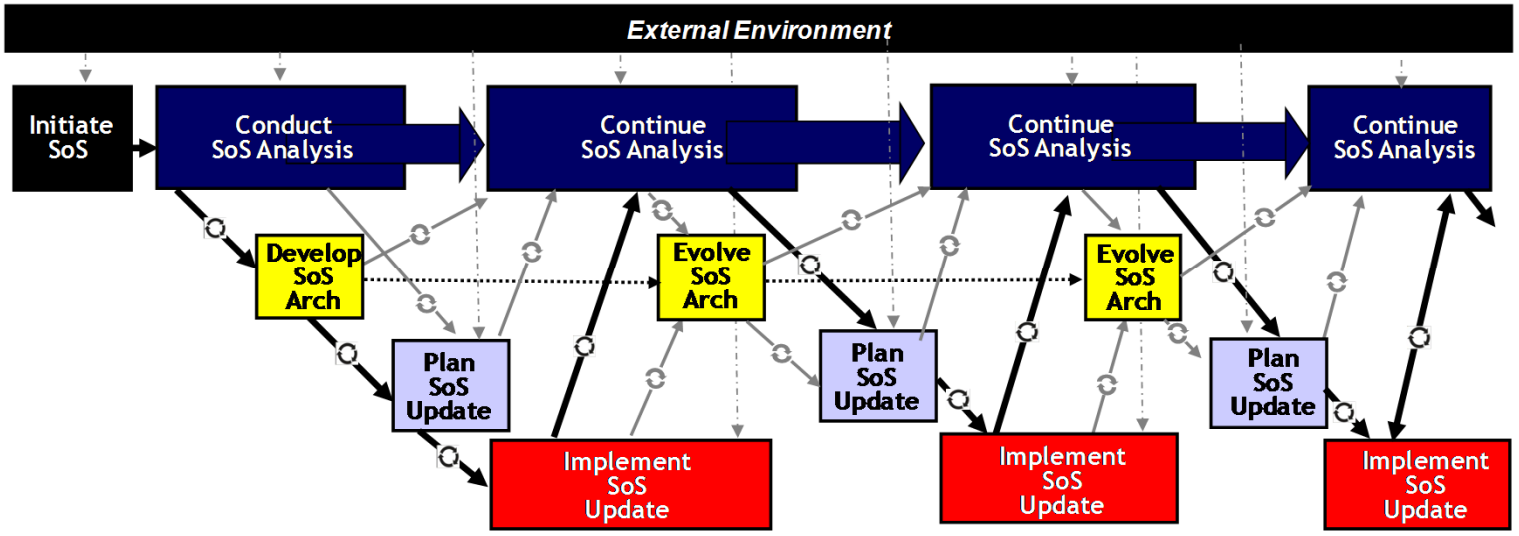
SoSE Wave Model – Implementer's View

An evolutionary systems engineering approach to evolving complex systems and systems of systems

- Recognizes need for disciplined iterations to systematically address impacts of inevitable change
  - Backbone of ongoing analysis
  - Architecture evolution
  - Overlapping iterations
  - Forward movement with feedback



Provides a framework for addressing SoS measurement

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Practical Systems and Software Measurement Workshop Context

PRACTICAL SOFTWARE AND SYSTEMS MEASUREMENT

Practical Software and Systems Measurement

Objective Information for Decision Makers

SoS Measurement
24 February 2016

Judith Dahmann, MITRE
Mimi Hailegiorghis, MITRE
Garry Roedler, Lockheed
Cheryl Jones, Army

PRACTICAL SOFTWARE AND SYSTEMS MEASUREMENT

Objectives of the Workshop

- *Layout the basic characterization of SoS, the SoS engineering workflow and the implications for measurement, with an example*
- *Review the PSM measurement approach to assess how it applies or can be adapted to SoS, including challenges and opportunities*

