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Papers

Paper#370

A Classical Modernization of the V-Model

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Keywords. Digital Engineering;V-Model;Systems Engineering;Modernization;Test and Evaluation

Topics. 1. Academia (curricula, course life cycle, etc.); 1.5. Systems Science; 5.3. MBSE; 5.5. Processes; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. This paper provides new iconography for the Systems Engineering “V-Model”. The “Arch Model” resets and refreshes the original iterative intent of the “V-Model” in a modern context integrated with digital engineering (DE). We will highlight common misperceptions that reduced the efficacy of the “V-Model” and explore how a “classical Roman engineering” metaphor can inspire a modern view of systems development based on historically successful, foundational engineering.

Paper#458

A Method for Human Systems Integration Requirements within Model Based Systems Engineering

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Keywords. MBSE;SysML;human factors;design;Vee-model;requirements engineering

Topics. 13. Maritime (surface and sub-surface); 2. Aerospace; 2.3. Needs and Requirements Definition; 4.1. Human-Systems Integration; 5.3. MBSE; 6. Defense;

Abstract. The Department of Defense (DoD) employs broad human factors requirements across various applications, resulting in a universal application of the same standards to a multitude of DoD acquisition systems. In unconventional warfare, specifically within missions conducted by the US Special Operations Command (USSOCOM), operators face intensified workloads and domain-specific challenges that current human factors considerations do not adequately address. The objective of this paper aims to introduce a novel framework, the Relational and Technological Capstone (RTC), designed to expand existing Human Systems Integration (HSI) requirements. The objective is to enhance the consideration of human factors in USSOCOM missions by addressing the unique challenges posed by intensified workloads and domain-specific ontologies. The RTC employs a methodology-driven approach utilizing both architectural and parametric diagrams. It integrates with Model Based Systems Engineering (MBSE) to improve the design of human-system interactions, incorporating a Special Operations Task List and Performance Shaping Factors (PSFs) into aggregated parametrics. The results of this paper demonstrate the efficacy of RTC within MBSE, showcasing its value through improved design processes and as a foundation for new programs. The containment tree format aids in developing USSOCOM MBSE and opens possibilities for automation tools. Continual use of RTC contributes to the maturity of MBSE models and diagrams, fostering the evolution of a federation-of-models and Program of Record standards. This not only benefits subsequent SOCOM programs and projects but also facilitates cross-cooperation with other nations in optimizing special operation acquisitions. The ultimate goal is to center the RTC around the operator, ensuring compatibility and optimization across cooperative nations' special operation acquisitions.

Paper#389

A Model for Cybersecurity Education through Challenge Events

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Keywords. Cybersecurity;Education;Competence;Cyber-physical System Security;Model-based Systems Engineering (MBSE)

Topics. 1. Academia (curricula, course life cycle, etc.); 11. Information Technology/Telecommunication; 3. Automotive; 4.7. System Security (cyber-attack, anti-tamper, etc.); 5.9. Teaching and Training;

Abstract. The INCOSE Vision 2035 sets an important Cybersecurity goal: “Cybersecurity will be as foundational a perspective in systems design as system performance and safety are today”. A critical enabler of achieving this vision is educating cyber informed engineers and professionals. Across industries, the demand for talented cybersecurity professionals is high, which means the personnel and students need inspirational education and training to fill these opportunities. This is particularly the case for complex systems in transportation, maritime, agriculture, aerospace, energy, and industries that rely on operational technology implemented with embedded systems. This broad category of sectors need talent and community to address cybersecurity concerns. Often these economic sectors have systems with long lifecycles, regulations, market forces, or other constraints that preclude security solutions envisioned for information technologies. To address the needs for cybersecurity personnel for these industries, a model for developing talent and building community is explained in general terms with specific examples as it relates to automotive, heavy duty, maritime, and agriculture. The model de-scribes the CyberX Challenge, where X is an industry sector, such as the CyberAuto Challenge, CyberTruck Challenge, CyberBoat Challenge, and CyberTractor Challenge. These Challenge Events are described in detail with a focus on the characteristics of what makes those successful or difficult. The successful events have strong industry support, elite instructors, and motivated students. The model for the event is described in detail, with the intention that other industry verticals may inspire additional students and further build communities able to address cyberthreats to our modern way of life. This work directly contributes solutions to addressing the needed foundational concept of Security Education and Competency development as highlighted by the INCOSE FuSE working group.

Paper#376

A Model for Trust and Distrust: The Systems Dynamics Approach

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Keywords. Trust;Systems Thinking;System Dynamics;Causal loop;AI

Topics. 1.4. Systems Dynamics; 1.6. Systems Thinking; 4.1. Human-Systems Integration;

Abstract. The dynamics of trust have evolved from a reliance on human interactions to a newfound dependence on the seamless integration of automation and Artificial Intelligence (AI) in relationships. Because trust is still treated as elusive in prior research, in this study, we consider a society that utilizes trust as a system and present a panoramic perspective of trust in social systems using the causal loop of systems thinking. The perspective of systems thinking is holistic (integrative) and focuses on the interrelationships among components rather than on the components of the system itself. Thus, the architecture was presented by integrating the trust and distrust models identified in previous studies. To overcome the challenges presented in previous studies, a model for trust and distrust was developed using a system dynamics approach. By using systems thinking, the dynamics of trust are clearly illustrated among individuals, between individuals and automation, and between individuals and AI. In addition, it will allow for a perspective on the dynamic relationship between trust, reliance, and dependability, which is being studied in "Humans" and "Automation and AI," and will contribute to Trust research.

Paper#490

A New Horizon for Healthcare Delivery: A System of Systems Perspective and Governing Proposition

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Keywords. Healthcare Delivery System;Systems of Systems;Fragmentation;Reform;Governance

Topics. 1.5. Systems Science; 1.6. Systems Thinking; 3.3. Decision Analysis and/or Decision Management; 4. Biomed/Healthcare/Social Services; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. The healthcare system is grappling with inherent challenges, functioning akin to a fragmented cottage-like industry, leading to significant cost implications and compromised care quality. This paper employs a systematic approach to scrutinize the Healthcare Delivery System (HDS) comprehensively, categorizing it as a Collaborative System of Systems (SoS), where multiple independent systems operate collectively, maintaining individual autonomy. Through a detailed examination, we identify the Collaborative SoS nature of the current healthcare system as the primary cause of its fragmentation. We address a gap in the current literature on the characteristics of SoS, focusing on the often-overlooked aspect of dependence and exploring why constituent systems collaborate to achieve common objectives. Then, we propose a hybrid SoS model where an external governing entity at the national level assumes the authority to determine objectives and drivers for the healthcare SoS. We contend that effective SoS governance is indispensable for addressing systemic issues, providing necessary coordination, allocating resources, establishing policies, fostering sustainable change, and ensuring a well-organized and efficient healthcare system.

Paper#9

A Proposal for Model-Based Systems Engineering Method for Creating Secure Cyber-Physical Systems

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Keywords. Security;Modeling;Cyber-physical systems;System threats;Vulnerabilities

Topics. 2. Aerospace; 21. Urban Transportation Systems; 4.6. System Safety; 4.7. System Security (cyber-attack, anti-tamper, etc.); 5.3. MBSE; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. Rising levels of risk as cyber-attackers look to exploit system vulnerabilities threatens the Air Traffic Control industry. Attacks on Air Navigation Service Providers' communications systems may lead to airspace closure and even cause safety issues. This paper presents a novel Model-Based Systems Engineering method that enables systems engineers, in collaboration with system security and software engineers, to perform threat-modeling analysis of cyber-physical systems early in the system development process and incorporate mitigation strategies into the system design. The proposed model-based method covers few security concepts, including misuse cases, system assets, threats, risks, vulnerabilities, and security control identification. The study found that the proposed method is suitable for conducting security analysis for complex cyber-physical systems early in the system development process.

Paper#194

A System Dynamics Model of Organizational Resilience

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Keywords. modeling and simulation;Systems Dynamics;resilience;adaptability;recruiting

Topics. 1.4. Systems Dynamics; 1.6. Systems Thinking; 22. Social/Sociotechnical and Economic Systems;

Abstract. Resilience is the ability to avoid, withstand, and recover from adversity. In this paper, we examine organizational resilience using a case study of an organization that suffers from a series of scandals that lead to problems with its reputation as an inclusive organization, which results in problems in recruiting and retaining employees. We suggest some policies involving leadership efforts to change the culture in the organization and thereby restore its reputation. Based on the results of a System Dynamics Model that mixes quantitative and qualitative measures, we find that changing organizational culture is difficult. There can be inertia and long delays before the leadership sees results in improved recruiting and retention statistics.

Paper#474

A Systematic Literature Review of Policy Analysis and Modeling in Systems Engineering

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Keywords. Model Based Systems Engineering;policy modeling;systematic review;systems approach;United Nations Sustainable Development Goals

Topics. 1. Academia (curricula, course life cycle, etc.); 22. Social/Sociotechnical and Economic Systems; 4.1. Human-Systems Integration; 5.3. MBSE; 5.9. Teaching and Training;

Abstract. The International Council on Systems Engineering (INCOSE) defines systems engineering as “a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.” The evolution of engineering practices requires new research in the disciplinary intersections of scientific, technological, and management methods, especially when considering the INCOSE System Engineering Vision of 2035, which identified political, economic, social, technical, environmental, and legal factors as becoming modern tenets of system engineering success. Because vast amounts of research have been performed in multidisciplinary engineering areas, this paper ex-amines the research landscape at the intersection of policy modeling and systems engineering by providing a systematic review of the literature to help guide future research based on trends and various guiding considerations. The results of this study will help identify gaps in the field while clarifying future research needs. We have applied the preferred reporting items for systematic reviews and meta-analyses (PRISMA) protocol, which yielded 38 peer-reviewed papers related to policy model-ing and systems engineering.

Paper#197

A Systems Engineering Methodology for Manufacturing Enterprises Planning and Design

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Keywords. Manufacturing Enterprise;Enterprise Architecture;Systems Engineering

Topics. 2.2. Manufacturing Systems and Operational Aspects; 20. Industry 4.0 & Society 5.0; 5.3. MBSE; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Manufacturing enterprises nowadays face increasing complexity challenges in terms of net-work-wide collaboration, inner business integration as well as rapid technology adoption. Previous studies have shown that systems engineering is promising for managing such complexity, there is still a need for a systems engineering methodology that support manufacturing enterprises planning and design taking into consideration the complexity challenges. This paper pro-poses such a methodology based on model-based systems engineering and enterprise architecture principles. An application ontology is first built to formalize core concepts in manufacturing enterprises planning and design. An architecture-centric approach is then developed to coordinate model-based planning and design activities. An integrated digital framework is further envisioned as critical infrastructure for implementing the proposed methodology. Use of the methodology facilitates concepts exploration and evaluation in integrated planning and design of future manufacturing enterprises.

Paper#20

A Systems Perspective on the Public Perception of Wind Power in Norway

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Keywords. wind energy;social acceptance;perception;renewable energy;sustainable development goals

Topics. 10. Environmental Systems & Sustainability; 12. Infrastructure (construction, maintenance, etc.); 2.1. Business or Mission Analysis; 4.1. Human-Systems Integration; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 8. Energy (renewable, nuclear, etc.);

Abstract. The Sustainable Development Goals, a set of ambitious targets embraced by United Nations member states, are designed to meet global challenges head-on while shaping a sustainable future. Of these, Goal 7, in particular, focuses on the critical need for affordable, reliable, sustainable, and modern energy for all. Wind energy holds a significant potential in fulfilling Goal 7 of the sustainable development goals.In Norway, there exists a unique scenario, where nearly 98% of electricity is generated from renewable resources. However, a deficit in power is projected by 2027 according to a short-term market analysis by Statnett, without a subsequent increase in power production. To prevent this, it is imperative to increase the production of electricity from wind. However, in recent years, there has been a significant rise in opposition towards wind power projects in Norway. Some of the wind power projects have even been put on hold because of the increase in protests.In light of this, we apply systems thinking methodologies to improve our understanding of this complex problem. Initially, we identify the stakeholders in our system of interest and categorize them through stakeholder salience analysis framework. Then, we developed a systemigram to graphically represent the system of interest. Finally, we carry out causal loop analysis to find causal loops in our system of interest. Our primary focus with this work is to better understand the factors shaping public perception of wind power projects in Norway. By gaining a deeper understanding about the factors influencing public per-ception of wind power projects in Norway, we aim to find better solutions to improve the social acceptance of these initiatives in Norway in future works.

Paper#269

Accelerating Digital Transformation through MBSE, Multi-physics Simulation and Digital Twin in Industry

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Keywords. MBSE;Digital Twin;Digital Transformation

Topics. 2. Aerospace;

Abstract. In the dynamic aviation industry, Aerospace Industries grapple with the intricate challenge of certifying products amidst integration requirements from aerospace manufacturers and airworthiness regulations imposed by aviation authorities. This paper underscores the indispensable role of Model-Based Systems Engineering (MBSE) in addressing the multiface issues inherent in our product com-plexity. The first focal point is the certification process, where Safran SEATS navigates the complexi-ties imposed by aerospace manufacturers and stringent airworthiness regulations. This intricate certifi-cation process demands the strategic deployment of MBSE to streamline and enhance procedural effi-ciency. The second challenge arises from the abstract nature of style and perceived quality requirements articulated by diverse customerss. With the goal of exceeding customer expectations and creating a genuine "WOW" effect, MBSE becomes instrumental in aligning product development with diverse and often oriented customers’ needs. The third dimension of complexity stems from the variability in emerging requirements, where innovations swiftly become industry standards. MBSE provides a struc-tured approach to handle this variability, ensuring adaptability and positioning products at the forefront of innovation. Additionally, we dissect the influence of Model-Based Design (MBD) on design pro-cesses, shedding light on its transformative effects. Introducing the concept of a digital twin, we explore its significance in the aerospace domain. Real-world implementations of digital twin technology exam-ined through concrete examples from aerospace projects. Finally, the presentation addresses uncertain-ties surrounding program efficiency, a critical consideration in the intensely competitive seat market. This paper unfolds a compelling industrial testimony, showcasing Safran SEATS' journey in overcom-ing the complexity of digital transformation in Aerospace Industries. It provides solutions to intricate challenges posed by certification, customers’ requirements, evolving industry standards, and economic competitiveness, encapsulating the transformative impact of MBSE in our pursuit of excellence.

Paper#562

AI Systems Modeling Enhancer (AI-SME): Initial Investigations into a ChatGPT-enabled MBSE Modeling Assistant

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Keywords. AI;AI-integration;ChatGPT;GPT-4;MBSE;SysML;Systems Modeling;Modeling Assistant

Topics. 1. Academia (curricula, course life cycle, etc.); 11. Information Technology/Telecommunication; 5.11 Artificial Intelligence, Machine Learning; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. As artificial intelligence (AI) becomes integral across industries, there is a growing opportunity to transform the generation of models for systems engineering. This research investigates the integration of OpenAI's GPT-4 Turbo into CATIA Magic for Model-Based Systems Engineering (MBSE), resulting in the creation of AI Systems Modeling Enhancer (AI-SME). This study explores the comparison between models generated by AI, specifically OpenAI's GPT, and those crafted by human systems engineers. While recognizing challenges in AI-generated models, this research underscores the potential of AI assistants to enhance the speed and accuracy of SysML model creation. Results demonstrate AI-SME's successes in generating requirements, block definition diagrams, and internal block diagrams. Despite identified limitations such as redundancy and lack of cohesiveness in AI-generated models, the study concludes that AI-SME represents a notable advancement in AI-assisted systems engineering.

Paper#473

Aligning technical and project management through participatory approaches: An industrial case study

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Keywords. Systems engineering;Project Management;Participatory Approaches;Human-Centered Design;Action Research;Co-design;Complexity management

Topics. 3.5. Technical Leadership; 3.6. Measurement and Metrics; 3.7. Project Planning, Project Assessment, and/or Project Control; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The importance of managing complexity in innovation has been highlighted both in research and practice, however the question remains: how can this be accomplished? Although there have been answers to this question, the practical alignment of process (project management) and system (technical management) viewpoints remains understudied. We responded to this challenge with an in-depth case study in high-tech industry. In this paper we applied Human Centered Design (HCD) and Action Research (AR) principles in a novel context, namely systems engineering. We identified main barriers and key players, essential information elements, and solution requirements. Using co-design, we iteratively generated solution concepts, out of which we selected and evaluated one candidate concept. We highlight two main areas in our results: 1) how participatory approaches can support solving systems engineering challenges in practice; and 2) how to align the process and system viewpoints. For the first, we discuss the implications, considering aspects like the time and effort investment, along with the benefits of ownership, empathy, democ-racy, and collective learning. Our insights show potential to further build on the application of participatory approaches in systems engineering to match existing solutions to the practice. For the latter one, we reflect on issues such as information overload, human aspects, and the new relationship between project managers and systems engineers. Considering the current complexity demands, it is crucial to establish a better alignment between these roles and between process and system viewpoints, as they cannot be left undefined and unsupported any longer.

Paper#332

An Agent-Based Ontology to Support Modeling of Socio-Technical Systems-of-Systems

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Keywords. Systems-of-systems;Modeling;Analysis;Agents;Ontology

Topics. 1.1. Complexity; 1.5. Systems Science; 1.6. Systems Thinking; 5.4. Modeling/Simulation/Analysis; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); Other domain;

Abstract. Systems-of-systems are characterized by the independence of their constituent elements. Those elements are usually socio-technical, comprising technology, humans, and organizations. To capture their independence, they need to be viewed as intelligent agents that rely on internal models of the world for their decision-making. Hence, a system-of-systems model will include agents that inside themselves contain other models of the same system-of-systems. Describing these overlapping subjective models and their usage by the agents is essential to properly understand the resulting behavior of the overall system-of-systems. Current modeling practices are not well suited for dealing with this, and the paper therefore outlines an ontology that makes the agents and their internal models more explicit. The paper also discusses the implications such models have on sys-tems engineering practices and how they address known system-of-systems engineering pain points.

Paper#260

Application of the ARCADIA Method on a Bulk Carrier Vessel Equipped with a Wind-assistance Device

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Keywords. Capella;Arcadia;Model-based Systems Engineering;Vessel;Wind-assistance Device

Topics. 13. Maritime (surface and sub-surface); 2.4. System Architecture/Design Definition; 5.3. MBSE;

Abstract. The maritime industry is undergoing a major transformation to achieve reduction of greenhouse gas emissions. Many new options such as alternative propulsion systems and fuels, optimized routes, or auxiliary propulsion systems such as wind-assistance devices have to be integrated and aligned within a wide network of different stakeholders. New ways are necessary to work with and manage the increasing complexity in the maritime industry. Model-based systems engi-neering approaches are a promising strategy to get a better understanding of the as-is situation and to develop advanced solutions. This paper shows the application of the ARCADIA method for the maritime industry with the target of integrating wind-assistance devices to vessels using the Capella modeling language and tool.

Paper#203

Application of the STPA methodology to enabling systems in the rail industry

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Keywords. Rail Safety;enabling systems;STPA;STAMP

Topics. 16. Rail; 4.6. System Safety;

Abstract. Investigations into several recent railway safety incidents have concluded that failures of enabling systems contributed significantly to the root cause of those incidents, suggesting a tendency towards poor management of safety risk associated with subsystems outside the immediate SoI boundary. This paper examines whether better application of systems thinking to the analysis of hazards, through use of the STPA technique, could have enabled safety risk to be better identified and managed in the circum-stances surrounding a serious derailment that occurred in Victoria, Australia in February 2020.

