System Engineering in a System of Systems Environment

A Defense Update

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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. **DoD Defense Acquisition Guide, System of Systems Engineering**

Accomplishments and Plans

- Completed SoS SE Guide v.9 in December 2006
- Executed six month pilot phase
  - Identified key SoS SE elements and principles
  - Identified SoS SE issues which require further attention
- Socializing insights (SE Forum, INCOSE, NASA, SSTC Conference, NDIA, others)
- Next Steps
  - Update SoS SE Guide with pilot findings
  - Update DoD SE Guides (SEP, DAG) for SoS considerations
  - Plan for DAU Continuous Learning Module in FY08
  - Implement FY08 activities to address identified issues

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

Pilot Participants

Objective of the pilots was to gain a 'boots on the ground' perspective

Research Community

INCOSE: International Council on SE

MIT: Massachusetts Institute of Technology

MITRE: MITRE Corporation

Purdue: School of Engineering

SEI: Software Engineering Institute

Stevens: Institute of Technology

USC: University of Southern California

UCSD: University of California San Diego

Australia: Defence Materiel Organisation

SE Practitioners

ABCS: Army Battle Command System

AOC: Air Operations Center

BMDS: Ballistic Missile Defense System

CAC2S: Common Aviation Command & Control System

DCGS-AF: Distributed Common Ground Station (MITRE)

DoDIIS: DoD Intelligence Information System (MITRE)

FCS: Future Combat Systems

MILSATCOM: Military Satellite Communications

NIFC-CA: Naval Integrated Fire Control – Counter Air

SR: Space Radar

NSA: National Security Agency

NSWC: Naval Surface Warfare Center Dahlgren

PEO GCS: Ground Combat Systems

SIAP: Single Integrated Air Picture

SMC: Space and Missile Systems Center

TMIP: Theater Medical Information Systems – Joint

USGC: US Coast Guard C2 Convergence (MITRE)

Emerging Insights from SoS Pilots
SoS: Is It New?

Insights From Pilots

- Most military systems today are part of an SoS whether or not explicitly recognized
  - 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
- An organization is identified as 'responsible for' the SoS 'area' along with definition of the objective of the SoS
  - 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

What Does SoS Look Like in the DoD Today?

Insights From Pilots

- Typically an overlay or ensemble of individual systems brought together to satisfy user capability needs
- Not new acquisitions per se
  - Cases like FCS are extremely rare and, in practice, still must integrate with legacy systems
- SoS 'manager' 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
- A functioning SoS takes start-up time but, in steady state, seems well-suited to routine incremental updates

Most military systems are part of an SoS operationally
Only by exception do we manage and engineer at SoS level

