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

www.incose.org/IW2024

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.

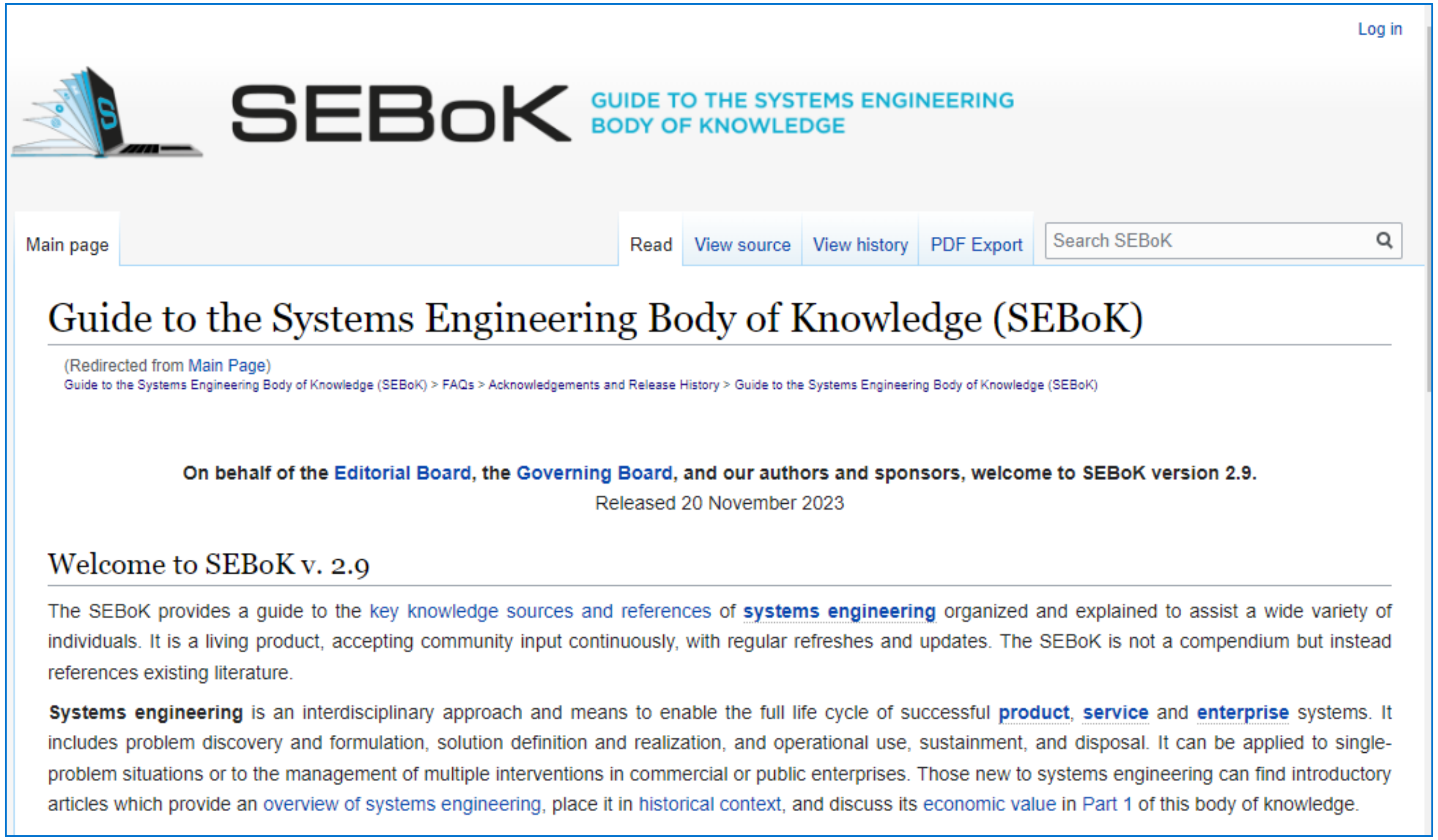
Monday, January 29: 9:30-12: SoSWG Business Meeting

- 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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SEBoK GUIDE TO THE SYSTEMS ENGINEERING BODY OF KNOWLEDGE

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Guide to the Systems Engineering Body of Knowledge (SEBoK)

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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

SoS Knowledge Area

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.

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

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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

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

https://sebokwiki.org/wiki/Systems_of_Systems_(SoS)

Emerging Knowledge: SoS and Complexity

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Part 2: Foundations of Systems Engineering
Part 3: SE and Management
Part 4: Applications of Systems Engineering

