

Systems of Systems (SoS) Engineering From the View of the INCOSE SoS Working Group

Presentation to the Washington Metropolitan Area Chapter

February 14, 2018

Dr. Judith Dahmann
The MITRE Corporation



Systems of Systems



How do we define 'Systems 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*

What are core characteristics of SoS? [Maier, 1998]

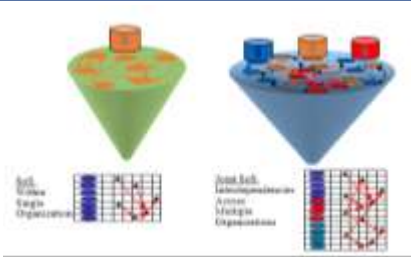
- ➔ Operational independence of component systems
- ➔ Managerial independence of component systems
- Geographical distribution
- Evolutionary development processes
- Emergent behavior



Systems of Systems Engineering – What makes this hard?



Management & Oversight



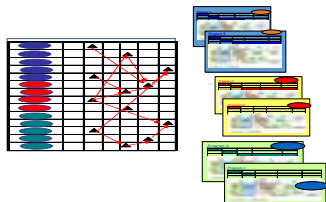
- Include systems which have their own users, funding, management structures and development plans
- Constraints of independent systems in managing changes to meet SoS objectives

Operational Focus



- Typically overlays/ extensions of sets of fielded systems
- Continue to support their original functions as well as new SoS functions
- Competing management and technical authority

Implementation



- Includes legacy systems, new systems or systems still in development
- Leveraging asynchronous developments of the constituent systems

Engineering and Design



- Complexity of multiple contributing systems with a focus on interactions versus boundaries
- Characterizing and measuring end to end SoS behavior

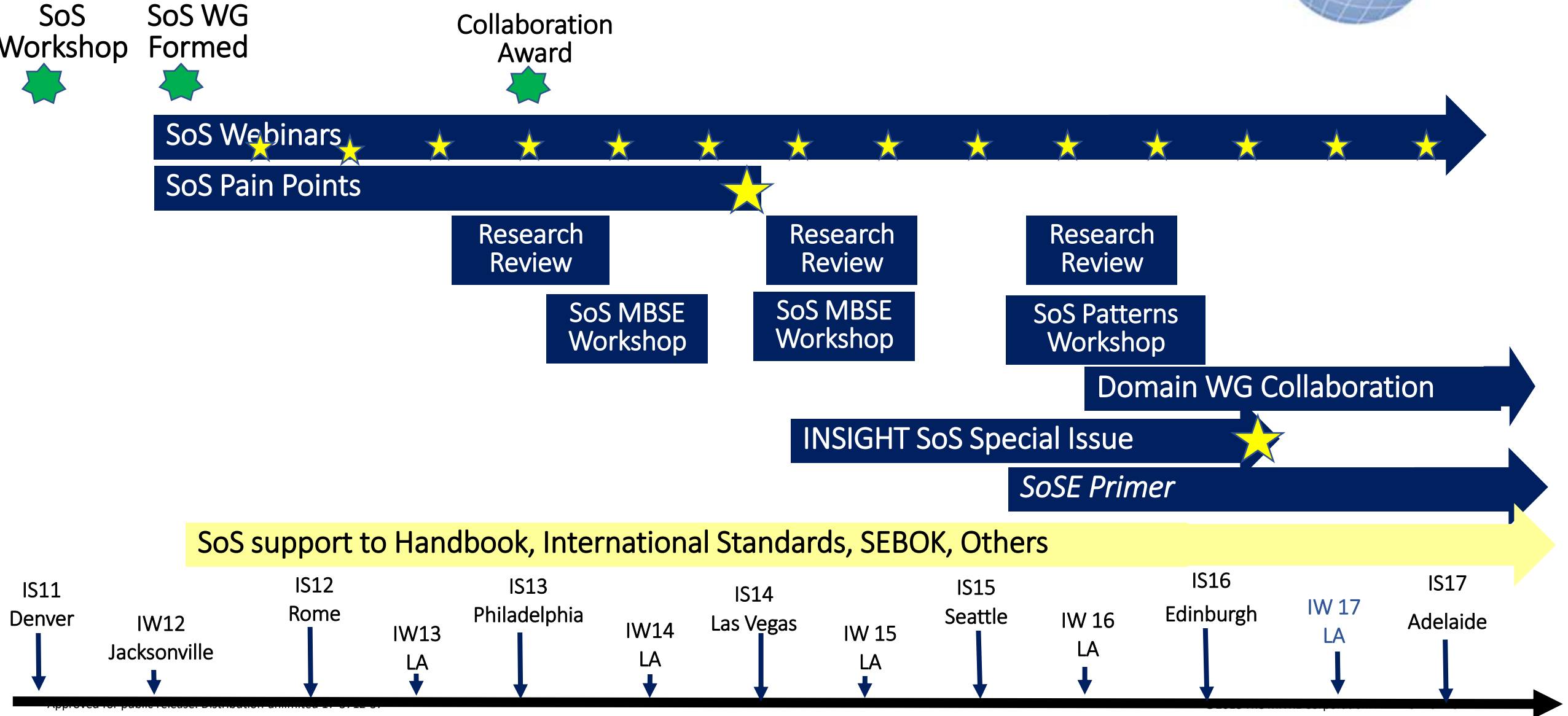
What is systems of systems engineering?