Paper#52

Architecture of Nature-Based Smart City Introducing BaaS by Utilizing UAF

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Keywords. biophilia;nature-based smart city (NBSC);system of systems;systems engineering;unified architecture framework (UAF)

Topics. 10. Environmental Systems & Sustainability; 5. City Planning (smart cities, urban planning, etc.); 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. Smart cities collaborate with various technological systems, including Internet of Things (IoT), artificial intelligence (AI), and drones, to fulfil the expectations of stakeholders and the needs of individuals and society. However, the use of such advanced technological systems imposes a burden on the natural environment, posing a risk to the sustainability of nature. Considering that people are a crucial element of smart cities, failing to incorporate a connection with nature could pose challenges to sustainable human well-being. Thus, future smart cities need to be a socio-technical system that not only provides convenience through the utilization of advanced technology but also maintains the relationship between humans and nature. This will enable the achievement of human well-being and sustainable natural environment. The concept of biophilia as a service (BaaS) has been introduced as a system of systems (SoS). BaaS is a service that contributes to human well-being and the sustainability of nature by emphasizing the relationship between humans and nature, promoting actions that safeguard nature, and collaborating with various organizations. In this paper, a smart, sustainable, and resilient city in harmony with nature is referred to as a nature-based smart city (NBSC). This study introduced BaaS to smart cities to contribute to the realization of NBSC as a socio-technical system. We defined the architecture of NBSC introducing BaaS using the Unified Architecture Framework (UAF). Furthermore, we illustrated the significance of introducing BaaS to NBSC to present a comprehensive picture of the realization of human and nature well-being by promoting actions that safeguard nature.

Paper#411

Black Hole Cinema: Application of Systems Engineering Methods to Expand and Enhance an Earth-sized Telescope

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Keywords. black hole;EHT;astronomy;system of systems

Topics. 2.3. Needs and Requirements Definition; 5.3. MBSE; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. On April 19, 2019, billions of people around the world caught a glimpse of infinity for the first time. The Event Horizon Telescope (EHT) released the first image of a black hole, shining a light on one of the darkest, most mysterious objects in the universe. To do so required the linking together of existing radio telescopes all over the world to create a “virtual” telescope array with the highest angular resolution of any telescope humanity had ever built. The result was an image that appeared on the front page of nearly every major newspaper on the planet. This iconic image was truly a breakthrough in astronomy. It’s considered one of the most widely viewed images in science history. But rather than being a culmination of a dec-ades-long effort, this image represents the beginning of a whole new era in astrophysics and in humanity’s ability to use the extreme environment surrounding a black hole as a laboratory to understand the fun-damental nature of space-time. To build on the effort and the momentum generated through its public impact, a team of EHT scientists and engineers is looking ahead to the next horizon: movies of black holes. This requires operating at a larger scale and faster pace than before, and a project team capable of designing and implementing a complex construction project in multiple countries simultaneously. It requires an investment of tens of millions of dollars and rigorous yet flexible project management controls and pro-cesses. In short, realizing the ambitious science goals of the next-generation EHT (ngEHT) project and managing all the complex interactions that come with those goals requires an organized, lean, efficient, and systematic approach.

Paper#465

Building a Scientific Foundation for Security: Multilayer Network Model Insights for System Security Engineering

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Keywords. Security;systems security engineering;network models;Trustworthiness;Loss-Driven;Capabilities-Based

Topics. 22. Social/Sociotechnical and Economic Systems; 4.7. System Security (cyber-attack, anti-tamper, etc.); 6. Defense; 8. Energy (renewable, nuclear, etc.);

Abstract. To help incorporate security into INCOSE's Systems Engineering Vision 2035, the INCOSE systems security engineering working group endorses a paradigmatic shift to reframe systems security in terms of being trustworthy, loss-driven, and capabilities-based. Similar research out of Organization A has explored cutting-edge approaches to systems security for national security applications. Taken together, these efforts both highlight to need for—and a path toward—a scientific foundation for security. Leveraging underlying tenets of systems theory, observed security heuristics, and the concepts emerging from INCOSE's SSE working helps triangulate a set of "first principles" as part of a scientific foundation for security consistent with the (often ignored) interactions between physical security designs, cyber security architectures, and personnel security programs. These first principles, in turn, are the basis for a set of derived systems security performance axioms that support current INCOSE SSE working efforts. The logic and designability benefits of this approach is demonstrated with a multilayer network model-based approach for systems security. The structure of this scientific foundation for security offers additional, innovative opportunities to achieve desired levels of trustworthiness, creative mechanisms to meet needs, innovative loss-driven approaches, and enhanced capabilities—all aimed to at producing more efficient and effective systems security solutions against current and emerging threats, uncertainties, and complexities.

Paper#401

Case Studies for Complexity Pattern Identification

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Keywords. Complex;Complicated;Chaotic;Heuristic;Assessment;Pattern

Topics. 1.1. Complexity; 1.5. Systems Science; 17. Sustainment (legacy systems, re-engineering, etc.); 2. Aerospace; 3.7. Project Planning, Project Assessment, and/or Project Control; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The INCOSE Complex Systems Working Group Heuristics Team has selected 67 Principles and Heuristics that are considered to be particularly relevant to Complex Systems. These have been incorporated into a Difficulty Assessment Tool that prioritizes the list of Principles and Heuristics based on an scoring of a matrix of four Difficulty Elements and six System Elements.The Difficulty Assessment Tool has been used to assess eight Case Studies by four assessment teams – one with three people working together, one with two people and the remaining two by individuals to perform the assessment.The results of these assessments have been compared using four different correlation methods, using the total weighted Heuristic score, the maximum weighted Heuristic score, a Match / Mis-match analysis of the top fifteen and bottom seven Heuristics, and a difference ranking between pairs of assessors of all 67 Principles and Heuristics. The last two assessment methods are shown to be more insightful. The assessment teams have then reviewed the relevance of highest and lowest ranked Principles and Heuristics to the full Case Study definitions (Problem and Outcome). There is good agreement of relevance for the highest ranking Principles and Heuristics, less so for the lowest ranking ones.

Paper#131

CHARTING THE DE/MBSE COURSE: AN ANALYSIS OF INITIAL EFFORTS AT LEONARDO-DRS LAND SYSTEMS TO EVALUATE DE/MBSE TOOLS AND ESTABLISH A ROADMAP TO DE/MBSE COMPLIANCE

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Keywords. Digital Engineering;Model-Based Systems Engineering;Digital Engineering Transition;Digital Engineering Trade Study

Topics. 4.1. Human-Systems Integration; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. In June 2018, the United States Department of Defense (DoD) put forward a Digital Engineering (DE) strategy to achieve greater performance and greater affordability in DoD operations and procurement efforts. By 2023, there were indications that DE and Model-Based Systems Engineering (MBSE) requirements were going to be included in Requests for Proposal (RFPs) for new material acquisitions from the DoD. This paper describes the efforts by [Company Name] to assess the DE/MBSE land-scape, identify an initial minimum viable capability required to be compliant with DoD DE re-quirements, and identify and assess potential vendors who could provide tools or services to support the [Company Name] DE/MBSE transition. Additionally, this paper describes the planned future activities by [Company Name] to continue its DE/MBSE journey.

Paper#247

Concept Design Failure Modes and Effects Analysis Using System Level Assessment

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Keywords. Concept FMEA;DFMEA;Concept Selection

Topics. 10. Environmental Systems & Sustainability; 2.4. System Architecture/Design Definition; 3. Automotive; 3.9. Risk and Opportunity Management; 5.2. Lean Systems Engineering;

Abstract. Design Failure Mode and Effects Analysis (DFMEA) is a process to identify and mitigate risks of failure of a product to perform the intended function(s) for the customer. DFMEAs can be performed at all stages of design from product concept to system to component. Several issues with concept level design FMEAs have been identified by Henshall, et all in 2014: large documents, focus on components with poorly defined connections, focus on hardware rather than integrated electro-mechanical systems. As a result of these challenges, improvements to the system-level product concept are unlikely. In 2023 Anonymous and Anonymous described a novel approach to eliciting design considerations representing the needs of both the customer and business using System Level Assessment. These design considerations form the basis for a concept level design FMEA. This approach was applied to a design concept for a technology that had not been previously developed. When compared to a concept DFMEA approach as part of Inclusive Customer Driven Conceptual Design defined by Hari and Weiss, the System Level Assessment based approach took 4.5 hours for the Critical System compared to 8 hours per concept for Inclusive Customer Driven Con-ceptual Design. When compared to a traditional Concept FMEA yielding 67% prevention tasks, the System Level Assessment Concept FMEA yielded 95% prevention tasks.

Paper#320

Conceptual Modeling for Early-Phase Decision-Making in the Maritime Industry: A Case Study of Power Generation System Concept Selection

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Keywords. Conceptual Modeling;Decision Making;Early Phase;Maritime Domain

Topics. 13. Maritime (surface and sub-surface); 2.4. System Architecture/Design Definition; 3.3. Decision Analysis and/or Decision Management;

Abstract. This study examines the use of conceptual modeling to aid in selecting a power generation system concept in the maritime industry. The research objective is to understand how conceptual modeling can enhance decision-making during the early phases of concept evaluation. The study was conducted at a world-leading maritime technology company to address the need for more formal processes to support decision-making in complex development projects. The study applied a conceptual modeling approach in an industry case to facilitate decision-making in the early phases of a development project. The study shows that conceptual modeling is effective in supporting early-phase decision-making in the development project. Conceptual models effectively manage complexity, enhance understanding, and enable effective communication among team members. By combining conceptual modeling with a Pugh matrix, informed decision-making is facilitated, aligning with stakeholders' objectives. Overall, conceptual modeling provides a structured representation of the problem domain, guiding early-phase decision-making.

Paper#529

Conditions for Defining Verification Models

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Keywords. theory of SE;verification;verification models;systems theory

Topics. 1. Academia (curricula, course life cycle, etc.); 1.5. Systems Science; 2.6. Verification/Validation; 5.3. MBSE;

Abstract. Systems Engineering (SE), as a discipline, has not yet established the conditions for defining verification models beyond qualitative statements made at the onset of an engineering endeavor. Our research has evaluated the conditions using quantitative means, grounded in the richness of systems theory. Note, this is not a method paper. However, a systems theoretic approach with some novelty was selected to address the underlying research question. The question being: Based on what conditions should we define verification models? The current state of the discipline suggests that the conditions for verification models are defined based on qualitative statements of high-, medium-, and low-fidelity. This is an example of a SE heuristic. The existence of heuristics as a current basis for the discipline of SE is well known. However, many heuristics have not been quantitatively validated, which means there may be errors in judgement that are leading to systems being engineered that are ultimately not fit-for-purpose. Verification models are currently defined under heuristic assumptions that have not been substantiated. In this article, we provide insights from our research to discover the sufficient, science-based conditions for defining verification models.

Paper#367

Contemporary Systems Engineering for the UN SDGs and NAE Grand Challenges

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Keywords. Social Systems Engineering;Public Policy;Systems Engineering Education

Topics. 1. Academia (curricula, course life cycle, etc.); 22. Social/Sociotechnical and Economic Systems; 4.1. Human-Systems Integration; 5.9. Teaching and Training;

Abstract. Systems engineering programs at US universities have been focusing more on sustainability, but systems approaches to sustainability are found in programs outside of a systems engineering context. Transdisciplinary collaboration has been emphasized to make progress toward the United Nations' Sustainable Development Goals (SDGs), requiring new approaches to collaborative understanding on the student and faculty levels in academic environments. This paper provides a qualitative network analysis of systems approaches to sustainability across disciplines using a US university as a case study. The analysis mapped systems approaches at Worchester Polytechnic Institute (WPI) within and outside of WPI's Systems Engineering Program. We specifically focused on thematic areas regarding systems in social science domains pertaining to the SDGs, which need to be brought into a systems engineering context. This paper aims to identify potential areas of collaboration to accelerate progress toward the SDGs using systems approaches.

Paper#482

Darth Vader's Secret Weapon: Implementing Mission Engineering with UAF

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Keywords. Mission Engineering;UAF;Enterprise Architecture;Acquisition;Mission Architecture;Mission Modeling

Topics. 2.1. Business or Mission Analysis; 2.4. System Architecture/Design Definition; 5.3. MBSE; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. When planning and conducting a mission engineering study, it is important to have a complete, correct, and coherent model of the mission architecture. The Unified Architecture Framework (UAF) has been found to be effective for this purpose. This paper will explore some of necessary modeling features and constructs that will enable this to occur. The paper “Implementing Mission Engineering with UAF” was presented at a previous conference and this paper will expand on that presentation and will discuss additional work that has been accomplished since then. This paper will also explore the proposed extensions for UAF to better support Mission Engineering. We created a prototype model using the Battle of Hoth from Star Wars as a proof of concept for these modeling extensions and used the process and mission engineering concepts defined in the Mission Engineering Guide (MEG). Since then there have been several concepts that were explored such as compatibility with the Model-Based Acquisition (MBAcq) approach, recent initiatives from the Office of the Assistant Secretary of Defense for Mission Capabilities, Enterprise Systems Engineering (ESE) process and methods, detailed resource engagement, use of different modeling languages (e.g., Systems Modeling Language (SysML), SysML v2 and UAF v2), Effects and Outcomes, variety of measures, additional attributes/stereotypes such as differentiation between enemy/friendly/neutral - Blue Force, Red Force, etc., provenance/confidence of enemy resources, and so forth. This paper will summarize the research and modeling done to date and explore these additional concepts as well as new ideas introduced in the MEG v2.

Paper#501

Design Basis Model for Hosting Small Modular Reactors

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Keywords. Nuclear Energy;Design Basis;Model-Based Systems Engineering;Nuclear Reactor Infrastructure

Topics. 19. Very Small Enterprises; 2.4. System Architecture/Design Definition; 3.9. Risk and Opportunity Management; 5.12 Automation; 8. Energy (renewable, nuclear, etc.);

Abstract. To provide energy security and head off further increases in global temperatures, an aggressive transition from fossil fuels to other types of energy implies the need to construct hundreds of nuclear power plants in the near future. However, the real and perceived risks of nuclear energy remain a significant impediment to this transition. This paper describes a comprehensive work process that combines the rigor of model-based systems engineering (MBSE) with 1) the Idaho National Laboratory's (INL) decades of experience with small reactors and with 2) modern project delivery processes. The objective is to reduce the risks of building new facilities or converting existing facilities to nuclear power generation.

Paper#216

Design Thinking in a Systems Engineering World, within a Governmental Context

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Keywords. Systems engineering;systems thinking;design thinking;government;DoD;concept development

Topics. 1.6. Systems Thinking; 2. Aerospace; 2.3. Needs and Requirements Definition; 4.1. Human-Systems Integration; 6. Defense; Other domain;

Abstract. Systems engineering evolution has been an incredible asset to innovation. This is particularly true in industries that drive its academic advancement and maturity. In these industries, systems engineering is a proven approach to developing a program from conception through retirement. Design thinking is a design methodology and separate from systems engineering/ thinking; it is defined by its intensely human-centered approach. This report hypothesizes that design thinking processes used during the concept development phase of the systems engineering process enables a more comprehensive view of key challenges due to the inclusion of more contextual stakeholder information, particularly in a government context. A mixed methods approach using 35 surveys and 11 interviews of subject matter experts, project managers, and innovation challenge participants was used to test the hypothesis. Interviewees disagreed on the impact that design thinking processes ultimately have on stakeholder information. There was a common consensus that the process yields key beneficiaries. The quantitative data showed a shift in familiarity with design thinking principles during the innovation challenge as a result of design thinking teaching modules. The increase in familiarity correlated with an increased likelihood to use various design thinking processes during concept development, and stronger agreement that design thinking affected understanding the stakeholders, key beneficiaries, and comprehension of the challenge space. Together, the qualitative and quantitative data agreement on the addition of key beneficiaries is evidence in support of design thinking processes affecting the context of stakeholder information. Embracing more contextual stakeholder information results in designers seeking a more comprehensive view of the challenge space. Additionally, analogous research can have a significant effect on comprehension of the challenge space but there is a higher barrier to entry for new practitioners.

Paper#42

Developing an Integrated Mission Simulation to Evaluate Technology Impact on Military Scenarios

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Keywords. MBSE;Model Based Systems Engineering;Military Mission;Modeling and Simulation

Topics. 1.6. Systems Thinking; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. Over the past decade, technology has experienced a rapid and widespread evolution, resulting in new capabilities across the defense sector. While these capabilities often bring about beneficial changes, they can also beget unforeseen consequences. As a result, it is becoming increasingly important for the military to understand how this changing technological landscape can impact its missions. To address this issue, we have developed an Integrated Mission Simulation (IMS) to assess the potential impact that different technologies may have on a given mission. The Integrated Mission Simulation combines a mission context model with several technology performance models, which enables users to assess the results of different 'what-if' scenarios on key performance parameters for a given mission. To illustrate its utility, we present two publicly available scenarios and simulate how known technological advances could have altered the outcomes of those scenarios.

Paper#266

Early Validation using Architectural Overviews (A3AO) a Case Study in an IoT Consultancy

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Keywords. A3 Architectural Overviews;Early Validation;A3AO

Topics. 1. Academia (curricula, course life cycle, etc.); 2.3. Needs and Requirements Definition; 2.4. System Architecture/Design Definition; 2.6. Verification/Validation; 3.7. Project Planning, Project Assessment, and/or Project Control; 5.9. Teaching and Training;

Abstract. This paper focuses on the use of A3 Architectural Overviews (A3AO) for early validation of stake-holder needs and system concept as part of a tender proposal in an IoT consultancy. Tender proposals are an essential part of communication between most companies working in the engineering field. Often with high-tech companies, a technical knowledge gap exists between the different stakeholders reading tender proposals. This knowledge gap increases the risk of miscommunication and wasteful work. A real-life case from an IoT consultancy tendering an IoT concept for a processing facility forms the basis for the research. Applying an action research approach, the researchers tailored the A3AO framework to fit within the consultancy's workflow and developed an A3AO describing the tendered system concept. The customer received and later accepted the tender proposal including the A3AO containing the stakeholders' problems and needs, a concept solution, and a roadmap detailing further work. In this study, we collected data from observations, semi-structured interviews, surveys, and a follow-up questionnaire to the customer. The study found that the A3AO functions as a tool for early validation and that it helped bridge the knowledge gap between the consultancy and customer. The study also raises questions and criticism regarding cost and complexity. The consultancy later decided to implement A3AOs in future proceedings.

Paper#453

Empowering Model-Based Systems Engineering Through Metamodeling

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Keywords. Model-Based Systems Engineering;Digital Engineering;Metamodeling;System Modeling;Model Validation;Model Analysis

Topics. 2. Aerospace; 2.4. System Architecture/Design Definition; 5.3. MBSE; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. A critical enabler for Model-Based Systems Engineering (MBSE) and Digital Engineering (DE) is the generation of coherent and consistent views of a system-of-interest based on information within a system model. In practice, system model development is facilitated through domain-specific profiles, style guides, reference models, and low-fidelity metamodels to create coherent and consistent system information. Each of these approaches are useful but are insufficient for robust and automated verification of system models to an ideal. Furthermore, the expression of domain-specific concepts and semantics relies on the proliferation of non-standard, domain-specific profiles as standard system modeling languages like the Systems Modeling Language (SysML) are general purpose. This paper proposes a novel approach to creating precise, machine-interpretable metamodels implemented as a lightweight Unified Modeling Language (UML) profile. The profile includes numerous features that allow model architects to quickly specify context and domain-specific modeling constructs without creating non-standard stereotypes to apply domain-specific meaning and usage rules. Three kinds of constraints can be inferred based on the relationships between metamodel elements: type, multiplicity, and default value. Applications of well-formed metamodels include a one-time programmatic generation of an encompassing suite of validation rules to evaluate a system model against the inferred constraints, thus ensuring consistency. Additional applications include programmatic generation of model analysis metrics, system models from metamodels, metamodels from reference models and element finding queries, and the ability to update a system model based upon the updated metamodel automatically. Use of the approach results in reduced time in system model development and analysis and ensures coherency and consistency of information thus increasing stakeholder use and confidence in the system model.

