

# Systems of Systems & Requirements

Dr. Judith Dahmann

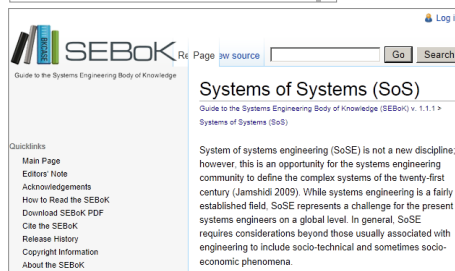
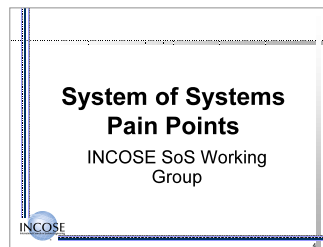
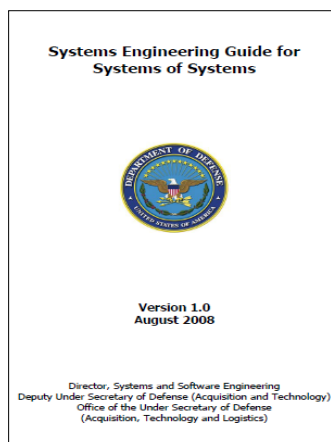
**Panel: Identifying Top Challenges for International Research on Requirements Engineering for Systems of Systems Engineering**

**21<sup>st</sup> International IEEE Requirements Engineering Conference**

**July 17, 2013**

MITRE

## Key SoS Resources



MITRE

## What is a 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 SoS SE Guide]

A SoS is an integration of a finite number of constituent systems which are independent and operatable, and which are networked together for a period of time to achieve a certain higher goal. [SEBoK 1.1]

© 2012 The MITRE Corporation. All rights reserved.

For internal MITRE use

MITRE

## Why SE for Systems of Systems (SoS)?

- **SE is a critical enabler for systems development**
  - Provides discipline and structure for successful system realization
- **Most systems today are part of an SoS whether or not explicitly recognized**
- **Increasingly, critical capabilities are dependent on SoS**
  - First recognized in military context
  - Applies to both government and industry as well

**Transportation** - the European rail network, integrated ground transportation, cargo transport, air traffic, highway management, and space systems,

**Energy** - smart grid, smart houses, and integrated production/consumption,

**Health Care** - regional facilities management, emergency services, and personal health management,

**Natural Resource Management** - global environment, regional water resources, forestry, and recreational resources,

**Disaster Response** - forest fires, floods, and terrorist attacks,

**Consumer Products** - integrated entertainment and household product integration, and

**Media** - film, radio, television.

[From SEBoK 1.1]

MITRE

## Key SoS SE Challenges

- **SoS are overlays of existing systems**
  - Many of today's capabilities require systems now in operations to working together to meet emerging user needs
- **Ownership/Management is not clean**
  - Individual systems are owned and managed independently introducing constraints on SoS management and SE
- **Enterprise level challenges**
  - SoS themselves must integrate with other SoS and enterprise architectures
- **Traditional SE processes and tools must be adapted**
  - SoS characteristics require adaptation of traditional SE to be more flexible, agile

July 25, 2013

MITRE

## Differences Between Systems and SoS as They Apply to Systems Engineering

| 6 |

	Systems Engineering	Systems of Systems Engineering
<b>Management &amp; Oversight</b>		
System	Physical engineering	Socio-technical management and engineering
Stakeholder Involvement	Clear set of stakeholders	Multiple levels of stakeholders with mixed and possibly competing interests
Governance	Aligned management and funding	Added levels of complexity due to management and funding for both SoS and systems; SoS does not have control over all constituent systems
<b>Operational Focus (Goals)</b>		
Operational Focus	Designed and developed to meet common objectives	Called upon to meet new SoS objectives using systems whose objectives may or may not align with the SoS objectives
<b>Implementation</b>		
Acquisition/Development	Aligned to established acquisition and development processes	Cross multiple system lifecycles across asynchronous acquisition and development efforts, involving legacy systems, developmental systems, and technology insertion
<b>Engineering &amp; Design</b>		
Process	Well-established	Learning and Adaptation
Test and Evaluation	Test and evaluation of the system is possible	Testing is more challenging due to systems' asynchronous life cycles and given the complexity of all the parts
<b>Engineering and Design</b>		
Boundaries and Interfaces	Focuses on boundaries and interfaces	Focus on identifying systems contributing to SoS objectives and enabling flow of data, control and functionality across the SoS while balancing needs of the systems OR focus on interactions between systems. Difficult to define system-of-interest
Performance and Behavior	Performance of the system to meet performance objectives	Performance across the SoS that satisfies SoS use capability needs while balancing needs of the systems
Metrics	Well defined (e.g. INCOSE handbook)	Difficult to define, agree, and quantify

[From SEBoK 1.1]

