System of Systems Challenges and Solutions: Case Study Insights

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Cliché?  Buzz word?

Any characteristics in an SoS different than a system?

Is the engineering effort in an SOS different than traditional Systems Engineering?

Welcome to the debate.
The views expressed in this presentation are those of the authors and do not reflect the official policy or position of the Air Force Institute of Technology, the United States Air Force, the Department of Defense or the United States Government.

As a professor, I am obligated to put this disclaimer on everything.

Thanks to the many interviewed (Gov’t, FFRDC, SETA, primes) and to many students:

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- Major Bode
- Major Couluris
- Major Ferko
- Major Gunn
- Major Sheesley
- Major Cohee
- Major Turner
Agenda

- System-of-Systems Challenges
  - Definition
  - Characteristics
  - Challenges and Example Cases

- Implementation Strategies/ Solution Considerations
  - Engineering the SoS
  - Architecture and Patterns
  - Interface Management
  - Test and Evaluation
  - Agile Development

- Summary
* Unclassified cases available for download http://www.afit.edu/cse
A SoS is defined as a set or arrangement of systems that results from independent systems integrated into a larger system that delivers unique capabilities.

-- Defense Acquisition Guide

- Maier (1998) highlights two characteristics that distinguish the SoS from very large complex monolithic systems:
  1. Operational Independence
  2. Managerial Independence

- Maier (1996) and others originally stated others characteristics
  3. Evolutionary Development.
  4. Emergent Behavior:
  5. Geographic Distribution:
Lots of DoD SoS Examples

- **Space Community**
  - “single, fully integrated, multi-INT architecture”
  - “Community-wide architecture” … “ground architecture”
  - “overhead enterprise architecture”

- **C4ISR Community**
  - Small Clusters of Systems (U2 – Datalink – DCGS)
  - Air Force Constellation Net
  - Air Force Research Lab’s Layered Sensing concept
  - Airborne Electronic Attack (AEA) SoS Architecture

* From DoD SoS Engineering Guide v1.0
SoS Challenges

LEADERSHIP

Competing Operational Demands (LDHD)

STANDARDS

InTEGRATION FUNDING

Test and Evaluation

SoS capabilities

SoS Performance

Complexity

Boundaries

Legacy Issues

Let’s focus on a few…

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<th>Survey Item</th>
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<td>Leadership</td>
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<td>Standards</td>
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<td>Interdisciplinary Teams</td>
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MILSATCOM (AEHF) Interface Management Case
Cost of Interface Management

In a 3 year period, 56% of baseline modifications were ICD-related. $31.5M of $71.2M (44%) of contract modifications were ICD-related.

Case Observation
- Cost and Effort of SoS Integration
U-2 SoS T&E case

Operational concern:
- Test events being planned without full coordination
- T&E plans not fully validated
- Missing opportunities to “piggy-back” test objectives

Examined Force Development Evaluation T&E Process

U-2S aircraft

Upgraded SYERS-2A
--multispectral (EO/IR) sensor

Dual Data Link 2 (LOS/ BLOS)

Distributed Common Ground Station
Test Objective: “Verify new SYERS-2A sensor end-to-end operations and to demonstrate full airborne/ground segment functionality with DLL2 in available configurations and operational representative architectures”
SoS T&E case

Case Observations

- SoS Integration is NOT Built Into the Process
- "Seamless" Seams Among Interdependent Systems still Real
- Ability to Define the "Ends" Disappearing
- Program Priorities Dominate

DoD T&E Summit, 2004, Dr. Glenn Lamartin

- Increasing complexity and interdependencies of systems
- Exponential growth in interfaces (network participants)
- Increased requirements for T&E (Evolutionary Acquisition)

Network Centric Warfare, 1996, Alberts, Garstka and Stein

“Testing systems will become far more complex since the focus will not be on the performance of individual systems by on the performance of the federation of systems”
SoS Emerging Solutions

- Importance of Architecture across the SoS
  - Focus on interfaces
  - Architectural Pattern