- 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

Key features

- Rarely ‘greenfield’ – typically constituent systems are in existence prior to SoS
- Focus on ‘capabilities’ versus detailed requirements
- Include policy, economic, and political considerations which impact technical considerations

SoS WG Activities In Review

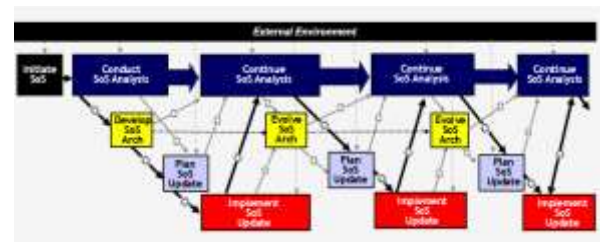
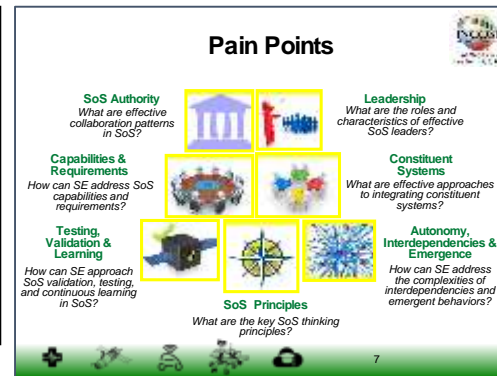
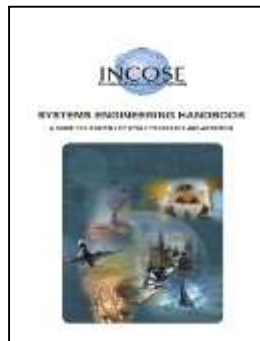


Systems of Systems Engineering

What is the State of the Practice?



- Recognition of importance of SoS Engineering (SoSE) to enable capabilities across domains
- SoSE practitioner community with shared views on SoSE challenges and growing body of practical applications





Scope of the SoS WG

This WG addresses the application of Systems Engineering to **all types** of Systems of Systems (SoS) in **all domains**. We see diversity as particularly important in this knowledge area, as do the WG members.

- Understand and share what we mean by SoS in our various contexts
- Develop guidance and advice
- Inform and up-skill practitioners
- Exert influence on BKCASE, Standards, SE Vision 2025 etc.
- Develop the practice of SE for SoS.
- Work in partnership with other groups addressing aspects of SoS (e.g. INCOSE WGs, IEEE, NDIA).
- Understanding and applying insights from relevant research

SoS Challenges



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?



Autonomy, Interdependencies & Emergence

How can SE address the complexities of interdependencies and emergent behaviors?

SoS Principles

What are the key SoS thinking principles?