Core Elements of SoS SE

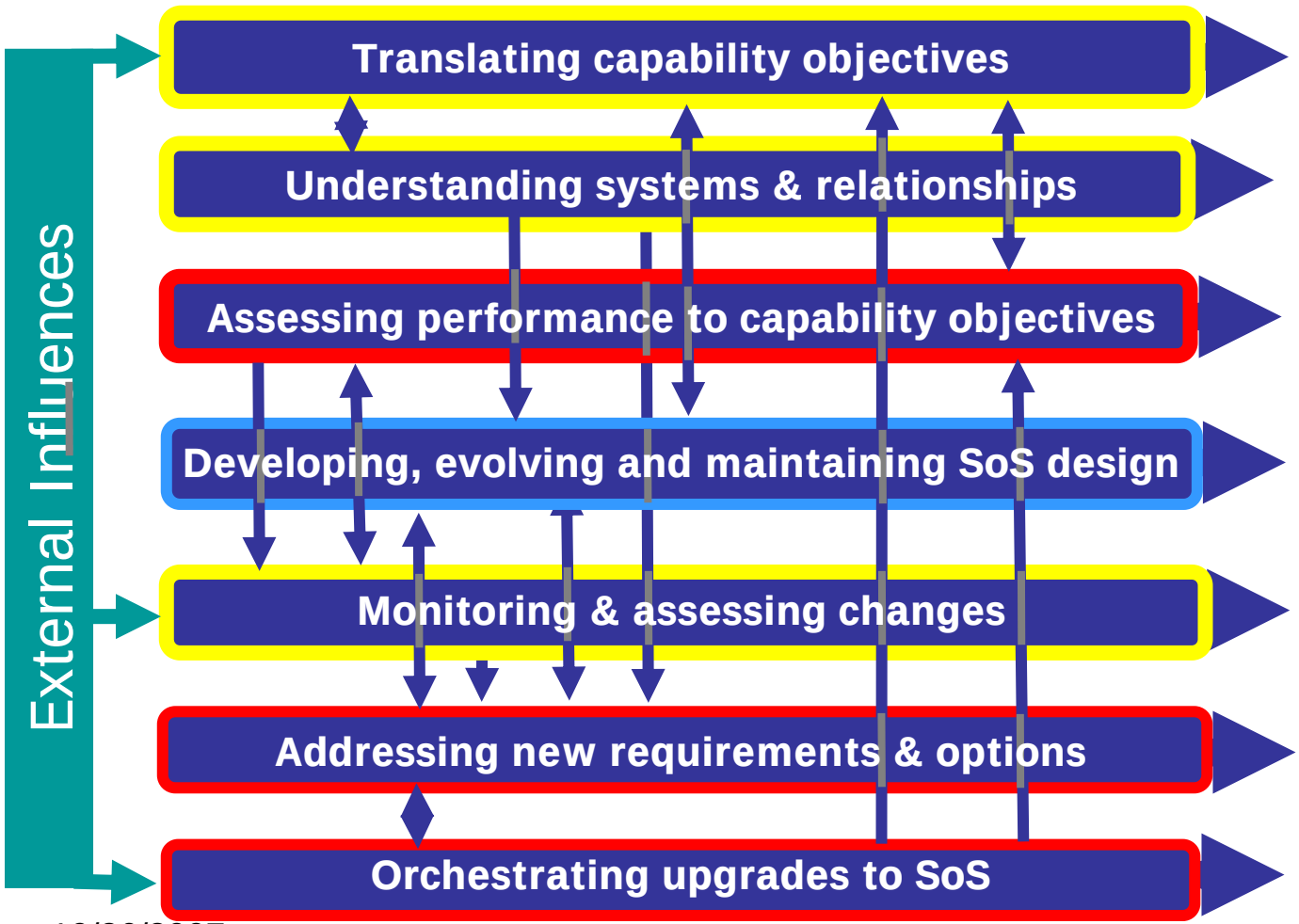
Insights From Pilots

- Translating SoS capability objectives into high level requirements over time
- Understanding the systems in the SoS and their relationships
- Assessing extent to which the SoS meets capability objectives over time
- Developing, evolving and maintaining a design for the SoS
- Anticipating and assessing impacts of potential changes on SoS performance
- Evaluating new and evolving requirements on SoS and options for addressing these
- Orchestrating upgrades to SoS

