



2024
Annual **INCOSE**
international workshop
HYBRID EVENT
Torrance, CA, USA
January 27 - 30, 2024

Systems of Systems Working Group

SEBOK – SoSE Implementation Approaches

Working Session



SoSWG At IW24

Sunday, January 28 - 1-5: Working session on approaches to SoS

Engineering

- The current SEBOK SoS knowledge area focuses on broad discussion of systems of systems (SoS) characteristics and systems of systems (SoS) challenges. When we look at progress which has been made in the last few years, it is time for a revision and a new focus on approaches to addressing SoS. This session will provide a venue for SoSWG members to share approaches they have implemented, and their lessons learned. The results of this session will provide input to the update of the SEBOK.

Monday, January 29: 9:30-12: SoSWG Business Meeting

- This meeting will review the status and plans for current activities of the SoSWG and open discussion of possible new initiatives.




Agenda

- Welcome and Introductions
- SEBOK Update – Tom McDermott and Garry Roedler
- SEBOK System of Systems (SoS) Knowledge Area (KA)
- ‘SoS and Complexity’ in Emerging Knowledge
- Plans for SoS KA Update
- SoS Implementation Approaches – Examples to Begin Discussion
- Open Discussion





SEBOK Update



SEBOK

GUIDE TO THE SYSTEMS ENGINEERING
BODY OF KNOWLEDGE

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Guide to the Systems Engineering Body of Knowledge (SEBoK)

(Redirected from Main Page)
Guide to the Systems Engineering Body of Knowledge (SEBoK) > FAQs > Acknowledgements and Release History > Guide to the Systems Engineering Body of Knowledge (SEBoK)

On behalf of the [Editorial Board](#), the [Governing Board](#), and our authors and sponsors, welcome to SEBoK version 2.9.
Released 20 November 2023

Welcome to SEBoK v. 2.9

The SEBoK provides a guide to the [key knowledge sources and references](#) of [systems engineering](#) organized and explained to assist a wide variety of individuals. It is a living product, accepting community input continuously, with regular refreshes and updates. The SEBoK is not a compendium but instead references existing literature.

Systems engineering is an interdisciplinary approach and means to enable the full life cycle of successful [product](#), [service](#) and [enterprise](#) systems. It includes problem discovery and formulation, solution definition and realization, and operational use, sustainment, and disposal. It can be applied to single-problem situations or to the management of multiple interventions in commercial or public enterprises. Those new to systems engineering can find introductory articles which provide an [overview of systems engineering](#), place it in [historical context](#), and discuss its [economic value](#) in [Part 1](#) of this body of knowledge.

- Tom McDermott
- Garry Roedler

Systems of Systems (SoS)

[Guide to the Systems Engineering Body of Knowledge \(SEBoK\)](#) > [Systems of Systems \(SoS\)](#) > [Socio-Technical Features of Systems of Systems](#) > [Architecting Approaches for Systems of Systems](#) > [Systems of Systems \(SoS\)](#)

Lead Authors: *Mike Henshaw, Judith Dahmann, Bud Lawson*

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.

Contents [hide]

- 1 Topics
- 2 Characteristics and Definition of Systems of Systems
- 3 Types of SoS
- 4 SoSE Application Domains
- 5 Difference between System of Systems Engineering and Systems Engineering
- 6 SoSE Standards

SoS Knowledge Area



Contents [hide]

- 1 The Role of System of Systems Architecting
- 2 Challenges in Architecting SoS
- 3 Architecture Analysis
- 4 The Open Approach to SoS Engineering
- 5 Networks and Network Analysis
- 6 Interoperability

Contents [hide]

- 1 The Socio-Technical Nature of Systems of Systems
- 2 SoS Governance
- 3 Situational Awareness

[https://sebokwiki.org/wiki/Systems_of_Systems_\(SoS\)](https://sebokwiki.org/wiki/Systems_of_Systems_(SoS))



Emerging Knowledge: SoS and Complexity

The screenshot shows the SEBoK website interface. At the top, there's a logo for SEBoK (GUIDE TO THE SYSTEMS ENGINEERING BODY OF KNOWLEDGE) and a 'Log in' link. Below the logo, there's a navigation bar with 'Page', 'Read', 'View source', 'View history', 'PDF Export', and a search box labeled 'Search SEBoK'. On the left side, there's a 'Stewards' section with logos for INCOSE and IEEE SYSTEMS COUNCIL, and a 'Quicklinks' section with links to 'Main Page', 'Editor's Corner', 'Governance and Editorial Boards', 'SEBoK Sponsors', 'Acknowledgements and Release History', and 'FAQs'. The main content area displays the article 'System of Systems and Complexity' by Lead Author: Judith Dahmann. The article text discusses the complexity of Systems of Systems (SoS) and the role of Systems of Systems Engineering (SoSE). A 'Contents [hide]' section is also visible, listing: 1 Complexity Dimensions Applied to Systems of Systems, 2 Guiding Principles to Complexity Thinking Applied in Systems of Systems Engineering, and 3 References (with sub-items: 3.1 Works Cited, 3.2 Primary References, 3.3 Additional References).

- Article in 'Emerging Knowledge' on SoS and Complexity
- Based on work of SoS and Complexity Working Groups
- Move into SoS KA?



Objective of this session is to discuss
current approaches to implementation of
SoSE as input to the SoS KA update





Some Approaches to Systems of Systems Engineering

Stephen Cook, stephen.cook@adelaide.edu.au

ABSTRACT

Given the wide span of challenges that are amenable to systems of systems engineering (SoSE), it is not surprising that there are a considerable number of rather different SoSE approaches in use. The paper opens by describing the generic nature of SoSE methodologies and argues that they should be value-driven, incremental, socio-technical, bespoke for each system of systems (SoS) problem, achieve their effect through influence and persuasion rather than control, and should be informed by evidence of what works in practice. The body of the paper describes three SoSE approaches and comments on the classes of SoS for which they have proved to be successful.

INTRODUCTION

Dahmann and Henshaw (2016) in their *Introduction to Systems of Systems Engineering* article in this issue of *INSIGHT* describe five types of systems of systems (SoS) (directed, acknowledged, collaborative, virtual and discovered), the difference between applying systems engineering to systems and SoS, and the key considerations in applying systems engineering to SoS. Pratt et al. (2015) add to this with the three additional top-level concepts: systems of systems engineering (SoSE) is multidisciplinary and practice-based; SoSE is a socio-technical activity; and SoSE is value-driven. This article builds on this foundation by introducing three SoS approaches that align with these principles to tackle SoS challenges by interpreting requirements and outlining how to go about the task. It is useful to

and more, so much so that this activity is better thought of as "architecting the SoS-approach" rather than "tailoring the systems engineering process." Cook and Pratt (2016) reveal nine factors that influence the choice of SoSE approach, the most important ones being the type of SoS under consideration and its context; the social versus technical balance of the SoS; the complexity of the SoS; and the domain, for example, transport, defense, or information and communication technology.