- SoS Pain Points were developed by the INCOSE SoS Working Group to characterize challenges facing application of SE to SoS

System of Systems Pain Points

Dr. Judith Dahmann
The MITRE Corporation
jdahmann@mitre.org

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Abstract. The INCOSE SoS Working Group (SoSWG) identified the need to understand the SoS issues of importance to the systems engineering community as an initial SoSWG activity at their meeting in January 2012 in Jacksonville, Florida. The results of the survey and follow-up interaction with SoSWG members, identified seven areas of challenge or SoS Pain Points. This paper summarizes the survey and working group feedback and describes the pain points along with the questions they pose for the systems engineering community. The work described in this paper is the product of the INCOSE Systems of Systems Working Group, and acknowledges the contributions of working group members, including Alan Harding, Scott Workinger, Kelly Griendling, Eric Honour, Claire Ingram, Michael Henshaw, Bryan Herdlick, and others who responded to the survey and participated in the formulation and discussions of these SoS pain points.

Paper presented at INCOSE IS14

SoS Webinars



SoS Architecture Patterns

- Templates to describe solutions to known problems
 - **Context - Problem - Solution**
- Provide a generalized guideline to realize certain architecture characteristics.
- Built on a common anatomy
- DANSE has developed an SoS pattern repository
 - Searchable database of patterns
 - UPDM profiles that can be inserted into the SoS model

Architecture Patterns

INCOSE Systems of Systems Working Group Webinar Series on Systems of Systems

Integrated SE and T&E Approach for "Collaborative" System of Systems (SoS): Digitally Aided Close Air Support

Walter Ott, SAIC

- Supports DoD's coordinated implementation of Digitally-Aided Close Air Support (DACAS)
 - Coordinates over 14 participating program offices and partner nations
 - Addresses joint and coalition interoperability gaps
- BA University of Maryland, MS George Washington University, doctoral candidate in SE, George Washington University.
- Over 25 years experience operating and managing complex programs and systems.

INCOSE Systems of Systems Working Group Webinar Series on Systems of Systems

Set Web Chair: Alan Harding, alan.harding@incose.org, +44 (0)1235 380394
Set Web Co Chair: Sarah Robinson, sarah.robinson@incose.org, +1 (703) 760-1260
Webinar Coordinator: Eric Heston, eric.heston@incose.org, +1 (813) 614-1189

Friday, 26 September 2014
11:00am - 12:00pm EDT

Advance SoS Architecture Patterns and Online Repository (DANSE)

In this Webinar we present aspects of our extensive research on advanced SoS architecture patterns that can be used to support Architecting, Modeling and Optimization of Complex Systems of Systems (SoS). We have created a novel framework that facilitates reuse of the patterns as well as supporting mining of legacy/future architecture patterns.

In addition, we will present our comprehensive and growing online repository, which includes over 120 architecture patterns. The repository incorporates sophisticated search facilities and can be accessed via standard web browsers or through an iPad via a free App. Many of the corresponding models are available in downloadable UPDM/ SysML profile format for ready use by the SoS architect. For example IBM Rhapsody, also ontological database version of the repository is also being developed to enable patterns to be reused in a wide range of tools that support the RDF format.

We will present an operational overview of how the architecture pattern repository can be used to populate an IBM Rhapsody SoS UPDM project in order to facilitate architecture analysis. This research forms part of the EU funded DANSE project. It is planned to make the repository fully available to the wider SoS community as an open source resource in the near future.

Prof. Roy Kalenovsky, Demetrios (Mitch) Ioannidis, Antara Bhatt, Loughborough University

Professor Roy Kalenovsky is Director of the Advanced VR Research Centre and Associate Dean (Enterprise) School of Electronic Electrical and Systems Engineering at Loughborough University. He has been a systems engineer for over 30 years (initially with BAE Systems). His research is concerned with developing next generation modeling, simulation and visualization tools and techniques to advance model based systems engineering. He leads many collaborative research projects and is responsible for the Systems Architecture work package in the DANSE project.

Mitch Ioannidis and Antara Bhatt are experienced systems engineering researchers who are working on multiple elements of the DANSE project. In particular they are working with Roy on developing the comprehensive online architecture pattern repository.