Paper#186

Enable Effective Digital Engineering Information Exchange using Digital Viewpoint Model (DVM) Framework

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Keywords. Digital Engineering;Digital Information Exchange;Digital View;Digital Viewpoint;Stakeholder Analysis;Digital Artifacts

Topics. 2. Aerospace; 2.3. Needs and Requirements Definition; 3.1. Acquisition and/or Supply; 5.3. MBSE; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The objective of the Digital Viewpoint Model (DVM) framework is to characterize the content and relationships involved in the exchange of digital artifacts and its curation for stakeholder use and consumption. The DVM Framework structures the characterizations in four inter-related ontological concepts – Stakeholder, Digital View, Digital Artifact and Process. The Stakeholder concept focuses on the definition of stakeholder needs in terms of perspectives. The Digital View concept focuses on the construction of views that relate inter-disciplinary data that conforms to stakeholder needs and constraints. The Digital Artifact concept focuses on ensuring the quality and trustworthiness of data being used to construct the digital views. The process concepts provide a construct to define necessary work activities to extract data to use. Applications of the DVM Framework are described in the form of use cases to demonstrate their utility in facilitating effective digital engineering information exchange.

Paper#99

Enabling Digital Engineering with Federated PLM – Experiences from the Heliple-2 Project

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Keywords. Federated Product Lifecycle Management;OSLC;Service oriented federation

Topics. 2.5. System Integration; 3.2. Configuration Management; 5.3. MBSE;

Abstract. Implementing a digital engineering infrastructure is a strategic endeavour for any organisation. In this paper an investigation in the feasibility of federated Product Lifecycle Management is presented, starting from a presentation of the guiding architecture pattern and an evaluation of implementation alternatives. The OSLC data linking standard is introduced along with presentation of tool infrastructure for automatic generation of OSLC interfaces. Implementa-tion experience validates that OSLC enabled federated PLM is a viable and attractive alter-native for implementing digital engineering.

Paper#167

Enabling FuSE Security Objectives through Cyber Survivability Methods

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Keywords. Cybersecurity;FuSE Security;Cyber Survivability;Mission Based Cybersecurity Analysis MBSE

Topics. 11. Information Technology/Telecommunication; 2.4. System Architecture/Design Definition; 3. Automotive; 4.7. System Security (cyber-attack, anti-tamper, etc.); 5.3. MBSE; 6. Defense;

Abstract. The importance of system security, especially cybersecurity, continues to grow as systems become more complex, more connected, and more vulnerable. The INCOSE Vision 2035 sets goals for systems engineering (SE) as a discipline in enabling engineering solutions for a better world: “Cybersecurity will be as foundational a perspective in systems design as system performance and safety are today”. A key objective of the INCOSE Future of Systems Engineering (FuSE) Security Foundations Roadmap is to recognize cybersecurity as a fundamental part of the mission, integrated into the system architecture, and not “bolted-on” as a separate subsystem or set of features in the detailed design. To achieve this, systems engineering must address cybersecurity early in the system lifecycle, during the mission analysis and concept development phase. Cybersecurity needs must be treated as fundamental system capability. The INCOSE FuSE Security foundations roadmap identifies six (6) objectives and eleven (11) foundational concepts necessary to achieve the FuSE vision for cybersecurity. Five of the objectives and five of the foundational concepts are directly related to systems acquisition and engineering lifecycle processes. The five objectives are: Stakeholder Alignment, Security as a Capability, Security as a Functional Requirement, Loss Driven Engineering and Modeled Trustworthiness. This paper examines these foundational concepts in comparison to several directives and publications addressing cybersecurity analysis from a specific organizational or engineering perspective. For each publication, we examine the methods used to support cybersecurity and the benefits the method can bring to a holistic cybersecurity analysis approach.The Cyber Test and Evaluation community has extensive cyber assessment and execution processes mandated through numerous Department of Defense (DoD) and individual service policies and directives. While cybersecurity affects both the commercial industry as well as defense programs, DoD methods and processes are more mature, better documented, and largely accessible. Each of the examined DoD-based documents includes processes and methods that directly support or enable the five FuSE foundation concepts related to system acquisition and systems engineering. This paper studies several of the cybersecurity assessment and process guidebooks, analyzing the processes and methods to identify areas where systems engineering should be responsible, and which SE activities and outputs are needed to enable the requirements of each guidebook. Next, the paper proposes a set of common activities represented across the various guides and explains how these commonalities enable the FuSE security objectives. This paper propositions an initial ontology to be examined by the system engineering community to enable a thorough definition and analysis of cyber survivability across the system design lifecycle.

Paper#262

Enterprise: Exploration of Concepts, Perspectives and Implications for Systems Engineering

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Keywords. Enterprise;Systems Engineering;Bibliometric Analysis

Topics. 1.1. Complexity; 2.1. Business or Mission Analysis; 3.5. Technical Leadership; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The purpose of this paper is to explore the concept of ‘enterprise’ in the context of Systems Engineering (SE). The term ‘enterprise’ has been used extensively to generally describe large complex entities that have an extensive scope of operations. However, a deeper examination of ‘enterprise’ significance for SE can provide insights as our challenges continue with increasingly complex, uncertain, ambiguous, and integrated entities struggling to thrive into the future. The paper explores three central topics. First, the concept of enterprise is introduced as a central aspect of the future focus for SE as recognized in the INCOSE SE Vision 2035. Second, a more detailed examination of the enterprise concept is developed in relationship to SE. The thrust of this examination is to understand the nature and role of ‘enterprise’ across a broad spectrum of literature and knowledge, ultimately providing a more informed perspective of enterprise. As part of this exploration, a bibliometric analysis of the term ‘enterprise’ is performed. This exploration extracts key themes (clusters) in the ‘enterprise’ literature. Third, challenges for further development and inculcation of ‘enterprise’ within the SE discipline and the SE 2035 Vision are suggested. These challenges point out the need to ‘think differently’ about ‘enterprise’ within the SE context. ‘Enterprise’ is proposed as a central, albeit different, perspective for the SE discipline. The paper closes with a first-generation perspective for ‘enterprise’ in pursuit of the SE Vision 2035.

Paper#107

Evaluating the Eco-Efficiency of Urban Air Mobility: Understanding Environmental and Social Impacts for Informed Passenger Choices

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Keywords. Urban air mobility (UAM);sustainability;eco-efficiency;unified architecture framework (UAF);causal loop analysis;mobility-as-a-system (MaaS)

Topics. 1.6. Systems Thinking; 10. Environmental Systems & Sustainability; 2. Aerospace; 5. City Planning (smart cities, urban planning, etc.); 5.4. Modeling/Simulation/Analysis; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. CO2 emissions during operations are zero for full electric aircraft and are considered a potential solution for the Fly Net Zero by 2050, a commitment proposed by the International Air Transport Association (IATA). In this sense, Urban Air Mobility (UAM) expects to offer an environmentally friendly alternative through electric Vertical Takeoff and Landing (eVTOL) aircraft. While eVTOLs produce no greenhouse gas emissions, the comprehensive eco-efficiency of UAM goes beyond the flight phase. This paper delves into evaluating UAM operation's environmental and social impacts, considering the urban space, public perception, operational profiles, and power consumption. Employing causal loop analysis, we uncover the relationships that add value or increase impact, assessing UAM passenger transportation's eco-efficiency. Furthermore, we use the Unified Architecture Framework to model the UAM ecosystem and to propose strategies to balance values and impacts in achieving eco-efficiency. By shedding light on the sustainability viewpoint, this paper aims to emphasize the importance of holistically understanding UAM's operational impact and empowering users to make eco-efficient choices when opting for UAM transportation. Finally, we discuss an integrated platform's role in providing sustainability awareness to the user.

Paper#554

Evaluating the Scalability and Combinatorial Effectiveness of Design-for-Resilience Heuristics

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Keywords. Systems of Systems;Ecological Network Analysis;Graph Theory;Design-for-Resilience

Topics. 1.3. Natural Systems; 12. Infrastructure (construction, maintenance, etc.); 22. Social/Sociotechnical and Economic Systems; 4.4. Resilience; 5. City Planning (smart cities, urban planning, etc.); 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. This study investigates the scalability of biologically inspired design-for-resilience heuristics in Systems of Systems (SoS) of varying sizes, simulating SoS with ten, twenty, and thirty constituent systems. We build upon previous research that identified thirteen design heuristics for SoS resilience based on Ecological Network Analysis (a subset of graph theory). We both extend their application to larger network sizes and combine them to enhance efficiency. Our analysis validates the application of design heuristics for random networks to evaluate the effectiveness of individual and combined design heuristics in network resilience compared to random network modifications. The outcomes provide insights into the scalability and efficiency of these heuristics, revealing the potential for systematic SoS design and resilience improvement. Key contributions of this research include the validation of the scalability of bio-inspired resilience metrics and the testing of nine new combined design heuristics for SoS. These contributions provide a tool for decision makers seeking to select resilient SoS architectures. The findings also pave the way for future research into broader applications beyond ecological networks and further exploration of the relationship between ecological robustness and resilience.

Paper#258

Evaluation of Visual ConOps in Early Solution Validation in a Small and Medium-sized Enterprise

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Keywords. Visual ConOps;Early Validation;Need elicitation

Topics. 1.5. Systems Science; 19. Very Small Enterprises; 2.6. Verification/Validation; 3.7. Project Planning, Project Assessment, and/or Project Control; 4.3. Reliability, Availability, and/or Maintainability; 5.4. Modeling/Simulation/Analysis;

Abstract. This paper focuses on the design, implementation, and assessment of the visual Conceptof Operations (ConOps) as an informal visualization technique employed for early solution validationin Small and medium-sized enterprises (SMEs). SMEs face significant challenges in early solutionvalidation due to the complex nature of modern systems and the constantly changing market demands. These challenges may be further intensified by immature leadership and ineffective communication within the organization. By applying an industry-as-laboratory approach in an SME industrycase, this study aims to reduce the negative impacts of miscommunication between internal andexternal stakeholders and contribute to needs elicitation and system validation process. The resultsshow that visual ConOps can effectively support the need elicitation process, which is crucial forearly validation, however, it may not independently serve as a comprehensive communication toolbetween the developer team and stakeholders. It is essential to supplement visual ConOps withcomplementary tools to effectively convey stakeholder input to the developer team.

Paper#410

Evolving Roles in Systems Engineering — Insights from Germany's Mechanical and Plant Engineering Sector

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Keywords. Systems Engineering Roles;German Industry;Role Evolution;Competencies;Job postings;Literature Review

Topics. 1. Academia (curricula, course life cycle, etc.); 5.5. Processes; 5.9. Teaching and Training; 9. Enterprise SE (organization, policies, knowledge, etc.); Other domain;

Abstract. Systems Engineering is developing differently in each sector and region. In German industry, especially in mechanical and plant engineering, Systems Engineering is of major importance. During the introduction of Systems Engineering, the question arises as to which roles and competencies are required. This article examines the evolution of roles in Systems Engineering from a German perspective. Based on a literature review, the evolution of the identified Systems Engineering roles over time, starting with the seminal publication by Sheard in 1996, is shown. It points out that only minimal adjustments and occasional role renaming have occurred. However, the review shows a common understanding of essential areas of responsibility within the SE and changes over time. The next step is to examine the current comprehension of Systems Engineering roles in the industry. A quantitative analysis of job postings in Germany reveals a diverse interpretation of the term 'Systems Engineer; more than half of the positions cannot be categorized according to INCOSE definitions. The job postings are used to determine which tasks are associated with it, how often they occur, and in what combination. The primary responsibilities of system engineers include creating and managing requirements, architecture processes, validation and verification processes, and coordinating with customers and stakeholders. Finally, three representative companies from the mechanical and plant engineering sector were selected to analyze existing roles and tasks. From this, a common understanding of tasks and responsibilities is combined and organized in clusters. These serve the companies to locate and thus derive their roles. This results in an integrative approach that enables companies, especially in the midsize and medium sectors, to design the introduction in line with stakeholder demands. In summary, the industry's ongoing adaptation necessitates the evolution of Systems Engineering roles and competencies for successful and sustainable implementation of Systems Engineering.

Paper#349

Extending Systems Engineering for Safety-Critical Defence Applications

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Keywords. systems safety;systems engineering;standards;IEC 63187;IEC 61508;ISO/IEC/IEEE 15288

Topics. 4.6. System Safety; 6. Defense;

Abstract. Defence sector applications are often characterized by a high level of complexity: in the tech-nical systems involved, in their management and supply chain arrangements, and in the dynam-ic nature of the risks involved. ISO/IEC/IEEE 15288 is well established as a standard that pro-vides a common set of life cycle processes and terminology for engineering complex systems. However, it takes a generic approach that does not directly address the needs of safety-critical systems. In contrast, safety-specific standards like for example IEC 61508 provides a well-known framework for the functional safety of electrical, electronic, and programmable electronic safety-related systems, but does not address the complexity commonly found in sys-tems in the defence sector.In IEC 63187, the International Electrotechnical Commission is drafting a new standard to pro-vide a safety framework for defence applications. It uses modern systems engineering princi-ples that build on ISO/IEC/IEEE 15288, extending it with requirements to make it appropriate for critical systems in the defence sector. This paper discusses how IEC 63187 uses ISO/IEC/IEEE 15288 to achieve the goals of system safety, why this approach was adopted, the expected benefits and some of the impacts of designing the new safety framework this way.

Paper#184

How Systems Thinking Provides the Foundation for A W-Shaped Model of an Effective Technical Leader

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Keywords. Systems Thinking;Technical Leadership;Leadership;Leadership Model;Leadership Skills;Technical Skills

Topics. 1.6. Systems Thinking; 3.5. Technical Leadership; Other domain;

Abstract. Technical Leadership is a relatively new subject that has not been adequately addressed in literature. Behaviors and skills of effective technical individuals and leaders are defined and cited often, in-cluding various shape models of individuals. However, a Systems Thinking approach for combining these two mindsets has not been documented. This paper’s goal is to provide a background on ef-fective technical and leadership behaviors and skills, relate them to the various shape-based models of individuals, and ultimately present a new W-shaped model describing an effective Technical Leader whose foundation is a Systems Thinking mindset.

Paper#434

How the INCOSE Model-Based Capability Matrix has Steered Model-Based Systems Engineering Transformation at NASA

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Keywords. MBSE;digital engineering;MBCA;MBCM

Topics. 2. Aerospace; 3.6. Measurement and Metrics; 5.3. MBSE; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The National Aeronautics and Space Administration (NASA) is embarking on new, complex, and diverse missions to accomplish its scientific and exploration objectives, and it views digital trans-formation as a key enabler for those missions. The NASA Model-Based Systems Engineering (MBSE) Leadership Team (MLT) is leading the charge in the digital transformation of the systems engineering domain at NASA, and it is using the INCOSE Model-Based Capability Matrix (MBCM) as a roadmap. This paper discusses the modifications and tailoring of the INCOSE MBCM (Hale & Hoheb, 2020) for use at NASA, the process the team has taken on multiple rounds of assessment, findings to date, and work products that have been generated as a result of the assessment. The paper will also discuss findings and potential changes that should be made to the original product.

Paper#160

Human Frailties: Springboard to Increased Systems Engineering Influence

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Keywords. Leveraging human frailties;systems engineering influence;strategies;tactics;case studies

Topics. 20. Industry 4.0 & Society 5.0; 3.3. Decision Analysis and/or Decision Management; 3.5. Technical Leadership; 3.9. Risk and Opportunity Management; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Systems engineers often struggle to deal effectively with decision-makers who ignore critically important information. It is easy to bemoan human limitations, but in this paper, we advocate something different: using human frailties for constructive purposes. We believe that it is possible to leverage human frailties to increase the influence that systems engineers can have on decision-makers. Advertisers have been using human frailties for their own purposes for centuries, and we think it is time for systems engineers to capitalize on strategies advertisers and other influencers use successfully. In this paper, we identify the human frailties that have the greatest potential leverage to increase the influence systems engineers can have on decision-makers and suggest specific strategies and tactics systems engineers can use to increase their positive impact.

Paper#371

Human-centered Smart Cities: an evaluation of a small community using the Smart Cities Initiative framework

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Keywords. Smart Cities;Domain application of SE;Infrastructure

Topics. 1.6. Systems Thinking; 12. Infrastructure (construction, maintenance, etc.); 2.1. Business or Mission Analysis; 22. Social/Sociotechnical and Economic Systems; 5. City Planning (smart cities, urban planning, etc.); 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.);

Abstract. In September 2023, the INCOSE Smart Cities Initiative released a framework to evaluate and define smart city systems. The framework includes a human-centered definition of a smart city and offers metrics of a smart city. The definition, metrics, and framework are based on a systematic process that allows consistent evaluation of city that focuses on providing for fundamental human needs.Many smart city applications still focus on technology, regardless of whether that technology provides a clear benefit to the stakeholders of the city. Systems engineering tools and practices offer potential for improving smart city implementations by improving the alignment of needs and solutions. Unfortunately, in new domains, such as the plethora domains involved with smart cities, systems engineering can be viewed as unnecessary overhead. Therefore, the usefulness of the systems engineering concepts that underlie the INCOSE Smart Cities framework could be over-looked unless it can provide immediate value. As a demonstration of how the new framework could be used by someone interested in engaging INCOSE Smart Cities concepts, a high level application of the definitions and framework was performed. The analysis demonstrated that a simple review of the city system, using the perspectives of the INCOSE Smart Cities initiative, could reveal strengths and weaknesses of a smart city and identify potential next steps for improvement. This paper is a case study of how to use qualitative analysis to apply the human-centered definition and framework to evaluate a Smart City. The case study provides an opportunity to evaluate the strengths and weaknesses of the new INCOSE framework.

Paper#545

Hyundai's Modular MBSE Approach to 'Purpose Built Vehicle' Architecture Development

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Keywords. system architecture;modularization;automotive;system of systems;PBV

Topics. 2.4. System Architecture/Design Definition; 2.6. Verification/Validation; 3. Automotive; 5.3. MBSE; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. This paper discusses an ongoing effort at Hyundai to develop a model-based systems engineering (MBSE) methodology for cross-domain vehicle performance development that is practical at the enterprise level. Our approach relies on a modular modeling process that complements MBSE. In the age of smart mobility, automobile systems are indeed interdependent elements of a system of systems (SoS). More connectedness favors numerous mobility features that emerge due to the interfaces among these constituent systems. Managing emerging variations in product lines, changing consumer de-mands coupled with faster market response require manufacturers to modularize their architecture development processes. This helps scale up MBSE across vehicle programs. This study proposes a modular system architecture approach for developing Hyundai's purpose-built vehicle (PBV) concept that maintains a link to the legacy vehicle breakdown structures already in use. Using the Arcadia MBSE method, the 'to-be' developed electric vehicle is expressed as a hierarchical functional parti-tioning of the subsystem modules. A physical architecture is defined as a solution to the functional partitioning based on an existing vehicle breakdown in a combined 'top-down/bottom-up' workflow, thereby capturing a realistic system decomposition. In the SoS hierarchy, the vehicle is at the highest level and is partitioned into multiple levels of nested subsystem architectures owned and developed by designated module teams in a distributed modeling environment. Results of the preliminary architecture modularization effort indicate significant potential for benefits over classical architecture modeling such as iterative knowledge capture, enhanced reusability across projects, products and programs, and distributed vehicle performance development across the extended MBSE enterprise, which includes the tier 1/2 suppliers.

Paper#325

Identifying Reference Architecture Types for Stakeholder Groups in Industry 4.0

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Keywords. Reference architecture;Industry 4.0;RAMI 4.0;Model-based systems engineering

Topics. 14. Autonomous Systems; 2.2. Manufacturing Systems and Operational Aspects; 2.4. System Architecture/Design Definition; 20. Industry 4.0 & Society 5.0; 5.3. MBSE;

Abstract. New developments in the area of the Industrial Internet-of-Things (IIoT) and Industry 4.0 offer huge potential for a more efficient and flexible industrial production, but are also accompanied by rising system complexity. Consequently, to deal with the increased system complexity, novel methods in systems engineering are emerging. However, most of these novel methods are not yet mature and rather theoretical than ready-to-use. Thus, companies need to be provided with frameworks that actively support the transformation of their systems towards Industry 4.0. One of those approaches has been introduced with Reference Architecture Model Industry 4.0 (RAMI 4.0), which counteracts the men-tioned complexity and can be used for various use cases. However, as most of its concepts are too general to be applied directly to actual systems, the need for directly applicable reference architectures emerges. Therefore, this paper proposes a method to derive more detailed reference architectures based on RAMI 4.0 by making use of model-based systems engineering (MBSE), which target single manufacturing domains rather than the whole industry. Therefore, relevant stakeholders are analyzed and different types of reference architectures targeting their concerns are identified. The resulting reference architectures should be ready-to-use for interested manufacturers and thus, enhance the acceptance of RAMI 4.0 as well as improve systems engineering in industrial manufacturing. Finally, the developed reference architecture is evaluated in a real-world case study of a flexible production system.