The two principal differentiating characteristics of SoS are the operational and managerial independence of the constituent systems (CS) (Maier, 1998). This means that the CS are separately acquired and integrated and maintain a continuing operational and managerial existence independently of the SoS. Indeed, SoSE invariably starts from a desire to better integrate pre-existing and capabilities in order to provide services and unique capabilities. practice, SoSE becomes an overlay of pre-existing systems (and new developments) that seeks to coordinate evolution of multiple, independent, substantial, CS in such a way as to achieve desired emergent properties of the SoS. It is important to note that the US DoD approach is aimed at Acknowledged

really complex organizational environment where:

- control has to be substituted by influencing and persuading;
- technical complexity can be mindboggling;
- decisions of all sorts need to be made without all of the desirable data;
- resource constraints mandate the use of small SoS teams supported by rudimentary models and developmental environments.

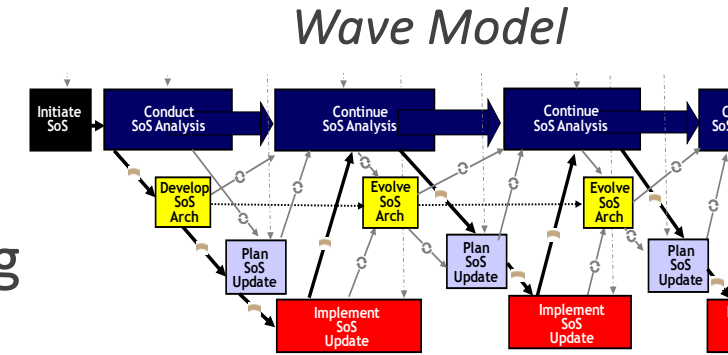
This is daunting but not impossible; the approaches described below outline three different ways of successfully addressing SoS problem spaces.

THE US DEPARTMENT OF DEFENSE (DOD) APPROACH – THE WAVE MODEL

Description
The US DoD approach has found utility in coordinating a variety of SoS activities both at SoS design time and during SoS operations. Given its breadth, readily available literature, and demonstrable success, see, for example, Scrapper et al. (2016), this approach is an exemplar of how top-down systems engineering can be adapted for SoSE. It is important to note that the US DoD approach is aimed at Acknowledged

Features Three Approaches

- US DoD Wave Model
- Complex Systems Engineering
- British Systems Thinking Approach (BSTA)



BSTA

Vision: Defence uses a structured, rigorous and joined up way of undertaking its business

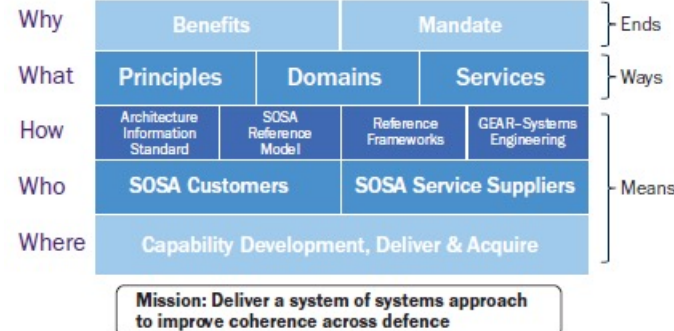


Figure 1. High-level SOSA blueprint, vision and mission (Reason 2014)

Complex SE

Table 1. Elements of Complex Systems Engineering

Elements of CSE	Description
Developmental Environment	The developmental environment is the ecosystem within which the SoS will evolve.
Outcome Spaces	The CSE team should define developmental and operational outcome spaces at multiple levels of scale and from multiple points of view. These should include regions that the SoS can only achieve by combinations of CS working together.
Rewards	Rewards need to shape the decision-making processes of CS project offices to help facilitate decisions that help the SoS reach its outcomes spaces.
Developmental Precepts	These are the "rules of the game" and are intended to stimulate contextual discovery and interaction among CS.
Judging	Judging is about the SoSE team associating CS evolutions with SoS outcome spaces and assigning rewards accordingly.
Continuous Characterization	The CSE team should continuously monitor the condition of the SoS against the outcomes spaces to evaluate not only the evolving SoS but also the efficacy of the outcomes spaces and the rewards.
Safety Regulations	Safety regulation applies to all development activities and aims to preserve the stability of the SoS during evolution.
Duality	Duality explicitly recognizes that in most SoS, "development time" is not completely separate from its "run time."



Stephen Cook

2016

Some Approaches to Systems of Systems Engineering

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really complex organizational environment where:

- control has to be substituted by influencing and persuading;
- technical complexity can be mindboggling;
- decisions of all sorts need to be made without all of the desirable data;
- resource constraints mandate the use of small SoS teams supported by rudimentary models and developmental environments.

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Stephen Cook



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A Capability Engineering Lifecycle Framework Based on Insights from Australian Defence

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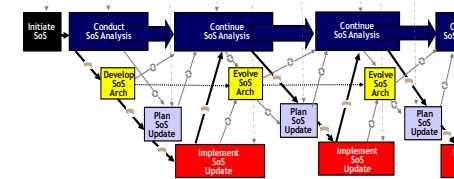
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2020

- 2016 INSGHT addresses 3 approaches
 - US DoD Wave Model
 - Complex Systems Engineering
 - British Systems Thinking Approach (BSTA)
- 2020 paper expands to add
 - Dynamic Optimization of SoS using Value Measurement (DOSVM)
 - SoS Governance
 - US Navy ME Approach
 - Capability Based Planning
 - UK SoS Approach



Wave Model



BSTA/SoSA

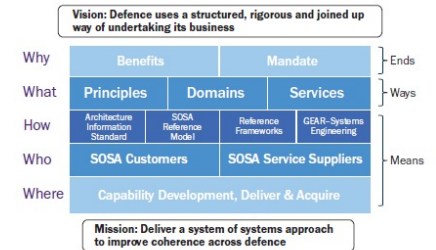


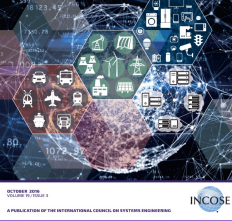
Figure 1. High-level SoSA blueprint, vision and mission (Reason 2014)

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INSIGHT

This Issue's Feature:
Systems of Systems



2016



Implementers View of SE for SoS: SoS Wave Model

An Implementers' View of Systems Engineering for Systems of Systems

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Abstract—This paper builds on and extends U.S. Department of Defense published guidance on systems engineering (SE) of systems of systems (SoS) by developing and presenting a view of SoS SE that translates the SoS SE core elements, their interrelationships, and SoS decision-making artifacts and information from a “trapeze” model to a more familiar and intuitive time-sequenced “wave” model representation. The information is thus rendered in a form more readily usable by SoS SE practitioners in the field and one that corresponds with incremental development approaches that are the norm for SoS capability evolution. The paper describes and motivates the development of the wave model, discusses its key characteristics, and provides examples of SoS efforts that reflect this view of SoS SE. Finally, the paper describes how the information critical to successful SoS SE is created, where it fits into the wave model, how it evolves over time, and in which artifacts the information is normally contained.

Keywords—system of systems, system of systems engineering, systems engineering artifacts.