<http://www.lboro.ac.uk/research/evrc/>
<http://www.lboro.ac.uk/research/systems-net/>

For further details please contact:
Professor Roy S. Kalenovsky, +44 (0)1509 635678, r.s.kalenovsky@lboro.ac.uk

Modelling Patterns for Systems of Systems Architectures

Claire Ingram (Newcastle University, UK)
Richard Payne (Newcastle University, UK)
Simon Perry (Atego, UK)
Jon Holt (Atego, UK)

Finn Overgaard Hansen (Aarhus University, DK)
Luis Diogo Couto (Aarhus University, DK)

INCOSE SoS Working Group Webinar
September 2014

COMPASS
www.compass-modeling.org

- Monthly online webinars
- Recorded and posted on SoS WG Connect Site
- Over 50 Webinars presented to date on a wide range of SoS topics
- Very well received
 - Up to 100 participants in webinars
- Contact:
 - Oliver Hoehne

<https://connect.incose.org/Library/Webinars/Pages/Working-Group-Webinars.aspx>

Systems of Systems (SoS)

Systems of Systems (SoS) > BKCASE Governance and Editorial Board > Systems of Systems (SoS) > Guide to the Systems Engineering Body of Knowledge (SEBoK) > Systems of Systems (SoS)

System of systems engineering (SoSE) is not a new discipline; however, this is an opportunity for the systems engineering community to define the complex systems of the twenty-first century (Jamshidi 2009). While systems engineering is a fairly established field, SoSE represents a challenge for the present systems engineers on a global level. In general, SoSE requires considerations beyond those usually associated with engineering to include socio-technical and sometimes socio-economic phenomena.

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- 3 Types of SoS
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Topics

Each part of the SEBoK is divided into knowledge areas (KAs), which are groupings of information with a related theme. The KAs in turn are divided into topics. This KA contains the following topics:

- [Architecting Approaches for Systems of Systems](#)
- [Socio-Technical Features of Systems of Systems](#)
- [Capability Engineering](#)