Paper#273

Implications of Cultural Differences in the Systems Engineering Professional Competencies

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Keywords. Professional competencies;Cultural differences;Organizational implications

Topics. 22. Social/Sociotechnical and Economic Systems; 4.5. Competency/Resource Management; 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.); 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. In 2018, the International Council on Systems Engineering (INCOSE) introduced a set of competencies for systems engineers in a framework structure that gives guidance as to the knowledge, skills, abilities, and behaviors important to systems engineering effectiveness at each of five “levels” of competence, ranging from awareness to expert. There are five categories of competencies: Core, Technical, Professional, Systems Engineering Management, and Integrating. This paper focuses on the Professional Competencies, specifically on culturally-based characteristics of systems engineers relative to them. First, though, there is a discussion of why the Professional Competencies are important to System Engineering effectiveness. Culturally-based research is then discussed. Finally, conclusions are drawn as to the importance of improving competence in the Professional Competencies and of how to use them in selecting systems engineers, forming and developing systems teams, and making design decisions using information related to cultural differences in how the Professional Competencies are expressed.

Paper#25

Innovation Ecosystem Dynamics, Value and Learning I: What Can Hamilton Tell Us?

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Keywords. Digital Thread;Hamiltonian;Hamilton’s Principle;Energy;Momentum;Machine Learning

Topics. 1.4. Systems Dynamics; 1.5. Systems Science; 11. Information Technology/Telecommunication; 22. Social/Sociotechnical and Economic Systems; 3.7. Project Planning, Project Assessment, and/or Project Control; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Held in Dublin, Ireland, IS2024 invites us to refresh understanding of contributions to systems engineering by Ireland’s greatest mathematician--Sir William Rowan Hamilton (1805 - 1865), Professor of Astronomy at Trinity College Dublin and Royal Astronomer of Ireland. His profound contributions to STEM deserve greater systems community attention. Supporting theory and practice, they intersect Foundations and Applications streams of INCOSE’s Future of Systems Engineering (FuSE) program. Strikingly, key aspects apply to systems of all types, including socio-technical and information systems. Hamilton abstracted the energy-like generator of dynamics for all systems, while also generalizing momentum. Applied to the INCOSE Innovation Ecosystem Pattern as dynamics of learning, development, and life cycle management, this suggests an architecture for integration of the digital thread and machine learning in innovation enterprises.

Paper#312

Institute for Convergent Systems Engineering: A Strategic Plan for Ethical Sustainability

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Keywords. Convergent systems engineering;ethical sustainability;value supply chains;research institutes;strategic plans

Topics. 1.6. Systems Thinking; 10. Environmental Systems & Sustainability; 20. Industry 4.0 & Society 5.0; 22. Social/Sociotechnical and Economic Systems; 4.1. Human-Systems Integration; 5.4. Modeling/Simulation/Analysis;

Abstract. The last few years have made it clear that the world is entering a new phase in which sustainability is of paramount importance to the survival and well-being of our global societies. This paper describes the strategic plan for the Institute for Convergent Systems Engineering which is addressing the challenge of ethical sustainability in which social, environmental, and economic implications are carefully considered and balanced. Included is a discussion of the criticality of convergent systems engineering and its values and principles. The paper also presents a three part strategy for sustainability at the macro, meso, and micro levels entailing the consideration of end to end global value supply chains. The foundational pillars of research, education, and collaboration are also described.

Paper#437

Integrating AI with MBSE for Data Extraction from Medical Standards

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Keywords. Model-Based Systems Engineering;Artificial Intelligence;Digitization;Norm Compliance;Large Language Model;Classification

Topics. 4. Biomed/Healthcare/Social Services; 5.11 Artificial Intelligence, Machine Learning; 5.3. MBSE;

Abstract. The growing adoption of Model-Based Systems Engineering (MBSE) in the medical sector has prompted a significant emphasis on the digitization of medical standards into norm models aiming to improve data efficiency and establish traceability between norm data from medical standards and other model data, such as SysML models. Despite these efforts, the current digitization activities heavily rely on manual extraction and transformation, particularly from PDF documents into SysML models. Concurrently, the proliferation of Artificial Intelligence (AI) applications in recent years presents an opportunity to enhance these digitization activities. This paper contributes to the integration of AI with MBSE, focusing on automating and optimizing the digitization of medical standards. It explores the initial outcomes of augmenting data extraction from medical standards using advanced AI technologies and integrating them into MBSE practices. The evaluation involves two approaches, an open-source multimodal classifier model and a proprietary large language model. The study assesses these approaches on a medical standard and outlines future work, including the introduction of a third approach.

Paper#23

Integrating IoT Technology with a Systems Engineering Approach to Improve the GHG Emission Accounting in the Waste Management Industry

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Keywords. Waste Management Industry;IoT;GHG emissions accounting

Topics. 10. Environmental Systems & Sustainability; 11. Information Technology/Telecommunication; 3.4. Information Management Process; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. This work presents how to automate emission accounting and analysis in the waste management industry. The methodology adopted is based on the combined use of Internet of Things (IoT) technology and a Systems Engineering approach. The presented methodology has been tested in an industrial case. In the case, there were multiple systems available to collect environmental data. However, the ac-cessibility and the interpretability of this environmental data were observed as a challenge. After gathering the data in a centralized database, the automation of the Green House Gasses (GHG) emission management and accounting was performed. Findings show that the operational emissions of the industry partner mainly occur from energy and fuel consumption. By measuring and categorizing energy usage, the industry partner identified several potential improvements for reducing emissions. Lowering energy usage can consequently decrease the associated carbon footprint. Finally, the authors suggest some useful insights for companies with the aim of improving the effectiveness and efficiency of industrial GHG emissions accounting.

Paper#292

Integrating STPA Extended for Coordination into SysML Using RAAML Methodology

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Keywords. Model-Based Systems Engineering;system safety;STPA;coordination;RAAML

Topics. 2. Aerospace; 4.6. System Safety; 5.3. MBSE; 6. Defense;

Abstract. As Model-Based Systems Engineering (MBSE) becomes prevalent in engineering practice, the Department of Defense (DoD) requires a consistent methodology to conduct and record system safety analyses in the system model. Systems Theoretic Process Analysis (STPA) is a relatively new safety and hazard analysis method that utilizes the principles of Systems Theory and abstraction to analyze today's complex systems. Systems Theoretic Process Analysis Extended for Coordination (STPA-Coord) provides a framework to design safe coordination among a system-of-systems architecture, which is needed for next-generation integrated military systems. This research presents results from conducting an STPA-Coord in Systems Modeling Language (SysML) using Risk Analysis and Assessment Modeling Language (RAAML), a recent extension to SysML that provides tools and guidance for multiple safety analyses. Results describe deviations from the RAAML standard and suggest extensions to RAAML for STPA-Coord. Results include qualitative and quantitative observations conducting an STPA-Coord using SysML, including time required for the effort and perceived benefit over document-based methodologies.

Paper#278

Interactive Aviation Maintenance Classroom

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Keywords. Virtual Reality;Training;Human-Systems Integration

Topics. 1. Academia (curricula, course life cycle, etc.); 2. Aerospace; 4.1. Human-Systems Integration; 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.);

Abstract. Aviation Maintenance Technicians (AMTs) play an important role in guaranteeing the safety, reliability, and readiness of aviation operations worldwide. Per Federal Aviation Administration (FAA) regulations, certified AMTs must document specific mechanic-related experience to maintain their certification. Currently, aviation maintenance training methods are centered around classroom instruction, printed manuals, videos, and on-the-job training. Due to the constantly evolving digitallandscape, there is an opportunity to modernize the way AMTs are trained, remain current, and are used for on-the-job training. This research explores the implementation of Virtual Reality (VR) platforms as a method for enhancing the aviation training experience in the areas of aircraft maintenance andsustainability. One outcome of this research is the creation of a virtual training classroom module for aircraft maintenance, utilizing a web- based, open-source, immersive platform called Mozilla Hubs. While there is a general belief that VR enhances learning in general, very few controlled experiments have been conducted to show that this is the case. The goal of this research is to add, and allow otherresearchers to add, to the general knowledge for the use of VR for training and specifically for aircraft maintenance training.

Paper#342

IT/OT Integration by Design

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Keywords. IT/OT integration;Digital Twin;MBSE;BPMN;RAMI4.0

Topics. 11. Information Technology/Telecommunication; 14. Autonomous Systems; 2.5. System Integration; 20. Industry 4.0 & Society 5.0; 5.3. MBSE; 5.5. Processes;

Abstract. The four Industry 4.0 design principles information transparency, technical assistance, interconnection, and decentralized decisions pose challenges in integrating information technology (IT) and operational technology (OT) solutions in industrial systems. These different solutions have conflicting requirements, making interfaces between them problematic for both systems and organizations. An Industrial Business Process Twin (IBPT) entity, acting as an intermediary between the realms of IT and OT, has been proposed in a previous work, to effectively reduce the amount of required IT/OT interfaces in an attempt of overcoming this situation. In this work, we investigate the effects of this approach during the design phase. We argue that, by eliminating interfaces between IT and OT components in the system design, this approach is therefore eliminating conflicting communication channels within the organization's communication structure. In order to verify our argument, we develop a model of our IBPT concept according to the Reference Architecture Model Industrie 4.0 (RAMI4.0) using an Industry 4.0 scenario addressing the four essential Industry 4.0 design principles. Results show that the IBPT approach indeed eliminates potentially conflicting IT/OT interfaces during the system design phase.

Paper#502

Lifecycle of Accident Pathogens: Common Systemic Factors in Construction System Accidents

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Keywords. construction system accident;temporary multi-organization;systemic factors;accident pathogen;system safety

Topics. 12. Infrastructure (construction, maintenance, etc.); 22. Social/Sociotechnical and Economic Systems; 3.7. Project Planning, Project Assessment, and/or Project Control; 4.3. Reliability, Availability, and/or Maintainability; 4.6. System Safety; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Construction system accidents are accidents due to defects embedded in the constructed systems (e.g., buildings, bridges, and other infrastructures) originating from failures in construction systems, which we can consider as temporary multi-organizations (TMOs) that are organic and ephemeral in nature. Understanding the mechanisms of such accidents in transient and multi-organizational systems requires a system-wide perspective and consideration of the temporary aspect. This paper examines six accident cases using the framed-and-layered accident pathogen propagation (FLAPP) model—an accident model we specifically developed to capture system-wide factors and the time dimension—and identifies five types of pathogen threads and eight types of thread elements, which contribute to the propagation of latent failures and defects, i.e., accident pathogens. With concrete reference to the processes and products found in accident cases, the concept of pathogen thread provides an explicit structure to the classic metaphor of pathogens that the safety literature has been using to describe latent failures. This paper further proposes the concepts of pathogen susceptibility and transmissibility to explain the mechanisms and dynamics that drive the generation and propagation of accident pathogens. Acknowledging the limitations of the modeling framework, this paper concludes with a discussion of the directions for future work to ensure system safety in the construction of future systems in various domains.

Paper#79

Long Term Trends in Security Threats and an Ap-proach for Integrating Them into System Architecture and Design

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Keywords. architecture;system security;trends;design;agile

Topics. 2.4. System Architecture/Design Definition; 4.7. System Security (cyber-attack, anti-tamper, etc.); 5.1. Agile Systems Engineering;

Abstract. Cyber security is an important consideration in today's systems, and it promises to be both relevant and challenging in the future. Our design and development processes are evolving to in-corporate modern methods such as agile development and model-based engineering with the intent to provide flexible and resilient capabilities to our customers quickly and with high quality. As we continue to enhance our practices to achieve these aspirations, security capabilities both at initial deployment and throughout the system lifespan should be an important consideration. A literature review of cyber concerns in general and challenges across a range of domains including civil aviation, smart cities, eLearning, finance and defense reveals a set of recurring long-term trends. These trends suggest challenges to security capabilities in the future. In this paper, we summarize and analyze these trends and propose an approach for addressing them in architecture and design activities.

Paper#254

Mean dependency length – a new metric for requirements quality

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Keywords. Requirements quality metrics;Natural language requirements;Dependency grammar

Topics. 2.3. Needs and Requirements Definition; 3.6. Measurement and Metrics; Other domain;

Abstract. This paper proposes the mean dependency length (MDL) as a metric for measuring natural language requirements quality. Dependency length is a linguistic feature based on dependency grammar, which natural language researchers have traditionally used to evaluate syntactic complexity in other contexts. In this study, aided by MATLAB-based algorithms, the authors assessed MDL over a requirements set composed of 249 original statements, rephrased into five pattern systems. Null hypothesis and effect size testings revealed that MDL is sensitive to the application of pattern rules and to the differences among the patterns, both in an absolute approach and in comparison with other metrics. Furthermore, it was also demonstrated that MDL is aligned with users' values, especially for understandability issues, and can be measured automatically. Finally, the work concluded that MDL is a convenient metric for assessing the quality of natural language requirements.

Paper#326

MissionML: A Mission Architecture Modeling Language based on Unified Architecture Framework

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Keywords. UAF;Mission Architecture;UAF profile.

Topics. 2. Aerospace; 2.1. Business or Mission Analysis; 21. Urban Transportation Systems; 5.3. MBSE; 7. Emergency Management Systems;

Abstract. The missions of complex systems, organizations, or groups can be identified through careful requirements and domain analysis. Mission architecture modeling is a crucial step for enterprise modeling and design. However, the concept of mission modeling is absent from the Unified Architecture Framework (UAF), in which the system engineers have to specify and model from the sketch. In this paper, we propose a Mission Architecture Modeling Language (MissionML), a two-layer architecture language that generalizes the general common knowledge and special knowledge from five typical missions as a shared layer and specific characteristic layer. Moreover, MissionML is implemented as a UAF profile, incorporating numerous domain concepts in its syntax and semantics for mission modeling. Finally, we use five public case studies to demonstrate the learnability and extensibility from the view of system engineers.

Paper#264

Model-Based Decision Support using Test and Evaluation: A Lightweight Architecture Approach

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Keywords. Digital Engineering;MBSE;Decision Support;IDSK;Reference Architecture;Test and Evaluation;DOT&E

Topics. 1.6. Systems Thinking; 2. Aerospace; 2.4. System Architecture/Design Definition; 3.3. Decision Analysis and/or Decision Management; 5.3. MBSE; 6. Defense;

Abstract. A standardized decision support tool to support test prioritization and decision-making is a prerequisite to achieving on-time delivery of weapon systems that are adequately tested and vetted by decision makers within distributed organization such as the defense industrial base. However, to achieve standardization, the core principles of systems thinking and systems engineering must be utilized in order to realize a holistic and evolvable process and product that integrates T&E data and information with decision-making in a consistent format to support program offices. To address this need, a model-based reference architecture for the standardization of the Integrated Decision Support Key (IDSK) data and decision formats is presented in this paper. The IDSK is a DoD mandated decision support tool (artifact) for capturing a program's decisions and the Test & Evaluation information necessary to support the decisions. The digital-IDSK reference architecture proposed is developed using a model-based systems engineering approach and facilitates the generation of standardized data and decision formats that are tailorable, adaptable to incremental future changes, and easy to integrate with other digital engineering artifacts all within a digital engineering ecosystem. In addition, this approach is also applicable not only to defense-based organizations, but also finds utility within organizations pivoting to a digital engineering strategy for informing product test and evaluation decision-making.

Paper#77

Model-Based Systems Engineering (MBSE) Application in Nuclear Power Plants (NPP)

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Keywords. MBSE;SysML;Nuclear;Impact Analysis;Lifecycle;Maintenance;Safety;Reliability

Topics. 2.4. System Architecture/Design Definition; 5.3. MBSE; 8. Energy (renewable, nuclear, etc.);

Abstract. Companies in the nuclear power sector are constantly being challenged to improve their safety and reliability due to increasing complexity arise from evolving safety regulations, long production life, interdisciplinary collaboration, and the need for analyzing the impact of the changes in an operational life cycle. Recognizing these challenges, the paper proposes a transition to Model-Based Systems Engineering (MBSE) as a transformative solution to improve the management of such complex systems. With this objective, this paper presents a workflow implementation that demonstrates the MBSE methodologies to define a concept model, system architecture, impact analysis, safety and reliability analysis, and operational decision-making of Nuclear Power Plants (NPP). The paper concludes that MBSE provides a potent approach to managing NPP by employing graphical models to develop interrelated systems that has strong adaptability to heterogeneous environments and regulatory changes. The simulation results demonstrated an NPP life cycle, impact analysis, and a test case for model-based safety and reliability analysis for regulatory compliance, operational efficiency, balance safety, and informed decision-making in NPP. The study also leads to a number of interesting directions of future work such as synchronization through Product Lifecycle Management, integration with Building Information Modeling, Model-Based Commissioning/Decommissioning, and Model-Based Cyber System Security tailored for nuclear power systems.

Paper#412

Model-Based Systems Engineering (MBSE) Methodology for Integrating Autonomy into a System of Systems Using the Unified Architecture Framework

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Keywords. Autonomy integration;Level of autonomy;SoS Architecture;MBSE methodology;UAF

Topics. 14. Autonomous Systems; 5.11 Artificial Intelligence, Machine Learning; 5.3. MBSE; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. Many stakeholders of existing Systems of Systems (SoSs) are interested in leveraging the new ca-pabilities provided by autonomous systems empowered by Artificial Intelligence (AI). This requires the integration of these systems into SoSs, resulting in Systems of Autonomous Systems (SoASs). SoAS architecting is different from SoS as the architecting challenges are exacerbated by the Level of Autonomy (LoA). An autonomous system has various LoAs depending on its AI advancement and the capabilities it provides. Each LoA impacts the managerial and technical challenges for SoAS architecting in a different manner. The managerial aspect covers concerns such as policies and agreements, whereas the technical aspect highlights issues such as compatibility between autonomous systems and legacy systems. Failure to address the LoA impact on these factors in the architecting phase results in an ineffective integration. In this paper, we propose a methodology that follows the SoS hierarchical lexicon, builds upon the standard steps of the Object-Oriented Systems Engineering Method (OOSEM), and leverages the Unified Architecture Framework (UAF) for modeling autonomy integration. The proposed methodology adds detailed sub-steps to OOSEM, where we introduce the required UAF views for modeling each aspect of the SoAS architecture. This methodology lays the foundation for the trade study analysis that helps stakeholders decide on suitable LoAs for SoAS. We also present an illustrative example to demonstrate the implementation and effectiveness of the proposed methodology.

Paper#287

Modeling Cybersecurity Operations to Improve Resilience

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Keywords. modeling and simulation;cybersecurity teams;Systems Dynamics;resilience;adaptability

Topics. 1.4. Systems Dynamics; 4.4. Resilience; 4.7. System Security (cyber-attack, anti-tamper, etc.);

Abstract. In this paper, we explore the concept of operational resilience of a computer system focusing on the processes of a cybersecurity team. The computer system under examination has faced a cyberattack that has reduced its capability. The organization’s reputation is damaged temporarily but can be restored if the cybersecurity team can quickly restore the system’s capability. After a cyberattack, we examine the processes for restoring the system’s capability to its original level. These processes will happen sequentially and require close coordination of the cybersecurity team members. We examine a balanced and adaptive assignment policy within the cybersecurity organization to the various processes, showing how these policies can impact the speed with which the system’s capability can be restored. Our findings reveal that the adaptive assignment policy among the team members can increase the system restoration rate even though recovering the complete capability of the system may be the same.

