

Systems Engineering for SoS

Presentation to
Modeling and Simulation Committee
Of the
NDIA Systems Engineering Division

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Topics

- Present highlights of the SoS SEG V1.0
- Briefly discuss the treatment of M&S in the guide
- Present request for advice from the NDIA SE Division M&S Committee

SoS SE Challenge

- US DoD builds and fields large systems employed to support Joint and Coalition operations
 - Conceived and developed independent by Military Services
 - Acquisition (and SE) on a system by system basis
- Focus of DoD investment shifting to broad user capabilities implemented in a networked environment
 - Mix of material and non-material assets which must work together to meet capability objectives
 - Individual systems are no longer considered as individual bounded entities and are evolved based on extant capabilities
 - Components in larger, more variable, ensembles of interdependent systems which interact based on end-to-end business processes and networked information exchange
- Increasingly SoS of various types proliferate despite continued focus on individual systems

What are the implications for SE?

DoD System of Systems SE Guide

SoS Guide Version 1.0

- Effort led by the Office of the Secretary of Defense
- Collaborative Approach with DoD, Industry, Academia
- Purpose
 - 6 month effort addressing areas of agreement across the community
 - Focus on technical aspects of SE applicable across SoS management constructs
 - Vehicle to *capture* and *debate* current SoS experience
- Audience
 - SoS and Program Managers and Lead/Chief Engineers

Pilot

- Pilot effort ‘Boots on the Ground’ basis for
 - Structured reviews with practitioners
 - Refine early draft guide content, identify areas for future study
 - Update findings and release Version 1.0

Active SoS SE Practitioners

Name	Acronym	Owner	Approach
Army Battle Command System	ABCS	Army	Acquisition Program
Air Operations Center	AOC	Air Force	Acquisition Program
Ballistic Missile Defense System	BMDS	Joint	Acquisition Program
USCG Command & Control Convergence	C2 Convergence	Coast Guard	Strategy
Common Aviation Command & Control System	CAC2S	Marine Corps	Acquisition Program
Distributed Common Ground Station	DCGS-AF	Air Force	Program Office
DoD Intelligence Information System	DoDIIS	Intel	DIA CIO Initiative
Future Combat Systems	FCS	Army	Program Office
Ground Combat Systems	GCS	Army	Program Executive Office PEO
Military Satellite Communications	MILSATCOM	Joint	AF Wing
Naval Integrated Fire Control – Counter Air	NIFC-CA	Navy	SE Integrator in PEO
National Security Agency	NSA	Intel	Agency
Naval Surface Warfare Center Dahlgren	NSWC	Navy	Warfare Center
Single Integrated Air Picture	SIAP	Joint	Acquisition Program
Space and Missile Systems Center	SMC	Air Force	SE Authority
Space Radar	SR	Joint	Acquisition Program
Theater Joint Tactical Networks	TJTN	Joint	PEO
Theater Medical Information Systems – Joint	TMIP	Joint	Acquisition Program

Provided a basis for understanding SoS in DoD Today

What does SoS Look Like in the DoD Today?

- Typically an **overlay to ensemble of individual systems** brought together to satisfy user capability needs
- Are **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

Definitions

SoS: *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)].

Accepted Taxonomy of SoS [Maier, M. 1998]

- Directed
 - SoS objectives, management, funding and authority; systems are subordinated to SoS
- Collaborative
 - No 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

US DoD Pilots identify a new SoS type:

- Acknowledged
 - SoS objectives, management, funding and authority; however systems retain their own management, funding and authority in parallel with the SoS

SoS SE Guidebook focuses on 'Acknowledged' SoS

Characteristics of Acknowledged SoS

- **Top-down direction** for an SoS capability concurrent with **independent direction and autonomy in system** operation and development
 - Multiple levels of **objectives**
 - Multiple **management authorities** with independent priorities, funding and development plans
 - Multiple **technical authorities**
- Much of SoS functionality is in **extant capabilities** of the systems
- SoS manager and SE **do not have control** over all the parts of the SoS
 - In fact, they may **not be aware** of all the systems which may impact their objectives and both the systems and the objectives may change over time.

