Systems of Systems

Presentation to Practical Systems and Software Measurement Users Group

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February 26, 2016

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Topics

- Definitions
- Characteristics
- SoS Types
- Comparing Systems with SoS
- Implications for Systems Engineering
- SoS 'Lifecycle'
- Challenges: "SoS Pain Points"

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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
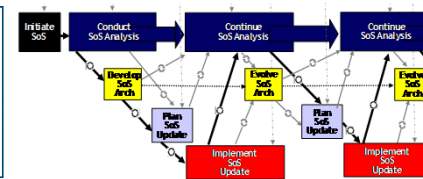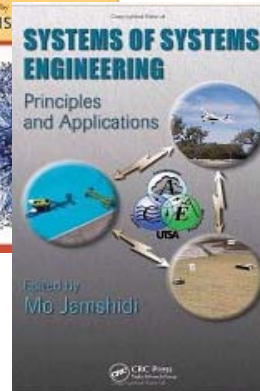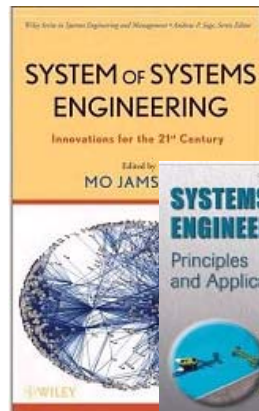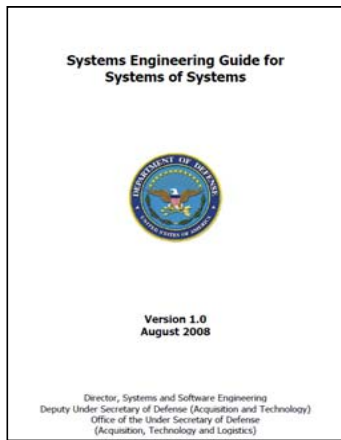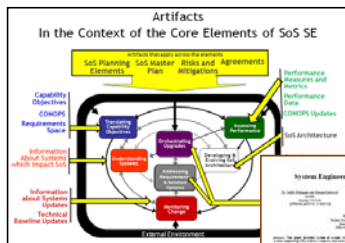
Systems of Systems Engineering

The process of planning, analyzing, organizing, and integrating the capabilities of a mix of **existing and new systems into a system-of-systems capability** that is greater than the sum of the capabilities of the constituent parts

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Definitions

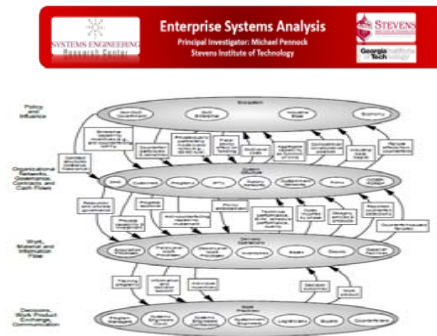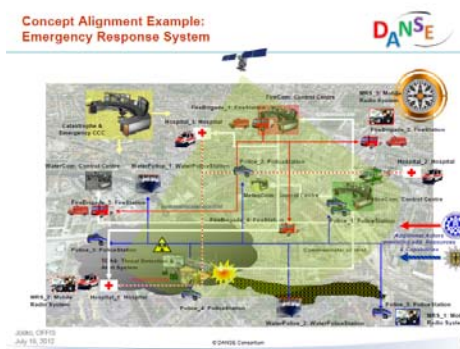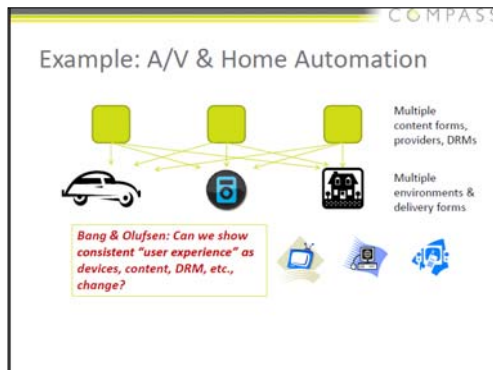| Source	Definition
SE Body of Knowledge	A SoS is an integration of a finite number of constituent systems which are independent and operatable, and which are networked together for a period of time to achieve a certain higher goal. (Jamshidi 2009)
INCOSE SE Handbook	[A] system-of-interest whose elements are managerially and/or operationally independent systems. These interoperating and/or integrated collections of systems produce results unachievable by the individual systems alone.
ISO/IEC/ IEEE 15288: 2015	A system of systems (SoS) is a system-of-interest (SOI) whose elements are themselves systems. A SoS brings together a set of systems for a task that none of the systems can accomplish on its own. Each constituent system keeps its own management, goals, and resources while coordinating within the SoS and adapting to meet SoS goals.
US DoD SoS SE Guide	A set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities.

