Understanding the Current State of US Defense Systems of Systems and the Implications for Systems Engineering

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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

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 Defense Acquisition Guide, 2004]**

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

Taxonomy of SoS

- What characterizes these SoS and how does this impact SE?

Maier Taxonomy of SoS

- 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

Putting these DoD SoS into a broader context

Taxonomy of SoS

- Where do these DoD SoS fit?

- Directed
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These SoS resemble

- "Directed"

  except that the systems in the SoS maintain autonomy

- "Collaborative"

  except they have SoS level management, objectives, funding etc.

Taxonomy of SoS

- A new category of SoS

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

Expanded Taxonomy of SoS

- Directed: SoS objectives, management, funding and authority; systems are subordinated to SoS
  - Relatively rare and are often not purely directed
  - FCS and BMDS most frequently cited examples
  - Closest to 'systems' and most amenable to tradition SE
- Acknowledged: SoS objectives, management, funding and authority; however systems retain their own management, funding and authority in parallel with the SoS
  - Growing in DoD as focus shifts to capabilities with need to leverage current systems as they continue to address their original needs
- Collaborative: No objectives, management, authority, responsibility, or funding at the SoS level; Systems voluntarily work together to address shared or common interest
  - Communities of interest are examples; no recognized systems engineer
- Virtual: Like collaborative, but systems don't know about each other
  - Broader, net-centric practices to support future ability to share data

All types of SoS are found in DoD

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

Technical Implications of Key Characteristics Acknowledged SoS (1 of 5)

- Broad SoS capability objectives
  - Need to translate these objectives into technical requirements
  - Understand the broader context for the objectives including the drivers for the user demand
    - Anticipate areas of change
- Composition of SoS
  - Set of existing systems which contribute to the SoS objectives
  - Extant system functionality serves as the starting point for the SoS
    - How does functionality of systems support the SoS objectives? How well?
    - What are gaps and overlaps or inconsistencies affecting performance of the SoS?
  - May not fully understand how these systems work, individually or together
    - Unanticipated effects or emergent behavior
  - May not have identified all the systems which impact the SoS objectives
  - Systems may be changing and new systems may be coming online independently of the SoS

Technical Implications of Key Characteristics Acknowledged SoS (2 of 5)

- Change impacting the SoS
  - Span of actual control for the SoS systems engineers is limited
    - Need to anticipate change and assess the implications for the SoS
    - Important to identify areas where changes are likely or critical to the SoS
  - Need to develop ways to
    - Monitor and identify changes early
    - Assess impacts while there are opportunities to influence changes or respond to maintain or capitalize on changes for the SoS
- Assessing SoS progress
  - Need performance measures independent of the systems
    - Assess alternative ways to address objectives
  - Performance of SoS are likely change without any action at the SoS level
  - Need opportunities to observe SoS performance in 'natural setting' to identify unanticipated changes or emergent behavior

Technical Implications of Key Characteristics Acknowledged SoS (3 of 5)

- Beyond technical
  - Need to understand aspects of the systems beyond their technical capabilities
    - Users/stakeholders, motivations, funding, development approach and pace, etc.
    - Context for system development, investment and user needs
  - Basis for knowledgeably working with the systems to negotiate ways they can support the SoS needs while still supporting their own objectives
- Importance of architecture
  - An 'overlay' to systems, a framework for how the systems will work together to meet the SoS objectives over time
    - Does not address the design of the systems themselves
      - Responsibility of the systems
    - Does define cross cutting attributes critical to the SoS
  - Challenging because it needs to consider both
    - Context of the individual systems
    - Changing needs of the SoS over time
  - Emphasis on flexibility and changeability over performance at any given time
  - Mechanism for addressing asynchronous changes in systems
    - Tolerant of change on the part of the systems

Technical Implications of Key Characteristics Acknowledged SoS (4 of 5)

- Moving the SoS forward incrementally
  - Because of asynchronous nature of systems, most SoS evolve incrementally
  - Start with the assessment of the current SoS performance
    - Areas for attention are identified
    - Consider the development approaches of the systems
    - Requirements to be addressed are identified and options for addressing these are assessed
  - Practicality of making changes in different systems at different times can have a strong impact on selection of requirements
  - Identify options for changes or additions toward meeting objectives through changes in systems
    - Managers and systems engineers of the systems are key decision makers in this process
    - Specific implementation options within systems remain in the purview of the systems
    - Assess changes to meet SoS needs like they do other requirements

Technical Implications of Key Characteristics Acknowledged SoS (5 of 5)

- Cross-system role of SoS SE
  - Cross-cutting role of negotiating plans with systems and *orchestrating the changes across the SoS*
  - A 'master SoS schedule' is done at multiple levels
    - SoS addressing cross SoS progress with a focus on key integration points for the SoS
    - System level focus on details for systems changes as part of the SE for the system
  - In an SoS, basis SE activities like functional allocation, requirements traceability, technical baselines, technical reviews, and work breakdown structures
    - No longer single entities which span the 'system' from top to bottom under the purview of a single SE authority
    - Distributed among the systems engineers of the SoS and systems
    - Are defined and executed in an asynchronous, incremental fashion, as the SoS evolves concurrently

Challenges

- Governance Impact on SE
  - What is the impact on SE of different approaches to organizing and executing SoS management and evolution?
  - Understand governance and business models which foster good SE
- Virtual and Collaborative SoS
  - What does SE look like in virtual and collaborative SoS?
  - Are systems in a collaborative or virtual SoS, better suited to support acknowledged SoS when they arise?
  - A better understanding of other forms of SoS and their relationships is needed to get a more integrated view of the systems world today
    - Different SoS types exist concurrently and overlap, and any system may be part of one or more SoS of different types
- Impact of SoS on SE of Systems
  - Implications of SoS for SE of systems as potential SoS components
  - If a system expects to be available as a part of an SoS
    - What does the systems SE do differently in the engineering and design of a system to ensure the system is an available future partner?
    - Or more defensively, how do you engineer a system so they are not adversely impacted by the need to work as part of a SoS?