- Acknowledging the different roles for SoS
  - SoS Integration and T&E Lessons Learned
  - Systems engineering versus SoS Engineering/Architecting

- Address acquisition management issues
  - Agile development methodologies
  - Appropriate contracting strategies
Emphasize Operational, Systems Engineering

• Top-down Architecting and Architecture frameworks (DoDAF, Zachman, TOGAF, FEAF, etc)
• Bottom-up system integration for new CONOPS and Capabilities
• Early Architecture Evaluation/Analysis
• Define, organize and communicate interfaces

“The greatest leverage in system architecting is at the interfaces ... the greatest dangers are also at the interfaces!”

Solution-Architectural Patterns

- Architect interfaces at all levels of abstraction for agility, adaptability (evolution) and growth
  - Layers and “Bowtie” architectural pattern for SoS agility*
  - SAB concept of “convergence protocol”**

* Rich Bryne, MITRE, from 2008 NRO Systems Engineering Conference
** Scientific Advisory Board 2004,
Solution SoS Integration/ T&E

- Annette Krygiel’s “Behind the Wizard’s Curtain”
- SoS Integration (mid 1990s) for
  - Digital Mapping Agency
    - Digital production
  - Army Task Force XXI
    - Digital battlefield
Solution - SoS Integration/T&E

1. Key Activities need to precede SoS integration
   ■ Architecture and architecture compliance, system test

2. Robust Testing strategy. Early, incremental and iterative integration
   ■ Build a little--test a little

3. Plan for substantial difficulties, significant time and resources

4. One site facilitates integration and test of SoS components

5. Address the leadership of the SoS integration

6. Prototyping the SoS provides early insight to ops requirements
   ■ Test with Operators
1. Translating SoS Capability Objectives into High-Level SoS Requirements over Time
2. Understanding the Constituent Systems and Their Relationships over Time
3. Assessing Extent to Which SoS Performance Meets Capability Objectives over Time
4. Developing, Evolving and Maintaining an Architecture for the SoS
5. Monitoring and Assessing Potential Risk and Opportunities on SoS Performance
6. Addressing SoS Requirements and Solution Options
7. Orchestrating Upgrades to SoS

* From DoD SoS Engineering Guide v1.0
Engineering an SoS
Two SoS extremes

“DIRECTED” SoS
(TO BE/ OBJECTIVE)

Ops Mission Architecture
+ Decompose Segments/ Systems

Lead Systems Integration (LSI)

Govt LSI
Prime (LSI w/ subs)
Design Control
LSI w/ multi Primes
(ACA) Coord/Plan/Architect

“ACKNOWLEDGED” SoS
(TO BE/ OBJECTIVE)

New Missions
+ New Capabilities

Modify + New Systems
+ Integration/ Design/ Architecture

Baseline Systems (AS IS)
Need for Agile/Adaptability

- Changing Requirements across the SOS
  - Add/Subtract/Move (phasing)
  - Clarify/Definition of Requirements based on Ops feedback
- Changing Schedule across the SOS
  - Move work requirements (phasing)
  - Deployment to sites/Ops tempo
- Changing Interfaces
  - Add new interfaces, Changing/Clarify Definition

One PM suggested the need for “Flexpoints”
Solution – Acq Implications

- **Organizational (People)**
  - Experience with SoS Strategies
  - Experience with Agile development methodology
  - Familiarity (or connection) with the Domain (system type)
  - Attitudes – collaborative, communicative

- **Development Method**
  - Spiral or Iterative Lifecycle
  - Scrum software practices
  - Ability to handle CHANGE
SoS Lessons can be learned from system, enterprise and SoS case studies

DoD policy and guidelines now reflect the changing IT landscape of system of systems
  - Leaders have predicted this changing landscape will directly impact engineering activities

Requirements & Acquisition community must address
  - Growing program interdependencies
  - Greater numbers of potential changes across the SoS
  - The ability to operational test (and resource those tests)
  - Organization aspects to best handle SoS challenges