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Energy

Water

Air Transportation

Missile Defense

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Investigations Into SoS SE for Defense & Beyond

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Maier SoS Characterization

- **Maier (1998) postulated five key characteristics of SoS:**
  - Operational independence of component systems
  - Managerial independence of component systems
  - Geographical distribution
  - Evolutionary development processes
  - Emergent behavior

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Scale and Scope of SoS

Technical ----- Socio -Technical ----- Enterprise

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SoS Domains in Defense

Tactical Vehicle

Military Satellite Communications
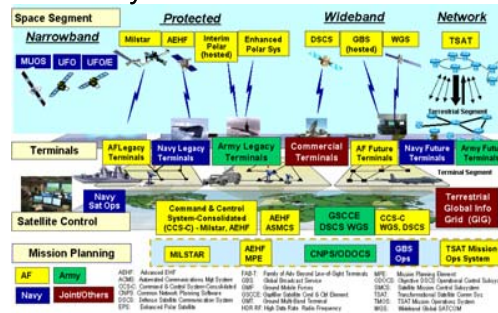

Operations Center
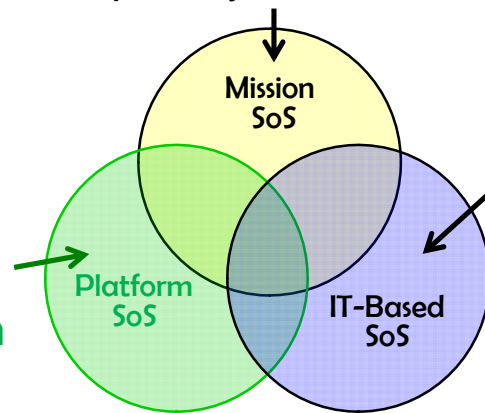#### AOC Weapon System Process

Platforms

A military platform (e.g. ship, aircraft, satellite, ground vehicle) equipped with independent systems (e.g. sensor, weapons, communications) needed to meet platform objectives
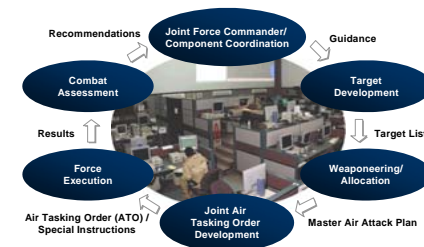
Missions
Sets of systems working together to provide a broader capability or mission

Information Technology

Networked information systems to support operations within or across platforms or systems to meet mission or capability objectives

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SoS Types

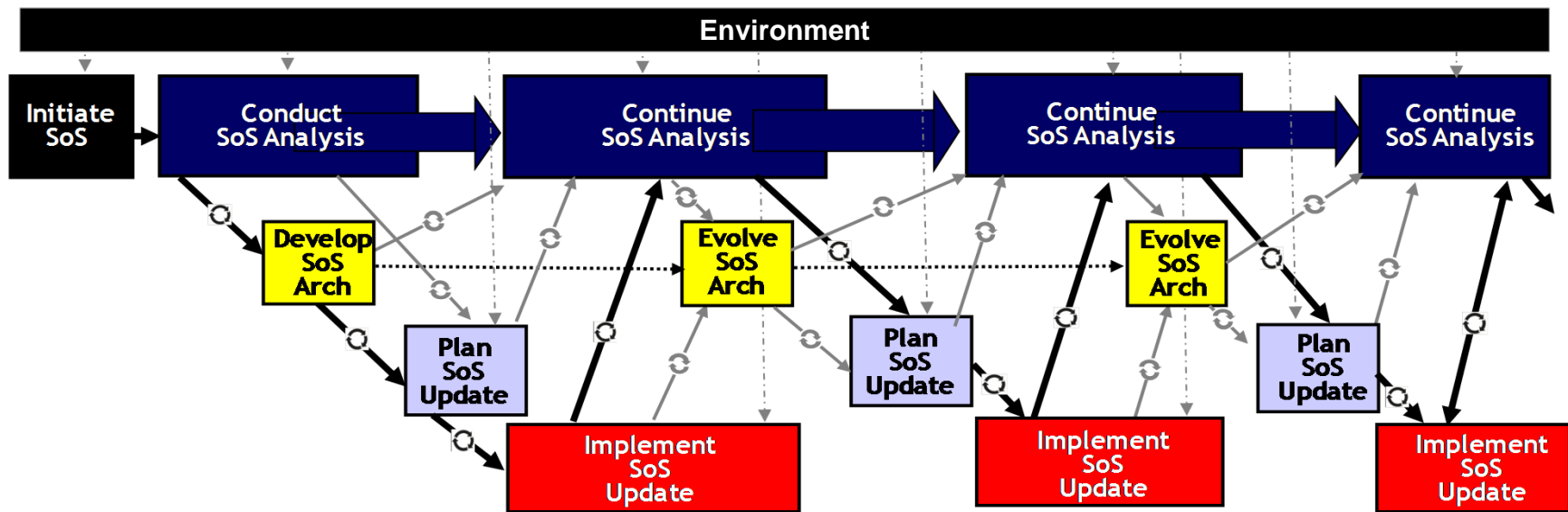| Type	Definition
Directed	Directed SoS are those in which the SoS is engineered and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the centrally managed purpose.
Acknowledged	Acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, development, and sustainment approaches. Changes in the systems are based on cooperative agreements between the SoS and the system.
Collaborative	In collaborative SoS, the component systems interact more or less voluntarily to fulfill agreed-upon central purposes.
Virtual	Virtual SoS lacks a central management authority and a centrally agreed-upon purpose for the system of systems. Large-scale behavior emerges—and may be desirable—but this type of SoS relies upon relatively invisible, self-organizing mechanisms to maintain it.

