INCOSE International Symposium
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System of Systems Pain Points

SoS Working Group Initiative

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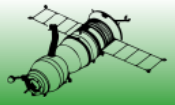
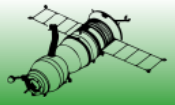



SoSWG Initiative

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.


Background and Purpose

- INCOSE SoS Working Group (SoSWG)
  - Address the need to understand the SoS issues of importance to working group members as an initial SoSWG activity
- Conducted an “SoS Pain Point Survey”
  - To collect information on major issues or 'pain points' in the area of Systems of Systems operation, management and systems engineering
  - To support planning for activities of the INCOSE Systems of Systems Working Group

The results of the survey and follow-up interaction with SoSWG members identified seven areas of challenge or SoS Pain Points.

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Systems of Systems

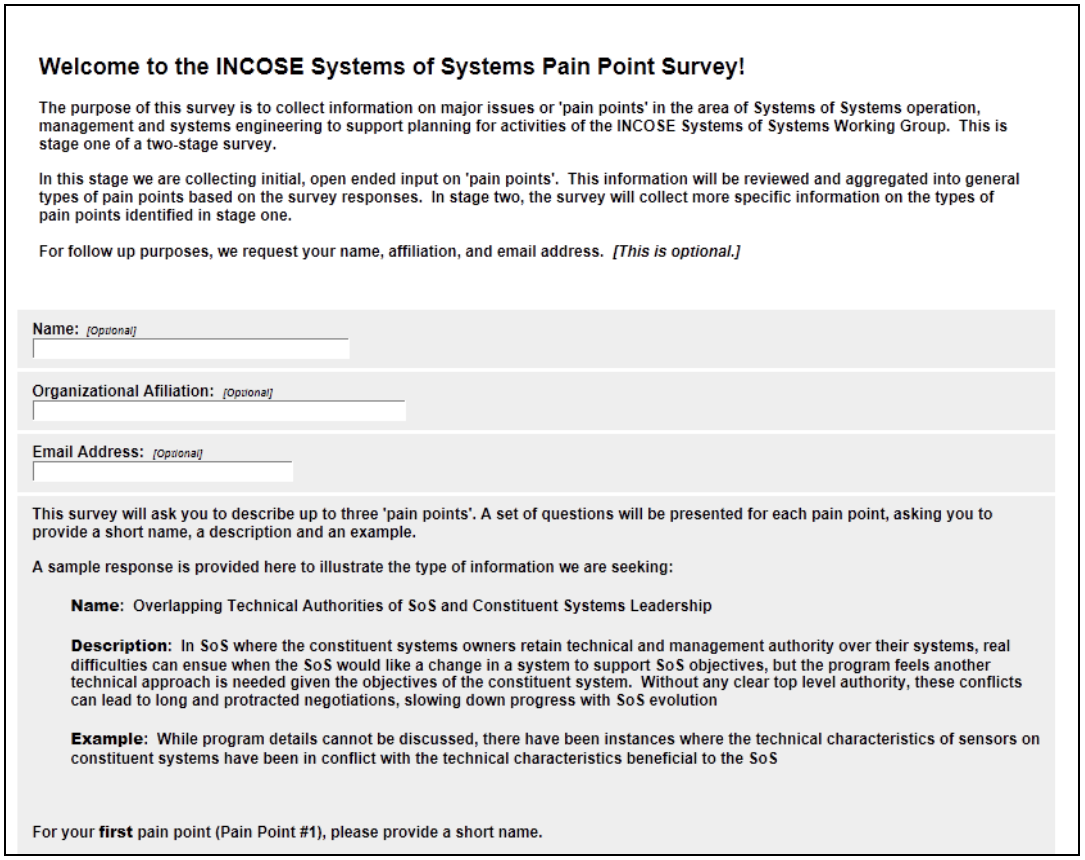
- SEBok Definition
  - A SoS is an integration of a finite number of constituent systems which are independent and operatable, and which are networked together for a period of time to achieve a certain higher goal. (Jamshidi 2009)

- 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

SoS Pain Point Development

- Survey logistics
  - Developed during February and March 2012, with several drafts and pretests
  - Released to the community in April 2012 with a cutoff in Mid-May 2012
  - Administered over the internet using KWIK Surveys (www.kwiksurverys.com)
- Survey questions
  - Asked respondents to identify and describe their priority SoS areas of concern: describe up to three 'pain points' including a short name, a description and an example
- Analysis and Follow-up SoSWG Actions
  - Results were analyzed, a paper on the results was drafted (July 2012), circulated for comment and updated (Jan 2013)
  - Drafted and reviewed ‘one-pagers’ on each pain point (June 2013) , updated and augmented with references from SoS WG bibliography (Jan 2014)

Survey Respondents



Welcome to the INCOSE Systems of Systems Pain Point Survey!

The purpose of this survey is to collect information on major issues or 'pain points' in the area of Systems of Systems operation, management and systems engineering to support planning for activities of the INCOSE Systems of Systems Working Group. This is stage one of a two-stage survey.