Join with the system measurement community to address SoS measurement

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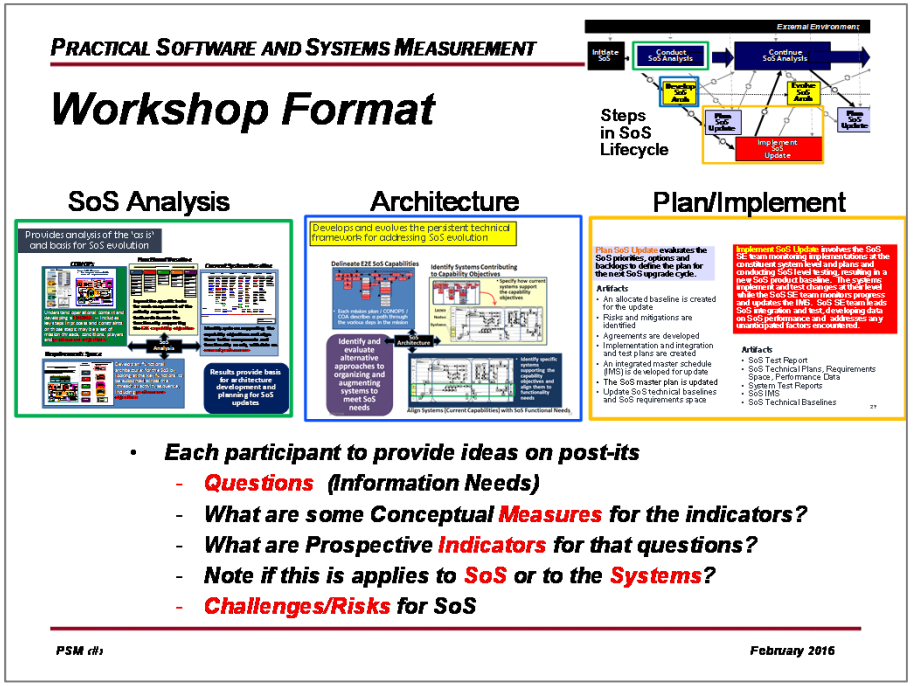
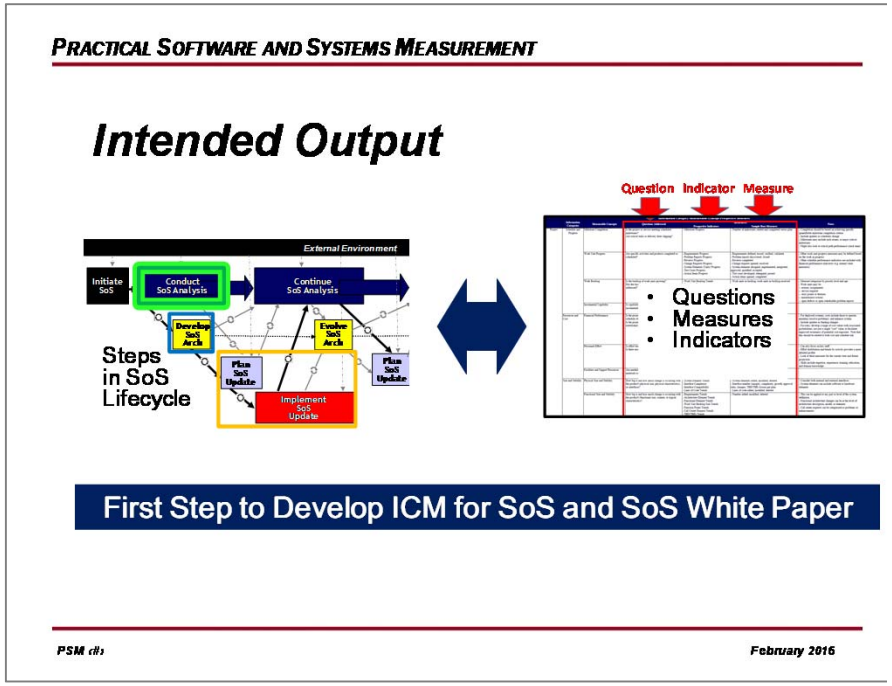
Workshop Format and Intended Output





First step is to understand unique SoS measurement issues

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Information Category-Measurable Concept-Prospective Measures (ICM) Table