System of Systems and Complexity

Guide to the Systems Engineering Body of Knowledge (SEBoK) > Emerging Knowledge > Emerging Topics > 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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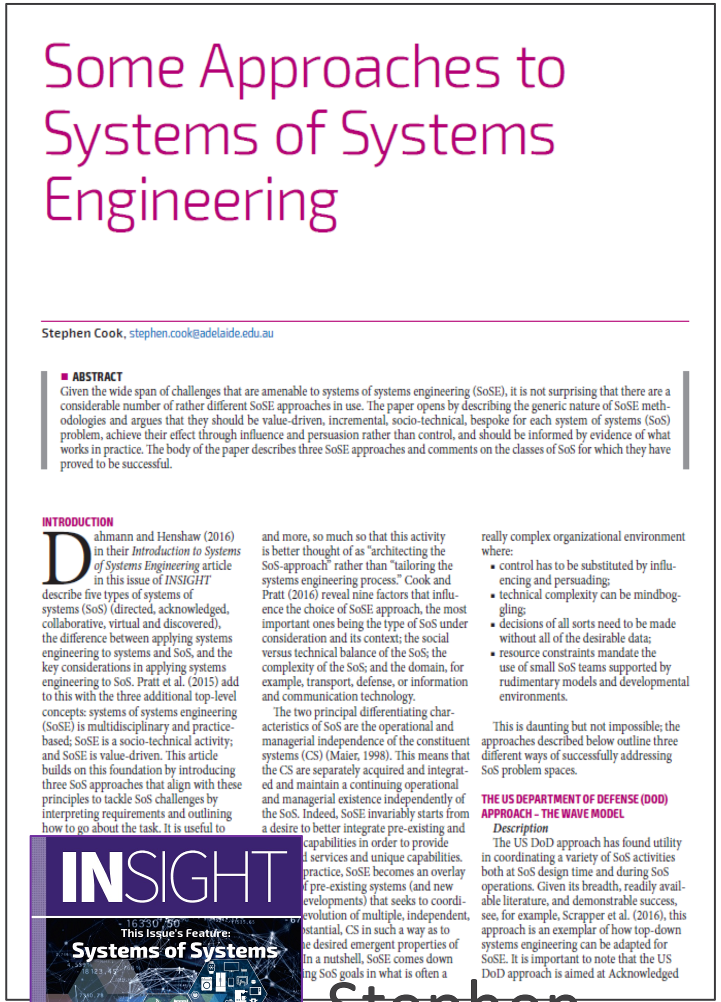
- Article in ‘Emerging Knowledge’ on SoS and Complexity
- Based on work of SoS and Complexity Working Groups
- Move into SoS KA?

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 ...d services and unique capabilities. ...practice, SoSE becomes an overlay ...f pre-existing systems (and new ...evelopments) that seeks to coordi-...evolution of multiple, independent, ...bstantial, CS in such a way as to ...e desired emergent properties of ... In a nutshell, SoSE comes down ...ing SoS goals in what is often a

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

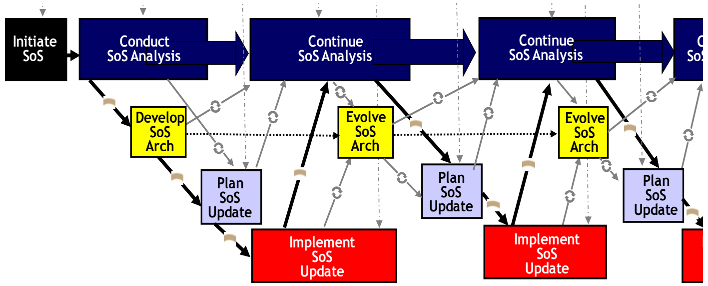
The US DoD approach has found utility in coordinating a variety of SoS activities both at SoS design time and during SoS operations. Given its breadth, readily available literature, and demonstrable success, see, for example, Scrapper et al. (2016), this approach is an exemplar of how top-down systems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

Stephen Cook

2016

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

Wave Model



BSTA

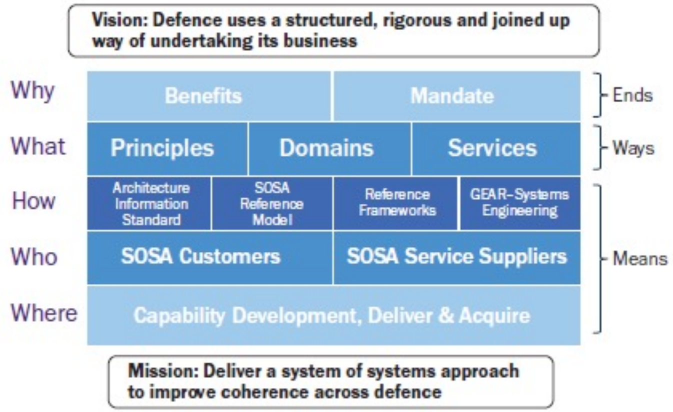


Figure 1. High-level SOSA blueprint, vision and mission (Reason 2014)

