

INCOSE Systems of Systems Working Group

November 13, 2014
Presentation to INCOSE Enchantment Chapter

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SoS Working Group Co-chair



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

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

Differences Between Systems and SoS as They Apply to Systems Engineering

| | Systems Engineering | Systems of Systems Engineering |
|--|--|---|
| Management & Oversight | | |
| 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 (Goals) | | |
| 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 development processes | 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 & Design | | |
| 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 |

INCOSE SoS Working Group



Charter: To promote application of SE to SoS through

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

- Formed in based on SoS workshop at IS 2011
- Responds to a growing recognition of the increasing inter-connectivity of systems and the role of systems engineering across complex systems of systems

SoS WG Activities



SoS Workshop
★

SoS WG Formed
★

Collaboration Award
★

SoS Webinars

Bibliography and Recommended References

SoS Pain Points

Case Studies to Address Pain Points

Research Review

Survey SoS Methods

Getting Starter Primer

SoS support to Handbook, International Standards, SEBOK, Others

IS 2011
Denver

IW 2012
Jacksonville

IS 2012
Rome

IW 2013
Los Angeles

IS 2013
Philadelphia

IW 2014
Los Angeles

IS 2014
Las Vegas





SoS Webinars

INCOSE
Systems of Systems Working Group
Webinar Series on Systems of Systems
 SoS WG Chair: Alan Harding, Alan.Harding@hcode.com, +44 1252 383596
 SoS WG Co-Chair: Judith Dahmann, [judahmann@mitre.org](mailto:jdahmann@mitre.org), +1 (703) 983-1363
 Webinar Coordinator: Eric Honour, ehonour@hcode.com, +1 (615) 614-1109


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, Modelling and Optimisation of Complex Systems. We have created a novel framework that facilitates reuse of the information mining of legacy/future architecture patterns.

at our comprehensive and growing online repository, which includes terms. The repository incorporates sophisticated search facilities and is available in downloadable UPDM/SysML profile format for ready use or example IBM Rhapsody. An ontological database version of the repository is developed to enable patterns to be reused in a wide range of tools that

an overview of how the architecture patterns repository can be used by SoS UPDM project in order to facilitate architecture analysis. If the EU funded DANSE project. It is planned to make the repository SoS community as an open source resource in the near future.

emetrios (Mitch) Joannou, **Loughborough University**
 is Director of the Advanced VR Associate Dean (Enterprise) School of Systems Engineering at Loughborough University. His research is concerned with system modeling, simulation and analysis and is responsible for the Systems Architecture work package in the DANSE project. In particular they are working with Roy on developing the comprehensive online architecture patterns repository.



Ra 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 patterns repository.
<http://www.lboro.ac.uk/research/avrrc/>
<http://www.lboro.ac.uk/research/systems-net/>
 For further details please contact:
 Professor Roy S. Kalawsky, +44 (0)1509 635678, r.s.kalawsky@lboro.ac.uk



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

Honorcode, Inc.

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

- Eric Honour
 <ehonour@hcode.com>

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.

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



www.compass-research.eu





SoS Bibliography and Recommended References

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File Edit Search View BibTeX Tools Plugins Options Help