Management of Acknowledged SoS

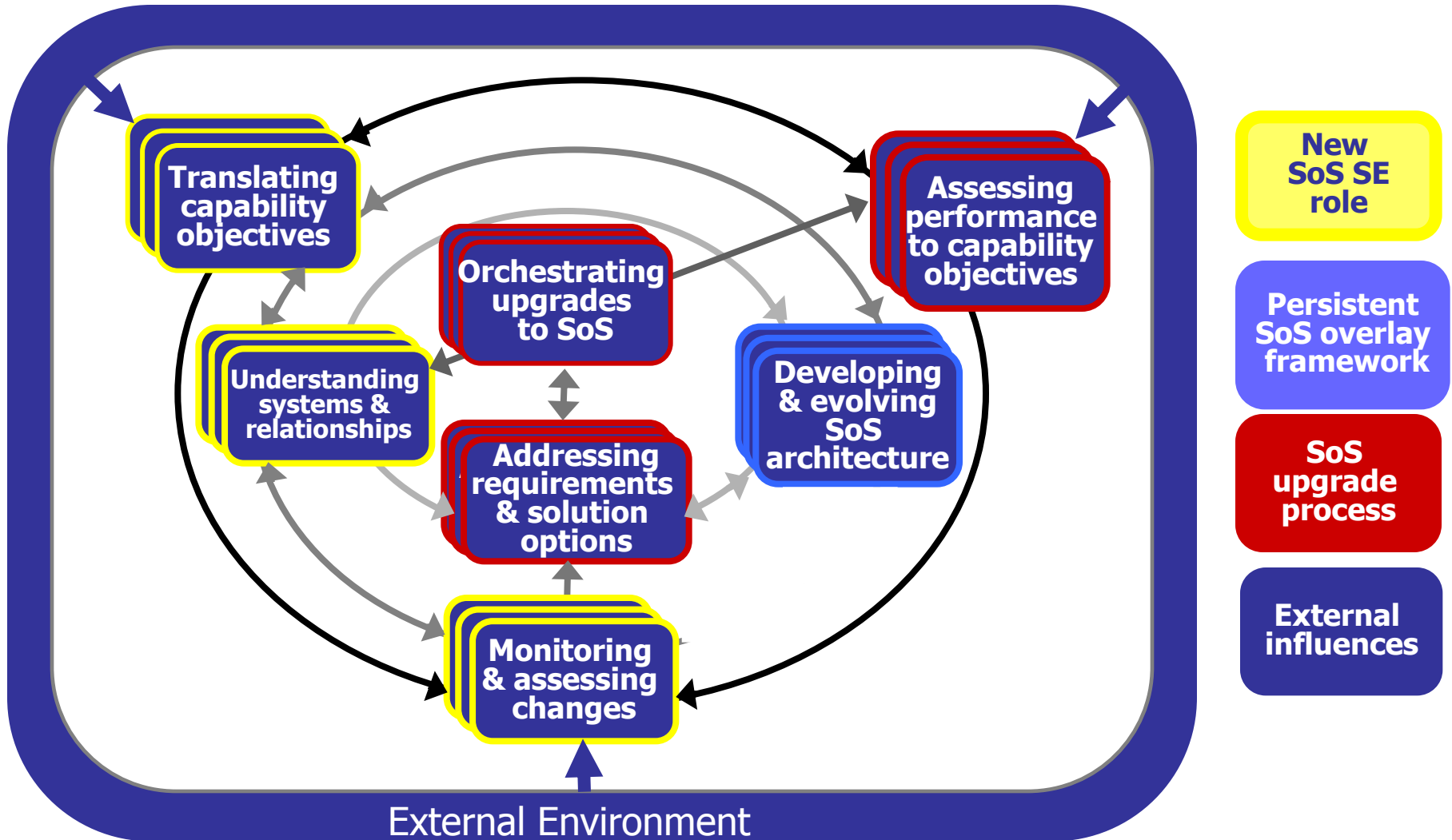
- Independent, concurrent management and funding authority pose management issues
- In defense, a solid governance & management approach is seen as key for SoS
 - Independent authorities are unlikely to accept direction from a systems engineer they do not control
 - Argue to make 'acknowledged' into 'directed' made difficult by 'multi-mission' systems which are important to multiple SoS
- Beyond defense 'acknowledged' SoS exist and evolve without top down management
 - Systems or services are designed to be broadly useful and have as their business objective to support numerous user applications
 - They naturally retain authority over decisions regarding their development and are not likely to agree to limit themselves to one specific customer