I. INTRODUCTION

To meet new and emerging operational needs, an increasing number of military capabilities are being fielded through a system of systems approach by leveraging legacy systems, together with some new development, while the individual systems continue to support current users. Recognizing this trend, the U.S. Department of Defense published guidance on systems engineering (SE) of systems of systems (SoS) in 2008 [5]. The guide presents SoS SE as seven core elements, each of which can be mapped to the 16 technical and technical management processes in the Defense Acquisition Guidebook [4]. The guide uses a “trapeze model” to depict and describe the interrelationships and interactions among the SoS SE core elements. Building on the guide, later work identified and characterized information critical to successful SoS SE and acquisition decision making, as well as the work products or artifacts that normally contain the information [6].

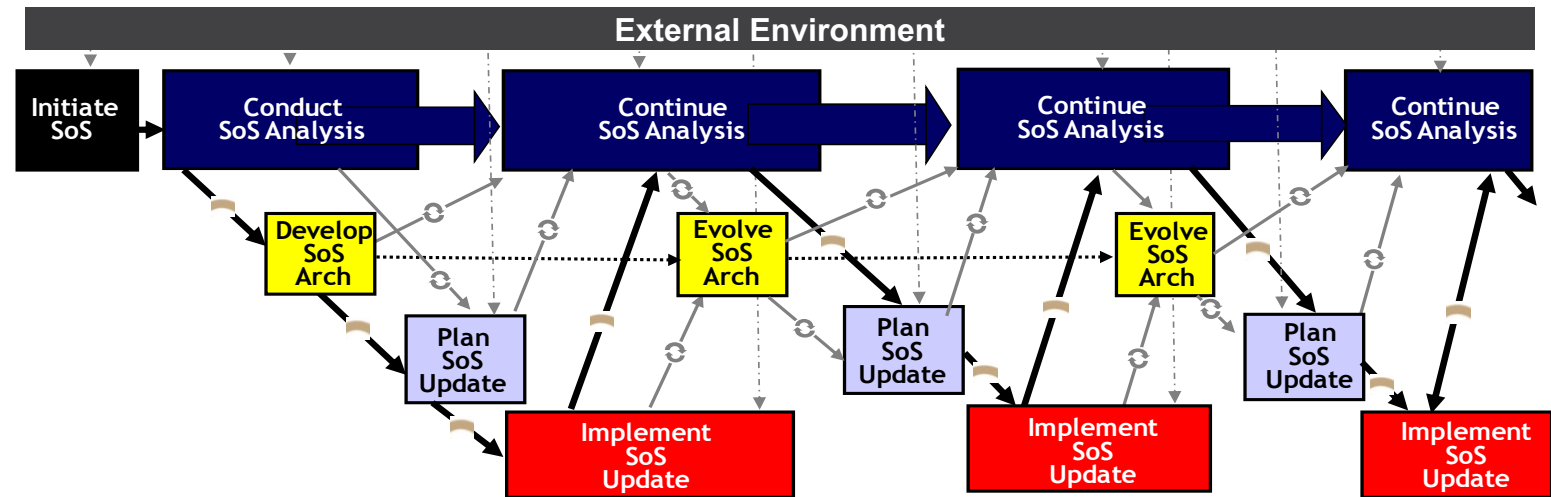
II. FOUNDATIONS

Although systems of systems have been defined in various ways [1,2,3], the key characteristic of SoS is the independence of the systems which comprise an SoS. For the purposes of this paper we define SoS as “a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities” [5]. This characteristic challenges the traditional application of SE, since many models of SE are based on the ability of the systems engineer to define boundaries and requirements clearly and to control the development environment so that requirements can be optimally allocated to components based solely on SoS technical trade analyses.

Today’s defense SoS environment makes this approach unworkable. Because SoS systems engineers frequently use existing systems as their “components,” they are faced with an allocation of functionality and implementation details that cannot be made optimal to meet SoS user needs. In addition, the lack of control over the development of the component systems with independent ownership, funding, development processes and, in some cases, different operational missions, requires the systems engineer to accommodate considerations beyond the technical when evaluating capability objective options. Finally, unanticipated changes in the external environment may occur during development (e.g., changes in national priorities, funding, threat assessments, and magnitude or nature of the demands placed on SoS capabilities), and they

IEEE Systems Conference, 2011

Judith Dahmann



• Initiate SoS:

Provides foundational information to initiate the SoS

• Conduct SoS Analysis:

Provides analysis of the ‘as is’ SoS and basis for its evolution

• Develop SoS Architecture:

Develops/evolves the persistent technical framework for SoS evolution and a migration plan identifying risks and mitigations

• Plan SoS Update:

Evaluates SoS priorities, backlog of SoS changes, and options to define plans for the next SoS upgrade cycle

• Implement SoS Update:

Oversees system implementations and plans/conducts SoS level testing, resulting in a new SoS product baseline

• Continue SoS Analysis:

Ongoing SoS analysis revisits the state of and plans for the SoS as the basis for SoS evolution

Complex Systems Engineering



Some Approaches to Systems of Systems Engineering



2016

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 **SEBoK** GUIDE TO THE SYSTEMS ENGINEERING BODY OF KNOWLEDGE

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System of Systems and Complexity

Guide to the Systems Engineering Body of Knowledge (SEBoK) > System of Systems and Complexity

Lead Author: Judith Dahmann

Systems of Systems are generally characterized as complex (Sheard, 2019) (Luzeau et al., 2011) (Simpson, 2009) (DeLaurentis, 2007) (Ireland, 2014) (Magee, 2004), as is noted in the systems of systems (SoS) knowledge area of the SEBoK.

The question for those seeking to perform SoS Engineering (SoSE) then is how to address/use SoS complexity? In an ongoing collaboration between the INCOSE SoS and Complexity Working Groups, recent work on characterizing complexity has been applied to SoS, to assess how and why SoS exhibit complexity, as the basis for identifying approaches from the complexity community to applications of systems principles to systems of systems. This collaboration was spurred by recent work in both communities on concepts to understand how complexity affects systems of systems (Watson, 2020) and guiding principles to complexity thinking can be applied in Systems of Systems Engineering. (INCOSE, 2016)

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Complexity Dimensions Applied to Systems of Systems

Guiding Principles to Complexity Thinking Applied in Systems of Systems Engineering

Ongoing Area of Inquiry

SoS Analytical Workbench



An SoS Analytical Workbench Approach to Architectural Analysis and Evolution

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■ ABSTRACT

This article summarizes the development of a System of Systems Analytic Workbench (SoS AWB) that provides a set of computational tools to facilitate better-informed decision-making on evolving SoS architectures. The workbench motif is adopted since SoS practitioners typically generate archetypal technical queries that can be mapped to appropriate analysis methods best suited to provide outputs and insights directly relevant to posed questions. After an overview of the workbench framework, four distinct methods currently available for use are presented along with their distinctive aspects in the concept of use.