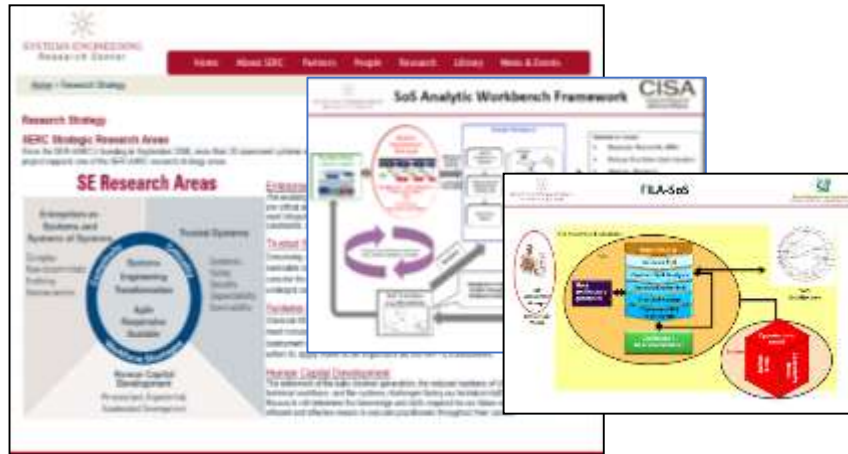
SEBoK SoS Knowledge Area

Last Update was
Spring 2017

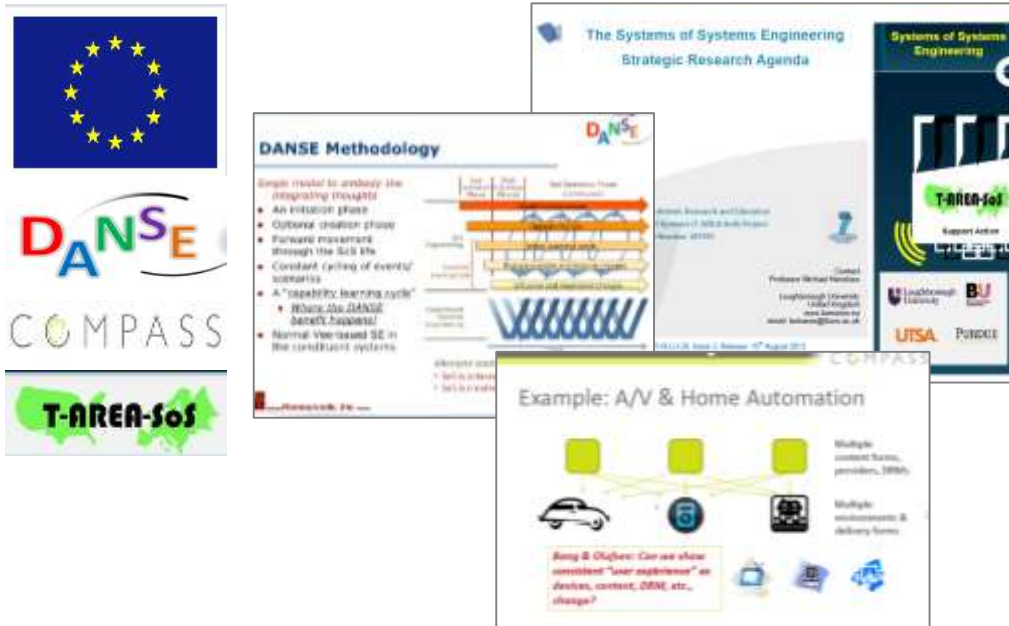
Next update

- Fall of 2018

SoS Research



- Many of the challenges facing SoS are the topic of ongoing research
- SoS Webinars regularly feature presentation on SoS research initiatives and results
- SoS WG sponsored “SoS Research Roundtables”
 - IS 2012, IS 2014 and IS 2016
 - Presentations are on the SoS WG Connect Site



**Last SoS Research Roundtable
INCOSE IW18**

IW18 SoS Research Roundtable Presentations



John Fitzgerald, Newcastle University, UK

- Bridging the Performance Gap: Model-Based SoS Engineering and the Learning Digital Twin

Daniel Selva, Cornell University

- Agent-based simulation framework and decentralized planning algorithm for opportunistic coalition formation in Earth observing systems of systems

William Miller, Stevens Institute

- Mission Engineering Competencies

Cihan Dagli and David Curry, Missouri

- A Cyber-Physical Systems Approach to Optimizing Internet of Vehicles Architecture with Rapidly Evolving Technology

Chuck Keating, Old Dominion University

- Complex System Governance Research: Advancing System of Systems Engineering

Navindran Davendralingam and Ali Raz, Purdue University

- SoS Analytic Workbench – Reflections on a Successful SERC Project and Directions for Future Projects