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.
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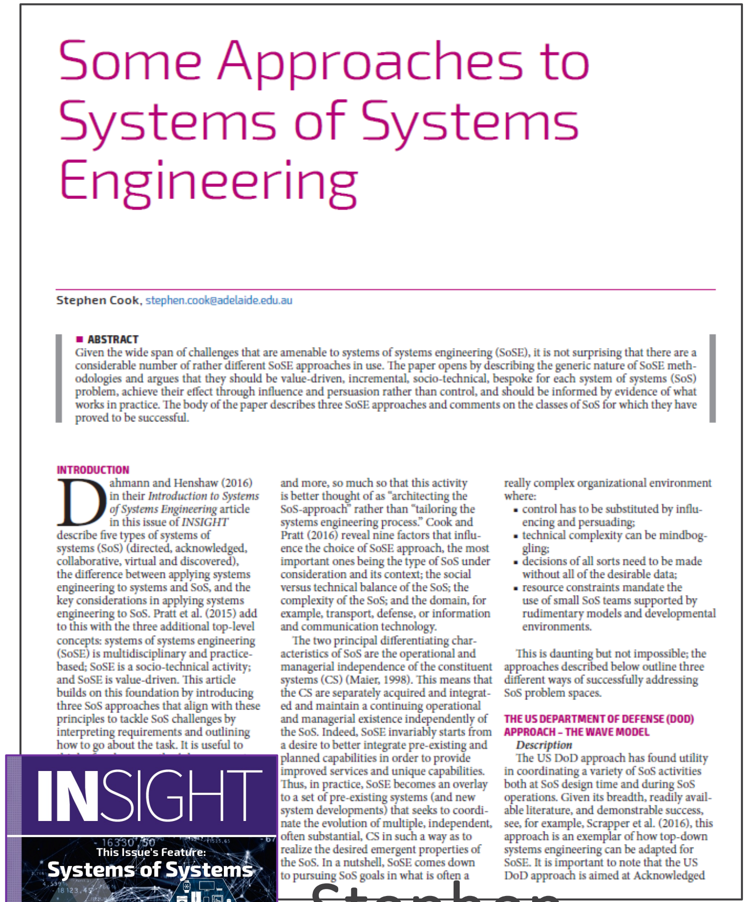
Continuous Characterization	The CSE team should continuously monitor the condition of the SoS against the outcomes spaces to evaluate not only the evolving SoS but also the efficacy of the outcomes spaces and the rewards.
Safety Regulations	Safety regulation applies to all development activities and 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."



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really complex organizational environment where:

- control has to be substituted by influencing and persuading;
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2016

Stephen Cook

A Capability Engineering Lifecycle Framework Based on Insights from Australian Defence

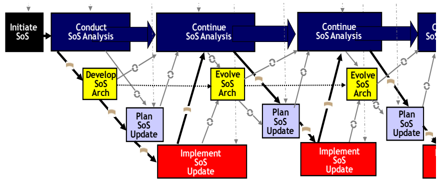
Stephen C Cook
Shoal Group & The University of Adelaide
Stephen.Cook@shoalgroup.com

Mark H Unewisse
Defence Science and Technology Group
Mark.Unewisse@dst.defence.gov.au

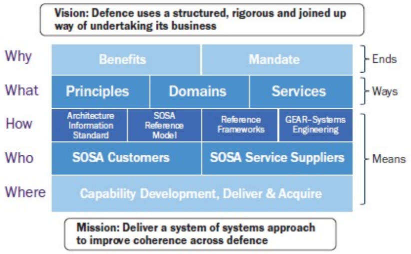
2020

- 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



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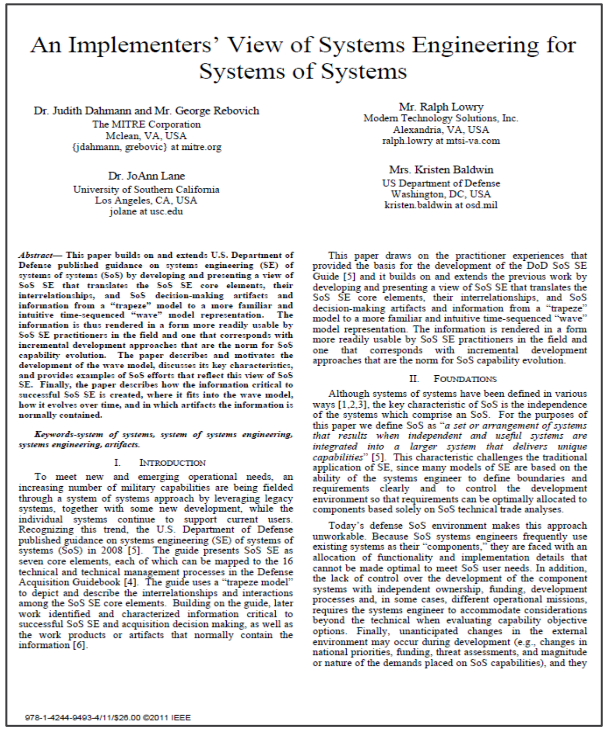
Implementers View of SE for SoS: SoS Wave Model



An Implementers' View of Systems Engineering for Systems of Systems

Dr. Judith Dahmann and Mr. George Rebovich
The MITRE Corporation
Mclean, VA, USA
{jdahmann, grebovic} at mitre.org

Mr. Ralph Lowry
Modern Technology Solutions, Inc.
Alexandria, VA, USA
ralph.lowry at mtsi-va.com

Dr. JoAnn Lane
University of Southern California
Los Angeles, CA, USA
jolane at usc.edu

Mrs. Kristen Baldwin
US Department of Defense
Washington, DC, USA
kristen.baldwin at osd.mil

***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].

This paper draws on the practitioner experiences that provided the basis for the development of the DoD SoS SE Guide [5] and it builds on and extends the previous work 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 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.