INTRODUCTION

The importance of systems of systems (SoS)-derived capabilities documented in this edition of *INSIGHT* implies the associated importance of sound analysis tools with which to reason about development and implementation options for SoS architecture evolution. Evolving and refining a SoS presents significant decision-making challenges across both technical and programmatic domains. SoS generally involve integrating multiple independently managed systems to achieve a unique capability, therefore involving needs for collaboration and negotiation as well as control. In such complex systems, human behavioral and social phenomena in collaboration are critical as are cascading impacts from interdependencies altogether, emergent outcomes are the norm. Handling such situations goes well beyond the immediate mental faculties of decision-makers and even capabilities of existing system-level decision-support tools. The current "cutting edge" in analysis for SoS seeks a collection of methods, processes and tools that provides the SoS practitioner with meaningful quantitative insights into projected SoS behavior and the possibilities for evolving the SoS, the set of options on system addition, deletion, reorganization required to meet the capability

objective. Current policies set forth in the acquisition guidance documents, emerging SoS standards, and informal guidance, such as US Department of Defense (DoD) Systems Engineering Guide for Systems of Systems (U.S. DoD 2008a) and Defense Acquisition Guidebook (U.S. DoD 2008b), provide useful guidance but are in need of a supporting analytic perspective to complete the picture for more informed decision-making. A number of research groups are working on advancements in this important area. Ongoing research is focusing on 'situational awareness' products for both SoS and constituent system-level decision-support as well as strategic approaches for modeling SoS architectures and their ability to restructure quickly to respond to failures, new needs and missions. In this short article, we exemplify this activity via overview of work in the area of SoS analysis methods funded by the DoD Systems Engineering Research Center (SERC). It is important to note, however, that analysis methods for SoS should be (and most are) applicable to civil/commercial applications as well, an especially relevant approach with emergence of smart, connected cyber-physics system networks, Internet-of-things, and more.

One analysis framework developed and demonstrated via the SERC is the Flexible and Intelligent Learning Architectures for SoS, FILA-SoS, (Dagli 2015) developed to provide a decision making aid for SoS managers based on the 'wave model' (Dahmann et al. 2011) described in earlier articles of this issue. FILA-SoS adopts a complex system approach, for example, fuzzy inference systems and genetic programming, together with the 'wave model' processes to address four of the most challenging aspects of system-of-systems architecting:

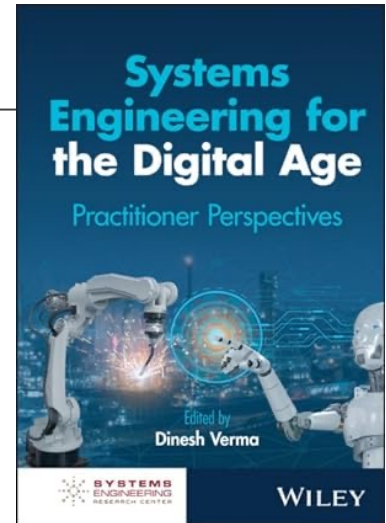
1. Dealing with the uncertainty and variability of the capabilities and availability of potential component systems
2. Providing for the evolution of the systems-of-systems needs, resources and environment over time
3. Accounting for the differing approaches and motivations of the autonomous component system managers
4. Optimizing systems-of-systems characteristics in an uncertain and dynamic environment with a fixed budget and resources.

The remainder of the article dives a bit deeper into a second example from the SERC SoS analysis portfolio. The Systems of Systems Analytic Workbench (SoS AWB)



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2024

Dan DeLaurentis



SoS Meta Architecture

2022



19th Annual Conference on Systems Engineering Research
Transdisciplinary nature of SE:
Impact on traditional and novel applications

March 24-26, 2022 - Norwegian University of Science and Technology

2022 Conference on Systems Engineering Research

A System-of-Systems Meta-Architecture Optimization to Recommend a Solution for Personalized Home Fitness

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Abstract

Due to the novel coronavirus COVID-19, businesses to cancel in-person activities, a exercise without leaving their homes. With like Peloton and NordicTrack. To help design Systems to optimize a meta-architecture for

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SoS Meta-Architecture Selection for Infrastructure Inspection System Using Aerial Drones

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Abstract—Infrastructure inspection using unmanned aerial drones has a great potential to support complex inspection tasks especially where inspection task can be dangerous, dull or dirty. The increased number of system in this type of inspection process makes it a very complex system-of-systems (SoS) which is hard to assess. As a result, it becomes very difficult to satisfy all stakeholder needs and requirements. Therefore, an assessment system is required that can efficiently assess the meta-architecture of drone based inspection system. This paper presents a method to generate and evaluate system of systems (SoS) architecture model for aerial inspection with drones. Where, a meta-architecture containing system component and a system to system interface is presented. To map the desired SoS attributes from stakeholders, different characteristics of the architecture capabilities are evaluated using some linguistic terms called key performance attributes (KPA). KPAs are combined in a Fuzzy Inference System (FIS) to evaluate an overall fitness value that is optimized using a Genetic Algorithm (GA) for the SoS within the meta-architecture. The integrated evaluation method presented in this paper utilizes the SoS explorer to evaluate the SoS meta-architecture using synthetic parameter values.

Keywords— Systems-of-Systems, Meta-architecture, Fuzzy Inference System, Genetic Algorithm, Aerial drone

I. INTRODUCTION

Infrastructure inspection using drones has become very popular for real-time data collection, especially where visual data collection is very dangerous, dull or dirty. Different types of drones have different sets of capability which can be used in different types of inspection activities. For example, some drones have the capability of thermal image capturing, that requires thermal cameras. Similarly, some drones may have the ability to capture data in extreme weather conditions that require

drone swarms, where hundreds of different categories of drones are involved.



Fig. 1. Overview of the meta-architecture of aerial inspection systems with drones

Numerous research has taken place to effectively generate architecture alternatives and to assess the architectures. For example, Ashit et al. [1] developed a model using SoS explorer [2] on a banking cybersecurity problem. They used the supplied Genetic Algorithm of the SoS explorer where a fuzzy assessor is used as a fitness function to choose the best combinations of methods to eliminate cyber threats. Similarly Curry et al. [3] used SoS explorer [4] to improve intelligent predictions and decisions in a time-series environment. Page et al. [5] used fuzzy logic that uses overlapping regions of the membership functions of attributes to evaluate and assess meta-architectures. To optimize the architecture selection process they coupled genetic algorithm with the fuzzy logic. Agrawal et al. [6] also used SoS explorer to analyze the architectural evolution in systems of systems. They have shown that, SoS explorer can be used as a system of systems decision making tool by combining multiple behaviors of systems participating in a complex adaptive SoS

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System of Systems Meta-Architecture Approach to Improve Legacy Metrorails for Enhanced Customer Experience

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Abstract— As technology surges forward, some Metrorail networks have become outdated customer-facing systems in need of updates. To help enhance overall traveler experience, the following Key Performance Attributes (KPAs) are identified: predictability, accessibility, reliability, affordability. By maximizing these KPAs, a legacy Metrorail increased ridership, thus potentially increasing generated by the system. In order to assess measure of the System of Systems (SoS), a Fuzzy Inference System (FIS) developed along with a set of feasible, pre and KPA-defining equations. A simple Genetic Algorithm (GA) used to find the optimized meta-architecture methodologies described in this paper, an architecture for improving a legacy Metrorail system and assessed.