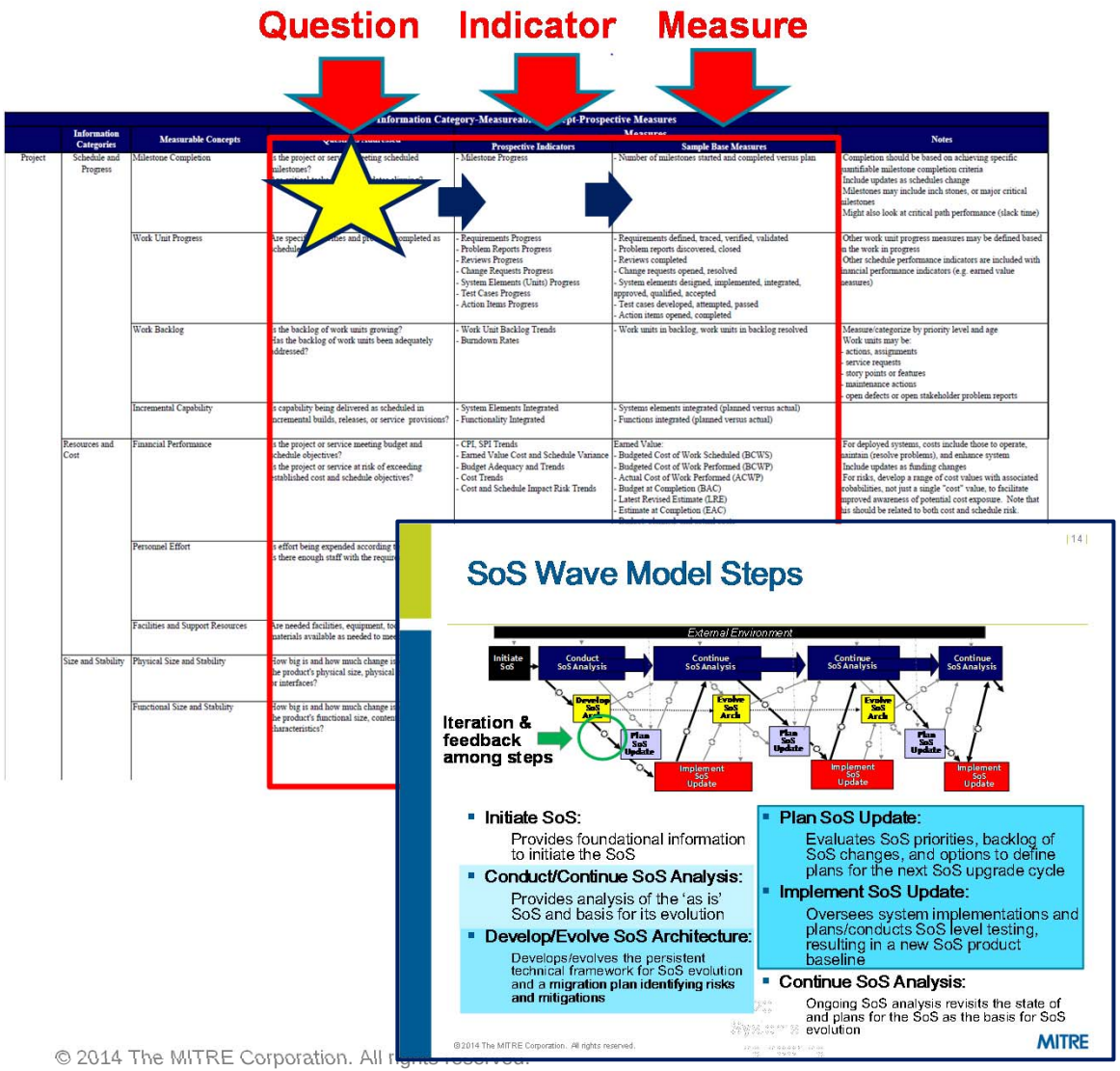
Information Category | Measurable Concepts | Questions | Measures (Prospective Indicators; Sample Base Measures) | Notes