sos.bib

| # | EntryType | Author | Title | Year | Journal | O... | Bibtexkey |
|----|---------------|---------------------|---|------|---------------|---------|----------------|
| 1 | InProceedings | Abbott | [Open at the top; open at the bottom; an... | 2006 | | | Abbt006 |
| 2 | TechReport | Abbott | Emergence Explained | 2005 | | | Abbt005 |
| 3 | InProceedings | AbuShaekh et al. | (Modeling Time in DoDAF Compliant E... | 2007 | | kgrt... | AbuShaekh |
| 4 | Article | Ackoff | Towards A System of Systems Concept | 1971 | Managem... | | Ackoff71 |
| 5 | Book | Alberts | Information Age Transformation: Gettin... | 2002 | | | Alberts02 |
| 6 | InProceedings | Alexander et al. | (Ensuring Dependable Systems of Syst... | 2007 | | | Alexander07 |
| 7 | InProceedings | Alghamdi and Ahm. | Comparative Analysis of Defense Indu... | 2010 | | | Alghamdi |
| 8 | TechReport | Atkins | System of Systems Think Piece Report | 2008 | | | Atkins08 |
| 9 | InProceedings | Bagdadi et al. | (A Method for Examining the Impact of I... | 2010 | | kgrt... | Kelivan&Burak |
| 10 | InProceedings | Bagdadi and Maris | Use of high-level architecture discre... | 2012 | | | HACIES |
| 11 | Article | Balci and Ormsby | Network-centric military system archite... | 2008 | Int. J. Syst. | | Balci08 |
| 12 | Article | Bar-Yam et al. | (The Characteristics and Emerging Be... | 2004 | NECSI C... | | Bar-Yam&04 |
| 13 | InProceedings | Berenji and Jamsh. | Fuzzy reinforcement learning for Syste... | 2011 | | | Berenji&11 |
| 14 | Article | Berry | Cities as Systems within System of Cities | 1964 | Papers an... | | Berry64 |
| 15 | PhdThesis | Bjorkemyr | System of Systems Characteristics in P... | 2009 | | | Bjorkemyr09 |
| 16 | TechReport | Bloomfield and Ga. | Evaluating the resilience and security o... | 2008 | | | Bloomfield&08 |
| 17 | InProceedings | Boardman and Sa. | (System of Systems – the meaning of ... | 2006 | | | Boardman&06 |
| 18 | InProceedings | Bodeau and Chase | Modeling constructs for describing a co... | 1993 | | | Bodeau&93 |
| 19 | InProceedings | Bodeau, D.J. | System-of-systems security engineering | 1994 | | | Bodeau94 |
| 20 | InProceedings | Boehm | A view of 20th and 21st Century Softwar... | 2006 | | | Boehm06 |
| 21 | Article | Boulding | General Systems Theory-The Skeleton... | 1956 | Managem... | | Boulding56 |
| 22 | Article | Butterfield et al. | A System-of-Systems Engineering GE... | 2008 | Systems J... | | Butterfield&08 |
| 23 | PhdThesis | Caffall | Developing dependable software for a... | 2005 | | | Caffall05b |
| 24 | InProceedings | Caffall and Michael | A new paradigm for requirements spec... | 2004 | | | Caffall02 |
| 25 | InProceedings | Caffall | Formal methods in a system-of-system... | 2005 | | | Caffall05a |

Status: Opened database 'C:\Users\jdahmann\Desktop\sos.bib' with 209 entries.

- **SoS Reference Resource on SoS Connect Site**

- Currently includes over 200 references
- Next step is to catalog and cross reference materials

- **Recommended References**

- In 2012, conducted survey of SoS WG members requesting recommendations of good introductory SoS materials

- **Lead: Kelly Griending**
<kelly.griending@asdl.gatech.edu>

Basic SoS Reference Survey Exit the survey

INTRODUCTION – INCOSE SoS Working Group SoS Reference Survey

One of the objectives of the INCOSE Systems of Systems (SoS) Working Group is to "Inform and up-skill practitioners" on systems of systems and systems engineering. Toward that end, we would like to compile a small list of SoS references that we as a working group would recommend to those interested in an introduction to SoS SE. In cooperation with the INCOSE SoSWG, we invite NDIA SoS SE Committee members to provide their input.

The purpose of this survey is to gather your recommendations for this list.

In particular, what papers would you recommend to a colleague who approaches you with the question:

"I have heard about SoS and SoS SE but have never worked in this area. What would you recommend I read to get a good introduction?"

The survey questions below ask for your input on recommended basic SoS references. You will be able to provide up to 5 references.

Recommendations

Most recommendations were made by a single respondent (53/101)

Three recommendations were made by seven or more respondents (23/101)

- 100 total recommended items
- 2 items recommended by 9 respondents
- 1 items recommended by 7 respondents
- 1 items recommended by 4 respondents
- 3 items recommended by 3 respondents
- 4 items recommended by 2 respondents
- 53 items recommended by 1 respondent

Top Three Recommendations

- Maier, Mark W. 1998. "Architecting Principles for System-of-systems." Systems Engineering 1 (4): 267-284. [9 recommendations]
- Office of the Under Secretary of Defense (Acquisition, Technology and Logistics) Systems Engineering Guide for Systems of Systems [9 recommendations]
- Jamshidi, M. (Ed.) System of Systems Engineering: Principles for the 21st Century Wiley, 2009 [7 recommendations]

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?