Keywords— Metrorail, Meta-Architecture, Fuzzy Inference System

I. INTRODUCTION

Throughout the 20th century, many American commuter rail systems, sometimes called M with city-wide transportation. Some of the upgraded as technology surged forward. If from experience, some city rail systems have and are still using older methods such as tickets and lack basic train arrival information. These older methods can result in lost revenue frustration from lack of train predictability smarter and more modern way to travel MetroCard and arrival prediction-based system implemented into the already existing Metrorail. These older methods can result in lost revenue frustration from lack of train predictability smarter and more modern way to travel MetroCard and arrival prediction-based system implemented into the already existing Metrorail.

To visually show the proposed update operational view (OV-1) in Fig. 1 shows a reusable plastic MetroCard at the starting train, and scanning the card again at an end only decreases material waste by having a reusable also for travelers to pay a scaled fare they traveled rather than a flat fee. To supply functionality, a train-card information system which will retain any relevant train arrival data

card check-in/out data, will need to be implemented into the existing system. This informational database could be a similar database, a consolidation of databases, and/or a

Complex System Methodology for Meta Architecture Optimization of the Kidney Transplant System of Systems

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Abstract—The demand for kidney transplants is growing and far outweighs the supply of kidneys. With approximately 20 percent of kidneys discarded each year, there is an opportunity to develop a methodology to analyze the key performance attributes of the complex kidney transplant system. This paper designs and analyzes a meta-architecture for the organ procurement system with a use case in the kidney transplant system. The complex system and interfaces create emergent behavior that will affect the key performance attributes of Performance, Discard Rate, Observed over Expected Kidney Transplants, Affordability, and Acceptability. These key performance attributes, interfaces, and rules are developed from multiple interviews and events with the system's stakeholders. We used fuzzy membership functions to assess the performance of the system and then optimized them using genetic algorithms. We chose two use cases with one donor and three donors to demonstrate the flexibility of the methodology to determine the meta-architecture for a given number of systems. The maximum overall value obtained for each system of systems and participating systems are shown on a map. Future work includes developing and integrating a system of systems simulation to determine the effect of policy changes on organ procurement systems.

Keywords—Complex Systems, Organ Transplant, System of Systems, Meta Architectures

I. INTRODUCTION

According to the US Renal Data System, approximately 750,000 are affected by end-stage renal disease (ESRD) [1]. Two primary treatments for ESRD are dialysis and kidney transplant. While both treatments are effective, kidney transplant is considered the most effective for the appropriate candidates [5]. The discard rate of

kidneys is high, with approximately 20% of kidneys discarded each year. The demand for kidneys is expected to increase continually based on the trend noted from 2010 to 2020.

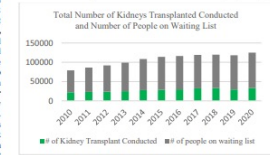


Fig. 1. Kidney transplants and number of waitlisted candidates [1]

Even with the great demand for kidney transplants, approximately 20% of procured deceased donors' kidneys are discarded in current practice. These lower-quality kidneys (KDPI > 85) have a high probability of being discarded [4]. Although some of the high-risk kidney discards are unavoidable, even lower-quality kidneys have been life-extending and cost-effective for the appropriate candidates [5]. The discard rate of

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UNDERSTANDING BEHAVIOR OF SYSTEM OF SYSTEMS THROUGH COMPUTATIONAL INTELLIGENCE TECHNIQUES

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Abstract – The world is facing an increasing level of systems integration leading towards Systems of Systems (SoS) that adapt to changing environmental conditions. The number of connections between components, the diversity of the components and the way the components are organized can lead to different emergent system behavior. Therefore, the need to focus on overall system behavior is becoming an unavoidable issue. The problem is to develop methodologies appropriate for better understanding behavior of system of systems before the design and implementation phase. This paper focuses on computational intelligence techniques used for analysis of complex adaptive systems with the aim of identifying areas that need methodology customization for SoS analysis.

INTRODUCTION

In today's world, business and government applications require integrated systems that exhibit intelligent behavior. Their success depends on the successful interaction between different groups of systems together. Conventionally, the style of operation for businesses and government was to develop or build what they can do and subcontract when they did not have the capabilities. Now, the operation style is to be the lead system integrator where business or government gets the best systems the industry develops and focuses on system engineering, integration, planning and control to provide a System of Systems.

System of systems describes the interaction between different independent and complex systems in order to achieve a common goal. There are many definitions of SoS depending on

the application area and focus [2], [11], [14] Future Combat Systems (FCS), NATO, transnational virtual enterprises, intelligent transportation systems are some of the networked systems that we are observing in governments and commercial enterprises. These networked systems consist of people, organizations, cultures, activities and interrelationships. The semi-autonomous systems (people, organizations) are integrated through cooperative arrangements. These systems are referred to as network-centric systems.

In System of system analysis, the architecture efforts are focused on the evolution of the existing communications and processing systems, moving towards the creation of an integrated system that can provide a seamless physical, information and social network. This brings the focus on understanding the system level behavior emerging from these sub-systems. It is feasible to understand any System of Systems as an artificial complex adaptive system [5]. The relation of SoS characteristics and CAS characteristics are outlined in [5]. Computational intelligence tools have been successfully used in analysis of Complex Adaptive Systems. Since System of Systems is collections of several Complex Adaptive Systems, we can utilize these tools for analysis of SoS behavior. Therefore, this paper aims to review some of the computational intelligence tools that are potentially suitable for analysis of SoS. The next section discusses the importance of architecture development in SoS and identifies several challenges associated with SoS analysis. The following section reviews the computational intelligence tools that system architects can utilize for their analysis. This section also provides several studies conducted in Smart Engineering Systems Lab at University of

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Rail Examples



Rail Systems Viewed from a System of Systems Perspective

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ABSTRACT
Transportation systems in general, and rail systems in particular, are large and geographically distributed systems. While individual carriers may be independently operated and managed, they often use the infrastructure and resources (roads, track, and stations) of other entities such as Amtrak or freight railroads. This *INSIGHT* article describes why rail systems are in fact systems of systems (SoS), and what types of SoS they represent. It will use the California High-Speed Rail System (CHSR), a rail system currently in design and build, as an example to illustrate insights into the application of systems of systems engineering (SoSE), and how it benefits from the growing awareness of SoS Engineering.

INTRODUCTION
The Northeast Corridor (NEC) as presented in Figure 1 is a prime example of a large and geographically distributed rail system in the Northeast region of the United States with a length of over 450 miles. The NEC runs through the states of Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, and the District of Columbia, and includes stops in Boston, New York City, Philadelphia, Baltimore, and Washington D.C. Amtrak primarily owns the corridor, with portions belonging to other such

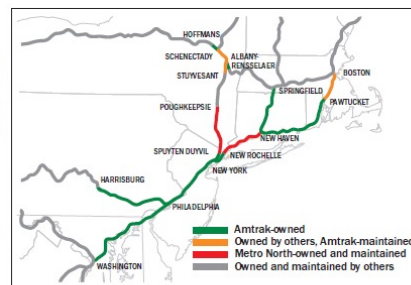


Figure 1: Northeast Corridor (Source: Amtrak)

WHY RAIL SYSTEMS ARE SYSTEMS OF SYSTEMS

Maier (1998) postulated five key characteristics of SoS: (1) **operational independence** of component systems, (2) **managerial independence** of component systems, (3) **geographical distribution**, (4) **emergent behavior**, and (5) **evolutionary development processes**. Operational independence and managerial independence are the two principal distinguishing characteristics for applying the term 'systems-of-systems'. **Operational and Managerial Independence:** As noted above, many different federal (Amtrak), state (MBTA, MNR, NJT, SEPTA, MARC), and private (CSX, NS) railroads use the NEC. They

Case Study: Achieving System Integration through Interoperability in a large System of Systems (SoS)

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Abstract. This paper provides a case study on system of systems engineering (SoSE) being performed in a multi-billion-dollar program – the California High-Speed Rail System – viewed from the systems integration perspective. The paper discusses why the subject program of projects (PoP) can be viewed as a system of systems (SoS), identifies the SoSE challenges faced, describes the SoSE activities performed, and summarizes the achieved outcomes and conclusions as of today.