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

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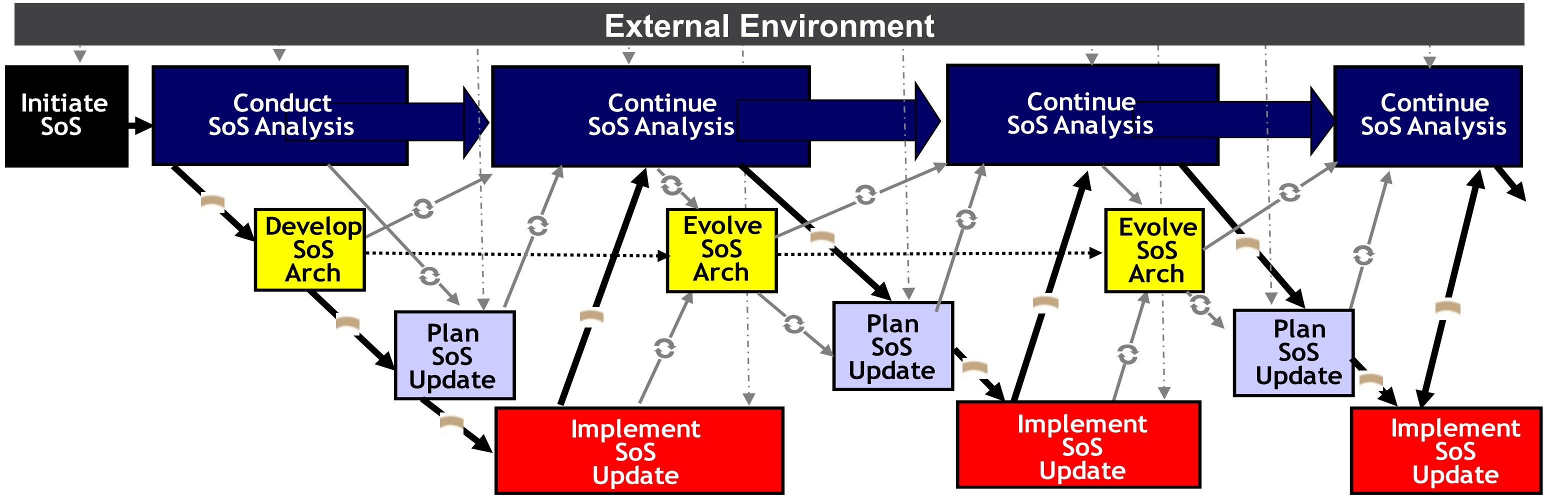
IEEE Systems Conference, 2011

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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System of Systems and Complexity

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Lead Author: *Judith Dahmann*

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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

Daniel DeLaurentis, ddelaure@purdue.edu; **Navindran Davendralingam**, davendra@purdue.edu; **Karen Marais**, kmarais@purdue.edu; **Cesare Guariniello**, cguarini@purdue.edu; and **Zhemei Fang**, fang59@purdue.edu; and **Payuna Uday**, payuna@gmail.com

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-system 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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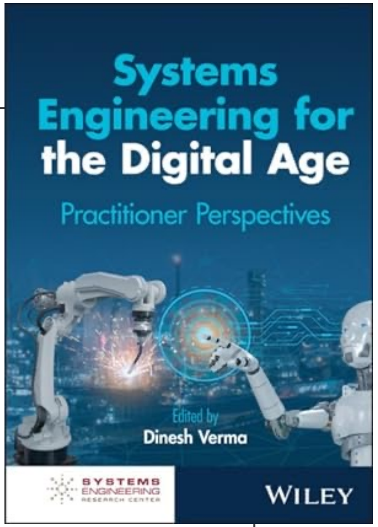

2024

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Dan DeLaurentis

SoS Meta Architecture

2007

2007 1st Annual IEEE Systems Conference
Waikiki Beach, Honolulu, Hawaii, USA April 9-12, 2007

UNDERSTANDING BEHAVIOR OF SYSTEM OF SYSTEMS THROUGH COMPUTATIONAL INTELLIGENCE TECHNIQUES

Cihan Dagli, University of Missouri-Rolla, Rolla, MO 65409, 573-341-4374, dagli@umr.edu
Nil Kilicay, University of Missouri-Rolla, Rolla, MO 65409, 573-341-6556, nkilicay@umr.edu

2021

2021 16th International System of Systems Engineering Conference (SoSE), Online, Västerås, Sweden, June 14-18

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

Maxwell Polley, Department of Engineering Management and Systems Engineering, University of Missouri S&T, Rolla, MO 65401, mnpmch@mst.edu
Cihan Dagli, Department of Engineering Management and Systems Engineering, University of Missouri S&T, Rolla, MO 65401, dagli@mst.edu

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

Demi Coolen[a], Cihan Dagli[b]
[a]Missouri University of Science and Technology, 300 W 13th St, Rolla, MO 65409, USA
[b]Missouri University of Science and Technology, 300 W 13th St, Rolla, MO 65409, USA