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

Relationships Among SoS SE Elements

Insights From Pilots



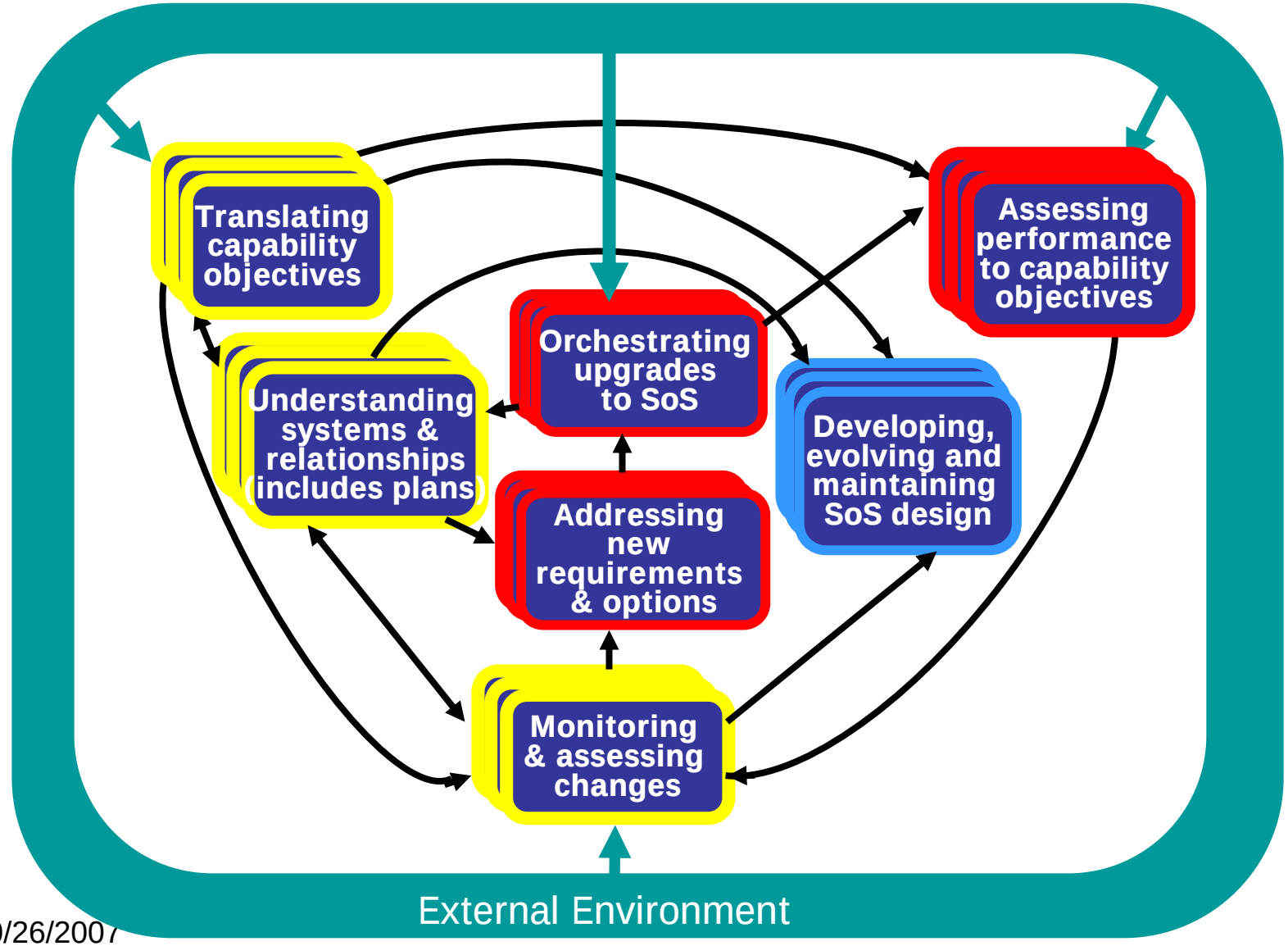
Typically not the role of the SE but key to SoS

Block upgrade process for SoS

Persistent framework overlay on systems in SoS [architecture]

Large role of external influences

Relationship Among Core Elements of SoS SE



What is Working? SoS SE Principles

Insights From Pilots

- Address organizational as well as technical perspectives
- Focus on areas critical to the SoS
  - Leave the rest (as much as possible) to the SEs of the systems
- Technical management approach reflects need for transparency and trust with focused active participation
- SoS designs are best when open and loosely coupled
  - Impinge on the existing systems as little as possible
  - Are extensible, flexible, and persistent overtime
- Continuous ('up front') analysis which anticipates change
  - Design strategy and trades performed upfront and throughout
  - Based on robust understanding of internal and external sources of change