Specific SoSE challenges discussed include SoS authority, leadership, architecting, collaboration, integration, and emergence. The paper reviews how decision-making in independently operated and managed constituent systems (projects) resulted in unanticipated SoS emergent behavior, which is one of the key challenges in the engineering of SoS.

The paper further discusses the performed SoSE activities, including an international best practice review, the tailoring of SoSE to the specific SoSE challenges, and provides examples where SoSE principles are being applied to perform successful SoS integration.

Brief Introduction: System of Systems

A system of systems 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 (CS) retains its own management, goals, and resources while coordinating within the SoS and adapting to meet SoS goals (ISO/IEC/IEEE 15288, 2015).

SoS Characteristics: SoS are characterized by **managerial and operational independence** of the constituent systems, which in many cases were developed and continue to support originally identified users of the constituent concurrently with users of the overall SoS. In other contexts, each constituent system itself is a SOI, with its existence often predating the SoS, while its characteristics were originally engineered to meet the needs of their initial users. As constituents of the SoS, their role is expanded to encompass the larger needs of the SoS. This implies added complexity particularly when the systems continue to evolve independently of the SoS. The



Steampunk System of Systems Engineering: A Case Study of Successful System of Systems Engineering in 19th Century Britain

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ABSTRACT
This article presents a case study of the Great British railway as it developed from over 300 individual railways, through a complex system of systems (SoS) to its eventual integration into a single railway. This evolution took place from the 1830s to the early 1950s. The case study focuses on the critical period from 1840 to 1860 when the railways collaborated to form a system of systems. The article evaluates the effectiveness of three current SoS frameworks at identifying the factors that enabled the SoS to operate. Much like the artistic and literary genre of Steampunk, this case study is a mixture of familiar SoS concepts and approaches in an unfamiliar Victorian setting.

INTRODUCTION
The vast majority of literature presents systems of systems' (SoS) challenges as novel and challenging at the edge of our understanding of systems engineering. The consensus is that the explosion of SoS is unprecedented, and therefore SoS engineers require unprecedented approaches. Whilst the authors do not disagree that SoS are challenging and require a different approach than product systems engi-

EVOLUTION Pre-1840
In 1830, the opening of the world's first intercity railway, between Liverpool and Manchester marked the beginning of the golden age of railway development. The success of the L&M Railway revealed unpredicted demand for passenger travel, prompting investors across the country to

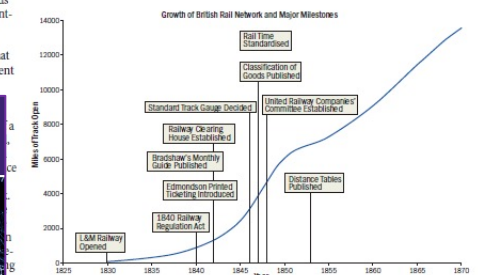


Figure 1: History of Great Britain's (GB) rail from systems, through system of systems and back again from 1825 to 1870; derived from data in: Cook and Stevenson, 1996; Simmons and Biddle, 2003; Wolmar, 2007

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Mission Engineering Methodology

Enabling Mission Engineering through a Reusable Digital Engineering Environment

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Abstract—Mission engineering is the deliberate organization and integration of a system of systems (SoS) to achieve a particular goal or mission. As such, it often requires the consideration of many alternative configurations of independent constituent systems and organizations over a diverse set of operating contexts with a focus on the achievement of desired mission outcomes. While digital engineering approaches and tools would seem to be a natural means to aid engineers in managing the associated complexity, mission engineering poses several challenges to its successful application. Among these challenges are the diversity of SoS constituents, complex system behaviors and interactions, and multiple relevant levels of abstraction. The direct consequence is that each mission may require a different characterization of the SoS architecture and corresponding set of simulation models. This paper presents an approach developed at the MITRE Corporation to partially mitigate these challenges by constructing a reusable digital engineering environment based on a shared modeling framework. The digital engineering environment leverages a multi-layered SysML architecture model that evolved through its application to multiple, real-world mission engineering efforts. The layered structure enables the reuse and rapid construction of new mission architectures and facilitates the coordination of multiple analysis efforts using different simulation tools.

Keywords—model-based systems engineering, systems of systems, mission engineering, digital engineering

I. INTRODUCTION

Increasingly systems engineering (SE) is addressing more complex systems including systems of systems which include organizations and complex socio-technical environments. An example is the recent movement toward what is termed 'mission engineering (ME)'. Mission engineering is the deliberate organization and integration of a system of systems (SoS) to achieve a particular goal or mission¹. In effect, ME combines more traditional mission analysis with System of Systems Engineering (SoSE) with the objective of improved mission outcomes [1].

Mission engineering requires evaluating multiple different configurations of the SoS over a set of relevant performance requirements, and these performance requirements may vary from mission to mission. These circumstances suggest the application of digital engineering approaches and tools to manage the technical complexity. For any given mission, alternative SoS configurations are engineered and tracked within a system architecture tool and then fed into simulation tools to predict performance against key mission requirements. The digital tool chain should accelerate the design cycle by providing an authoritative repository for data, leveraging the reuse of model artifacts, and enabling the rapid reconfiguration of models to evaluate alternatives.

In practice, the authors have found several challenges to the application of digital engineering approaches to mission engineering. Among these challenges are the relative diversity of SoS constituents, complex system interactions, and multiple relevant levels of abstraction. The direct consequence is that each mission may require a different characterization of the SoS architecture and corresponding set of simulation models. This means that the ostensibly reusable models must be reworked resulting a diminished yield from the digital engineering approach.

To partially mitigate this problem, the MITRE Corporation developed a reusable digital engineering environment (DEE) through the application of digital engineering approaches to multiple, real-world mission engineering efforts. This empirical approach enabled the identification of abstractions and model components that were stable across multiple contexts as well as which aspects should be tailorable. The resulting digital engineering environment leverages a multi-layered SysML architecture model. The layered structure enables the reuse and rapid construction of new mission architectures and facilitates the coordination of multiple analysis efforts using different simulation tools.