Management issues have technical implications for SE

A Comparison

	System	System of Systems
Management & Oversight		
Stakeholder Involvement	Clearer set of stakeholders	Two levels of stakeholders with mixed possibly competing interests
Governance	Aligned PM and funding	Added levels of complexity due to management and funding for both SoS and systems; No SoS does over all systems
Operational Environment		
Operational Focus	Designed and developed to meet operational objectives	Called upon to meet operational objectives using systems whose objectives may or may not align with the SoS system's objectives
Implementation		
Acquisition	Aligned to established acquisition processes	Cross multiple system lifecycles across acquisition programs, involving legacy systems, developmental systems, and technology insertion; Capability objectives but may not have formal requirements
Test & Evaluation	Test and evaluation the system is possible	Testing more challenging due systems' asynchronous life cycles and given the complexity of all the moving parts
Engineering & Design Considerations		
Boundaries & Interfaces	Focuses on boundaries and interfaces	Focus on identifying systems contributing to 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 performance objectives	Performance across the SoS that satisfies SoS user capability needs while balancing needs of the systems

SE Model for SoS Based on 7 Core Elements of SoS SE



Core Elements of SoS SE (1 of 3)



Translating capability objectives

- Translating SoS capability objectives into high level requirements over time
 - SoS objectives based on broad capability objectives
 - SE team plays strong role in establishing requirements and understanding dynamics of the environment



Understanding systems & relationships

- Identifying and understanding the systems that impact SoS objectives
 - Focus on components and dynamics vs boundaries
 - Extends beyond technical to broader context of management, organizational, development plans, funding, etc.



Monitoring & assessing changes

- Anticipating and assessing impacts of potential changes on SoS performance
 - Given scope of SoS authority, key to SoS SE is identifying and addressing changes in systems and other areas (e.g. threat) which may impact the SoS

Core Elements of SoS SE (2 of 3)



- Developing and evolving SoS architecture
 - This includes
 - Concept of operations
 - Systems, functions and relationships and dependencies, both internal and external
 - End-to-end functionality, data flow and communications within the SoS.
 - Provides the technical framework for assessing options and implications for meeting requirements over time
 - Persistence, tolerance for change
- An **architecture** is the structure of components, their relationships, and the principles and guidelines governing their design evolution over time (IEEE Std 610.12 and DoDAF).
- The architecture of an SoS is a persistent technical framework for governing the evolution of an SoS over time.

Core Elements of SoS SE (3 of 3)

Addressing requirements & solution options

- SoS requirements and solution options
 - Requirements addressed at both SoS & systems
 - Recommend SoS requirements based on both priority and practicality
 - SoS and system SE teams identify and assess options
 - Result is plan for development for next increment