Relationship to Core SE Processes

Insights From Pilots

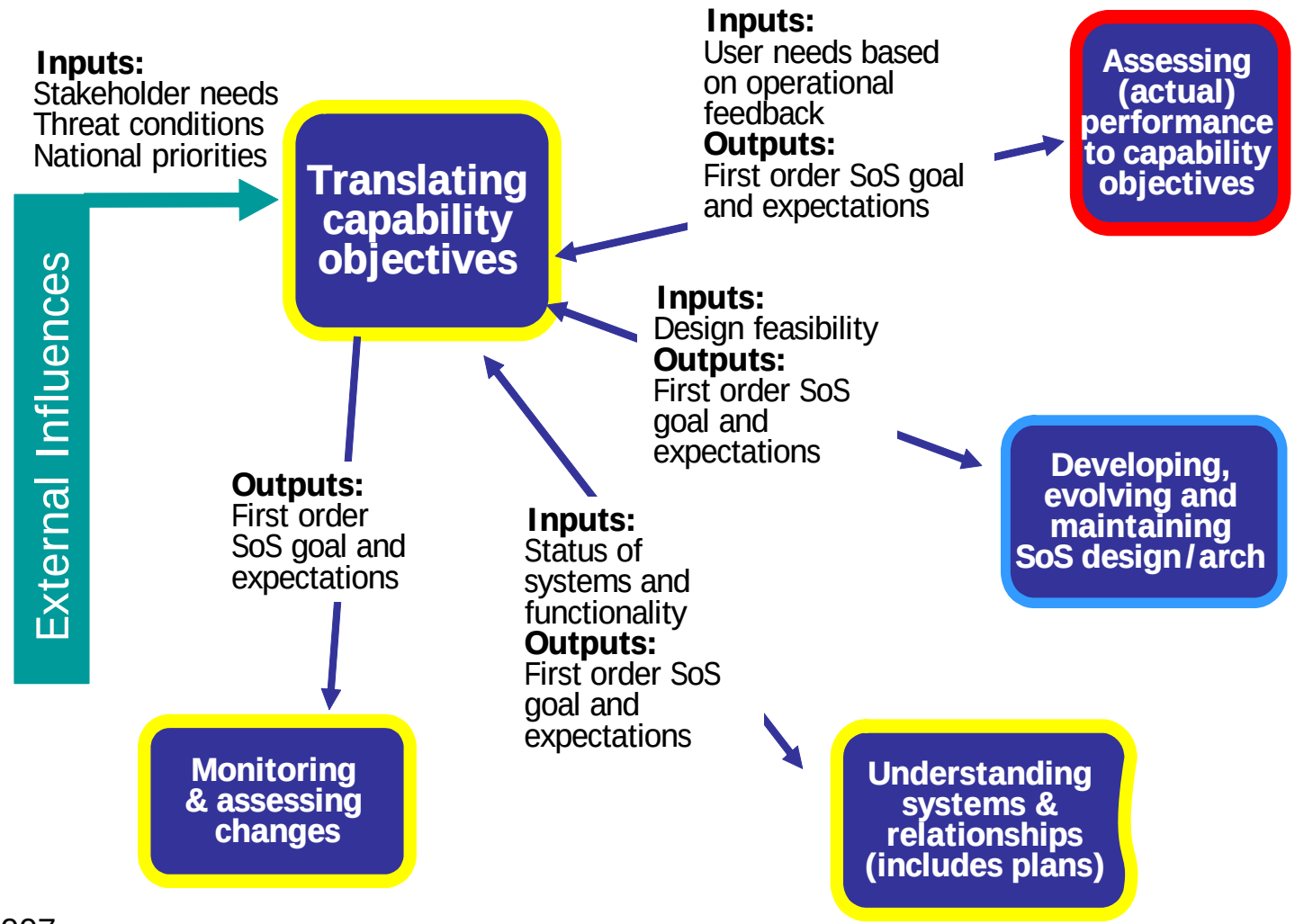
- 16 SE processes apply across the SoS SE elements
  - Offer a 'toolbox' to apply to SoS SE needs

SoS SE Elements	Technical Processes								Technical Management Processes							
	Rqts Devel	Logical Analysis	Design Solution	Implement	Integrate	Verify	Validate	Transition	Decision Analysis	Tech Planning	Tech Assess	Rqts Mgt	Risk Mgt	Config Mgt	Data Mgt	Interface Mgt
Translating Capability Objectives	X											X			X	
Understanding Systems and Their Relationships		X							X				X	X	X	X
Assessing Performance to Capability Objectives		X					X		X		X		X		X	
Developing, Evolving & Maintaining SoS Design	X	X	X						X	X		X	X	X	X	X
Monitoring and Assessing Changes									X				X		X	
Address New Rqts & Options to Implement	X		X						X	X		X	X		X	X
Orchestrating Upgrades				X	X	X	X	X	X	X		X	X		X	X

Reflect the fact that technical processes are primarily implemented by systems

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

Information Flow Among SoS SE Elements



SE Processes Supporting Each SoS SE Element

Translating Capability Objectives *(sample)*

"The **Requirements Development** process takes all inputs from relevant stakeholders and translates the inputs into technical requirements." [DAG]	• **Top level capability objectives ground the requirements for the SoS** • **In an SoS, in most cases requirements development is an ongoing process.** • **As the SoS evolves over time, needs may change. The overall mission may be stable, but the threat environment may be very different.** • **In a SoS, capability objectives may be more broadly conceived** … • …
"Requirements Management provides traceability back to user-defined capabilities... "[DAG]	• **The requirement management process begins with translating SoS capability objectives into high level requirements in the SOS SE process. The work in this element provides the grounding for the work done over time in defining, assessing, and prioritizing user needs for SoS capabilities.** • **…..**
"**Data management** … addresses the handling of information necessary for or associated with product development and sustainment." [DAG]	• **Translating SoS capability objectives into high level requirements is the start point of building a knowledge base to support the SoS development and evolution.** • **In this element the SE develops and retains data on the the capability needs and high level requirements for the SoS for use throughout the SoS elements**.