Paper#456

Modeling NASA's Procedural Requirement Processes - Implications for Digital Future

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Keywords. MBSE;SysML;process modeling;data-centricity;NASA;digital engineering

Topics. 2. Aerospace; 2.1. Business or Mission Analysis; 3.5. Technical Leadership; 5.3. MBSE; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The National Aeronautics and Space Administration (NASA) has an ongoing Digital Transformation effort and to leverage and showcase the power of Digital Transformation, an effort is underway to develop an integrated, datacentric, model representing NASA's key process requirements. The task was divided into three phases: As Is modeling, Analysis, and To Be Planning. As part of this effort, a team has completed the first Phase I of the modeling task and is nearing completion of the second phase. This effort will capture the key elements as requirements, responsibilities, allocations, roles, products and associated lifecycle ele-ments. The scope of modeling included NASA's NPR 7120.5 (Project and Program Management), NPR 7123.1 (Systems Engineering) and NPRs 8705.2 (Risk classification for Robotic Missions) and 8705.4 (Human-Rating Requirements for Space Missions). This paper will summarize the approach, scope, parsing patterns applied, metamodel, and associated workflows for the As Is modeling. It will also summarize the results and insights gleaned during that phase, including the review process. These insights have informed the analysis and will be discussed. The analysis modeling phase will also be summarized including how the stakeholders were engaged, how the common elements were handled and dispositioned, and will also describe some of the plans for the future of NASA NPDs and NPRs.

Paper#220

Modeling Principles to Moderate the Growth of Technical Debt in Descriptive Models

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Keywords. MBSE;descriptive models;technical debt;model architecting;modeling principles

Topics. 2.4. System Architecture/Design Definition; 5.3. MBSE;

Abstract. Model-Based Systems Engineering (MBSE) is next step in the evolution of systems engineering (SE) in which documents are replaced by descriptive models as the authoritative embodiment of SE knowledge. These descriptive models are a unique combination of the features and characteristics of documents, software, and data. Model architects should conscientiously apply appropriate modeling principles and practices is essential to make informed decisions to moderate the accumulation of model technical debt. This paper describes 18 foundational modeling principles that model architects should consider when making architectural and implementation decisions about their models and describes some of the key model technical debt tradeoffs that result when these principles are not followed. These principles address commonly observed problems regarding model federation architecture, the selection and use of model layers, the modeling of the domain, and the semantics of modeling constructs. Applying disciplined model architecting practices to conscientiously manage the accrual and payoff of technical debt can make the difference between an enduring model that provides substantial value throughout the life cycle of the modeled entity and a model whose value collapses under the weight of uncontrolled technical debt.

Paper#232

Modeling swarm mission with COTS characterization: a series of return on experience

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Keywords. Architecture Frameworks;MBSE;COTS;return on experience

Topics. 1.1. Complexity; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. System design in defense systems is a competitive field, in which economical viability relies on a sequence of architectural decisions, aiming at quality, resource and time (Q,R,T) compromises. Furthermore, the investment to conduct weapon acquisitions and lifecycle maintenance until dismantlement involves major investments in industries. If systems engineering (SE) practice mostly focuses on early design activities and development, we observe that there is little information in literature in SE field that relate to general quality, resource and time compromises or quantified return-on-investment. On the other hand, we observe that low-cost unmanned ground vehicles (UGV) and drones appear as new threats on current battlefield. To face these new threats, ministries of defense have organized challenges around robotization of battlefield, to design future employment doctrines and help technologies to reach maturity in a reasonable time. This article exposes a set of NATO Architecture Framework (NAF) 3.1 views that match a recent robotic military challenge over two yearly iterations. The capabilities depicted are requirements to compete in the challenge, constituent systems are based on Components-Off-The-Shelf (COTS) answering to both edition of the challenge. For the second iteration, we re-used views that were selected at first, and realized documented return on experience (RetEx) reports for both editions. This article details how manually re-injecting feedback from field back to the system model failed to help for the second iteration of the challenge. Our works propose conclusions on capabilities iterations from a general perspective, and develop propositions that introduces the necessity to create realistic simulation environments threads to verify and validate emergent behavior of systems composed of COTS in a constrained time and resource context.

Paper#196

MULTI-DIMENSIONAL TRADESPACE STUDY – A PRACTICAL EXAMPLE OF IMPLEMENTATION

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Keywords. Tradespace;Trade Space;Set-Based Design;Consensus;Pareto Front;Multi Domain Optimization;Morphological Matrix;Morphological Box;Architecture

Topics. 2.4. System Architecture/Design Definition; 3.3. Decision Analysis and/or Decision Management; 5.3. MBSE;

Abstract. Decision making is a critical element of all Systems Engineering activities. The challenge for the Systems Engineer in charge is, that not only the technical facts and parameters, but also organizational factors influence the decision-making process. Furthermore, it is critical, at least at some core decision points, to not just get compromises between stakeholders, but reliable consensus. Tradespace Study can be one powerful tool for the Systems Engineer to make fact-based decisions while supporting set-based design and agile working methods in parallel. However, to be a powerful tool, such tradespace study must be easy to use and well implemented in the Systems Engineering process and well accepted in the organization. If this is given, tradespace study can furthermore support the means of set-based design into the digitization efforts like digital thread and digital twin. This paper will highlight some insights on the way towards a practical implementation in the day-today Systems Engineering process. This paper will also give some outlook towards the next steps to broaden usage of this powerful tool as well as a smoother integration in modern MBSE environments and into a digital thread.

Paper#275

Multiple Pathways of Influence for Tightly and Loosely Structured Organizations: Implications for Systems Resilience

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Keywords. organizations;structure;influence;decision-making;systems resilience

Topics. 10. Environmental Systems & Sustainability; 22. Social/Sociotechnical and Economic Systems; 3.3. Decision Analysis and/or Decision Management; 4.4. Resilience; 5.4. Modeling/Simulation/Analysis; Other domain;

Abstract. Organizations play a key role in supporting various societal functions, ranging from environmental governance to manufacturing of goods. The behaviors of organization are impacted by various in-fluences, including information, technology, authority, economic leverage, historical experiences, and external factors, such as regulations. This paper introduces a generalized framework, focused on the relative structure of an organization (tight vs. loose), that can be used to understand how different influence pathways can impact decision-making within differently structured organizations. This generalized framework is then translated into a modeling and simulation platform approach to support and assess implications of these structural differences on overall behaviors of the organizations. Specifically, a systems dynamics approach is used to simulate tightly structured and loosely structured organization in the context of varying amounts of information quality present within the environment. Preliminary results indicate that a tightly structured organization is less timely at processing information within the environment, and it could be more resilient to how much poor quality information is incorporated within its final decisions under certain conditions, in comparison to the loosely structured organization. Ongoing work is underway to understand the robustness of these findings and to align current model design activities within empirical insights.

Paper#488

NASA's Use of MBSE and SysML Modeling to Architect the Future of Human Exploration

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Keywords. NASA;exploration mission planning;Moon2Mars;Artemis;complexity management;MBSE;SysML modeling

Topics. 1.1. Complexity; 2. Aerospace; 2.5. System Integration; 5.3. MBSE;

Abstract. One of the key roles of National Aeronautics and Space Administration (NASA) is to help mitigate the risk and expense of exploration, science, and discovery to the point where industry is willing and able to profitably take on the associated scope. To enable the NASA to take on larger, more complex science and exploration missions and continue to effectively engage and collaborate with domestic industry and international partners, the Agency must undertake a transformation to modern integrated Digital Engineering. However, the complexity of the mission coupled with flat or decreasing budgets, a de-mand to go from concept to operations in less time, and societal expectations of risk aversion, NASA cannot achieve these goals using the planning, engineering, and operational approaches which got us where NASA is today. New ways of integrating, managing, sharing and leveraging information is required and this paper will highlight how NASA is utilizing Model-Based Systems Engineering (MBSE) and associated models to link work groups from Headquarters to Programs to engineering teams at the field Centers to enable mission feasibility, planning and operations in taking humanity to the Moon and on to Mars.

Paper#169

Promoting Neurodiversity Through a Lifecycle Modeling Approach to MBSE

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Keywords. Neurodivergent;Autism;MBSE;Data-Driven;Lifecycle Modeling

Topics. 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.); 5.3. MBSE; 5.4. Modeling/Simulation/Analysis;

Abstract. The Systems Engineering industry employs a large number of people from the neurodivergent community. This research is important because it explores how we can promote diversity through systems engineering. The challenge we face in the industry is finding ways to work on complex systems that are inclusive of different neurological processes. This paper begins by looking into the meaning of neurodivergence, which shows us different ways our industry can include that community. Extensive research on the neurodiverse community shows that many lean toward visual learning styles and strict rules. Using this information, the industry could use a data-driven approach to Model-Based Systems Engineering (MBSE) to help the neurodivergent community better understand systems engineering, specifically using a common ontology. This research highlights the ontology, Lifecycle Modeling Language, a structured and behavioral modeling language. Through a heavier focus on Data-Driven MBSE and a collective ontology across our industry, we can create opportunities and foster positive change from a new community with a new perspective.

Paper#428

Providing tailored heuristic advice to Systems Engineers

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Keywords. Complex;Difficult;Assessment;Heuristic;Advice;Approach;Principles

Topics. 1.1. Complexity; 22. Social/Sociotechnical and Economic Systems; 3.3. Decision Analysis and/or Decision Management; 3.7. Project Planning, Project Assessment, and/or Project Control; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Difficulty Assessment Tools (DATs) have been used for many years to characterize a problem to provide tailored advice. An INCOSE-wide initiative has exposed at least 600 heuristics and counting. Previous work indicates that rationalizing and simplifying this set to make it a useful memorable set is likely to be intractable. This paper explores using a DAT to characterize a problem and provide a range of advice including heuristics advice to the users. To test this approach, 57 heuristics and 10 principles were scored and embedded into an online DAT. An experiment was conducted to determine if the discussion, ap-proach and heuristic/principles advice was relevant and/or useful. The results indicate that the discussion, approach and Heuristic advice provided were considered highly relevant by the users of the tool. The discussion was considered very useful, the approach advice somewhat useful and the heuristics considered a bit useful on average. The usefulness score was tempered by the perceived newness of the advice. The tailoring of the heuristics to the task was not noticeable by the users of the tool, though it aligned with the authors' expectations. The relevance and usefulness results indicate that Systems Engineers should use the DAT to inform their approach.

Paper#276

Real to Real: Deriving Software Development Practices from Film Production Principles

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Keywords. project management;software development;film production;cross industry learning

Topics. 11. Information Technology/Telecommunication; 3.5. Technical Leadership; 3.7. Project Planning, Project Assessment, and/or Project Control; 5.1. Agile Systems Engineering; Other domain;

Abstract. Software development projects face significant risks of going over budget, over schedule, and of failing to deliver expected benefits. These risks have endured despite the industry's shift towards agile methodologies. This research looks outside of the software industry, and seeks inspiration from film production, which has developed different management strategies to address challenges similar to those faced by software development projects.First, an analysis of film production project management reveals four principles, each evidenced by a set of practices used throughout the industry. Next, we identify sets of practices that would enable software development projects to also align to those same four principles. The synthesis of each principle from its set of supporting film production practices is then validated through structured interviews with veteran film producers. Lastly, the derivation of each principle to a parallel set of supporting practices within the context of software development is validated in a second series of interviews with experienced software development project managers.In total, this research identifies a set of software development project management practices that mirror film production principles. These practices offer a framework for software development project managers to consider when seeking to tailor existing methodologies, particularly in scenarios that present challenges similar to those encountered in film production.

Paper#403

Risk Assessment Method for Systems-of-Systems Operation

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Keywords. System-of-Systems;Risk assessment;Operational strategy

Topics. 1.6. Systems Thinking; 10. Environmental Systems & Sustainability; 22. Social/Sociotechnical and Economic Systems; 4.6. System Safety; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 7. Emergency Management Systems;

Abstract. A SoS is a set of collaborating systems that act towards a common achievement. Risk assessment is important in the early stages of SoS operational development, both for mission objectives and to enable technology which is developed responsibly. The method considers risks that stems from both internal and external interactions which leads to losses for different kind of actors. The method has been applied to a case study of wildfire fighting. The internal interactions are mostly communication between the CSs while external interactions represent dependencies of other systems as well as impacts on other systems. The outcome of the methodology is a network of connected hazards to be used for risk management and for high level SoS requirements.

Paper#54

Secure Design: A Practical Approach for Systems Engineers

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Keywords. Security;System Security;Resilience;Design;Architecture;System Security Engineering

Topics. 2.4. System Architecture/Design Definition; 4.4. Resilience; 4.7. System Security (cyber-attack, anti-tamper, etc.);

Abstract. INCOSE's Systems Engineering Vision 2035 sets a goal that security will be as foundational a perspective in systems design as system performance and safety are today. Informed by related activities by , this paper provides a guide in-forming such a perspective when creating an inherently secure design and a basis for necessary security functionality, borrowing heavily from concepts of inherently safe. Inherently secure design is a design where hazards, susceptibilities, and vulnerabilities are eliminated to the extent possible and the remaining ones are controlled, while still enabling the system to meet performance requirements.

Paper#564

Securing Your Eggs in Multiple Baskets – Assuring a Resilient and Secure Supply Chain

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Keywords. Supply Chain;UAF;Systems of Systems;MBSE;Enterprise;Assurance;Risk Management

Topics. 17. Sustainment (legacy systems, re-engineering, etc.); 20. Industry 4.0 & Society 5.0; 3.1. Acquisition and/or Supply; 4.3. Reliability, Availability, and/or Maintainability; 5.3. MBSE; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The global supply chain is a complex system of systems made up of and relying on other complex systems of systems (SoS) to achieve its goals. To take a typical example, Enterprise A is supplied essential parts on a regular basis to manufacture its products. To place the order requires global financial systems, integrated email systems, the internet, multiple telecommunications systems, and supply software provided by large companies. To deliver the parts may require air and maritime transportation systems, the rail network, interstate highway systems, road haulage companies, state and local transportation systems and so forth. When any of these complex systems fail, the impact can be global, and the results catastrophic. Recent examples include the shortage of Personal Protective Equipment (PPE) during the COVID pandemic, computer chip shortages delaying the assembly and sales of cars, and, most recently, the baby formula shortage. These were due to disruptions in the supply chain caused by an overreliance on single sourced suppliers who failed to deliver, transportation disruptions, outsourcing of critical parts, supplies, medicines to distant countries, and an overreliance on “Just In Time” for inventory management. This is the case of placing too many eggs in too few baskets, and often just one basket. In addition, counterfeit or substandard parts and products can enter the supply chain. This has included critical mechanical parts on aircraft, chips containing spyware, and substandard or out of date medicines substituted for the real thing resulting in serious illness and death. This complex SoS needs to be examined, studied, and understood in the same way as a mission critical system; threats, vulnerabilities, and risks need to be identified and mitigated and assurance cases defined to ensure a solid and reliable supply chain. This paper will look at the supply chain of an example factory system to determine how some of these problems can be predicted, prevented, mitigated, and solved using the UAF, RAAML and assurance case techniques.

Paper#265

Sustainability Mindshift: Incorporating the Systems Perspective

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Keywords. Sustainability;Paradigm Shift;Systems Engineering;SE Vision 2035

Topics. 1.5. Systems Science; 1.6. Systems Thinking; 10. Environmental Systems & Sustainability; 17. Sustainment (legacy systems, re-engineering, etc.); 3.5. Technical Leadership;

Abstract. The pursuit of sustainability is a noble undertaking and unarguably ‘a good thing’. The concept can hardly be denied as something that is good for future societal wellbeing. However, beyond a superficial acknowledgement of the inherent ‘goodness’ of sustainability, there is much to be gained through the re-framing of sustainability as an engineered product from an underlying system as opposed to a ‘development goal’. In pursuit of this Mindshift, following an introduction and discussion of the sustainability landscape, three challenges for sustainable systems development are explored. The first Mindshift challenge examines sustainability as a product from an underlying system. Thus, the focus is shifted from sustainability as a goal to sustainability as a purposefully designed product from an engineered system. The second Mindshift challenge explores sustainability through the lenses of Systems Theory. Systems Theory exist as a set of axioms (taken for granted ‘truths’) and propositions (system concepts, laws, and principles) that govern the behavior, structure, and performance of systems. The implications of Systems Theory have profound implications for how we view sustainability. The third Mindshift challenge suggests that sustainability can be enhanced through the purposeful identification, assessment, and resolution of violations of system propositions (pathologies) spanning design, execution, and development. Thus, sustainability is a ‘systems engineered product’ resulting from an underlying system and developed by addressing systems-based disparities (pathologies) in the system. The paper closes with a capsule of Mindshift challenges for sustainability and their implications for supporting the INCOSE SE Vision 2035.

Paper#463

Synergizing Structure and Agility: A Comprehensive Analysis of SAFe Agile Framework through the Lens of Stafford Beer's Viable System Model

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Keywords. VSM;SAFe Agile Framework®;Systems Thinking;Agile Methodologies;IDEF0 Functional Modeling;Organizational Management;Cybernetics in Business;Agile Transformation;Systemic Analysis;Agile Systems Engineering

Topics. 1.6. Systems Thinking; 3.5. Technical Leadership; 5.1. Agile Systems Engineering; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. This paper presents a novel examination of the SAFe® (Scaled Agile Framework®) through the theoretical framework of Stafford Beer's Viable System Model (VSM). By applying the principles of VSM, renowned for its systemic and cybernetic approach to organizational management, we offer a unique perspective on the structural and functional aspects of SAFe® in its various configurations: Essential, Large Solution, Portfolio, and Full. The study employs functional modeling to delineate the congruencies and divergences between VSM and SAFe®, aiming to illuminate how VSM's systemic insights can enhance the implementation and efficacy of SAFe® practices. This interdisciplinary approach not only contributes to a deeper understanding of SAFe's® capabilities and limitations but also demonstrates the practical applicability of VSM in contemporary agile environments. The findings propose actionable insights for organizations seeking to optimize their agile practices through a more structured, systemic lens, thus bridging a crucial gap in agile and systems thinking literature. This paper is poised to benefit practitioners and theorists alike, offering a fresh perspective in the agile systems domain.

Paper#84

System Revisited - Again

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Keywords. system;systems engineering;concept;abstract-virtual-physical

Topics. 1. Academia (curricula, course life cycle, etc.); 1.5. Systems Science; 3.5. Technical Leadership; 5.9. Teaching and Training;

Abstract. This paper reviews the revised foundational definitions of system and systems engineering in the recently published (2023) fifth edition of the INCOSE Systems Engineering Handbook. The new INCOSE definitions derive from an earlier INCOSE Fellows' Initiative on System and Systems Engineering Definitions that begun in 2016 and finally reported in 2019. After introducing the concept of system and reviewing the new definition, the paper concludes that the concept, not rooted in a single science or exemplar domain, is so pervasive as be a meta-concept that does not have a dominant scientific definition. It proposes further work towards a more scientific definition of an engineered or artificial system – the primary interest of INCOSE -- at a lower level of abstraction.While the authors define systems engineering functionally as a process or approach, we see the essence of systems engineering as abstraction. Using the more accepted metaphysical distinction between the real, virtual, and abstract, we define the output of systems engineering as an abstract (simplified symbolic) representation or model that is the basis for defining the real; firstly, the virtual representation of something not (yet) existing physically but made to appear so and, finally, the physical. Thus, we position systems engineering as the abstract phase within a three-phase abstract-virtual-physical engineering design and realization process.

