

Systems of Systems Challenges for Systems Engineering

INCOSE

SoS SE Panel

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INCOSE System of Systems Panel July 2006

- One of a number of events addressing issues of SoS
- Quotable quotes
 - “There is no nice line between Systems and SoS”
 - “There is no difference between SE for systems and SoS”
 - “There is simply a need for better requirements management for SoS”
 - “Thinking that traditional SE methods/techniques are sufficient for SoS is dangerous”
 - “Standard SE applies but requires extensions”
 - “Only difference is no one in control in a SoS”
 - “Nothing is new. Any system that has sub-systems is a SoS. We have been doing this forever.”

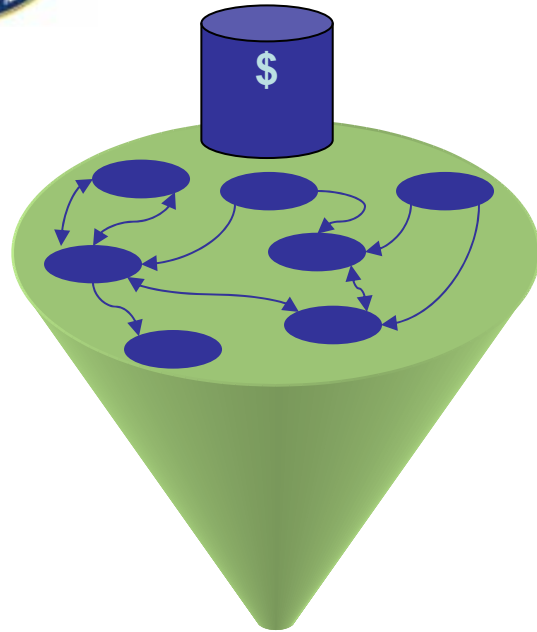


Acquiring Defense Capabilities SoS SE Considerations

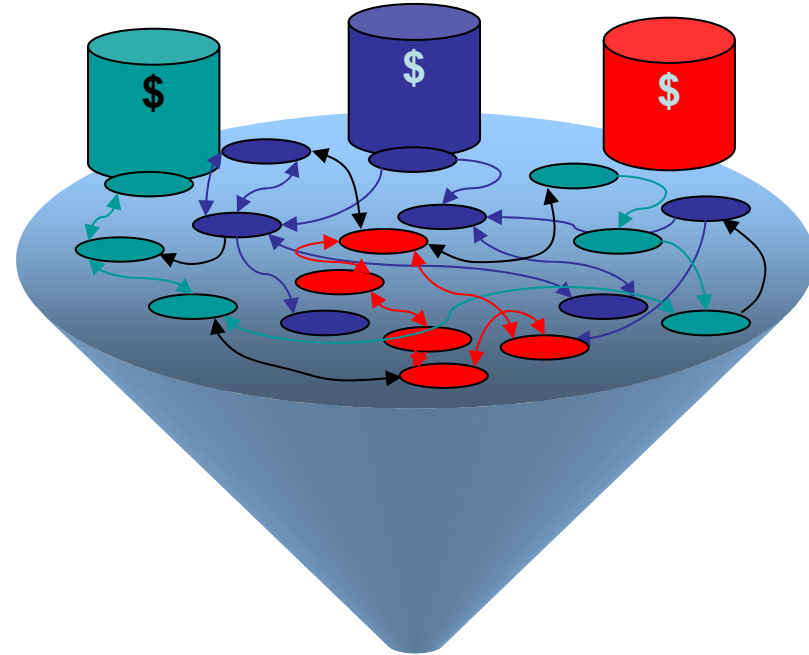
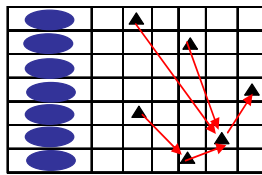
- Capability needs will be satisfied by groupings of legacy systems, new programs, and technology insertion – Systems of Systems (SoS)
- DoD Considerations for SoS:
 - Ownership/Management: Individual systems are owned by the military services or agencies
 - Legacy: Current systems will be part of the defense inventory for the long-term and need to be factored into any approach to SoS
 - Changing Operations: Changing threats and concepts mean that new (ad hoc) SoS configurations will be needed to address changing, unpredictable operational demands
 - Criticality of Software: SoS are constructed through cooperative or distributed software across systems
 - Enterprise Integration: SoS must integrate with other related capabilities and enterprise architectures
 - Portfolios: Systems engineering will provide the technical base for selecting components of the systems needed to support portfolio objectives