¹ US Department of Defense, Defense Acquisition Guidebook; <https://www.dau.edu/doi/gag>, retrieved 1/16/2021. ME is defined as: "the deliberate planning, analyzing, organizing, and integrating

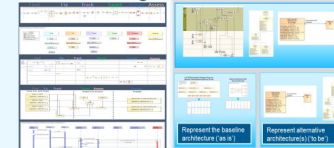
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Systems of Systems Pain Points: A 10-year Retrospective

Dr. Judith Dahmann
Technical Fellow
The MITRE Corporation

Digital Engineering and Operational Analysis Applied to Mission Engineering

Digital Mission Models



Tool: CAMEO/SysML

Operational Simulation



Tool: AFSIM

- Baseline** • Digital representation of the baseline Mission Threads (MTs) scenario independent activities and Mission Engineering Threads (METs) adding scenario specific organizations and activities
- Alternatives** • Updated MTs and METs to include RDER Concepts with associated changes
- Representation of the baseline MTs/METs within scenario including threat, systems' attributes and behaviors – conduct baseline analysis of mission metrics
- Update the systems' attributes and behaviors as specified in RDER concepts and assess impact on mission metrics

MISSION THREAD ALIGNMENT
[TRACEABILITY]

QUANTITATIVE ANALYSIS
[MISSION METRICS – OUTPUTS]

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Social Dimensions of SoS



Mike Yokell

Detecting and Mitigating Social Dysfunction within Systems of Systems

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ABSTRACT

What are systems engineers supposed to do when social dysfunction leads to operational dysfunction? This article elaborates on a means of assessing the managerial relationships between the organizations that own constituent systems (CS) within a system of systems (SoS), with a goal of detecting social dysfunction that could adversely affect operations. For each of the relationship types, or affinity options, tangible, actionable guidance is offered that could help mitigate the social and operational dysfunctions. Results from a case study are included to illustrate the application, detection, and successful mitigation of social dysfunction within a system of systems.

KEYWORDS: system of systems, SoS, operational independence, managerial independence, social dysfunction

INTRODUCTION

ISO/IEC/IEEE 21839:2019 defines a system of systems (SoS) as a "set of systems and system elements that interact to provide a unique capability that none of the constituent systems (CS) can accomplish on its own," while noting that each CS is a "useful system by itself, having its own development, management, utilization, goals, and resources, but interacts within the SoS to provide the unique capability of the SoS." Sometimes, organizations and their systems do not function together properly. Detecting and then mitigating social dysfunction between organizations that own CS within SoS is an important aspect of SoS engineering.

By rating the importance of the exchanges in the relationships between systems and the organizations that manage them, the strength of alignment or affinity can be assessed. SoS Operational Affinity provides insight into the extent to which systems share common interests, while SoS Managerial Affinity provides insight into the extent to which organizations that own CS share common interests.

SoS Managerial Affinity provides a means to detect social function and dysfunction between organizations or people responsible for CS within an SoS. In the

cases of dysfunction, the next step is to mitigate those dysfunctions. SoS Managerial Affinities, their implications, and summary guidance to both the supplier and acquirer are available to understand and mitigate the dysfunctions.

The approach has been applied successfully with positive results. A case study illustrates the approach. Unfortunately acknowledging dysfunctions as well discussing them to facilitate resolving them are exceptionally difficult.

BACKGROUND ON SYSTEMS OF SYSTEMS

SoS are not just collections of systems. Additional characteristics, often referred to as operational and managerial independence, are what distinguish SoS from systems (Maier 1998). Constituent systems (CS) within SoS can and do operate independently. The organizations are independent, but somehow interdependent. The systems the organizations own are independent but must interoperate with each other. ISO/IEC/IEEE 21840:2019 provide a more thorough exploration of these differences and their implications.

To explore these concepts, say Organization A owns System V, which takes inputs and produces some outputs (Figure 1).

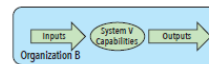
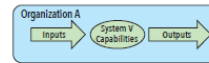


Figure 1. Systems that do not interact are not part of an SoS

Likewise, Organization B owns System W, which takes inputs and produces some outputs. The organizations could be separate corporations, governmental agencies, or business units within a larger organization. Because these systems do not interact with each other, there is not an SoS here. Organizations exert managerial control over their respective systems through goals and objectives, which are subject to laws, regulations, and other constraints. This is nothing new – organizations leverage humans to manage programs or projects that oversee systems.

An essential characteristic of CS within an SoS is that they remain operationally



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A Socio-Technical Perspective on SoSE

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ABSTRACT

Through some illustrative case studies, it is shown that effective development and operation of Systems of Systems (SoS) can only be achieved if the owners and operators of constituent systems can understand the effect of their decisions on the wider SoS. It is shown that appreciating the role of human beings in SoS is essential for successful operation of SoS. The role of human beings must be understood in an organisational sense to be useful in understanding SoS. A socio-technical perspective and approach is needed to manage SoS; two aspects of this, governance and situation awareness, are considered to be the most important human-related considerations for effective operation of SoS. These can be addressed by taking an open approach to information sharing in SoS.

1.0 INTRODUCTION

It is generally understood that Systems Engineering must proceed by taking account of the involvement of people in systems; however, in Systems of Systems (SoS) that involvement happens at several different levels and in different forms. In this paper, we shall consider the nature of SoS and show that the operation and engineering of such systems requires the human, or social, aspects to be a foremost consideration.

We begin with clarification of the meaning of 'socio-technical' before illustrating the issues that will be discussed through three case studies in section 2. In section 3 we examine the characteristics and ambiguities of SoS, from which we demonstrate the significance of a socio-technical perspective for SoS engineering. Two main themes emerge from this discussion: governance (section 4) and situational awareness (section 5). Some concluding remarks are given in section 6.0.

1.1 The meaning of Socio-Technical

The term, socio-technical, is used rather loosely to refer to the involvement of people in technical systems and is almost inevitably imprecise in its meaning. Klein¹ asserts that the term was first used in the context of industrial democracy, by which she meant the ability of workers to organise themselves to work within a technologically constructed system. She views its application to technology design to be either the way in which the design affects human behaviours, or the way in which anticipated human behaviours affect the way the system is designed. She believes that these two perspectives are largely held by two different communities that approach the task of design from opposite ends, rather than recognising that the way in which people affect the working of technology and that technology affects the way people work, should be considered as interdependent from the outset.

Klein² draws attention to the main difference between the two perspectives (system affects people – people affect system) is where the system boundary is drawn. The system boundary defines what is included in

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Other Methods – Graph Analysis

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SPECIAL SECTION ON THEORETICAL FOUNDATIONS FOR BIG DATA APPLICATIONS: CHALLENGES AND OPPORTUNITIES

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The Role of Graph Theory in System of Systems Engineering

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Construction and Application of Knowledge Graph of Weapon and Equipment System of Systems

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Abstract—In the context of diversified types of weapon and equipment and massive data quantification, how to model and store, manage and apply the data of various types of weapon and equipment is a problem that needs to be solved. The article analyzes the characteristics of the weapon and equipment system and proposes a method to construct the knowledge graph of the weapon and equipment system based on this method, which first constructs the ontology in the top-down order, then defines the edge nodes and fills in the structured data. Finally, the application is carried out according to the constructed knowledge graph, and the future development direction is proposed.