2020

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

Richard Threlkeld, Engineering Management and Systems Engineering, Missouri University of Science and Technology, Rolla, MO, USA, ORCID 0000-0002-5448-531X
Lirim Ashiku, Engineering Management and Systems Engineering, Missouri University of Science and Technology, Rolla, MO, USA, ORCID 0000-0002-3788-7202
Cihan Dagli, Engineering Management and Systems Engineering, Missouri University of Science and Technology, Rolla, MO, USA, ORCID 0000-0003-4919-1699

2022

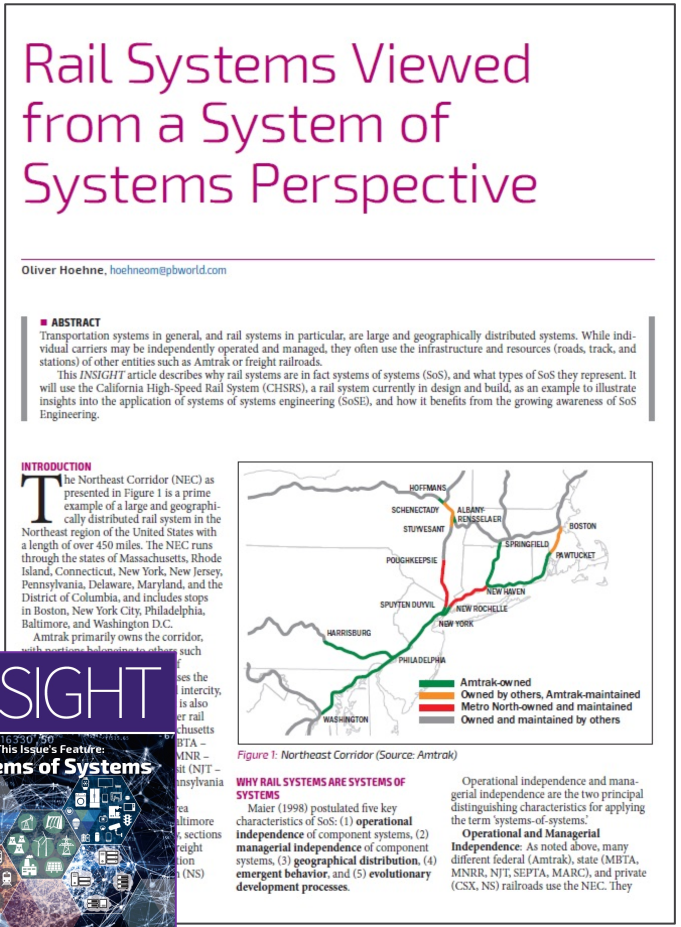
SoSE 2020 • IEEE 15th International Conference of System of Systems Engineering • June 2-4, 2020 Budapest, Hungary

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

Muhammad Monjurul Karim, Department of Engineering Management and Systems Engineering, Missouri S&T, Rolla, MO 65401, USA
Cihan H. Dagli, Department of Engineering Management and Systems Engineering, Missouri S&T, Rolla, MO 65401, USA, dagli@mst.edu

Cihan Dagli

Rail Examples



Rail Systems Viewed from a System of Systems Perspective

Oliver Hoehne, hoehneom@pbworld.com

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 (CHSRS), 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.

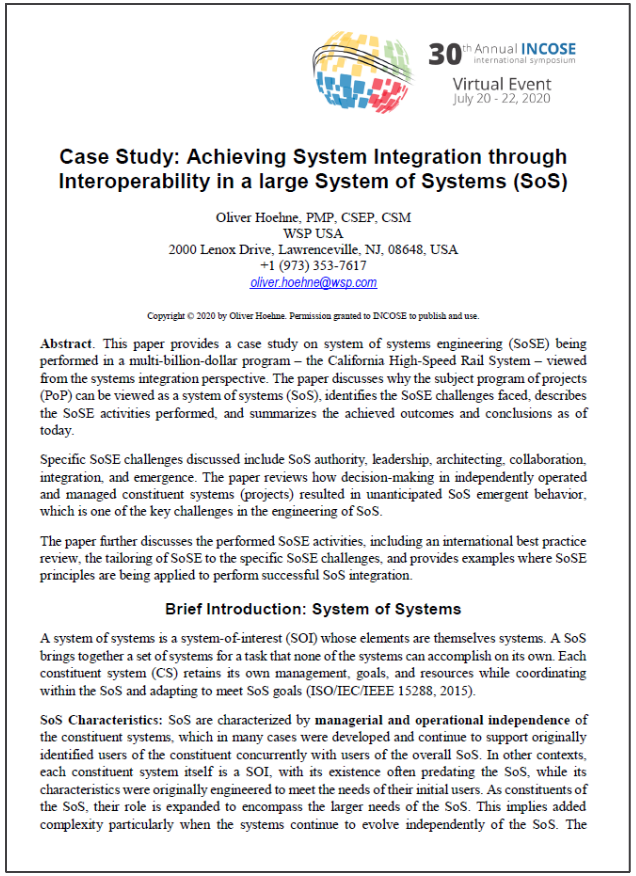
INTRODUCTION
The Northeast Corridor (NEC) as presented in Figure 1 is a prime example of a large and geographically distributed rail system in the Northeast region of the United States with a length of over 450 miles. The NEC runs through the states of Massachusetts, Rhode Island, Connecticut, New York, 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, ...