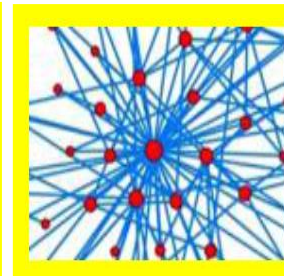
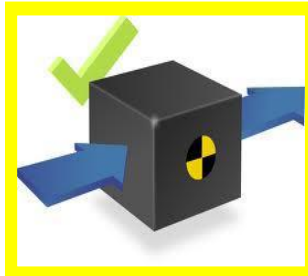


Constituent Systems

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?

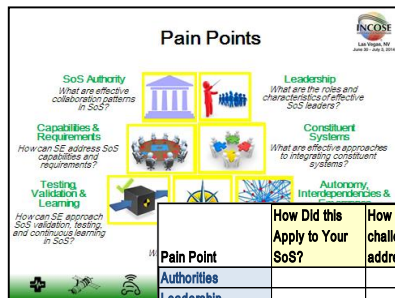
SoS Case Studies to Explore Pain Points



| Case Study Author | |
|---|---|
| We would like to understand the role of the person or people providing details of the case study. | |
| What is your role? | Prior project experience - Test Manager of Wireless Customer Care and Billing platform |
| What is your SE or SOSE experience? | Project participant from designing of initial platform, first deployment onto refinement of release process. Project was to replace legacy CC&B instance. |
| Are you a stakeholder for the SoS? | Yes |
| Contact Details | julian@mitre.org |
| Have details of this case study been published previously? | High level accomplishment has been publicized. But no case study that I am aware of. |
| What sources have you used to gather details for this case study? | Personal project experience. Available information on web. |
| Previous publications of material on the SoS | |
| List | |
| http://www.billingworld.com/articles/2002/09/nestel-completes-conversion-to-amdpc-ensemble.aspx | |
| http://www.rcwireless.com/article/20011115/sub/nextel-launches-ensemble-billing-platform-2/ | |
| http://www.ca.com/cavord/Presentations/AV006SN.pdf | |
| http://www.getflings.com/cmps0000324169.html | |
| http://books.google.com/books?id=xqoAAAAAMBAJ&pg=PA38&lpg=PA38&dq=Dick+Lefave+nextel+clo&source=bl&ots=RNDdJQkdsN&sig=GQv01Wkdn3FMCmI | |

Detailed Case Framework

- In-depth case studies as a way to gain insight into options for addressing the Pain Points
- Five cases as part of initial review
 - A single Traffic Management Systems (TMS) the interurban network
 - A National SoS, the Netherlands road network including multiple Traffic Management Systems (TMSs)
 - Digitally Aided Close Air Support (DACAS)
 - Emergency Management System
 - Wireless Consumer Care and Billing (CCB)



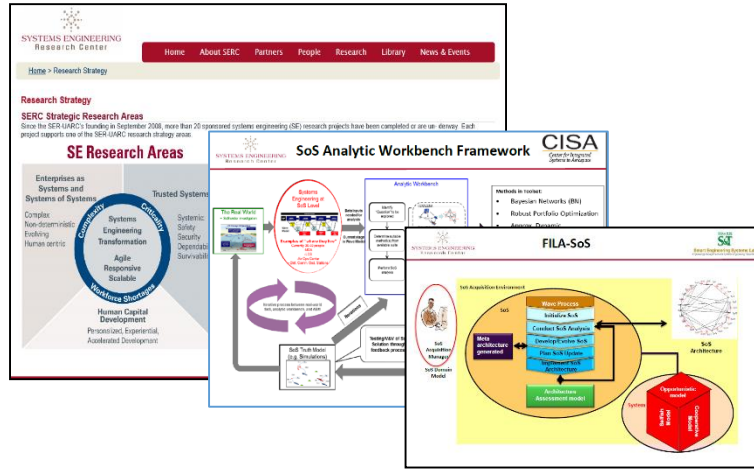
Pain Point Profiles

| Pain Point | How Did this Apply to Your SoS? | How was the challenge addressed | What worked? | What did not work? | Comments? |
|--|---------------------------------|---------------------------------|--------------|--------------------|-----------|
| Authorities | | | | | |
| Leadership | | | | | |
| Capabilities and Requirements | | | | | |
| Constituent Systems | | | | | |
| Testing Learning & Validation | | | | | |
| Autonomy, Interdependencies, Emergence | | | | | |
| SoS Principle | | | | | |