	Information Categories	Measurable Concepts	Questions Addressed	Measures: Prospective Indicators	Measures: Sample Base Measures	Notes
Project	Schedule and Progress	Milestone Completion	Is the project or service meeting scheduled milestones? Are critical tasks or delivery dates slipping?	- Milestone Progress	- Number of milestones started and completed versus plan	- Completion should be based on achieving specific quantifiable milestone completion criteria - Include updates as schedules change - Milestones may include inch stones, or major critical milestones - Might also look at critical path performance (slack time)
		Work Unit Progress	Are specific activities and products completed as scheduled?	- Requirements Progress - Problem Reports Progress - Reviews Progress - Change Requests Progress - System Elements (Units) Progress - Test Cases Progress - Action Items Progress	- Requirements defined, traced, verified, validated - Problem reports discovered, closed - Reviews completed - Change requests opened, resolved - System elements designed, implemented, integrated, approved, qualified, accepted - Test cases developed, attempted, passed - Action items opened, completed	- Other work unit progress measures may be defined based on the work in progress - Other schedule performance indicators are included with financial performance indicators (e.g. earned value measures)
		Work Backlog	Is the backlog of work units growing? Has the backlog of work units been adequately addressed?	- Work Unit Backlog Trends - Burndown Rates	- Work units in backlog, work units in backlog resolved	- Measure/categorize by priority level and age - Work units may be: -- actions, assignments -- service requests -- story points or features -- maintenance actions -- open defects or open stakeholder problem reports
		Incremental Capability	Is capability being delivered as scheduled in incremental builds, releases, or service provisions?	- System Elements Integrated - Functionality Integrated	- Systems elements integrated (planned versus actual) - Functions integrated (planned versus actual)	
	Resources and Cost	Financial Performance	Is the project or service meeting budget and schedule objectives? Is the project or service at risk of exceeding established cost and schedule objectives?	- CPI, SPI Trends - Earned Value Cost and Schedule Variance - Budget Adequacy and Trends - Cost Trends - Cost and Schedule Impact Risk Trends	Earned Value: - Budgeted Cost of Work Scheduled (BCWS) - Budgeted Cost of Work Performed (BCWP) - Actual Cost of Work Performed (ACWP) - Budget at Completion (BAC) - Latest Revised Estimate (LRE) - Estimate at Completion (EAC) - Budget, planned, and actual costs - Cost and schedule risk	- For deployed systems, costs include those to operate, maintain (resolve problems), and enhance system - Include updates as funding changes - For risks, develop a range of cost values with associated probabilities, not just a single "cost" value, to facilitate improved awareness of potential cost exposure. Note that this should be related to both cost and schedule risk.
		Personnel Effort	Is effort being expended according to plan? Is there enough staff with the required skills?	- Staff Level Sufficiency - Effort Distribution and Trends - Skill Profiles - Staff Turnover Rates	- Number of staff on project and projected - Number of staff by skill level - Number of staff by activity - Staff added, removed, quit	- Can also focus on key staff - Effort distribution and trends by activity provides a more detailed profile - Look at these measures for the current state and future projection - Skills include expertise, experience, training, education, and domain knowledge
		Facilities and Support Resources	Are needed facilities, equipment, tools, and materials available as needed to meet milestones?	- Resource availability - Resource utilization	- Quantity needed, available - Time required, available, used	
	Size and Stability	Physical Size and Stability	How big is and how much change is occurring with the product's physical size, physical characteristics, or interfaces?	- System Element Trends - Interface Complexity - Interface Compatibility - Lines of Code Trends	- System elements added, modified, deleted - Interface number (unique), complexity, growth, approval rates, changes, TBD/TBR closure per plan - Lines of code added, modified, deleted	- Consider both internal and external interfaces - System elements can include software or hardware elements
		Functional Size and Stability	How big is and how much change is occurring with the product's functional size, content, or logical characteristics?	- Requirements Trends - Architecture Element Trends - Functional Element Trends - Work Unit Backlog Size Trends - Function Points Trends - Call Center Request Trends - TBD/TBRs Trends	- Number added, modified, deleted	- This can be applied at any part or level of the system definition - Functional architecture changes can be at the level of architecture description, model, or elements - Call center requests can be categorized as problems or enhancements