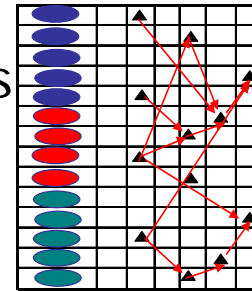
System of Systems – The Management Challenge



SoS:
Within
Single
Organization



Joint SoS:
Interdependencies
Across
Multiple
Organizations



***Political and Cost Considerations impact on
Technical Issues***



DoD System of Systems SE Guide

SoS Guide Version 0.9

- ❖ Initiative of the Office of the Secretary of Defense
- ❖ Collaborative approach with DoD, Industry, Academia
- ❖ Purpose:
 - Conduct six month effort to address areas of agreement across the SE community – completed December, 2006
 - Focus on technical aspects of SE applicable to SoS
 - Provide means to capture and debate current SoS experiences
- ❖ Audience: PMs and Lead/Chief Systems Engineers

Pilot

- ❖ 6 month pilot phase: “Beta test” the SoS SE Guide
 - Based on structured walkthroughs with practitioners
 - Refine guide content, identify areas for future study
- ❖ Update findings and release Version 1.0 (Fall 2007)

A mechanism to share emerging insights on SoS and implications for SE



SoS SE Guide Pilot Process

❖ SoS SE Guide currently addresses

- Definitions and depictions of SoS and SoS SE
- SE process challenges and suggestions for SE in SoS

❖ Pilot reviews designed to

- Gain understanding of pilot SoS context and approach
- Assess how well different depictions of SoS and SoS SE reflect pilots' experience
- Elicit feedback on the content for each of the 16 SE processes

Practitioners & Enterprise	
MILSATCOM (AF) ✓	TMIP (Joint) ✓
CAC2S (USMC) ✓	PEO GCS (Army) ✓
NIFCA-CA (Navy) ✓	NSWC Dahlgren ✓
AOC (AF) ✓	SMC (AF) ✓
NSA ✓	
Research	
MIT ✓	USC ✓
UCSD ✓	Purdue ✓
FFRDC	
MITRE (BMDS, DCGS-AF, DoDIIS, Coast Guard) ✓	
SEI ✓	
International	
Australia ✓	Canada <input type="checkbox"/>



Characterizing the SoS Environment*

Community Involvement: Stakeholders, Governance

- System:** stakeholders generally committed only to one system
- SoS:** stakeholders at both the systems and SoS levels with different objectives and priorities

Employment Environment: Mission Environment, Operational Focus

- System:** mission environment is relatively stable with clear operational focus through inevitable change
- SoS:** SoS mission objectives need to be met in context of systems addressing their own mission objectives

Implementation: Acquisition/Test and Validation, Engineering

System: aligned to ACAT Milestones, specified requirements, a single DoD PM, SE with a Systems Engineering Plan (SEP), T&E plan

SoS: ongoing efforts to satisfy user capability needs through systems with their own lifecycles; no clear 'completion'; involve mix of legacy & new systems, and technology insertion with multiple DoD PMs and operational and support communities; testing is more difficult