Comparison of Engineering Focus Areas (1 of 2)

Area	Systems	System of Systems
What to engineer	**Based on a set of functional and performance requirements for the system of interest**	• **Based on a set of SoS capabilities that are then translated into high level requirements for further analysis** • **A single capability can result in multiple requirements that affect multiple constituent systems**
View of system-of-interest	**Clear system boundaries** **Interfaces**	• **Systems that contribute to SoS capabilities and the interrelationships between those systems**
Architecture	**Developed and optimized to support single purpose of system**	• **Net-centric, focused on information sharing** • **Does not address design details within constituent systems, but rather the way the systems work together to meet user needs** • **Sufficient versus optimized**
Design approach	**Often top-down**	• **Combined top-down and bottom-up, with focus on** – **Existing assets (systems) that are within the SoS** – **Opportunities within constituent system lifecycles for changes**

Comparison of Engineering Focus Areas (2 of 2)

Area	Systems	System of Systems
Implementation	**Contract-controlled, often using an incremental, evolutionary, or spiral process** **Focus on total system**	• **SoS functionality implementation accomplished through combination of negotiation, sometimes funded by SoS or system owner, not always done via formal agreements** • **Asynchronous and incremental due to lifecycles of constituent systems** • **Primarily concerned with the implementation of SoS functionality,** • **Monitors the evolution of constituent systems to ensure that SoS is not adversely impacted, but not typically involved in the implementation details**
Testing	**Traditional testing activities, e.g., DT&E and OT&E**	• **Attempt to leverage off of constituent system testing** • **Often impossible to test full-up SoS in a lab—often rely on constituent system integration labs and operational testing** • **Operationally, looking for how users use the system and identifying emergent behavior for further analysis**

Issues to be Addressed

- Testing in a systems of systems environment — *Briefed to T&E DSB*
- SoS risk and cost drivers — *FY08 SSE Initiative*
  - Identify and plan for; mitigate interdependency risk
  - Inform leadership of risk
- Community questions — *Ongoing SoS IPT Exchange*
  - Should we change the way we engineer individual systems?
  - What is the role of net-centricity in SoS?
- Enablers to allow SEs to better operate in SoS environments, such as — *INCOSE Working Group*
  - Additional processes or new ways to implement current processes
  - New contracting methods
  - New models of governance

Summary and Discussion

- US plans to continue SoS project in FY08 and beyond
  - Publish SoS Guide Version 1.0
  - Update SE policy/guidance/training with SoS findings
  - Address open issues
  - Apply findings to program support activities
  - Apply findings to portfolio managers – C2, JNO, others

Backup Slides

Definitions

System

An integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective

Mil-Std 499B

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

DoD Defense Acquisition Guide, System of Systems Engineering

System of Systems Engineering

Planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a SoS capability greater than the sum of the capabilities of the constituent parts

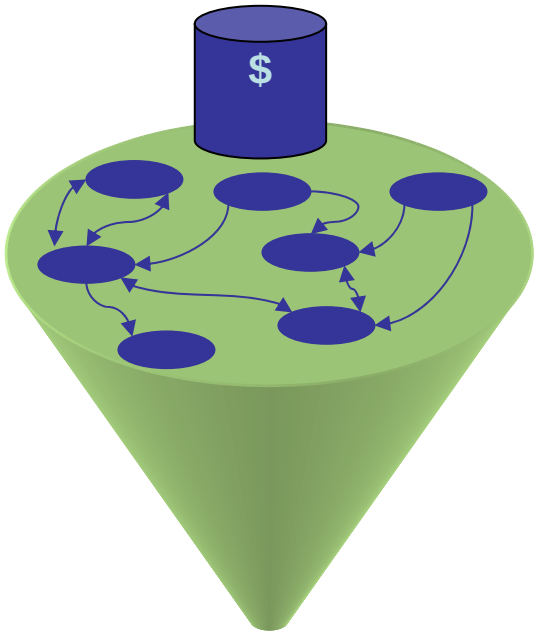
DoD Defense Acquisition Guide, Chapter 4