MITRE

## Types of SoS

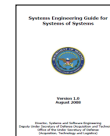
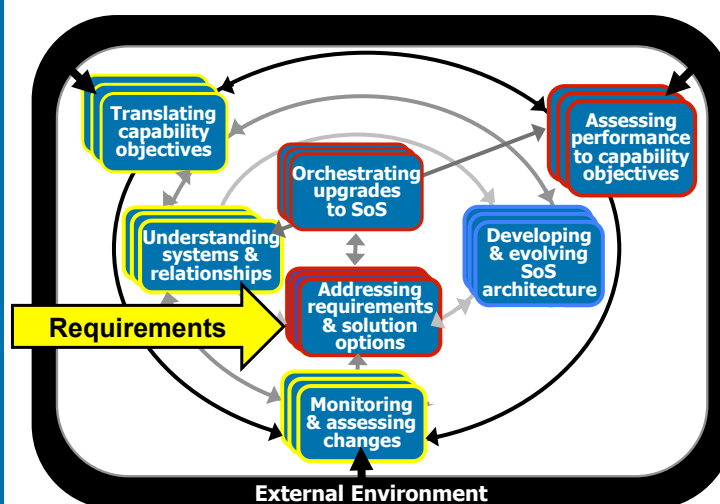
- **Directed** - The SoS is created and managed to fulfill specific purposes and the **constituent systems are subordinated to the SoS**. The component systems maintain an ability to operate independently; however, their normal operational mode is subordinated to the central managed purpose;
- **Acknowledged** - The SoS has recognized objectives, a designated manager, and resources for the SoS; however, the **constituent systems retain their independent ownership**, objectives, funding, and development and sustainment approaches. Changes in the systems are based on cooperative agreements between the SoS and the system;
- **Collaborative** - The component systems interact more or less **voluntarily** to fulfill agreed upon central purposes. The central players collectively decide how to provide or deny service, thereby providing some means of enforcing and maintaining standards;
- **Virtual** - The SoS **lacks a central management authority and a centrally agreed upon purpose** for the SoS. Large-scale behavior emerges—and may be desirable—but this type of SoS must rely on relatively invisible mechanisms to maintain it.

[From SEBoK 1.1]

SoS 'type' affects requirements engineering

MITRE

## Requirements in US DoD SoS Guide



New SoS SE role

Persistent SoS overlay framework

SoS upgrade process

External influences

MITRE

## Assessment of SoS Capabilities Basis For Defining System Requirements

Translating  
capability  
objectives

Assessing  
performance  
to capability  
objectives

Addressing  
requirements  
& solution  
options

- **Translating SoS capability objectives**
  - SoS objectives based on broad capability objectives – *'purposeful'*
  - SE team plays strong role in understanding capability objectives the SoS
- **Assessing SoS performance**
  - Most SoS exist in some form when SoS is recognized
  - First step is to assess how well capability objectives are being met
  - Provides basis for identifying SoS *'requirements space'*
- **SoS requirements and solution options**
  - Requirements addressed to meet both SoS & system needs
    - Constituent systems continue to evolve to meet user needs
  - SoS and system SE teams identify and assess options to meet SoS needs
  - *Result is added requirements on systems*

MITRE

## Requirements in INCOSE SoS Pain Points

### SoS Pain Point Summary

System of Systems  
Pain Points  
INCOSE SoS Working  
Group

Requirements

Pain Points	Question
SoS Authority	<i>What are effective collaboration patterns in systems of systems?</i>
Leadership	<i>What are the roles and characteristics of effective SoS leadership?</i>
Constituent Systems	<i>What are effective approaches to integrating constituent systems into a SoS?</i>
Autonomy, Interdependencies & Emergence	<i>How can SE provide methods and tools for addressing the complexities of SoS interdependencies and emergent behaviors?</i>
Capabilities & Requirements	<i>How can SE address SoS capabilities and requirements?</i>
Testing, Validation & Learning	<i>How can SE approach the challenges of SoS testing, including incremental validation and continuous learning in SoS?</i>
SoS Principles	<i>What are the key SoS thinking principles, skills and supporting examples?</i>



Survey identified seven 'pain points' raising a set of SoS SE questions

## Need for New Approaches for SoS Recognized

| 11 |

### Capabilities and Requirements

- In SoS SE, it is not useful to develop detailed requirements at the SoS level, but rather to look at user capability needs at a higher level of abstraction
  - Identify a multiple alternatives to adapt systems to meet the higher level SoS needs since the systems will each have their own constraints (both technical and non-technical)
  - Important for the SoS to have a wider range of options available since the preferred approach may not be feasible.
  - SoS capabilities may draw on a wider variety of non-material aspects of organizations which means that addressing SoS capability needs may go beyond adapting systems specific functionality and interfaces.

*How can SoSE address SoS capabilities and requirements?*



MITRE

## In Sum

| 12 |

- Growing interest and energy around application of systems engineering to SoS
- SoS have key characteristics that pose challenges to traditional systems engineering approaches
- Recognized need for new approaches to address SoS capabilities and resulting requirements on constituent systems

MITRE