Paper#109

Systems Engineering Application for Better Design and Analysis of an Assembly Process

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Keywords. SysML-PPR Model Transformation;System Behavior based Trade-off Analysis;Production-Specific Simulation;Assembly Scenario;Product-Process-Resource (PPR) View

Topics. 2.2. Manufacturing Systems and Operational Aspects; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis;

Abstract. The use of systems engineering has proven effective in managing complexity and improving system design. Model based system engineering utilizing the Systems Modeling Language (SysML) espe-cially helps in multidisciplinary environments where engineering data needs to be transformed and integrated between environments. Manufacturing is another discipline same as systems engineering is on active digitalization transformation. In the paper, we propose method and solution to apply MBSE for improvement of process planning of assembly lines leveraging model based approach. SysML modeling and execution enable automation of analysis activities as trade-off, where the be-havior of various assembly scenarios of an assembly line can be captured using SysML behavioral diagrams and compared based on various evaluation criteria. However, relying solely on descriptive SysML system models without integrating the virtual representation of the assembly line is insuffi-cient to verify all aspects of system behavior, such as ergonomics and collision avoidance. The main objective of this work is to present a concept for transforming SysML assembly scenarios into the process and resources models of the computer-aided design and manufacturing (CAD/CAM) envi-ronment. This yields a holistic view that serves as a foundation for further production-related simu-lations and analyses, enhancing efficiency, ergonomic design, factory layout, and material flow, ensuring effective assembly workstation design optimized at systems engineering level.

Paper#124

Systems Engineering roles to handle emergent properties and behaviors in complex technical systems

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Keywords. Systems Engineering roles;requirements;specification;properties;features;emergent phenomena;automotive

Topics. 2.3. Needs and Requirements Definition; 3. Automotive; 3.5. Technical Leadership; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Engineering projects for complex technical systems demand extensive requirement specifications and corresponding hierarchy levels in system architectures. Especially when considering emergent phe-nomena, such as total weight or aerodynamics, a closely networked collaboration of disci-pline-specific and cross-disciplinary roles is required. Further, in large organizations with a group structure, resulting functional and non-functional contents are managed by distinct roles. For exam-ple, the role property manager takes care of achieving overarching product properties, such as aer-odynamics, which cannot be directly fixed. This paper proposes new Systems Engineering roles and their application in a German Original Equipment Manufacturer (OEM). For validation, the roles have already been applied in everyday engineering projects at the OEM. The concept proved to be in-dispensable and transferable to other Systems Engineering projects.

Paper#110

Systems Lessons from the Panama Canal

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Keywords. Panama Canal;Lessons;Use case;Emergence;Purpose;Organization;Leadership;Realization systems.

Topics. 1.6. Systems Thinking; 12. Infrastructure (construction, maintenance, etc.); 2.1. Business or Mission Analysis; 3.3. Decision Analysis and/or Decision Management; 3.5. Technical Leadership; 3.7. Project Planning, Project Assessment, and/or Project Control;

Abstract. This paper addresses the building of the Panama Canal (particularly from 1870-1914) and looks at lessons that modern day Systems Engineers can apply from this significant infrastructure project. There were great successes and failures during the attempts to build a canal. The Systems issues include the importance of understanding the environment, recognizing the need to think beyond the physical object - Panama Canal project had significant health issues, need for infrastructure / “realization systems”, and even the need for a political revolution in Panama to enable it to be built. The importance of the organization building the system, and its leadership was also important.It is always instructive to look back at significant historical projects and learn the lessons (positive and negative). There is much to learn from a project and a system as big and important as the Panama Canal

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Paper#489

Systems-Theoretic Concept Design: An Intent Model for Early Concept Generation

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Keywords. Systems Theory;System Design;Early Concept Generation;STAMP

Topics. 1.1. Complexity; 1.6. Systems Thinking; 2. Aerospace; 6. Defense;

Abstract. The complexity of engineered systems has grown leaps and bounds over the last forty years. One of the main challenges in modern engineering is managing this complexity, particularly as the pace of tech-nological change continues to accelerate across industries. While most systems professionals agree, a viable early design concept is crucial to meeting stakeholders' needs and successfully scoping a devel-opment program, traditional early concept generation approaches focus on a design-first approach, often glossing over an analysis of system intent and a synthesis of system goals and objectives. This tendency leads to an early focus on low-level, highly-granular design activities that focus on advanced technologies as design components instead of on the high-level policy or desired emergence that the new system is being designed to achieve. To combat these shortcomings, this paper introduces a new framework for conceptualizing an early design for novel, complex systems in aerospace and defense that are employed as part of a portfolio-of-systems in an attempt to achieve a high-level policy or portfolio-level capability. It outlines an intent model for framing a new system's contribution to a portfolio-level capability, and it posits a framework for delivering a new model for early design concepts while providing a foundation to extend system-theoretic hazard and security analysis techniques to systematically analyze safety and security engineering challenges for the designs in the earliest possible phase of their lifecycle.

Paper#519

Tailoring of NASA-STD-3001 to the Lunar Gateway Program Requirements

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Keywords. systems engineering and integration;human systems integration;moon to mars;artemis;gateway;lunar exploration

Topics. 2. Aerospace; 2.5. System Integration; 4.1. Human-Systems Integration; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. The Gateway Program must meet NASA's Agency-level human rating requirements, which are in-tended to accommodate human capabilities and limitations while protecting the safety of the crew, and providing to the maximum extent practical, the capability to safely recover the crew from hazardous situations. Human systems integration requirements represent a key component of human rating of Moon to Mars systems to support the execution of Artemis missions, including compliance with mandatory standards for Health and Medical, Safety and Mission Assurance, and Engineering. The human system requirements, together with the human systems integration plan, medical operations requirements, and Gateway subsystem specifications, represent the flow-down of NASA Health and Medical Standards (NASA-STD-3001, Volumes 1 and 2) into the Gateway system. This paper discusses how these documents and other human systems integration activities provide full consideration of human capabilities and limitations as part of the total system design trade space, serving as an example on how the human must be effectively integrated as part of the system in order to achieve mission success.

Paper#180

The Convergence of COSYSMO Parametric Cost Estimation with Model-Based Systems Engineering

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Keywords. COSYSMO;Parametric Cost Estimation;MBSE;Systems Engineering;Project Planning;Reuse

Topics. 2. Aerospace; 3.6. Measurement and Metrics; 3.7. Project Planning, Project Assessment, and/or Project Control; 4.2. Life-Cycle Costing and/or Economic Evaluation; 5.3. MBSE; 6. Defense;

Abstract. The promise of Model-Based Systems Engineering (MBSE) and its advertised benefits hinge on the ability of our profession to integrate engineering disciplines and project management across the system life cycle. In particular, connecting system architecture to the economics of developing such a system is a critically important topic but has not drawn significant attention by the system engi-neering community. Such integration requires two things: (1) the standardization of mul-ti-disciplinary terms and functions, and (2) the establishment of rules that govern relationships be-tween cross-functional models and modeling environments. The contribution of this paper sits squarely in those two areas by (1) establishing common terminology that describes systems engi-neering and cost estimating and (2) proposing specific cost factors and counting rules that can be used to estimate systems engineering effort using the COSYSMO cost model in an MBSE environ-ment.This paper enables the convergence of COSYSMO and MBSE by updating the COSYSMO counting rules to specifically address size driver selection and assignment in a SysML model; demonstrating how advanced queries and cross cutting views provided by modern, MBSE tools increase the completeness, quality and consistency of the parametric cost estimation results, and to reduce the cycle time from architecture to cost estimation. It defines the critical modeling patterns and guidelines for identifying system model content and level of detail for cost estima-tion and provides an approach to connect attributes and properties in a system model to the vari-ables in the COSYSMO cost estimating relationship.

Paper#558

The Effects of the Assessed Perceptions of MBSE on Adoption

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Keywords. model-based systems engineering;diffusion of innovations;adoption rate;MBSE adoption

Topics. 1.1. Complexity; 3.5. Technical Leadership; 5.3. MBSE; 5.9. Teaching and Training;

Abstract. With modern systems' increasing complexity, traditional document-based SE practices have proven inadequate, leading to shortcomings in systems engineering (SE) outcomes.To address these limitations, model-based systems engineering (MBSE) has emerged with an emphasis on the system model as the primary SE artifact. Despite its potential, MBSE has not achieved widespread adoption. This study explores MBSE adoption challenges through the lens of the diffusion of innovations theory to identify factors hindering its adoption. The study's methodology includes a survey distributed to SE professionals focusing on perceptions of attributes of MBSE identified by the diffusion of innovation theory, current use of models and MBSE, and basic demographic information. Results highlighted that respondents recognize the relative advantage of MBSE in improving data quality and traceability, but perceived complexity and compatibility with existing practices still present barriers to adoption. Subpopulation analysis reveals that those who are not already involved in MBSE efforts face the additional adoption obstacles of limited trial opportunities and tool access.The survey underscores the potential for closer alignment between MBSE and existing SE methodologies to improve the perceived compatibility of MBSE. Future studies would benefit from examining additional variables identified by the diffusion of innovations theory, incorporating control questions to differentiate between perceptions of SE generally and MBSE specifically, identification of better methods to assess current MBSE use by participants, and measures to broaden the participant scope. The imminent introduction of SysML v2 presents a significant opportunity to recalibrate the adoption trajectory of MBSE and enhance its accessibility among SE professionals.

Paper#466

The Human-Technology Spectrum: A Framework for Evaluating Sociotechnical System Function Allocation, Risk, and Performance

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Keywords. Sociotechnical Systems;Function Allocation;Risk Assessment;Human-Technology integration;Function Risk Analysis;System Architecture

Topics. 2.4. System Architecture/Design Definition; 2.5. System Integration; 22. Social/Sociotechnical and Economic Systems;

Abstract. This paper investigates the interplay of human and technological elements performing functions within socio-technical systems. With rapid technological advancements, understanding the various possible human-technology configurations, and their unique implications, is crucial. This research proposes a conceptual schema to demarcate particular kinds of human-technology relationships, as it pertains to function allocation, and aims to guide system design and risk management. The Human-Technology Spectrum (HTS) framework considers a continuum of systemic risks, lifecycle management strategies, and evaluation processes, offering a valuable resource for engineers and designers. For each stage along the HTS, we provide examples and discuss function across types of sociotechnical systems. We conclude with a discussion on the importance of understanding the tradeoffs between humans versus technologies enacting system functions.

Paper#165

The Importance of being Björn - Experiences from Five Generations of Female Engineers

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Keywords. Systems engineers;Technical leadership;Working life;Diversity;Sociotechnical systems;EWLSE

Topics. 2. Aerospace; 22. Social/Sociotechnical and Economic Systems; 3.5. Technical Leadership; 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.); 6. Defense;

Abstract. This paper gives an overview of the situation for Swedish female engineers at an engineer-ing-dense company (Saab Group) and societal factors of impact for their situation. We have interviewed five generations of female engineers and let them share their personal experiences. Some key findings are that the older generation has paved the way for the younger, but that has in many cases been costly for the individuals. The changes in society have contributed to better conditions for female engineers, e.g., the parental leave compensation and possibility for childcare at a low cost. A remaining problem is the lower proportion of female technical leaders compared to female systems engineers. They are often head-hunted for roles as project manager or line manager, and therefore the technical leader roles still are heavily male dominated.

Paper#174

The Nature of Technical Debt in the Development of Descriptive Models in MBSE

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Keywords. MBSE;descriptive models;technical debt

Topics. 5.3. MBSE;

Abstract. Model-Based Systems Engineering (MBSE) is the growing practice of systems engineering (SE) in which descriptive models replace documents as the embodiment of SE knowledge. These descriptive models capture SE information in place of documents, are developed in a similar manner to software source code, and are encoded and used in machine-to-machine applications as data. This paper describes how the technical debt concept widely used in the software domain—-rework deferred to the future for expediency-—needs to be modified to the domain of descriptive models. Consciously applying appropriate modeling principles and practices is essential to make informed decisions during the modeling process to prevent the accumulation of excessive model technical debt, which can require substantial rework to correct. The paper establishes a foundation for subsequent work to characterize the technical debt implications of key model architecture and implementation decisions that are made explicitly or implicitly by modelers when developing descriptive models. To illustrate the model technical debt concept, several examples of modeling principles pertaining to model purpose and implementation are described along with their implications on model technical debt.

Paper#163

The Updated SERC AI and Autonomy Roadmap 2023

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Keywords. Artificial Intelligence;Machine Learning;Autonomy;AI4SE;SE4AI;FuSE

Topics. 1. Academia (curricula, course life cycle, etc.); 20. Industry 4.0 & Society 5.0; 5.11 Artificial Intelligence, Machine Learning; 5.12 Automation;

Abstract. The first Systems Engineering Research Center (SERC) Artificial Intelligence (AI) and Autonomy Re-search Roadmap was developed in 2020 and published in the first quarter 2021 special INSIGHT issue on Systems Engineering and AI. This roadmap development was heavily informed by the INCOSE Future of Systems Engineering (FuSE) initiatives. Following on in 2020, INCOSE and the SERC collaborated with the Association for Advancement of AI (AAAI) to execute two workshops entitled “AI meets Systems Engineering.” These resulted in version two of the roadmap which was published as an introductory chapter to the book “Systems Engineering and Artificial Intelligence.” In 2020 through 2023 the SERC hosted four SE4AI/AI4SE workshops with the U.S. Army that have further informed research and application at the intersection of AI and SE. This paper presents the updated version of the roadmap resulting from en-gagement across those four workshops. It is provided as a means to inform the SE community of the critical research needs and related applications emerging at the intersection of AI and SE.

Paper#487

Towards a Systems Engineering Ontology Stack

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Keywords. semantic web technologies;ontology;digital engineering;verification;education

Topics. 1. Academia (curricula, course life cycle, etc.); 3.4. Information Management Process; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Semantic Web Technologies (SWTs) provide an approach to the structuring and understanding of data. SWTs utilize ontologies, reasoners, and query languages to structure existing knowledge, validate knowledge, and infer new knowledge. Ontologies in particular play a central role in enabling reusability and interoperability between domains. A common way to organize ontologies and their dependencies is in a layered ontology stack. These layers often in-corporate top-level, core and domain ontologies. Libraries of standard instances can also be used. Federating the conceptualization of a domain across upper- and lower-level ontologies improves the reusability of higher-level terminology in other domains, and therefore improves interoperability between them. The University of XXXXX Ontology Stack (UXOS) is a layered, modular ontology stack that has been developed to support digital engineering activities at the University of XXXXX. It is based on the Basic Formal Ontology (BFO), and currently comprises five core ontologies and 12 domain ontologies. The UXOS reuses existing ontologies and standards wherever possible. The core ontologies, for example, are based on the Common Core Ontologies, developed at CUBRC, and the Provenance Notation (PROV-N), a W3C standard. Domain ontologies include the System Architecture Ontology, based on ISO 42010, and the Orbits and Trajectories Ontology, based on CUBRC's Space Object Ontology. In this paper, we report on the development of the UXOS, present examples of how it has been used to support digital engineering research, discuss the challenges of integrating ontologies from multiple sources into a cohesive stack, and highlight topics of interest for future research.

Paper#148

Traceability – A vision for now and tomorrow

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Keywords. Traceability;Systems Engineering;Configuration Management;INCOSE Vision 2035

Topics. 20. Industry 4.0 & Society 5.0; 3.2. Configuration Management; 3.7. Project Planning, Project Assessment, and/or Project Control;

Abstract. Traceability has been addressed in the past from the perspective of relationships between the digital artifacts within the data and the information model of the system of interest (SoI) being developed. This paper enhances this view from both a systems engineering (SE) and a configuration management (CM) perspective. The paper looks at what traceability is today and how it can help systems engineering (SE) practitioners meet future needs to realize the INCOSE Vision 2035 and satisfy all needs and requirements for a SoI, including compliance with standards and regulatory organizations. Provenance and pedigree are two aspects discussed of how traceability enhances the management of digital artifacts from a CM point of view. This paper provides a vision of how traceability can aid project management and systems engineering practitioners to develop quality products that deliver what is needed, within cost and schedule and with the needed quality.

Paper#331

Usage of AI within the INCOSE Technical Process

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Keywords. Artificial Intelligence;Product Development Process;INCOSE Technical Process;Customer Need Identification;Architecture Definition

Topics. 2.4. System Architecture/Design Definition; 5.11 Artificial Intelligence, Machine Learning;

Abstract. The purpose of the research described herein is to analyze the use of AI platforms by a user implementing a generic Product Development Process (PDP) mapped onto the INCOSE Technical Process (ITP) and to identify the advantages and disadvantages. The team's original work on a previously finished project, which followed the PDP without using AI tools, served as a crucial benchmark for conducting a comparative analysis with responses from the AI platform. It was found that only some of the stages of the ITP allow for effective template prompts. Much of the useful work requires an open dialog with the AI platform, not a plug-and-play approach. The wording is important for each prompt, so the user must under-stand the aspects of the problem they are trying to solve. Depending on the prompts, available platforms can vary greatly. ChatGPT and Bing provide very different results based on similar or identical responses. Although there was a smaller sample size observed, Bing seems to misinterpret the intent of questions and bases its responses on information that can be cited. In contrast, ChatGPT responds in a more "human" manner that seems to be correct but must be reviewed for accuracy. While AI platforms have comparable responses, the output depends heavily on the prompt context. Evaluating the AI platform performance is difficult because the AI platform response (output) and the prompt inserted by the user (input) are not mutually exclusive. The team found that AI can be more useful in customer needs definition and stakeholder identification, and less effective in concept selection and search internally steps. The recommendation is to employ AI as a supplement to the ITP rather than an exclusive contributor. As technology continues to advance, we can expect to see new applications emerge, and AI's impact likely will be significant.

Paper#516

Using VR to Validate and Visualize MBSE-Designed Interfaces

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Keywords. MBSE;VR;Interface;Validation

Topics. 2.5. System Integration; 2.6. Verification/Validation; 5.3. MBSE; 6. Defense;

Abstract. Several unique challenges arise in the new field of integration between Model-Based Systems En-gineering (MBSE) models and game-based digital twin visualizations. First, no known standardized interfaces between the MBSE model and game engine visualization are defined, which can lead to custom or stove-piped solutions. Additionally, visualizing digital twin models in true to life scale is insufficient with typical desktop computers. The Bi-Directional Interface Requirements Operational System Test (BIFROST) prototype, funded by the US Army Program Executive Office (PEO) Avia-tion, seeks to address these challenges.Progress of the BIFROST prototype is covered in the paper. The prototype aims to determine the feasibility and challenges of validating interfaces through visualizing changes to an MBSE model in a 3D game engine. Research was performed to visualize part of an uncrewed aircraft system ground control station in 3D using the Unity game engine. A Mission Control Architecture MBSE model, developed by PEO Aviation, is used to drive the digital twin of the ground control station through a set of virtual reality (VR) controls. Users can visualize, analyze, and test the human-machine interaction of the 3D models in VR prior to real-world system changes. This paper presents the recommended interfaces between the MBSE model and 3D engine, lessons learned, and future research areas.

Paper#168

When Moving Backward Means Moving Forward – Educating Systems Engineers in Designerly Ways of Thinking

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Keywords. Design thinking;Education;Concept development

Topics. 1. Academia (curricula, course life cycle, etc.); 2.4. System Architecture/Design Definition; 5.9. Teaching and Training;

Abstract. Systems Engineering as a discipline provides many tools for managing complexity and reducing risks. However, these tools come with drawbacks when ideating new product concepts in early lifecycle phases when the problem and solutions spaces are open. This paper suggests that methods from the Design field have a complementing role early in the systems lifecycle, but that those methods need to be accompanied by a different way of approaching problems, something that takes time to learn. We present experience from a hybrid university course where regular students were mixed with professional systems engineers for more rapid development of design method experience in both groups.