- Initial review underway
- Contacts

Claire Ingram <claire.ingram@newcastle.ac.uk>
 Judith Dahmann <jdahmann@mitre.org>

SoS Research



- Many of the challenges facing SoS are the topic of ongoing research
- European Union – US Research agenda “Trans-Atlantic Research and Education Agenda on Systems of Systems” (T-Area-SoS) research thrusts align with the SoS Pain Points
- SoS WG sponsored an “SoS Research Review” at IS 2012
 - Presentations are on the SoS WG Connect Site
- SoS Webinars regular feature presentation on SoS research initiatives and results



SoS Organizational Survey on SoS Approach and Tools



| Approaches | # | % |
|------------------------|----|-----|
| Cross cutting teams | 20 | 36% |
| Models as core | 6 | 11% |
| Architecture as core | 6 | 11% |
| Traditional SE process | 10 | 18% |
| New approaches | 8 | 14% |

| Tools | # | % |
|------------------------|----|-----|
| Architecture Tools | 24 | 32% |
| Requirements Mgt Tools | 15 | 27% |
| Spreadsheets | 11 | 20% |
| Models | 11 | 20% |
| Modeling Tools | 17 | 30% |
| MBSE | 14 | 25% |

| Gaps | # | % |
|----------------------|----|-----|
| SE Approaches to SoS | 25 | 45% |
| Culture/Governance | 11 | 20% |
| Tools and Techniques | 23 | 41% |

- Conducted at request of INCOSE Corporate Advisory Board
 - Delivered July 2014
- Objective: Understand current methods and tools for application of SE to SoS
- Survey was sent to the INCOSE CAB, INCOSE SoS WG, and NDIA SoS Committee
 - 56 responding organizations
 - Most (79%) report extensive experience (5+yrs)
 - 70% in Defense, 30% Non-Defense
 - Varied engagement with SoS

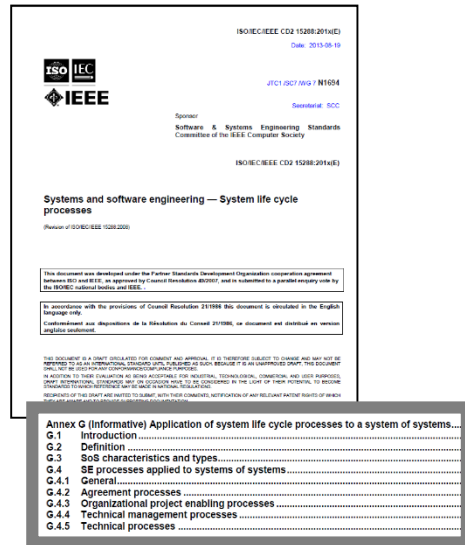
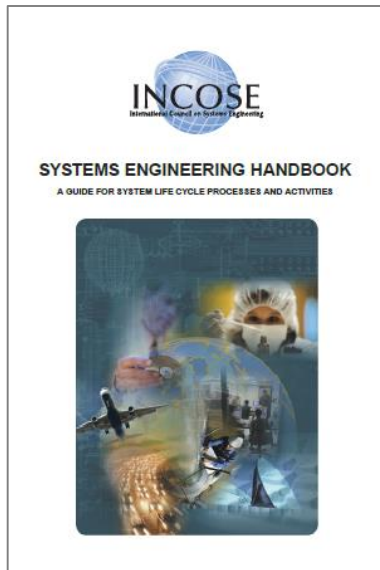
| Engagement | # | % |
|----------------------------------|----|-----|
| SoSE application at SoS Level | 20 | 36% |
| SoSE application at System Level | 11 | 20% |
| Developing SoSE Approaches | 4 | 7% |
| Research or teach SoSE | 5 | 9% |
| New to SoSE | 7 | 13% |
| No response | 9 | 16% |
| Total | 56 | |