- PSSM product
- Provide set of reusable measures
- Currently focused on project measurement

Can the current ICM be applied or adapted to SoS

SoS Workshop Approach
Address Core Elements of ICM for SoS



- Start with SoS questions addressed at each step in SoSE using the SoS wave model framework
- Identify common indicators and measures for questions

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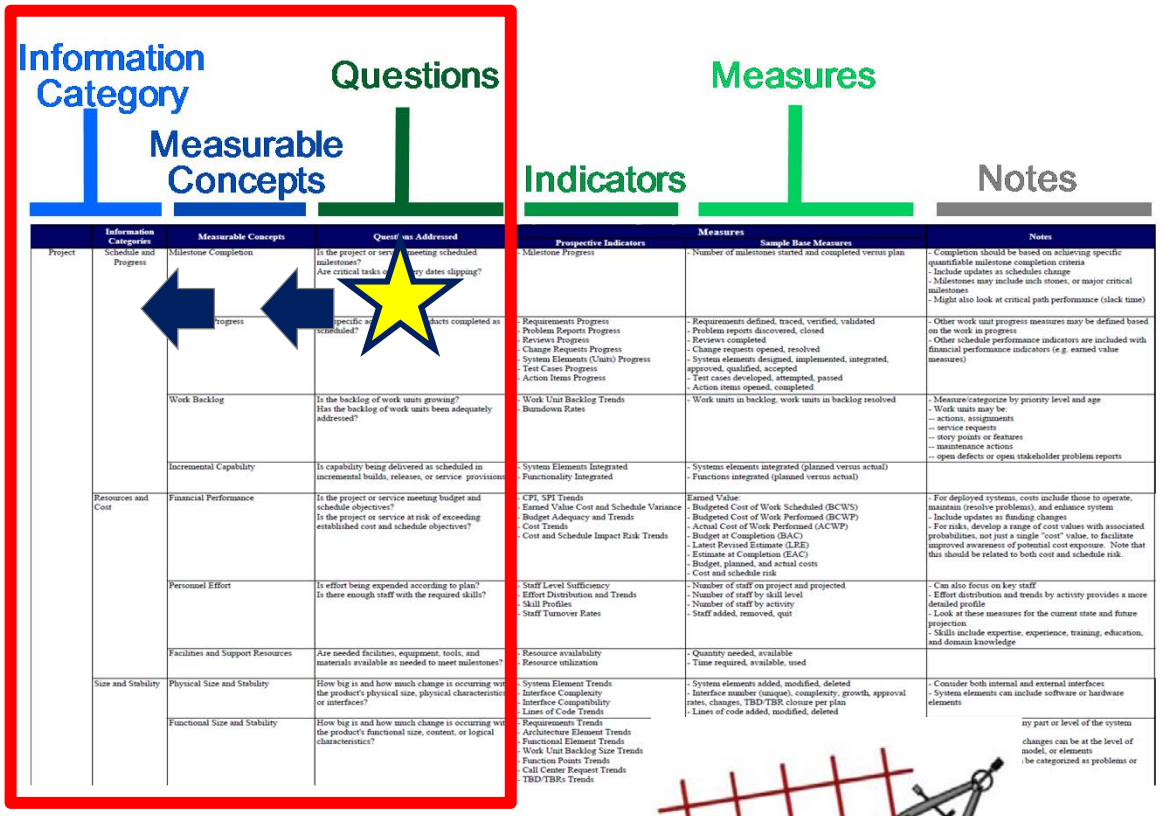
Workshop Results



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- For new SoS measurement considerations
  - Identified core questions
  - Discussion focused on measurable concepts and information categories
  - Indicators and measures may not be reusable but more specific to the SoS