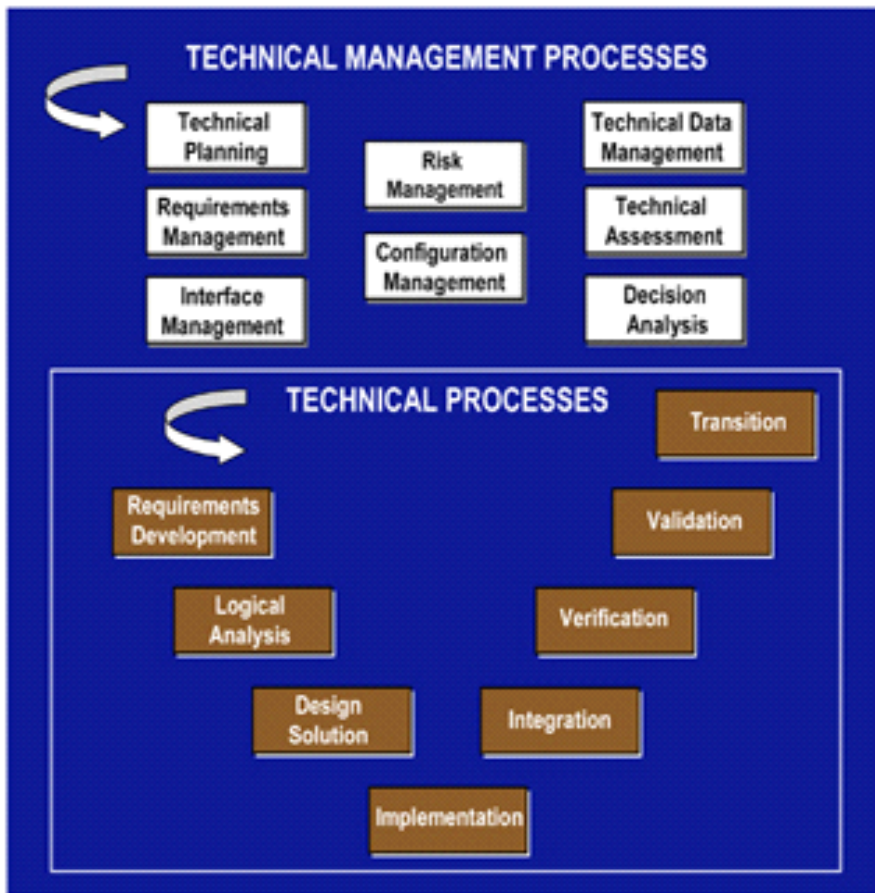
*MITRE Corporation, Stevens et al

General agreement on distinctions but diverse views on depicting SoS dynamics

*Updated based on pilot results



Challenges of SoS for SE Processes*



From Defense Acquisition Guide, Chapter 4

- **Guide Chapter 3 examines SE processes for SoS**
 - Implications of SoS
 - Challenges these pose for the SE
 - Approaches to address challenges
- **SE processes apply, but SoS environment affects approaches, methods and tools needed by SE**
 - More collaboration, less top down
 - More complexity to accommodate requirements, approaches and tools used by constituent systems
 - Balance between roles of SoS SE and the system SE
 - More need to determine ways to employ existing systems and to discover effects of combined systems

*Updated based on pilot results



Emerging Insights from SoS Pilots

SoS: Is It New?

- **Most military systems today are part of an SoS whether or not explicitly recognized**
 - Operationally we act as a SoS, but development has focused on independent systems
 - Most systems are created and evolve without explicit SE at the SoS level
- **A formal SoS comes into existence when something occurs to trigger recognition of SoS; reasons vary**
 - Appreciation for criticality of SoS area (e.g. Air Operations Center)
 - New needs are identified which cannot be supported without cooperative efforts of multiple systems (e.g. Single Integrated Air Picture)
- **An organization is identified as ‘responsible for’ the SoS ‘area’ along with definition of the objective of the SoS**
 - Typically does not include changes in ownership of the systems in the SoS
- **The SoS is then structured**
 - Membership is defined starting with identification of systems in the SoS
 - Processes and organizations are established for the SoS, including SE

**SoS in the DoD is not new;
Recognizing SoS in development, and recognizing SoS SE is new**



Emerging Insights from SoS Pilots

Distinguishing Characteristics Of SoS in the DoD Today

- **Tend to be ongoing efforts to satisfy user capability needs through an ensemble of systems**
 - May be no clear 'completion', blurring sustainment and development
- **Are not new acquisitions per se**
 - Cases like FCS are extremely rare and, in practice, still must integrate with legacy systems
 - Typically SoS is an **overlay**, evolving, or enveloping, individual systems
- **SoS 'manager' typically does not control the requirements or funding for the individual systems**
 - May be in a role of influencing rather than directing, impacts SE approach
- **Focus of SoS is on evolution of capability over time**
 - Enhancing the way current systems work together
 - Anticipating change in internal or external effects on SoS
 - Adding new functionality through new systems or changes in existing systems
 - Eliminating systems or re-engineering systems to provide better, more efficient capability
- **A functioning SoS takes start-up time but, in steady state, seems well suited to routine incremental updates**
 - Ownership and synchronization issues, contractual issues, trust, time/bandwidth