SoS Primer

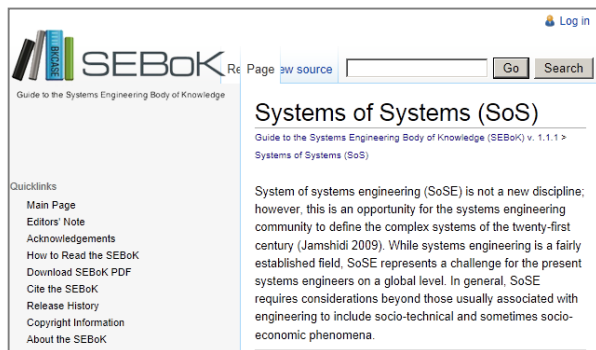


- Request from INCOSE Corporate Advisory Board (CAB)
- Advice on how to get started with SoS SE
- Team has formed and a draft is in progress
- Biggest challenge has been in the scope; raised a number of new issues
- Contact
 - Michael Henshaw
<M.J.d.Henshaw@lboro.ac.uk>

SoS Support to INCOSE Handbook, International Standards, SEBOK



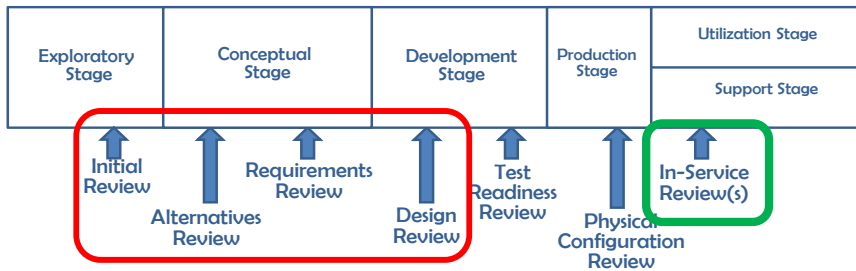
- Provide leadership across the SE community on SoS guidance and standards
- INCOSE Handbook Updates
- 15288 SoS Annex on SoS Life Cycle
- SEBOK SoS Knowledge Area
- Input to other SoS guidance



SoS WG Input

Recommended Practices: SoS Considerations for Engineering of Systems

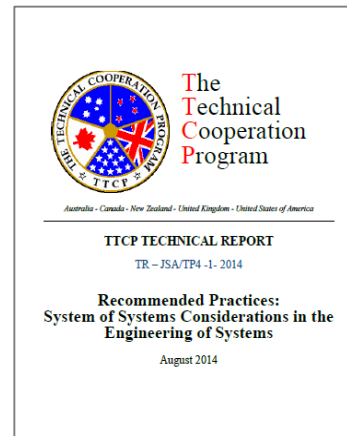
SoS Considerations in the Engineering of Systems



ISO 15288 provides common framework for key review points

- State of Program at this Review Point
- Information Available at this Point
- System Issues at this Review Point
- SoS Issues Impacting the System
- Questions
 - Benefits
 - Risks
 - Evidence/Metrics
 - Potential Actions/Mitigations
- SoS Supporting Technical Base

- Product of International SoS Work Stream of **The Technical Cooperation Program's** panel on SE for Modernization
 - Defense R&D with US, UK, Canada Australia participants
- INCOSE SoS WG provided valuable input on drafts during development



Recommended Practices

Provide material for Nations to augment or evolve their current National practices to address SoS issues



Upcoming: SoS and MBSE

The screenshot shows a web page titled "MBSE WIKI" with the subtitle "MBSE:INCOSE_MBSE_IW_2015". The page is part of the OMG (Open Group) website, which states "WE SET THE STANDARD". The page content includes a "Table of Contents" with links to the workshop agenda, breakout sessions, and related meetings. The main text provides a summary of the MBSE Workshop at INCOSE IW 2015, held on January 24-25, 2015, in Torrance, CA. It also mentions other MBSE-related meetings on January 26-27, 2015, and provides a link to the INCOSE website for registration details.

• MBSE and SoS Track

- Introduction on “Why MBSE for SoS?”
- COMPASS Project MBSE Approach
 - Presentation and demonstration
- DANSE Project MBSE Approach
 - Presentation and demonstration
- Panel and group discussion

- **Model Based Systems Engineering (MBSE) Workshop at 2015 INCOSE International Workshop**
- **January 24-25, 2015 in Torrance, California**

For more information

Alan Harding (co-chair)

Judith Dahmann (co-chair)

INCOSE Connect address:

<https://connect.incose.org/tb/soswg/>

INCOSE Web page:

<http://www.incose.org/practice/techactivities/wg/details.aspx?id=sos>