Presentations

Presentation#70

"See it to Believe It" - MBSE Driven Next-Generation Simulation

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Keywords. digital twin;Model Based System Engineering (MBSE);visualization technologies;authoritative source of truth;specifications;simulation;SysML;Unified Architecture Framework (UAF);simulation based validation

Topics. 18. Service Systems; 2.6. Verification/Validation; 3.3. Decision Analysis and/or Decision Management; 5.4. Modeling/Simulation/Analysis; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Mini AbstractWe view digital twins as living companions to systems, able to simulate behavior when key parameters are modified and able to present this behavior to the user in a comprehensible manner. We demonstrate how to pair MBSE models with compelling visualization technologies to produce useful digital twins. Further, we describe an ontology for an authoritative source of truth used to connect the various tools and views used in the construction of the digital twin.Full AbstractImplementing simulations earlier in the development process has long been a goal that can now be realized by the introduction of digitally connected tools. MBSE models have been used for years to capture early abstract views of the system of interest using static diagrams and simple tool-based simulations using the underlying meta-data. From inception, a digital instantiation of a system is created in many forms. A simulation model provides an overarching ‘realism’ of the design. This is often referred to as a “digital twin.” Care must be taken to ensure stakeholders and decision makers aren’t fooled by the realistic appearance of the visualization based on the simulation data. Validation is key to ensure the visualization accurately represents the underlying real system of interest. Our digital twins are composed of three layers: specifications, simulation, and visualization. (1) Specifications are created using MBSE models to store the goals, requirements, constraints, and parameters of systems. (2) Simulation provides the software to execute simulated use-cases for the system. (3) Visualization provides views of the real and simulated system to stakeholders. A key underlying enabler is the connections between all three parts providing the information flow to synchronize the digital twin with the system under design and future real systems. As a framework to bound the research, an easy-to-understand scenario was chosen to highlight the digital thread. The system of interest was “Cutting the Cord” which captures the design aspect of replacing paid cable television with an over-the-air (OTA) free local television antenna system. A detailed MBSE model containing all nine types of system modeling language (SysML) diagrams was created and the meta-data used to create the digital thread to the simulation and the visualization.Specification is the beginning of the process. Architecture planning activities identify a new capability or technology gap. The new capability and/or technology gap is captured in an enterprise Unified Architecture Framework (UAF) model using standardized aspects and viewpoints. Next, the model elements created in the UAF model are used as technology anchor points to create the proof-of-concept SysML model further defining and describing alternative designs supporting solution optimization. The UAF and SysML models are configuration managed and connected in a cloud-based modeling eco-system. A key aspect of design is establishing whether the simulation captures the fundamental features of the system environment and elicits behaviors of sufficient fidelity to provide actionable information for the use cases. Simulation activities are created in parallel and connected with the modeling activity with a continual feedback loop significantly shortening development. Once a minimum viable product is achieved, the simulation undergoes a review process which validates both the models and simulation for initial use. Visualization provides a means for a decision maker to understand the impact of high-level requirements on architectural layers and ultimately, the end user. This type of analysis during proof-of-concept activities provides the opportunity to run multiple scenarios to optimize

solutioning based on tunable variables. Simulation-based validation includes providing a visualization that subject matter experts, stakeholders, and decision makers can experience in multiple formats supporting “what if” scenario experiences while providing the necessary feedback loop to further enhance the simulation.The digital twin is only as valuable as the accuracy of its information for the real system design. Maintaining coherent data connections between the digital twin and the system is critical. Data connections take various forms including automated hardware application programming interfaces, enterprise database access, and periodic manual reporting processes. The fidelity and timeliness of the connections is dependent on the use cases for which the digital twin is utilized. Using the digital twins created during this process provides the benchmark for evidence-based methods in establishing the fidelity and validity of the simulation. Validation of the three-step process is imperative since real decisions will be made based on the simulation outcomes. It is important to employ multiple means of comparing model performance against real data, including statistical testing. Verification, which is the task of determining if the implementation of a model has been done correctly, is another key factor that must be considered. Verification data must be generated at various points in the model for comparison of expected values. SummaryUsing validated digital twins helps both the practitioners and decision makers visually decompose complex systems into constituent parts and analyze end-to-end capabilities. This flexible, iterative approach is scalable, reusable, and provides a continuous feedback mechanism allowing information gained during the design process to be quickly integrated. Using digital twins helps to identify and resolve capability gaps and quantify impacts of alternatives based on validated and trusted data.

Presentation#223

A Comprehensive Risk Assessment Methodology for Extended Product Lifecycles

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Keywords. Risk Management;Model-based Systems Engineering;Digital Engineering;Defense Acquisitions;Mission Readiness

Topics. 2. Aerospace; 3. Automotive; 3.3. Decision Analysis and/or Decision Management; 3.9. Risk and Opportunity Management; 5.3. MBSE; 6. Defense;

Abstract. Overview. This presentation will describe an approach to characterizing risk in a manner consistent with both acquisition and operational project management decision-making, and normalizing communications between the Operations and Acquisition communities within the US Department of Defense (DoD). Management of risk to warfighter operations has historically been decoupled from acquisition risk management, yet these acquisition programs are launched specifically to develop capabilities which are directly related to the warfighter’s ability to successfully conduct missions. The purpose for this effort is to specify that relationship in a manner that is easily understood and scalable across multiple programs so that risks in acquisitions that pose significant impact to mission readiness are identified and can be mitigated earlier in the lifecycle. In turn, this will enable capabilities critical to meeting future threats to be delivered to the warfighter more effectively and with greater speed. Benefits to the acquisition community include improved portfolio management to meet the most critical needs based on an evolving operational landscape. Benefits to the operational community include improved and defensible strategizing and planning based on projected capabilities available from an evolving acquisition landscape. Problem. There are elements of risk inherent in every product development lifecycle, particularly with complex systems where the time to design and deploy can stretch over several years. Engineers and program managers work constantly to identify risks to project success at every stage of a product’s lifecycle. Similarly, the intended users of a new system must manage their ability to conduct their efforts in an everchanging environment with or without the assistance of

the new system until the day it is delivered. Even under the best of circumstances, the factors that affect a product's ultimate success can change significantly between the time it was originally conceived and the time it is delivered. While creating and deploying defense systems, much of the discussion regarding project risks focuses on the acquisition perspective. However, the Operations community (i.e., the users of the systems) are more concerned with being able to complete their missions. Their risks are largely driven by mission readiness (i.e., their ability to deploy personnel, systems, and support resources at the time they are needed) and the constant changes to the operational environment driven by their adversaries. Over the years that are required to define, develop, produce, and deploy a new defense system, the threat environment can change significantly. Risks to acquisition programs translate to potential capability and capacity gaps. Those gaps directly affect the ability of the Operations community to complete their missions. Conversely, as the threat environment evolves, so could the system's capability requirements. The impacts of these risks to the delivery of the system necessitates a constant, two-way conversation. Approach & Methods. With the advent of Model Based System Engineering (MBSE) the capability now exists to better integrate risk modeling and risk management into multiple domains, using system models and integrated model-based testing. By modeling based on domain-specific ontologies for risk in acquisition and risk in mission engineering, the two may then be related through a standardized architecture framework. Such frameworks already relate the things being acquired to the operational context in which they are used via mission engineering threads. A risk profile and library in the Systems Modeling Language (SysML) facilitates the modeling approach. This approach enables dynamic updating in both directions: mission risks update as acquisition information updates, and acquisition requirements and priorities update as operational threats change. Impact. Defense System Acquisitions and Operations are not the only communities where this capability would be useful. Normalizing risks across the research & development, supply chain, manufacturing, test & evaluation, sustainment, and other disciplines would provide a comprehensive understanding of risks associated with a particular product line. Furthermore, this capability has the potential to help decision makers understand risks holistically across multiple product lines, programs, portfolios as well as entire enterprises. When applied appropriately, this would represent a multi-dimensional spectrum of risk as a function of time; applying analysis could then better inform decision-making. Any industry that exhibits long product lifecycles (e.g., automotive, aerospace, energy, etc.) could find substantial benefit in utilizing this methodology to manage capital investment strategies across their portfolios. This presentation outlines the Digital Engineering approach and MBSE methods used to identify issues in the development of a fictional spacecraft throughout the early stages of its lifecycle through delivery. This example illustrates some of the common issues that arise across a product's lifecycle and how the corresponding risks can be captured, communicated, and mitigated across the spectrum of stakeholders. Presenter Bio. Mr. Jason Stroup has 20+ years of professional experience as a Systems Engineer and Program Manager in the Energy, Defense and Aerospace industries. Mr. Stroup is currently serving as a Research Program Manager at Georgia Tech Research Institute (GTRI) where he supports several complex development programs. Mr. Stroup has completed master's degrees in both Electrical Engineering and Systems Engineering and is as certified Project Management Professional (PMP).

Presentation#172

A flexible MBSE SysML Profile for effective Test & Evaluation Planning and Integration: Approach and Lessons from the Real World

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Keywords. Test;verification;validation;MBSE;Architecture

Topics. 2. Aerospace; 2.4. System Architecture/Design Definition; 2.6. Verification/Validation; 3. Automotive; 4. Biomed/Healthcare/Social Services; 5.5. Processes;

Abstract. A complete Test and Evaluation (T&E) process extends beyond general verification and validation (V&V) to assess the performance, reliability, and safety of systems, products, or technologies, and can include evaluation of behavior as well as performance for deployment, operations, & maintenance. By systematically examining and validating the system under test, T&E helps identify flaws, limitations, or areas for improvement, enabling design updates to be made as early as possible in the lifecycle, reducing cost and improving performance. Critical to T&E is the design and execution of experiments, simulations, and assessments to collect relevant data and evaluate the product functionality, reliability, and effectiveness. While MBSE and model-based verification and validation (V&V) are primary components of a digital engineering approach, these digital methods often focus on modelling simulation and analysis without encompassing a complete T&E process. Structuring integrated product teams to include T&E/V&V from the outset of a program is often cited as critical to closing this gap.We present that this gap can be closed through use of a novel SysML model architecture that addresses the full scope of T&E from initial planning and design of experiments through execution and data reduction and measures of effectiveness. The approach integrates with common aspects of MBSE & model-based V&V, while emphasizing the design architecture of the T&E process itself, through use of a T&E specific SysML profile and stereotypes that can be used effectively within a digital ecosystem. The approach presented is a model-based method to augment or replace the classical document centric approach to T&E through a model-based planning and reporting architecture for T&E. The Object-Oriented Systems Engineering Methodology (OOSEM) and Object Oriented (OO) concepts of “is a” and “has a” are leveraged in this approach: A Test Plan has test events. Test Events have Test Procedures. Test Procedures are (is a) Test Cases. Test Cases require (has a) tools (software &/or hardware) and people to execute them. Each of these Test-X items have metadata that can be organized, leveraged, and measured for effectiveness before, during, and after test. The approach uses SysML constructs of containment, aggregation and inheritance, through T&E specific stereotypes and an OO approach to define a re-usable and scalable architecture for model-based planning and execution of T&E. Examples from use of the approach on real world programs are included.The presentation will show the rationale behind the development of a T&E SysML Profile and stereotypes and how this was derived from real world programs. The stereotypes are used to build a test architecture with relevant traceability between Requirements, Test Plans, Test Events, Test Procedures, Test Cases, Test Results, and Test Reports. The approach is tool agnostic. Examples presented are constructed in Cameo SysML. We show that use of the presented approach has not only made T&E more effective and integrated, but also resulted in improved requirements capture as T&E metadata is defined earlier than is typically done for system requirements review (SRR) criteria. Two examples based on usage of the approach are presented with lessons learned from the real world. One example from a mixed hardware/software development program, and the other from a program that used Agile to develop a software intensive system.

Presentation#530

A Model-based approach to architecting and evaluating autonomous network-centric weapon systems: A UAV and Small Satellite System-of-Systems Exemplar

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Keywords. Unmanned Aerial Vehicle;Satellites;SWARN;Network-Centric Warfare;Weapon Systems

Topics. 1.6. Systems Thinking; 2. Aerospace; 2.1. Business or Mission Analysis; 5.3. MBSE; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 6. Defense;

Abstract. The need to limit the number of warfighters on the battlefield has led to an increase in research and application of unmanned robotic vehicles (URV) for battlespace operations and missions. Increasing the effectiveness, survivability and suitability of these URV systems (e.g., Unmanned Aerial Vehicles (UAV)) for successful military operations, requires an effective communication architecture that exhibits network-centric warfare capabilities. As an architectural concept for autonomous weapon systems operating collaboratively, and without an active human-in-the-loop, Network-Centric Warfare (NCW) serves as an enabler for the combination of tactics, techniques, and procedures that are employed by a URV weapon System-of-Systems (SoS) to create a decisive warfighting advantage for desired mission objective. NCW also known as Net-Centric Operations (NCO) is an information superiority-enabled concept of operations supporting a multidomain configuration that includes manned and unmanned platforms, weapons, infantry, and special operations amongst others. In order to achieve warfighting capability as an NCW weapon system, traditional NCW architecture concepts will need to be adapted to accommodate autonomous-only sets of weapon systems operating as an intelligent network of nodes. Any adaptation of NCW architecture for autonomous weapon systems must begin with the identification of stakeholder needs and requirements. Thus, the stakeholder needs directly help to identify the concept of operations and mission objectives.It is important to note that a majority of current approaches to the design of swarm URV architectures as observed in literature are examined from the perspective of specific engineering disciplines. This includes a focus on concepts such as communication network infrastructure, command and control architectures, sensors, and vehicle platforms. However, a major drawback to this development approach is the absence of a systematic and disciplined system development approach which focuses on the mission and operational contexts of the NCW SoS. A lack of mission conceptualization, operational and system contextualization will obscure gaps and vulnerabilities in the NCW architecture, and significantly impact the suitability of the autonomous weapon SoS configuration to achieve mission objectives.For this reason, the work outlined in this presentation addresses the architectural development and evaluation of a multidomain configuration of small satellites systems and a suite of autonomous heterogeneous UAVs collaborating as a multi-layered NCW weapon SoS for deployment in complex and highly specialized battlespace scenario. A model-based systems engineering approach (MBSE) utilizing the unified architecture framework (UAF) and modeling language is used to specify and define various intra- and inter-layer architecture alternatives and concept of operations for the multi-layered NCW weapon SoS architecture. In addition, an architectural trade study analysis is performed to evaluate multiple multi-layered NCW architecture configurations based on a set of defined measures of performance (MOP) and Measures of effectiveness (MOE) metrics regarding multiple attributes (i.e., networks, C2ISR, payload capability, and operational), and their suitability for specific notionally defined battlespace special operation scenario.

Presentation#191

A Systems Engineering Approach To An Integrated Design Controls and Risk Management Framework in Medical Device Development

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Keywords. Design Controls;Risk Management;Medical Device Product Development

Topics. 1.6. Systems Thinking; 2.3. Needs and Requirements Definition; 3.5. Technical Leadership; 3.8. Quality Management Process; 4. Biomed/Healthcare/Social Services; 5.5. Processes;

Abstract. Medical device development is regulated by various regulatory bodies and the common theme across all the agencies is the application of a risk based system prioritizing product development process with patient safety at its center. Among the diverse elements involved in this process design controls and risk management hold pivotal roles in ensuring the success of medical device development.ISO 13485 (Quality Management for Medical Device Companies) requires that “Organizations apply a risk based approach to the control of appropriate processes needed for the quality management system”. A considerable number of medical device companies face the challenge of implementing a risk-based system and in particular for the design control process. The term design control process refers to the systematic translation of requirements into a realized product through a phased approach. The design control process primarily consists of five phases that include User Needs, Design Inputs, Design Outputs, Design Verification and Design Validation. All these elements closely interface with the risk management process as in, the risk associated with the use of the medical device influences the actions for design requirements and product specifications. A considerable portion of this process is not automated and relies heavily on manual input by the users/team to establish the appropriate connections. In addition, the complexity of medical devices and project structures often leads design and risk management teams to operate in silos, executing design controls and risk management activities independently. While effective within their boundaries, this approach poses challenges during design reviews, resulting in misalignment with design requirements and unexpected risk outcomes which may impact patient/user safety after product release. An example for this could include that in most instances a reactive risk approach is opted in product development process wherein, design inputs criticality is often reconciled with the outcomes of risk management at later stages in product development leading to discrepancies in identifying the criticality level for a design requirement. This failure further cascades into device manufacturing as the product specification criticalities are misaligned with design requirement criticalities. The above can be an outcome of following a passive approach towards including risk management in the design process. This can cost the development teams significant delays in their project schedules and can bring unforseen cost to the project.The proposed presentation addresses a system engineering challenge in medical device development by proposing a proactive risk-based system through the implementation of an integrated framework for design controls and risk management. Scope of this presentation is specific in harmonizing design controls and risk management subsystems and in particular to address two key challenges that significantly contribute to the success in a product development process. These include the identification of critical design requirements and determination of critical product specifications and how they relate to the risk posed by the use of the medical device.Requirements definition is a crucial phase in product development process and understanding the importance of critical product specifications is of paramount value as they exert influence on the selection of design choices in terms of features and risk controls that improve safety, reliability and efficacy of a product. Moreover, misalignment in requirement criticality can drive inaccurate downstream manufacturing decisions which may result in a direct impact on cost/time and safety of a medical device. The intent is to propose a proactive risk based system in design wherein, the criticality of a design requirement should have a trace to the risk analysis method (Ex FMEA/FTA) by means of a risk/design control trace matrix. This link is established early in design and therefore risk estimation is a constant input to the design requirement development. This proactive method ensures that design analysis and risk analysis are not two separate entities but function as one element to influence and drive better design choices with patient safety as its nucleus. The desired objective of the risk

control trace is to establish a continuous link between two independent systems (i.e. design requirements and risk management) in order to identify what is the highest criticality associated with a design requirement. The establishment of this trace significantly reduces the effort of a manual reconciliation to determine highest criticality for a design requirement which generally occurs prior to one of the design reviews. Moreover, this aids in determining the critical product specifications using a risk based approach. An additional key benefit with this method also includes the determination of the appropriate design verification/reliability test strategies (i.e. confidence/reliability levels) based on risk level/severity.The presentation provides an integrated process flow diagram, driven by a risk based approach between the two systems and depicting the connections and the data flow required to enable a successful integration. The desired outcome is to propose a map highlighting the key components of a risk based approach followed by an illustration depicting the implementation of the technique. The intent of this topic is to propose a systems thinking mindset with patient safety as its core element, such that it can be adopted and scaled to any medical device product development process and thereby enable enhanced efficiencies early in the medical device development process.The presentation will additionally touch on the best practices to be followed when performing early stage risk assessment and considerations required to assess criticality of applicable design requirements. This is followed by a discussion on the efficacy of the method in performing impact assessments for a future design change in product lifecycle.

Presentation#573

A Systems Engineering Approach to Driving the 'Right' Organizational Culture and Life at the 'Right' Pace

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Keywords. Systems Engineering;Systems Engineering Process;Self-leadership;Leadership Theory;Authentic Leadership;Culture of Inquiry;Culture of Reflection;Culture of Innovation

Topics. 1.6. Systems Thinking; 2. Aerospace; 22. Social/Sociotechnical and Economic Systems; 3.3. Decision Analysis and/or Decision Management; 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.);

Abstract. As systems engineering leaders, we often feel pulled in multiple directions by our desire or a call to assist and lead in multiple areas of life: work, school, non-profit organizations, family, and our communities. How should we effectively manage it all?Excellence in our organizations and lives hinges upon an individual's ability to drive towards goals, where execution quality leans upon leadership frameworks and processes that unlock timely strategic decision-making and critical thinking capabilities. The systems engineering process and systems thinking methodologies can invoke self-management and leadership practices that open equitable innovation and success pathways across life and work.The presenters will walk through their case studies (spanning the aerospace and defense industry and engineering nonprofits) leveraging systems engineering processes and systems thinking methodologies as a methodology driving equitable success across life and work that foster thought leadership, innovation, collaboration, and positive results at work, in our communities, with our families, and within ourselves. We all want to "win" in these domains, which requires a teaming dynamic and self-management system that fosters the right culture-driving behaviors, habits, and designs that create the right future process, responses, and systems across each domain.After attending, attendees should be able to leverage the systems engineering process and systems thinking tools to identify what is and is not working to help systems engineering leaders thrive in their careers while driving an organizational culture that fosters innovation and measurable progress.The presenters will review applied research findings across aerospace engineering & tech organizations, universities, and nonprofit associations, which has led to a reusable and early framework that will be shared with attendees.