In this stage we are collecting initial, open ended input on 'pain points'. This information will be reviewed and aggregated into general types of pain points based on the survey responses. In stage two, the survey will collect more specific information on the types of pain points identified in stage one.

For follow up purposes, we request your name, affiliation, and email address. *[This is optional.]*

Name: *[Optional]*

Organizational Afiliation: *[Optional]*

Email Address: *[Optional]*

This survey will ask you to describe up to three 'pain points'. A set of questions will be presented for each pain point, asking you to provide a short name, a description and an example.

A sample response is provided here to illustrate the type of information we are seeking:

Name: Overlapping Technical Authorities of SoS and Constituent Systems Leadership

Description: In SoS where the constituent systems owners retain technical and management authority over their systems, real difficulties can ensue when the SoS would like a change in a system to support SoS objectives, but the program feels another technical approach is needed given the objectives of the constituent system. Without any clear top level authority, these conflicts can lead to long and protracted negotiations, slowing down progress with SoS evolution

Example: While program details cannot be discussed, there have been instances where the technical characteristics of sensors on constituent systems have been in conflict with the technical characteristics beneficial to the SoS

For your **first** pain point (Pain Point #1), please provide a short name.

- 38 survey respondents
- 65 SoS 'pain points' reported
- Respondent location
  - US (86%).
  - UK (8%)
  - Australia (6%)
- Respondent SoS experience
  - Extensive (60%)
  - Some (37%)
- Almost all (94%) are from defense sector

Results of the survey provided basis for SoSWG follow-up reviews and exchanges to develop the Pain Points

Pain Points

SoS Authority

What are effective collaboration patterns in SoS?

Leadership

What are the roles and characteristics of effective SoS leaders?

Capabilities & Requirements

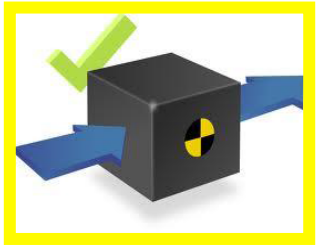
How can SE address SoS capabilities and requirements?

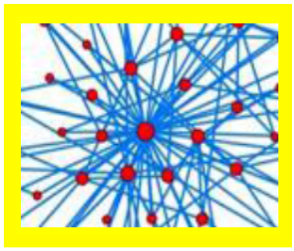
Constituent Systems

What are effective approaches to integrating constituent systems?

Testing, Validation & Learning

How can SE approach SoS validation, testing, and continuous learning in SoS?



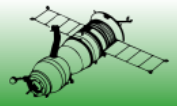


Autonomy, Interdependencies & Emergence

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

SoS Principles

What are the key SoS thinking principles?



SoS Authorities

- SoS have been characterized in terms of these authority relationships (SEBoK 1.0)
  - Directed
  - Acknowledged
  - Collaborative
  - Virtual

- In defense applications
  - Authority conflicts often dominate discussion of SoS
  - Focus on how to legitimately arbitrate these opposing forces to balance the values of the systems with those of the SoS
- In non-defense contexts
  - Same issues can prevail but without the larger organizational constraints
  - Focus is on creation of the incentives and development environment which allow the systems to proceed to meet their own objectives while working cooperatively to support broader objectives

What are effective collaboration patterns in SoS?

Leadership

- **Leadership issues implied in the SoS authority pain point**
  - Lack of structured control assumed by SE for systems faces a void, calling for alternatives to provide coherence and direction, including influence and incentives
  - Without the type of traditional top down control, there are clear challenges for application of SE at the SoS level
  - An issue in both defense and non-defense

- **Increased discussion about organizational leadership skills as a key element in SE effectiveness**
  - Especially as systems have become more complex as has the SE environment
- **SoS organizational and technical complexity -- multiple independent stakeholders with their own interests and independence -- makes the role of leadership in SoS even more important**

What are the roles and characteristics of effective SoS leaders?

Constituent Systems (1 of 2)

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- **Coordination and management of multiple independent constituent systems in SoS**
  - Legacy systems which "… not configured or managed to allow insertion into the over-all system of systems. This creates interoperability concerns between the older and newer systems."
  - Managerial and evolutionary independence can mean that "Constituent systems change in response to the perceived goals for that system, usually with little regard for the impact on SoS goals or behaviors."

- **Risks of coordinated constituent system SoS support beyond data exchange**
  - "In the cases where systems are owned/operated by different organizations … the systems may transfer data and information reliably between systems (if you're lucky), but different processes, cultures, working practices between different participating organizations can lead to problems."

What are effective approaches to integrating constituent systems?

Constituent Systems (2 of 2)

- **Poses core technical issues for SoS**
  - Systems identified for the SoS be limited in the degree to which they can support the SoS initially and their commitments to other users may mean that they may not be compatible with the SoS over time
  - Risk of mismatch in understanding the action or data provided by one system to the SoS if the systems context differs from that of the SoS
  - Impact on the architecture for the SoS which is essentially an overlay to these systems providing the framework for their cooperative activity and evolution over time (Ref SEBOK 1.0 SoS)
  - Implications may be felt in unpredictable SoS behavior as discuss below in technical area of autonomy and emergence.