Orchestrating upgrades to SoS

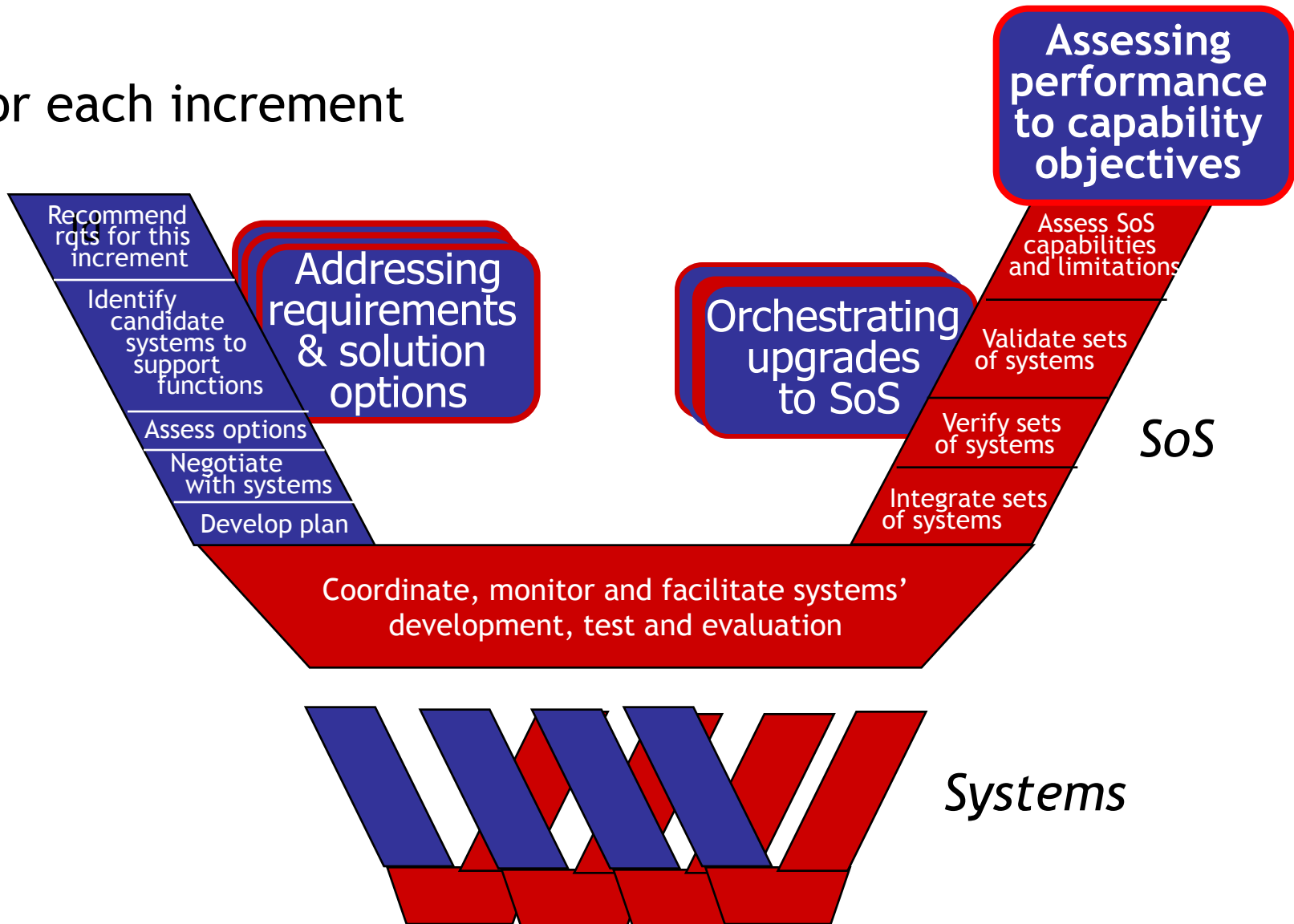
- Orchestrating SoS Upgrades
 - Upgrades implemented by systems under system SE teams
 - SoS SE team plans, facilitates, integrates and tests upgrades to the SoS
 - Development based on incremental approaches (bus stop, wave) which accommodate asynchronous system developments