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, MNRR, NJT, SEPTA, MARC), and private (CSX, NS) railroads use the NEC. They

2016

Oliver Hoehne



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

Oliver Hoehne, PMP, CSEP, CSM
WSP USA
2000 Lenox Drive, Lawrenceville, NJ, 08648, USA
+1 (973) 353-7617
oliver.hoehne@wsp.com

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

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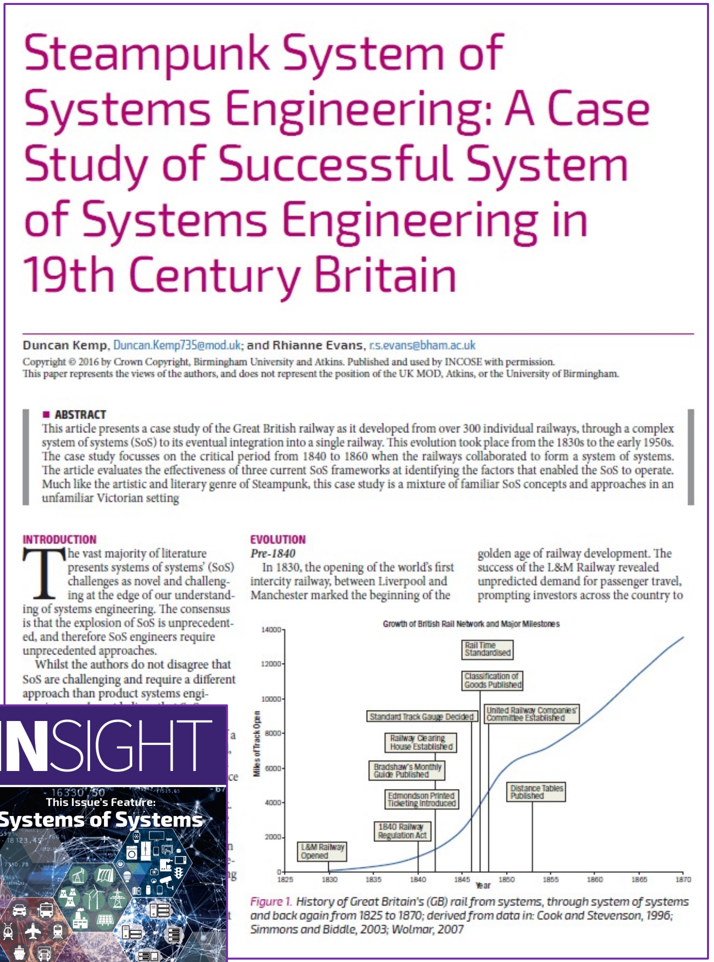

Steampunk System of Systems Engineering: A Case Study of Successful System of Systems Engineering in 19th Century Britain

Duncan Kemp, Duncan.Kemp735@mod.uk; and Rhianne Evans, r.s.evans@bham.ac.uk

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 focusses 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

2016

Duncan Kemp

Mission Engineering Methodology

Enabling Mission Engineering through a Reusable Digital Engineering Environment

Michael J Pennock, MITRE Labs, The MITRE Corporation, McLean, VA, USA, mpennock@mitre.org
Gabriela I Driscoll, MITRE Labs, The MITRE Corporation, McLean, VA, USA, gidriscoll@mitre.org
Judith S Dahmann, MITRE Labs, The MITRE Corporation, McLean, VA, USA, jdahmann@mitre.org
Meg Adams, MITRE Labs, The MITRE Corporation, McLean, VA, USA, madams@mitre.org

***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 mission[1]. 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/tools/dag, retrieved 1/16/2021. ME is defined as: "the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system capabilities to achieve desired operational mission effects"

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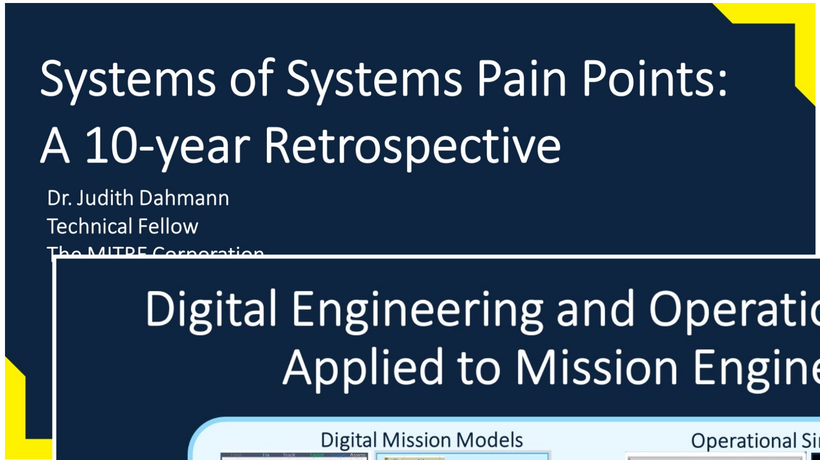