What are effective approaches to integrating constituent systems?

Capabilities & Requirements (1 of 2)

- The issue
  - Traditionally, SE process begins with a clear, complete set of user requirements and SE provides a disciplined approach to develop a system to meet these requirements.
  - Typically, SoS are comprised of multiple independent systems with their own requirements working towards broader capability objectives.
  - In the best case the SoS capability needs are met by the systems as they meet their own local requirements, but in many cases the SoS needs may not be consistent with the needs of the constituent systems.
- In these cases, the SoS SE needs to identify alternative approaches to meeting those needs through changes to the constituent systems or additions of other systems to the SoS.
  - This is in effect asking the systems to take on new requirements with the SoS acting in a way as the 'user'.

How can SE address SoS capabilities and requirements?

Capabilities & Requirements (2 of 2)

- **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 SE address SoS capabilities and requirements?

Autonomy, Interdependencies & Emergence

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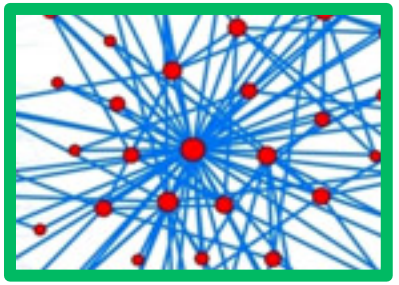
- Combining component systems into SoS produce unexpected behavior.

  "Well-structured approaches for 'design for emergence' are not available."



- Complex relationships among systems in an SoS are often poorly understood and difficult to analyze

  "Systems often have interdependencies that are either unknown or unacknowledged. This is exacerbated by interdependencies between systems in development, a system in development and fielded systems, and fielded systems; further, this is compounded by multiple combinations of all of these."

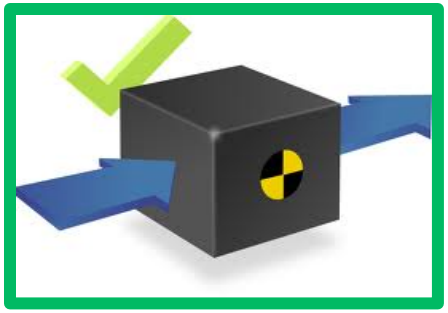
  "We lack methods for representing the SoS analytically so these interdependencies can be understood, and the SE of the SoS could examine impacts of different SoS changes."

- Need for methods and tools to support the modeling and prediction of complex SoS behaviors including analysis and architecting methods

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

Testing, Validation & Learning (1 of 2)

- **Most SoS face issues of conducting end- to-end testing**
  - Need a clear understanding of the SoS objectives and metrics
  - Depending on the SoS context there may be not funding or authority for SoS testing.



  - With multiple constituent systems on asynchronous development cycles, finding ways to conduct tradition testing across the SoS can be difficult is not impossible.
  - Many SoS are large and diverse making tradition full end-to-end testing with every change in a constituent prohibitively costly.
  - Often the only way to get a good measure of an SoS performance is from data collected from actual operations.
- **Nonetheless the SoS SE team needs to ensure continuity of operation and performance of the SoS despite these challenges**

How can SE approach SoS validation, testing, and continuous learning in SoS?

Testing, Validation & Learning (2 of 2)

- **These problems have been recognized and addressed in several ways**
  - Modeling and simulation environments for addressing effects of changes on SoS performance and providing test tools for augmenting system testing to assess SoS impacts
  - Architectures which minimize impacts of changes in one part of the SoS on other parts and the SoS performance as a whole.
  - Methods to identify the areas which may pose greatest risk and focus attention on these using data from a variety of sources as well as from more traditional testing.
  - Built-in ongoing validation throughout SoS evolution
- **Focus on approaches like incremental validation, reflecting a perspective that looks at significant learning going on over the life of an SoS**

How can SE approach SoS validation, testing, and continuous learning in SoS?

SoS Principles

- **Indicated were either [missing] (needed) items for successful SoS, including:**
  - [“Lack of] formalized processes”
  - [“Lack of] examples of SoS Success
  - [“SoS requires] better trust to the work flow
  - (“Keep a SoS together) - It is very important to plan, design, purchase and maintain a SoS entity based on the SoS idea.”
- **Cross cutting area – basic principles underlying other areas**
  - This area is one where progress in identifying and articulating SoS principles (‘SoS Thinking’) and examples, could have benefit to the discipline

What are the key SoS thinking principles?

Summary and Next Steps

- **Pain Points Impact**
  - Reflect general view of key SoS challenge areas
  - Provide an effective outreach and communications mechanism
  - Highlighted in SoS research thrusts (e.g. T-Area-SoS Research Agenda)
  - See progress being made across the community in all the areas
- **Reflected in Ongoing SoSWG Initiatives**
  - Provided structure in SoS section in the INCOSE Handbook
  - Reflected in the SoS Primer now under development
  - SoS case studies are being developed to further understand prospective approaches