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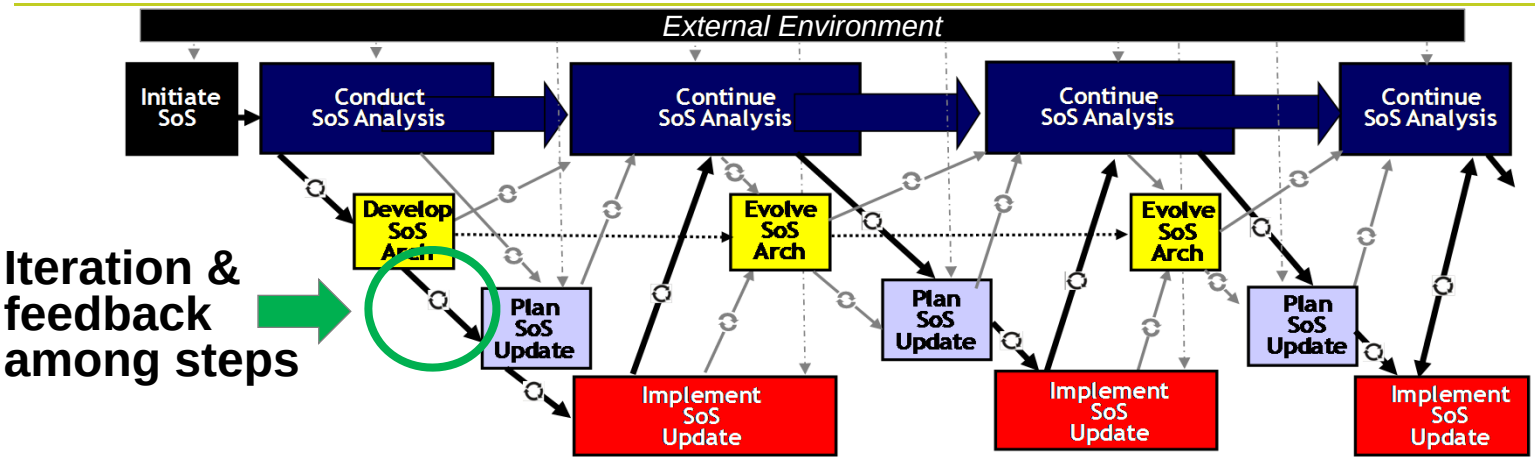
SoS Wave Model Steps



- **Initiate SoS:**
  Provides foundational information to initiate the SoS
- **Conduct/Continue SoS Analysis:**
  Provides analysis of the 'as is' SoS and basis for its evolution
- **Develop/Evolve SoS Architecture:**
  Develops/evolves the persistent technical framework for SoS evolution and a **migration plan identifying risks and mitigations**
- **Plan SoS Update:**
  Evaluates SoS priorities, backlog of SoS changes, and options to define plans for the next SoS upgrade cycle
- **Implement SoS Update:**
  Oversees system implementations and plans/conducts SoS level testing, resulting in a new SoS product baseline
- **Continue SoS Analysis:**
  Ongoing SoS analysis revisits the state of and plans for the SoS as the basis for SoS evolution

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Workshop Results - 1st Step Developing SoS Measurement Approach

SoS Analysis

Provides an analysis of the "as is" SoS, including
- Describe current SoS
  - CONOPS
  - Systems
  - System relationships
- Assess performance against objectives
  - Expected performance
  - Actual (measured) performance
- Fault isolation
  - Source of gaps

SoS Architecture

Technical analysis of changes or alternatives to the current architecture to improve SoS effectiveness or performance
- New, added, different or updated systems in current archietcture
- New architecture with new ways to organize and employ systems

Produces recommendations for changes

Plan SoS Update
- Evaluate SoS priorities, options and backlogs
- Define the plan for the next SoS upgrade cycle.