These characteristics of SoS impact the way SE is conducted



Emerging Insights from SoS Pilots

Emerging SoS SE Principles

- **Must address organizational as well as technical perspectives**
 - Foster relationships among the owners and SE of the systems (people)
 - Technical understanding of systems functionality, interrelationships & dependencies
 - SoS trades factor in objectives, motivations and plans of systems
- **SoS SE focuses on areas critical to the SoS**
 - SE processes applied to SoS issues: CM, Test, Risk, Data...
 - SoS Integrated Master Schedule (IMS) focuses on key synchronization (intersection) points and dependencies
 - Leaves the rest (as much as possible) to the SEs of the systems
- **SoS technical management approach reflects need for transparency and trust with focused active participation**
 - Not sustainable for all systems to participate in all SoS IPTs in steady state
- **SoS designs are best when open and loosely coupled, ie.:**
 - Impinge on the existing systems as little as possible
 - Provide systems maximum flexibility to address changing needs of original users and applying technology best suited to those needs
 - Are extensible, flexible, and persistent overtime
 - Allow the addition or deletion of systems and changes in systems without affecting other systems or the SoS as a whole
- **Continuous ('up front') analysis which anticipates change**



Emerging Insights from SoS Pilots

Core Elements of SoS SE

- **Translating SoS capability objectives into high level requirements over time**
 - Understanding at a technical level expectations for the SoS
- **Understanding the boundary and scope of the SoS over time**
 - Systems included in the SoS and interfaces of the SoS to external systems
 - Stakeholders, including users, of SoS and systems, including their organizational context
- **Assessing extent to which the SoS meets capability objectives over time**
 - Establishing SoS metrics and methods for assessing performance
- **Developing, evolving and maintaining a design for the SoS**
 - Concept of operations
 - Systems, functions and relationships and dependencies, both internal and external
 - Including end-to-end functionality and data flow as well as communications
- **Monitoring and assessing potential impacts of changes on SoS performance**
 - Internal changes in the systems as well as external demands on SoS
- **Addressing ongoing new requirements on SoS and options for addressing these**
 - Requirement on SoS and requirements on systems
- **Orchestrating upgrades to SoS**
 - Planning, facilitating, testing

SoS SE is responsible for creation and continual application of approaches to accomplish these



Emerging Insights SE Processes Applied to SoS

- 16 SE processes apply across the SoS SE elements
 - Offer a 'toolbox' to apply to SoS SE needs

SoS SE Core Elements	Technical Management Processes								Technical Processes							
	Decision Analysis	Tech Planning	Tech Assess	Rqts Mgt	Risk Mgt	Config Mgt	Data Mgt	Interface Mgt	Rqts Devel	Logical Analysis	Design Solution	Implement	Integrate	Verify	Validate	Transition
Translating Capability Objectives				X			X		X							
Understanding Boundary and Scope	X				X	X	X	X		X						
Assessing Performance to Capability Objectives	X		X		X		X			X					X	
Developing, Evolving and Maintaining SoS Design	X	X		X	X	X	X	X	X	X	X					
Monitoring and Assessing Changes	X				X	X	X									
Addressing New Requirements and Options for Implementation	X	X		X	X		X	X	X		X					
Orchestrating Upgrades to SoS	X	X	X	X	X	X	X	X				X	X	X	X	X

Reflect the SoS SE role of technical coordination and direction across systems

Reflect the fact that technical processes are primarily implemented by systems



Next Steps

- Continue pilots and analysis of results
- Evolve understanding and share emerging insights
 - DoD Senior SE Forum and Supporting IPT
 - SSTC
 - INCOSE
 - NDIA
- Update guide for review and publication in fall
- Develop plans for AT&L SE ongoing SoS SE program

Welcome input from community as we continue to capture experiences and lessons learned