https://acc.dau.mil/dag4

- Many SoS exist but are not recognized and develop and evolve without benefit of SE
- Types apply when the SoS is recognized and treated as an SoS
- In reality, most actual SoS are a combination of these types

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Differences Between Systems and SoS as They Apply to SE

Management & Oversight

Operational Focus (Goals)

Implementation

Engineering & Design

	Systems Engineering	Systems of Systems Engineering
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
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
Implementation		
Acquisition/Development	Aligned to established acquisition and ...sses	Cross multiple system lifecycles across asynchronous acquisition and development efforts, involving legacy systems, developmental systems, and technology insertion
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
Engineering and Design Considerations		
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

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A View of the SoSE Lifecycle

Environment

Initiate SoS

Conduct SoS Analysis

Continue SoS Analysis

Continue SoS Analysis

Continue SoS Analysis

Develop SoS Arch

Evolve SoS Arch

Evolve SoS Arch

Plan SoS Update

Plan SoS Update

Plan SoS Update

Implement SoS Update

Implement SoS Update

Implement SoS Update

Iterative Evolutionary Approach to Evolving an SoS

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SoS Pain Points

SoS Authority
What are effective collaboration patterns in SoS?

Leadership
What are the roles and characteristics of effective SoS leaders?

Capabilities & Requirements
How can SE address SoS capabilities and requirements?

Constituent Systems
What are effective approaches to integrating constituent systems?

Testing, Validation & Learning
How can SE approach SoS validation, testing, and continuous learning in SoS?

SoS Principles
What are the key SoS thinking principles?

Autonomy, Interdependencies & Emergence
How can SE address the complexities of interdependencies and emergent behaviors?

Challenges and Opportunities

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SoSE Measurement Workshop
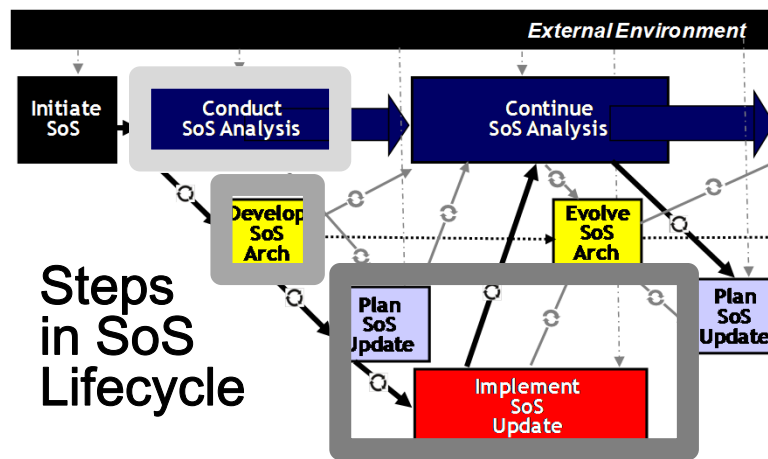
Steps in SoS Lifecycle

Question   Indicator   Measure

- Questions
- Indicators
- Measures

What Questions, Indicators, and Measures apply at each step in the SoSE Lifecycle?

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