Assessing performance to capability objectives

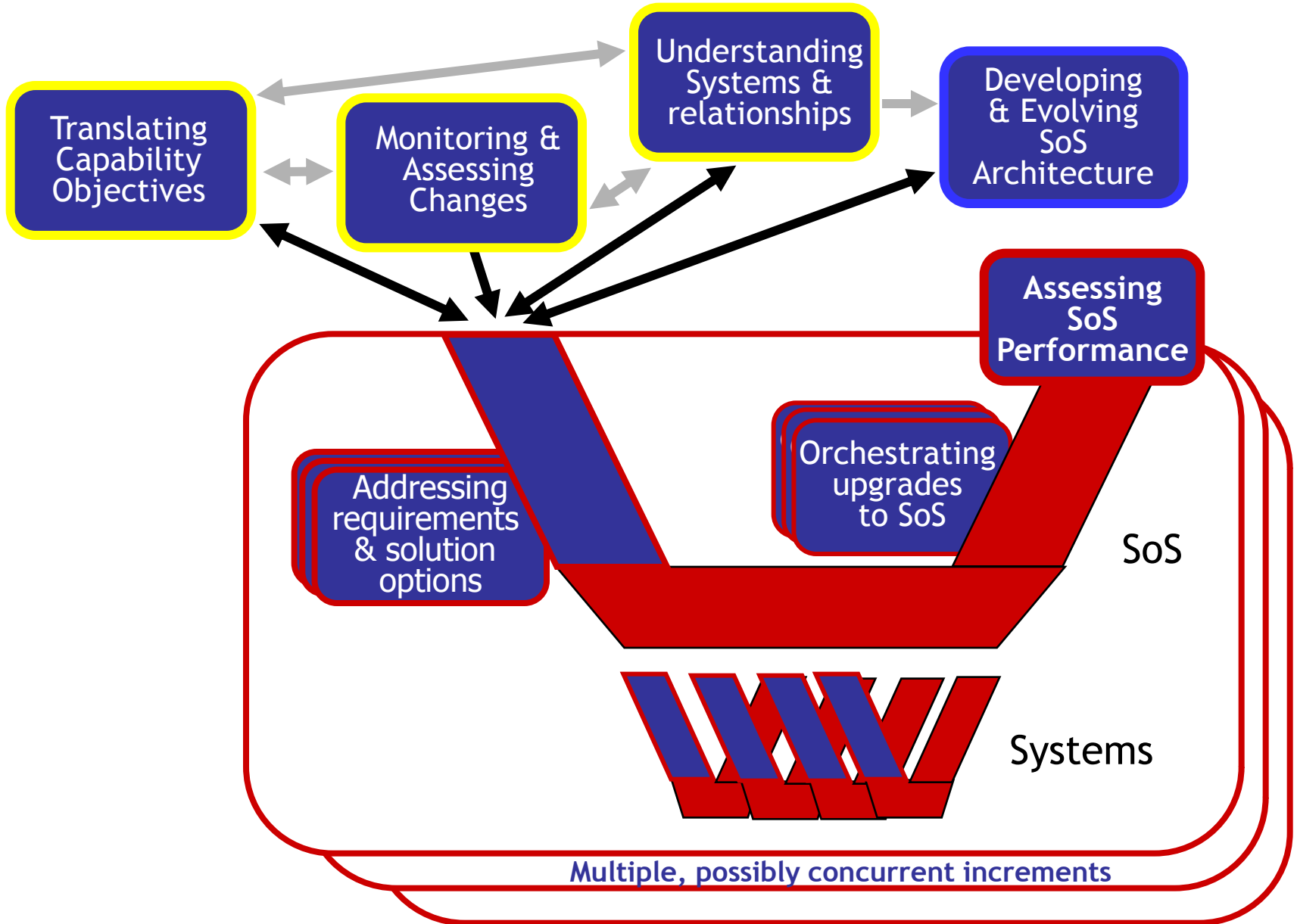
- Assessing SoS Performance
 - Based on measures of SoS user results applied in different settings (test, exercises, M&S, operations)
 - Opportunity to identify changes and emergent behavior

View of SoS Upgrade (1 of 2)