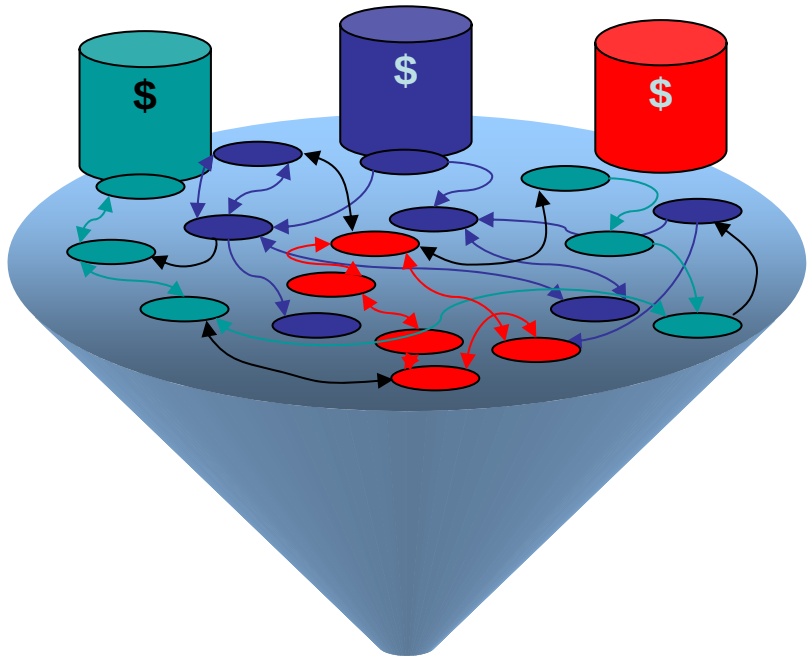
Acquiring Defense Capabilities
SoS SE Considerations

- **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** SE will provide the technical base for selecting components of the systems needed to support portfolio objectives

Capability needs will be satisfied by groupings of legacy systems, new programs, and technology insertion – Systems of Systems (SoS)

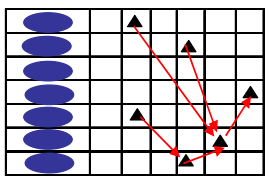
System of Systems – The Management Challenge





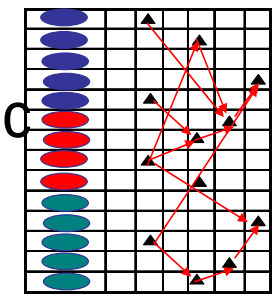
SoS:

Within Single Organization



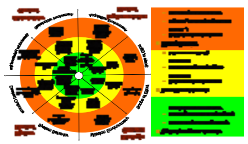
Joint SoS:

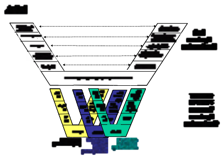
Interdependencies Across Multiple Organizations



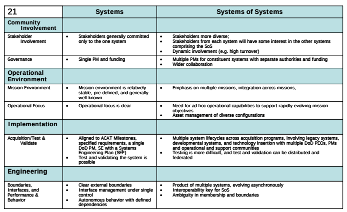
Political and Cost Considerations Impact on Technical Issues

Initial Pilot Results





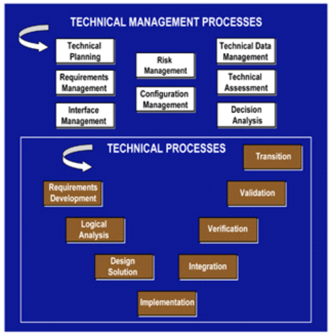
- **Wide range of views on the SoS depictions**
  - Still sorting out a good approach, inputs welcome
  - Most felt current depictions did not adequately portray the dynamics and complexity faced in SoS SE



- **General agreement on Systems vs SoS distinctions**
  - Need for more careful wording
  - Particular need to clarify discussion of ‘stakeholders’

Gap!

- **Most felt that the guide needed an explicit discussion of SoS and SoS SE in the DoD today**
  - Need to describe the elements of SoS SE and clearly differentiate between the role of the SoS SE and the System SEs in SoS
  - Provide context for discussion of 16 processes



- **16 SE processes**
  - General agreement that these apply to SoS and with the thrust of the discussion on each process
  - Need to clarify how these are implemented at the SoS and how these relate to the same processes for the systems

- **Guide too long and hard to use**