Eric Honour, Honourcode

- SoS Solutions in Driverless Vehicles

Kristin Giammarco, Naval Post-Graduate School

- Lessons Learned from Engineering Emergence Research

Collaborations



IEEE Systems Conference

April, 23-26, 2018
Vancouver, British Columbia



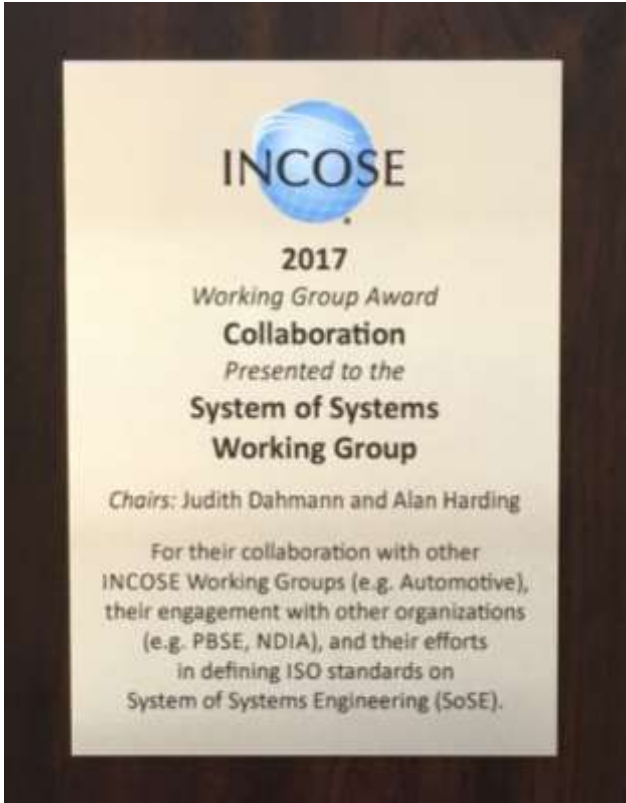
IEEE SoSE Conference

June, 19-22, 2018
Paris, France



INCOSE Domain Working Groups

- Automotive
- Health
- Critical Infrastructure



SoSE Standards



Annex G (Informative) Application of system life cycle processes to a system of systems...

Virtual	<ul style="list-style-type: none"> Lack a central management authority Lack of centrally agreed upon purpose Rely upon relatively invisible mechanisms to maintain it Constituent systems interact voluntarily to fulfill agreed upon purposes
Collaborative	<ul style="list-style-type: none"> Constituent systems interact voluntarily to fulfill agreed upon purposes Collectively decide how to interoperate, enforcing and maintaining standards
Acknowledged	<ul style="list-style-type: none"> Recognized objectives, a designated manager, and resources for the SoS Constituent systems retain their independent ownership, management, and resources
Directed	<ul style="list-style-type: none"> Integrated SoS built and managed to fulfill specific purposes Centrally managed and evolved Constituent systems maintain ability to operate independently Normal operational mode is subordinated to central purpose

SEBoK
SoS KA

• 3 New Standards Developments in Progress

- ISO 21839: **“SoS Considerations in Across a System’s Lifecycle”** [Based on TTCP Recommended Practices]
 - Release for review as Draft International Standard (DIS) planned for next month
- ISO 21841: **Taxonomy** on SoS Types [Elaboration of 15288 Annex G]
 - Update of Committee Draft (CD) in progress
- ISO 21840: An in-depth application of **SE processes for SoSE** across the life cycle [Elaboration 15288 Annex G]

ISO
IEC

Draft Report of the SC7 SG on Systems of Systems Engineering

The Technical Cooperation Program
TC7P TECHNICAL REPORT
Recommended Practices: Systems of Systems Considerations in the Engineering of Systems

ISO/JTC1/IEC
NEW WORK ITEM PROPOSAL

SoSE In Practice



Special SoS Issue of INSIGHT



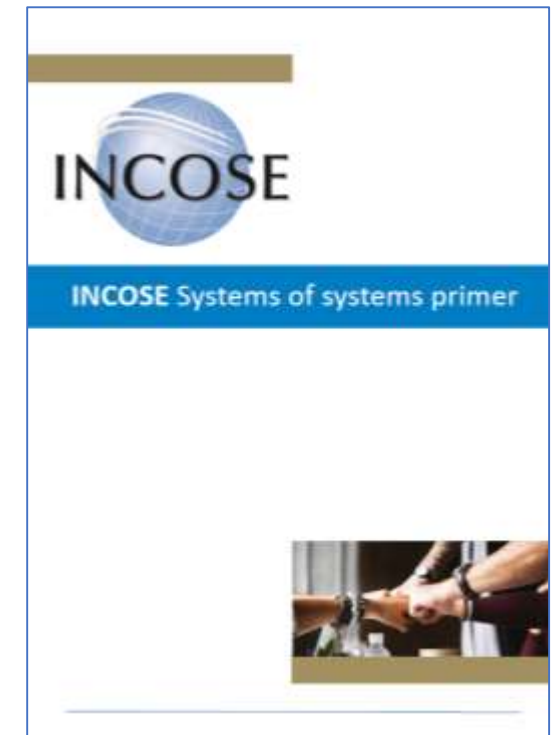
- Practitioner focus
- State of the practice
- Case studies from different domains

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Coming Attraction: SoS Primer



- Draft in review
- Tri-fold presentation
- Builds on INSIGHT
- Release planned for IS 2018





Discussion