For each increment



View of SoS Upgrade (2 of 2)





What is Working? SoS SE Principles

- Address **organizational** as well as technical perspectives
 - Factor in broader set of consideration into trade space and technical planning
- Focus on **areas critical to the SoS**
 - Leave the rest 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

Challenges

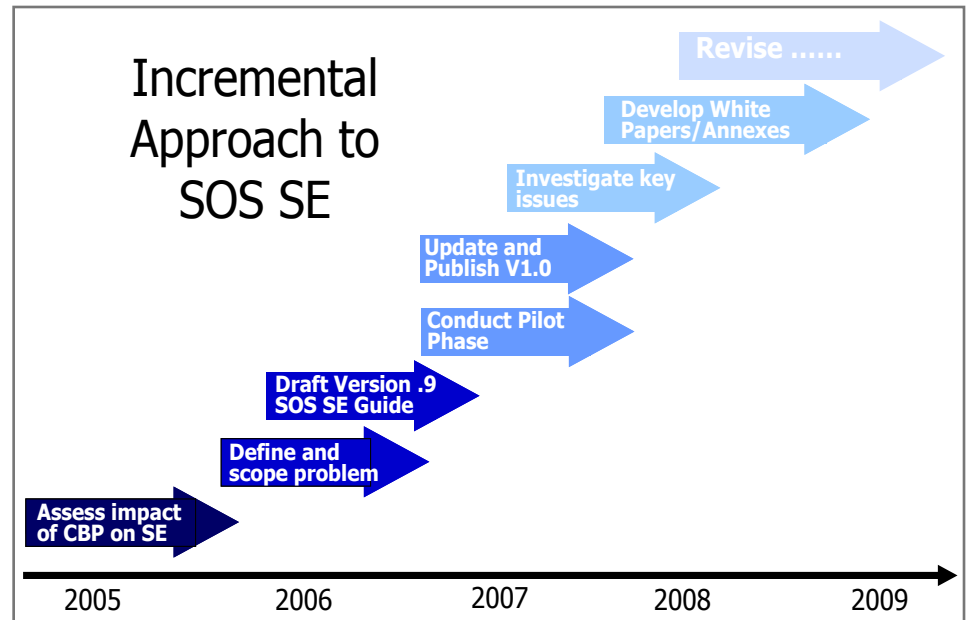
- Challenges and options for **SoS test and evaluation**
- Role of SoS SE in the **front-end capabilities analyses** currently conducted under the JCIDS process
- Role of SoS in **early SE**, during concept definition and refinement
- **Systems assurance** issues posed by SoS
- Impact of growth in SoS SE on the SE of **individual systems**
 - (e.g., How to best engineer individual systems to enhance their ability for integration into SoS)
- Impact on systems when they have to adapt to multiple SoS
- Special characteristics of **SoS SE for C2ISR networked systems**
 - (e.g., How the SE processes, including requirements management, deployment, and integration and test of service-oriented architectures differ from traditional SoS)
- Options and impacts of varying **SoS organizational strategies**, including management, engineering, T&E, funding and governance and their **impact on SE**
- Role of SE to support **ad hoc reconfiguration** of SoS under changing operational situations including interoperability implications.

Modeling and Simulation?

- How does the SoS SE Guide address M&S?
 - Initial .9 Version included M&S throughout the draft
 - The practitioner reviews indicate limited use of M&S
 - Main place where M&S was cited is in the emulation of systems not otherwise available for testing
 - Consequently the 1.0 Working Draft limited M&S to this area
 - Comments on the draft identified more uses of M&S
 - The final 1.0 Version has an M&S section and added places where M&S is discussed

Where does M&S fit in SoS SE?

- Propose a survey of input from committee members: for each core elements of SoS SE
 - Where are the possibilities?
 - What is the reality?
 - What needs to be done to realize the possibilities?
- Product
 - White paper ->
 - Annex to Guide ->
 - Guide Revision



AT&L SSE Request for NDIA M&S Committee Support