Implement SoS Update

Systems
- Implement and test changes systems
- SoS SE team leads SoS integration and test

SoS SE
- Monitors system implementation
- Conducts SoS testing
- Addresses unanticipated factors encountered

- On technical management measures - many ICM elements apply directly to SoS management
- On technical measures - integrating across wave model steps, extract questions and driving measurement concepts for systems and SoS

Area	Measurement Concept	Questions
SoS	Effectiveness	What are top-level objectives for the SoS?
		Is the SoS achieving the user capability objectives?
		How do stress conditions impact SoS effectiveness?
		How does SoS performance impact SoS effectiveness?
		What are gaps between expected and observed SoS effectiveness?
		What are root causes of gaps?
		How alternative architectures compare in terms of SoS effectiveness?
		TBD
	Performance	Is the SoS performing as expected?
		How do stress conditions impact SoS performance?
		How does the systems' performance impact SoS performance?
		TBD
System	Effectiveness	Do the systems maintain system level effectiveness when part of the SoS?
		Which systems have largest impact SoS effectiveness?
		TBD
	Perfomance	How are the systems performing in the SoS context?
		How do the systems contribute to the SoS?
		TBD

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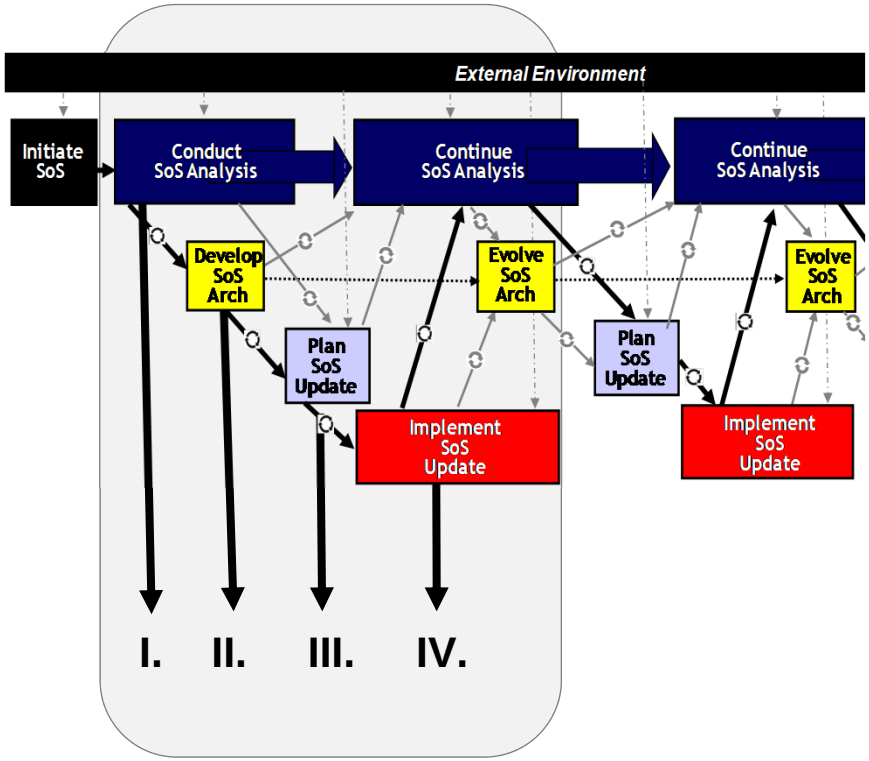
2017 Workshop – Next Step
Measurement at Each Step the Wave Model



- **At each step (I – IV)**
  - What are the **questions** to be addressed?
  - What **measures** would you need?
    - Technical? Technical management?
    - At SoS level? At the system level?
  - What are the **measurement challenges**?
    - For technical and technical management
- **Start with acknowledged SoS**
  - Assess what is different for other types

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Structure for Results

Conduct SoS Analysis	
Questions	
SoS	
Technical	
Tech Managemet	
System	
Technical	
Tech Management	
Challenges	
Evolve SoS Architecture	
Questions	
SoS	
Technical	
Tech Managemet	
System	
Technical	
Tech Management	
Challenges	
Plan Update	
Questions	
SoS	
Technical	
Tech Managemet	
System	
Technical	
Tech Management	
Challenges	
Orchestrate Update	
Questions	
SoS	
Technical	
Tech Managemet	
System	
Technical	
Tech Management	
Challenges	

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Join Us for Workshop #1

Systems of Systems (SoS) Engineering Measurement Through the SoS Life Cycle

Tuesday June 13
1:30 – 5:00

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