Keywords—component; formatting; Weapon and Equipment System of Systems; Knowledge Graph

I. INTRODUCTION

Nowadays, modern warfare has changed from weapon-centered operations to network-centered system operations, and joint warfare in this environment is a confrontation between systems, with weapons and equipment as the material basis and capability support for system confrontation. Therefore, it is necessary to adhere to systematic design, systematic construction and systematic application. The definition of weapon and equipment system of systems can be described as a higher-level system consisting of various weapon and equipment system of systems that are functionally interconnected and interact with each other to accomplish certain combat missions under certain strategic guidance, combat command and security conditions [1]. And from the definition can be seen, the mission is the purpose of the existence of the weapon and equipment system of systems and the description of the way to achieve the purpose, so the study of the weapon and equipment system of systems also needs to be combined with the mission to carry out. Weapon and equipment data itself is multi-source heterogeneous, loosely structured, and poorly intuitive, which is not easy to manage and apply, while knowledge graph, as an emerging information technology, can make good use of applied mathematics, graphics and information visualization and other related

and by establishing the association links between data, the fragmented data can be combined organically, which is easier for human and machine to understand. The construction of a weapon and equipment knowledge graph can intuitively and three-dimensionally show the relationship between existing weapons and equipment, and can also provide a unified data model and data standard to flexibly integrate and associate different types and uses of weapon and equipment data to achieve multi-dimensional equipment system analysis, which can be used for combat command, equipment analysis, simulation and rehearsal, and improve the overall combat efficiency. At present, there have been related researches on weapon and equipment knowledge graphing [2-5], but the combination with combat tasks and its systematic features are not enough, while the knowledge graph construction in this paper starts from combat tasks, designs the weapon and equipment architecture, and builds it based on structured data.

The paper defines the conceptual layer of weapon and equipment system and fills the structured data, constructs the knowledge graph, and carries out relevant applications through the structure of the knowledge graph and the association relationship between the nodes, which can realize the query of weapon and equipment and the recommendation of weapon and equipment system of systems.

II. CONSTRUCTION OF THE KNOWLEDGE GRAPH OF WEAPON AND EQUIPMENT SYSTEM OF SYSTEMS

Knowledge graph can be defined as a technical method of describing knowledge and modeling the association relationship between everything in the world with graph models, and can also be interpreted as consisting of a series of interconnected entities and their attributes, which is essentially a semantic web describing the relationship between entities and entities, and contains nodes and edges, where nodes represent concepts and edges represent the relationship between two different entities, and is generally divided into general knowledge graph and domain knowledge graph.

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Towards Unified Graphical Modeling of System of Systems Engineering

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Abstract— This paper contributes towards multilevel / multiscale graphical modeling of behavior of a set of component systems in a System of Systems. The aim of this model is to describe, in representation, the behavioral part of component systems and organizational system of systems. We propose a method Hyper Graph, used for modeling component systems, and Bond Graph, modeling of component systems, in modeling of system of systems.

Index Terms— System of Systems, Hyper Graph, Bond Graph.

I. INTRODUCTION

System of Systems (SoS) concept is the past century due to increased complex systems. In fact, several definitions terminology of SoS depending on. However, there is no unified definition SoS can be best described as a concept of several Component Systems (CSs), various hierarchical levels, and should respect with respect to specific properties [1], necessary requirements to be satisfied

1. Operational independence of CSs as an independent entity by itself.
2. Managerial independence of CSs managed as a separate entity.
3. Geographic distribution of CSs: a relatively wide geographic area of SoS.
4. Emergent behavior: CSs cooperate to achieve tasks that one CS alone cannot fully formed or achieved. Missions continuously evolve to achieve goals.
5. Evolutionary and adaptive development.

Since the introduction of its term, SoS has been applied in several fields in [4], military combat systems [5,7,8], tr

[6,11,13], power micro-grids [9], infrastructure planning [10], economy [12] and many other applications.

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An Interactive Portfolio Decision Analysis Approach for System-of-Systems Architecting Using the Graph Model for Conflict Resolution

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Abstract—A novel approach based on the graph model for conflict resolution (GMCR) methodology is proposed to address the problem of multistakeholder system portfolio decision analysis encountered in architecting a system of systems (SoS) with desired capabilities. More specifically, a flexible four-process framework, for capability-based SoS architecting containing interactive portfolio decision analysis to promote multistakeholder design negotiations on system portfolio selections is presented. By taking full advantage of the inherent realistic and flexible design of the GMCR paradigm, an interactive portfolio decision analysis approach is designed to facilitate the systematic modeling and analysis of system portfolio decisions at the SoS level in order to achieve potential compromises among all key stakeholders having disparate preferences and interacting according to different conflict behavior patterns. This approach permits the prediction of possible mutually agreeable system portfolios for SoS architecture development. Last, the feasibility of the proposed approach is demonstrated using an illustrative example.

Index Terms—Capability development, graph model for conflict resolution (GMCR), multiple stakeholders, portfolio modeling and analysis, system of systems (SoS), systems architecture.

I. INTRODUCTION

PORTFOLIO decision analysis has emerged as a strategic decision analysis paradigm, which places emphasis on portfolio choice rather than on the selection of a single optimal

Spectrum-Based Fault Localization on a Collaboration Graph of a System-of-Systems

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Abstract—A System-of-Systems (SoS) consists of independent and autonomous constituent systems (CSs) which collaborate to achieve an SoS goal. For SoS engineers, it is important to verify the results of the collaboration for an SoS goal. Statistical verification can be used to verify a large and complex SoS and to provide quantitative verification results. However, even when a failure of an SoS goal or a violation of a verification property

there is a need to reduce the cost of finding faults of an SoS for efficient debugging.

The cost can be cut down by localizing areas or entities that induce failures or by providing search priorities. Studies on fault localization have tried to provide systematic methods to find the location of bugs in a system. The studies have focused on localizing bugs in the source code or components of the system. However, the granularity of localization is not suitable for SoS debugging, and those techniques do not take into account the characteristics of an SoS that the independent and autonomous CSs collaboratively achieve SoS goals. Therefore, a localization technique that considers the unique characteristics of an SoS is necessary. In this paper, we propose a spectrum-based fault localization technique to prioritize debugging of suspicious CSs or interactions that induce an SoS failure. The main goal of this study is to propose a fault localization technique specifically applicable to an SoS, and the major features of our technique can be summarized as follows:

- It applies a spectrum-based fault localization (SBFL) technique to the collaboration graph of an SoS, which is an abstract model of CS collaboration and interactions. This technique aims to localize CSs and interactions that induce a failure of an SoS.
- It considers the lack of information available to SoS engineers about independent and autonomous CSs. By representing an SoS as a collaboration graph, it can be used even when the only information available is the presence or absence of entities participating in the collaboration.
- It utilizes the quantitative results of statistical verification of an SoS. Accumulated statistical verification results of diverse collaborations of an SoS can be used for fault localization.

The remainder of this paper is organized as follows: Sections 2 and 3 introduce the related works and background of this work. Section 4 introduces our fault localization technique on the collaboration graph of an SoS. Sections 5 and 6 show the experiment and evaluation to validate our localization technique. Section 7 introduces the discussion points of this study. Section 8 concludes this study by noting its contributions and pointing towards future work.

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Other Examples? Open Discussion





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