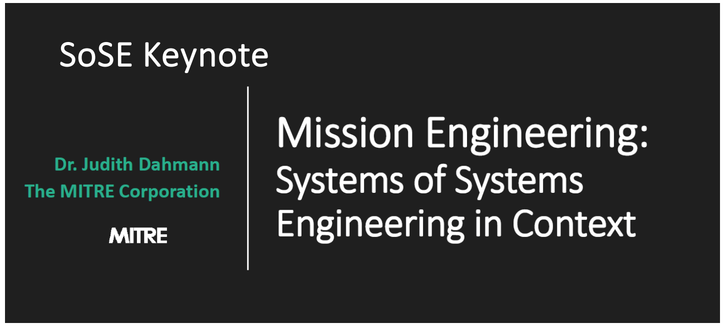

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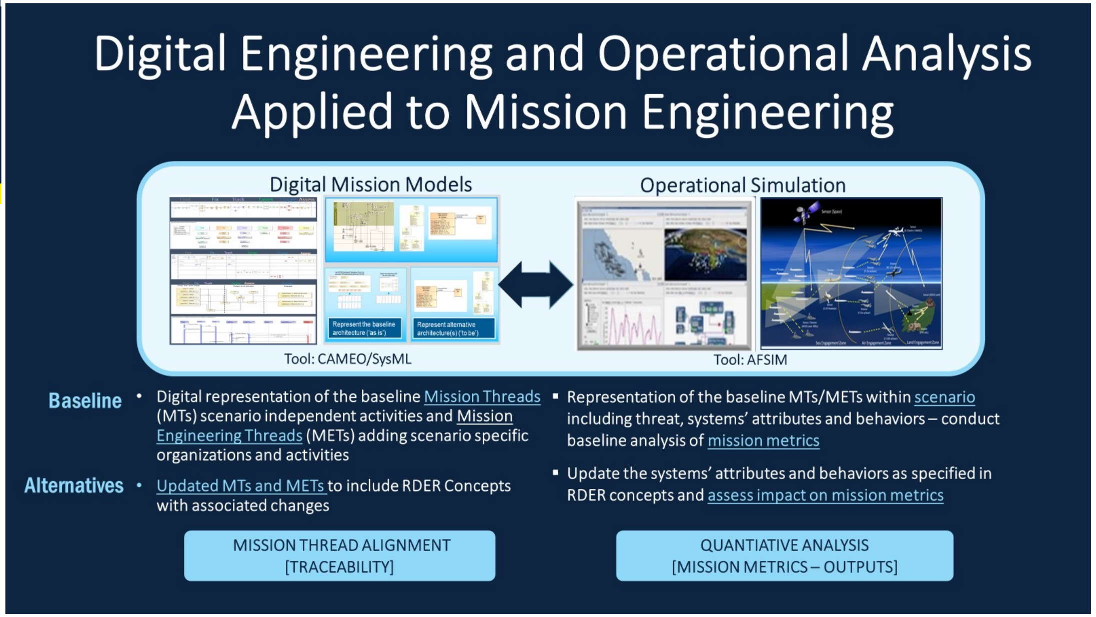

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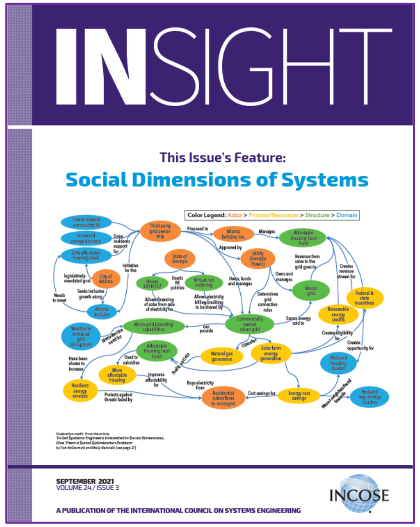
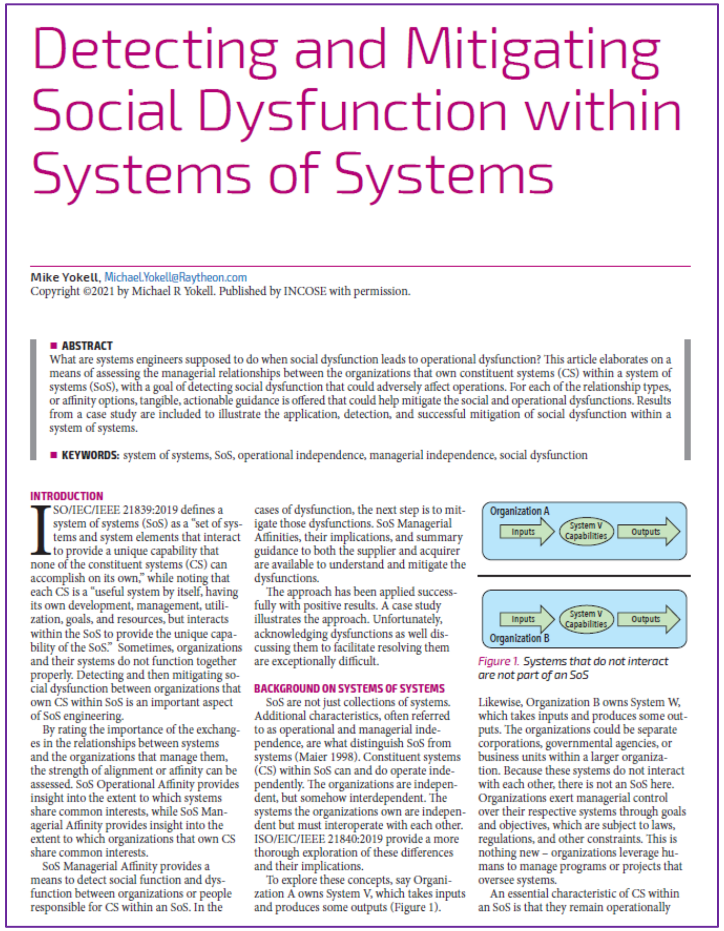
Judith Dahmann

Social Dimensions of SoS



Mike Yokell



Detecting and Mitigating Social Dysfunction within Systems of Systems

Mike Yokell, Michael.Yokell@Raytheon.com
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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 as 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/EIC/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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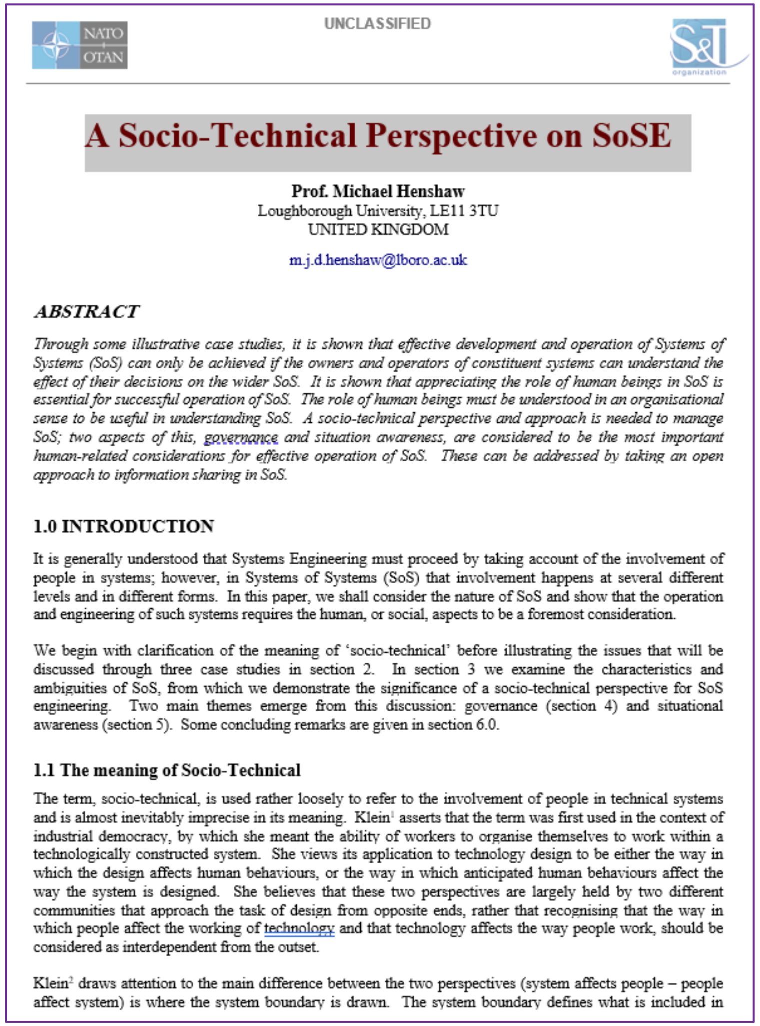

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A Socio-Technical Perspective on SoSE

Prof. Michael Henshaw
Loughborough University, LE11 3TU
UNITED KINGDOM
m.j.d.henshaw@lboro.ac.uk

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. Klein[1] 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 that 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.

Klein[2] 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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Michael Henshaw

Other Methods – Graph Analysis

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The Role of Graph Theory in System of Systems Engineering

WILLIE K. HARRISON

2016

2021 International Conference on Electronic Information Engineering and Computer Science (EIECS)

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

Xiao Li, Desheng Liu — Science and Technology on Complex Electronic System Simulation Laboratory, Space Engineering University, Beijing, China

2021

2019 6th International Conference on Control, Decision and Information Technologies (CoDIT'19) | Paris, France / April 23-26, 2019

Towards Unified Graphical Modeling of System of Systems Engineering

Ahmad Koubeissi[1] and Rochdi Merzouki[2]

2019

IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS: SYSTEMS, VOL. 44, NO. 10, OCTOBER 2014

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

Bingfeng Ge, Member, IEEE, Keith W. Hipel, Fellow, IEEE, Liping Fang, Senior Member, IEEE, Kewei Yang, and Yingwu Chen

2014

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

Yong-Jun Shin, Sangwon Hyun, Young-Min Baek, and Doo-Hwan Bae — School of Computing, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea

2019

Other Examples?

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