Presentation#494

A Value-Focused Thinking Approach to Assessing Container on Barge Readiness within Maritime Transportation Systems

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Keywords. Maritime transportation systems;Container on Barge;Readiness assessment;Value-focused thinking;Scorecard

Topics. 13. Maritime (surface and sub-surface); 3.3. Decision Analysis and/or Decision Management; 3.6. Measurement and Metrics;

Abstract. Container on Barge (COB) utilizes barges to transport shipping containers between seaports and inland ports via navigable inland waterways. Rapid development of COB in Asia and Europe has provided regional benefits including lower shipping costs, reduced emissions, and land-side congestion mitigation. However, COB shipping has been slow to develop in other countries, partly due to inadequate multimodal supply chain coordination, poor infrastructure conditions, and limited governmental support. Sustaining a cost-effective, efficient, and environmentally-friendly transportation system within the United States requires reduced fuel consumption, lower freight transport costs, decreased transportation emissions, and congestion mitigation. Given its demonstrated benefits as part of the Asian and European transportation systems, COB has strong potential to be integrated into future transportation systems within the United States and other navigable inland waterway systems that have not yet capitalized on these benefits. Motivated by this demonstrated potential, the team has developed a COB Readiness Assessment Scorecard to aid systems engineers and other maritime transportation stakeholders in assessing the feasibility of a maritime port to initiate COB development. The Scorecard, built upon the framework of value-focused thinking (VFT) developed in 1992 by Ralph Keeney, allows transportation system engineers and other decision-makers to: 1) broaden the decision contexts for measuring COB transportation readiness, 2) identify success factors that can assist a port terminal in launching COB successfully and generate the associated measurements for these factors, and 3) enhance decision-maker and stakeholder thinking towards developing COB transportation solutions to generate better COB development plans. Furthermore, the Value Hierarchy built into the Scorecard provides a framework to search for and identify engineering challenges ahead of the COB development planning phase. By integrating the VFT philosophy into the scorecard design, the essential attributes and hidden aspects of COB development success are identified. Once the COB Readiness Assessment Scorecard identifies advantages and weakness of COB readiness, system engineers can generate strategies to amplify advantages and improve weaker conditions for their ports to increase readiness for COB development. This presentation will inform an overall understanding of COB development requirements, present the COB Readiness Assessment Scorecard as a practical readiness assessment tool for ports to improve the associated decision process, and assist transportation system engineers in understanding the benefits of COB within the global supply chain. To demonstrate the application of the Scorecard, a case analysis of the Port of Shanghai will be presented along with an overall assessment of nine global COB ports in total.The presenter, Heather Nachtmann, is director of the Maritime Transportation Research and Education Center, a U.S. Department of Transportation University Transportation Center, and Professor of Industrial Engineering at the University of Arkansas. She holds the Earl J. and Lillian P. Dyess Endowed Chair in Engineering. Dr. Nachtmann has conducted research in inland waterway operations for more than twenty years and led over seventeen million dollars in research grants as principal investigator. She is a Fellow of the American Society for Engineering Management and the Institute of Industrial and Systems Engineers and a member of the Arkansas Department of Transportation Research Advisory Council and National Science Foundation Engineering Research Visioning Alliance Standing Council.

Presentation#6

Advancing Transdisciplinarity from Concept to Practice

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Keywords. transdisciplinarity;systems science;complexity

Topics. 1.1. Complexity; 1.5. Systems Science; 10. Environmental Systems & Sustainability; 20. Industry 4.0 & Society 5.0; 22. Social/Sociotechnical and Economic Systems; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. Systems science uses the concept of transdisciplinarity as a fundamental approach to exploring the nature of systems and better our understanding of how to develop systemic solutions. To recognize the foundational contributions of systems science to the practice of systems engineering (SE), the definition of a system was updated to include TD as fundamental to the SE practice: “Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.” This presentation will discuss how systems science can help systems engineers become more transdisciplinary in their practice by focusing on outcomes and how its processes, methods, and tools can support achieving a desired outcome. There is a challenge in defining and understanding the Transdisciplinarity (TD) concept due to several facts: (a) definitions vary among scholars and practitioners, (b) it is not yet defined in most dictionaries, (c) it is often (mis)used interchangeably with interdisciplinarity, and (d) it is sometimes defined metaphorically. The “trans-“ term means “across, beyond, though, to the other side.” The term “discipline” means “(1) an organized field of knowledge; (2) a set of rules.”In academia, there are several key characteristics of the TD research paradigm: problem-driven, action-oriented, highly collaborative, integrative, and socially relevant. These characteristics all point towards achieving a desired outcome instead of focusing on processes, tools, and methods. TD’s focus on achieving an outcome arises in response to four major concerns: a) A growing concern about a host of urgent, complex, real-world problems, b) The need to seek solutions to these problems, c) A realization that contemporary science can neither properly understand nor address these urgent problems and d) There is a need for a more democratic governance of knowledge production.Transdisciplinarity is a new way of conducting research in which multiple contributors and stakeholders, both from within and outside academia, work together to identify specific real-world problems and find solutions to these problems. Here are typical examples of complex, urgent, real-world problems that TD aims to address:Real-world problems ======== Potential outcomesEnvironmental pollution ======== Clean energy technology; carbon sequestrationHuman rights violations ======== Equitable society; accurate enforcementSpread of antibiotic resistance ======== Reduce the impact of bacteria on humans; ethical and fair use of antibiotics.Nuclear insecurity ======== Nuclear materials/waste traceabilityUnsustainable use of resources ======== Shift economic benefits to reward sustainable use of resources.Health risks from new technologies ======== Advanced modeling to understand health risks before releasing “The man who wears the shoe knows best that it pinches and where it pinches, even if the expert shoemaker is the best judge of how the trouble is to be remedied.” ‒ John Dewey, 1927It is helpful to compare the TD approach to its “kissing cousin”: interdisciplinarity. Two well-known interdisciplinary fields of research are paleontology and biomimicry. Here is a way to think about interdisciplinarity from the perspective of the field of academic research: Disciplines A, B and C agree upon a common research question, however they each conduct the research within their own discipline with some slight overlap. In contrast, the TD approach can be illustrated like this: The various disciplines work with non-academic participants to together define the "real-world problem". From this both groups work together to formulated an integrated knowledge set. Then, together they come up with the integrated solution that addresses the various aspects of the problem as defined by the integrate team of disciplines and non-academic participants. There are successful examples of TD use in the real world. An example of a TD project is the development of the “tissue chip” for a drug screening project. Notice the primary characteristics of this project that indicate its TD nature:- project is problem driven, focusing on addressing the problem of drug failure in clinical trials- they are action oriented, developing 3-D human tissue chips to predict drug safety in humans- highly collaborative, with collaboration between NIH, DARP and FDA- integrative by combining academic knowledge with non-academic knowledge- socially relevant, translating scientific discoveries to the real world so they can more ready be applied to addressing social problems.“We envisage

that SE can be transformed into a truly transdisciplinary discipline – a foundational meta-discipline that supports and enables collaboration between all the disciplines that should be involved in conceiving, building, using, and evolving a system so that it will continue to be successful and fit for purpose as time passes.” H. Sillitto et al., ‘Envisioning Systems Engineering as a Transdisciplinary Venture,’ INCOSE International Symposium, vol. 28, no. 1, pp. 995–1011, 2018However, we lack a reference approach to guide TD efforts. To begin exploring how to develop a TD guide, we must distinguish between what TD outcomes and SE processes, methods, and tools focus on. TD deals with what Prof. Mike Jackson calls general complexity, while SE processes, methods, and tools are designed to deal with restricted complexity.Multi-disciplinarity, interdisciplinarity, and SE processes, methods, and tools are designed to deal with restricted complexity. These approaches largely depend on systemic reductionistic arguments and are informed by the scientific method and traditional engineering disciplines. This approach has served the SE discipline well but often creates a significant gap between ontological and cognitive complexities. Through this approach, we are forced to reduce the complexity of our designs by ignoring real-world aspects and limiting the scope of applications. On the other hand, transdisciplinarity deals with general complexity as it embraces complex, urgent, real-world problems that require focusing on outcomes. As a result, TD depends on using systemic holistic arguments to help bridge the gap between ontological and cognitive complexities. The ontological complexity of complex, urgent, real-world problems is such that traditional SE approaches are ill-equipped to handle them, resulting in inadequate cognitive models that limit our ability to comprehend them and pursue the attainment of a desired outcome. We then need to focus on developing approaches to integrate SE processes, methods, and tools toward attaining desired outcomes that resolve complex, urgent, real-world problems. This is the challenge for the systems science working group and for INCOSE.“Transdisciplinarity is not a single form of knowledge but a dialogue of forms.” ─ Kate Maguire, 2015See attached file for some informative graphics that enhance understanding of this extended abstract.

Presentation#380

AI-Enhanced Autonomous Formation Flying - Definition of a Mission-driven and Safety-critical Software Development Environment

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Keywords. Autonomy;Mission;Safety-Critical Systems;AI/ML-Enabled Subsystems;Airworthiness;Certification;MBSE;Safety;Simulation

Topics. 14. Autonomous Systems; 2. Aerospace; 4.6. System Safety; 5.11 Artificial Intelligence, Machine Learning; 5.3. MBSE; 6. Defense;

Abstract. The challenges posed by the introduction of autonomy in mission-critical and safety-critical aeronautics applications are driving a strong shift toward the utilization of Artificial Intelligence/Machine Learning (AI/ML)-based techniques. These applications must function in complex and uncertain environments, support autonomous and pilot-assistance systems, ensure system safety, and facilitate the design of efficient system performance, such as energy-aware trajectories or area-coverage maximization. Examples of such applications include formation flying and teaming, man-unmanned teaming, collision avoidance, last-mile delivery, urban air mobility (UAM) and aerial infrastructure inspection.Standardization bodies, such as SAE and EUROCAE, have explicitly identified, in the "Artificial Intelligence in Aeronautical Systems: Statement of Concerns," the necessity to produce a standard supporting the integration of AI/ML-enabled sub-systems into safety-critical aeronautics software, hardware, and system development.To address these development and

regulatory challenges, this session introduces an Autonomy Model-Based Systems Engineering (MBSE) Framework, heavily reliant on simulation, for developing and validating mission and safety-critical applications, including AI/ML-based constituents within a safety-critical function implemented in a model-based environment. This framework enables users to build digital models, covering mission and vehicle behavior, and lays down the foundations of a digital training and validation environment for autonomous systems, that can provide early and accurate feedback to autonomous systems developers. Furthermore, this framework aims at complying with emerging AI-based safety standards such as the future SAE ARP6983.Users of the Autonomy Framework include both system developers and system operators, who can build and use digital and executable reference models covering mission and vehicle behavior. This enables the inclusion of operational experience into a digital validation environment that system developers can leverage to assess their design and implementation. Reciprocally, simulating the system in an actual mission environment allows system operators to better understand system behavior and provide earlier and more accurate feedback to system developers.In this presentation, we will go over the main aspects of the Autonomy MBSE Framework, before illustrating each step of this approach with a concrete Fixed Wing Formation Flying Case Study.Autonomy MBSE Framework:In the initial stages of the system development cycle, standard Systems Engineering and Safety tasks are being performed:- Functional Hazard Assessment (FHA)- System Architecture Definition- Preliminary System Safety Assessment (PSSA)- Operational Design Domain (OOD) and Scenario Mission Definition, to train an application that is typically made of traditionally developed and AI/ML constituentsThe AI/ML training process involves simulating these scenarios within the framework, varying their parameters according to their probability distribution. This process accommodates supervised learning for perception and reinforcement learning for decision-making. Sensitivity and robustness analyses are then carried out to further characterize the resulting neural networks.Once trained and validated, the AI/ML constituents are integrated within the overall application design model, and simulation is used again to conduct reliability analysis and estimate the probability of failure of the mission. In the case where system performance and/or safety objectives of the application over its Operational Design Domain (ODD) are not met, the recommended approach is to trigger further training or redesign activities if necessary. Finally, the embedded code is generated from the software model using a certified code generator.Overall, the framework facilitates AI/ML-based decision-making for autonomous systems in complex and uncertain environments, supporting both autonomous and pilot-assistance systems while ensuring system safety.Fixed Wing Formation Flying Case Study:A Case Study will be presented to demonstrate formation flying (two fixed wing aircraft) executing a series of 90 degree turns at a high speed, following the different steps of the Autonomy MBSE Framework.The functions to be developed include:- Traditional Flight and Engine control for ego aircraft (automatically following the lead aircraft)- AI-based perception software based on camera sensors for ego aircraft calculating position and orientation of lead aircraft- AI-based automated ego aircraft stick agent to achieve formation flying objective (aircraft proximity comprised between 250ft and 500ft)As part of this demo, the use of You Only Look Once (YOLO) v7 algorithm, OpenAI's Proximal Policy Optimization (PPO) from stable-baselines3 and SysML V2 for System Architecture Modeling will be demonstrated.

Presentation#33

All Decisions Are Reconciliations of Inconsistencies: Preparing for the Digital Thread and Machine Learning

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Keywords. Decision-Making;Consistency Management;Digital Thread;Machine Learning;Innovation Ecosystem

Topics. 2. Aerospace; 3.3. Decision Analysis and/or Decision Management; 3.4. Information Management Process; 3.7. Project Planning, Project Assessment, and/or Project Control; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. IntroductionThis presentation characterizes, in an unconventional way, the diverse decisions that occur across system life cycles. The benefits of this framing are that it (1) unifies understanding of the life

cycle, (2) enables the organization to gain from the digital thread, and (3) prepares for machine learning.Industry DomainsImproving performance of innovation and life cycle management is a critical issue across many industries, especially those seeking to improve competitive advantage over commercial, defense, and natural adversaries. This includes mil/aero, biomedical/health care, cybersecurity, consumer products, and other domains. Issues Addressed, and Their ImportanceThe primary issue addressed is improving ability to make timely, quality decisions with managed trust in the information supporting them, and learning from those decisions for future use. That we expect decisions to be made by experienced decision-makers is a hint that merely invoking a digital “source of truth” can be overly simplistic. What is the basis for understanding, planning, and improving the performance of these enterprise and human capabilities? In many cases, just “making the right decision” may omit the importance of urgency. How can we best balance the need to make good choices with the need to make them soon enough? What have we learned from decades of study of capability maturity models, agile methods, reusable product line assets, and related methods? How does uncertainty and group trust figure into this?The secondary issues addressed are laying the application level ground work for the digital thread, learning in general, and ultimately for machine learning, in an integrated reference architecture. All of these have high levels of importance in either current or planned industry programs. Methods, Results, Presentation Take-awaysA descriptive (not prescriptive) reference architecture is used here to describe any enterprise or program as a system of systems in its own right--the configurable Innovation Ecosystem Pattern. It is also known as the INCOSE Agile SE Life Cycle Management (ASELCM) Pattern (Schindel and Dove, 2016). The MBSE Patterns Working Group uses it for several purposes--in this case to introduce the Consistency Stack, appearing in the AIAA Aerospace Digital Thread reference model (AIAA, 2023). It is a core take-away of this presentation, helping enable the successful AIAA-INCOSE-NAFEMs collaboration leading to that reference model. The Consistency Thread: Precursor of the Digital Thread A central historical aspect of all engineering and life cycle management approaches (ISO, 2023) (Walden et al, 2023) is that they wrestle with achieving “consistencies” (by other names) between a collection of pair-wise elements that need to align. A small sample of this long list is:• Is System design consistent with requirements? • Are requirements consistent with stakeholder needs?• Are requirements consistent with experience in similar programs? • Is production consistent with design?• Are requirements consistent with empirical observations?• Is utilization consistent with requirements? • Is design consistent with regulations?• Is system representation consistent with consortia framework?To our knowledge, there has not been a dominant systems community term in wide use for this, and we favor the use of “consistency” (or “inconsistency”) management, noted in (Herzig and Paredis, 2014). Although the term itself is not so widely used, the resulting thread of traced information is widely demanded across numerous domains, including aerospace and automotive APQP and PPAP (SAE, 2016) and medical devices (ISO, 2016). We have termed this the “consistency thread”, as the historical precursor of what is now emerging as the Digital Thread (Schindel, 2022).A Consistency Stack is the collection of consistency types that a program chooses to actively manage, and the processes and technologies (including humans) for doing so. The managed consistency relationships include the dynamical state variables of current consistency as well as consistency uncertainty. We assert that all the life cycle management decisions made about a system are to address “reconciliations” of inconsistencies detected by the consistency stack. The term “reconciliation” is used because, in real projects, detected inconsistencies are not always closed by “correcting” some downstream item (e.g., a system design), to achieve consistency with some upstream item (e.g., a system requirement). In the real world, sometimes “back pressure” results in upstream adjustment, as when a requirement is relaxed or restructured to accommodate design realities. Accordingly, the web of consistencies is viewed as in part elastic, based on time urgencies and other factors, and “reconciliation” best describes the adjustments that are made, both ways. The resulting combination of decisions leads to learned information that is “purchased” through the execution of a project or program—including its late stages as well as early. Once this is understood as a form of learning, it is striking to note how this reconciliation resembles machine deep learning algorithms. (LeCun, Bengio, Hinton, 2015). Much of traditional SE literature tells us what information to capture and validate, as if we were discovering it for the first time. But what about what we already know? Figure 3 integrates the roles played by learned patterns and learning agents, and their relationships to consistency and its management during future use of that learning—whether by human, machine, or hybrid agents. Conclusions and ImplicationsThe figures of this presentation and references suggest a reference architecture that can be used to represent, plan, analyze and integrate the digital thread with current and future organizational learning, optimized to serve the flow of decision-making at the heart of life cycle management. It includes the roles of Consistency Management Agents (human, automated, or hybrid) to (1) detect, and (2) reconcile inconsistencies across the life cycle. It includes the roles of information extracted and distilled (by human, automated, or hybrid agents) as learning to inform future cycles.Figures and References: (Will appear in the presentation)

Presentation#429

An adaptation of the ISO/IEC/IEEE 29110 system engineering process for the development of CubeSats

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Keywords. systems engineering;ECSS;standards;nanosattelites

Topics. 19. Very Small Enterprises; 2. Aerospace; 5.2. Lean Systems Engineering; 5.5. Processes;

Abstract. • Overview of the Topic – Define the SE Challenge of Interest and Its ContextThe objective of this presentation is:i) To share the observation of the need to support SMEs in the NewSpace domain in organizing their system engineering approach during the development of nanosatellites like CubeSats,ii) To present the chosen approach to define a simple, well-guided engineering framework suitable for these companies,iii) To make a proposal for this framework.To address this issue and transform SME practices towards streamlining system engineering processes, our proposal is to rely on a simplified system engineering standard to guide the processes and specialize it to the constraints of the space sector. Regarding the choice of the system engineering standard, orienting towards ISO 29110, designed for use by SMEs to guide system engineering processes, seems pertinent. However, to fully address the considered issue, it is necessary to adapt this generalist standard to consider the specific requirements of the NewSpace sector. Currently, there is no space-adapted standard for NewSpace, although the European Space Agency (ESA) is becoming aware of this issue. Therefore, ECSS standards for satellite development contain over 100 process requirements. It is essential to reduce this set of requirements to a subset of essential requirements for the development of small satellites. The result of this work leads us to propose customizing ISO 29110 by injecting a small number of essential requirements from ECSS-E-ST-10C to ensure minimal compliance with system engineering standards and those of the specific CubeSat sector. This proposal has been tested in ExpleoGroup's projects.• Clearly Identify Specific Related Industries – Explain Why the Problem Is Important and Is Worth Studying Under a SE ApproachToday, the space domain is undergoing significant changes, with the dynamic emergence of NewSpace. However, more than 50% of CubeSat missions fail, mainly due to a lack of mastery over the complexity of systems and system engineering processes. Due to limited human resources, often inexperienced, and extremely restricted budgets, companies developing CubeSats, mainly SMEs, face major obstacles in following system engineering processes as described in standards. A comparison of industry practices against the recommendations of major system engineering standards (such as ISO/IEC/IEEE 15288) and space standards (such as ECSS standards produced by the European Cooperation for Space Standardization) reveals a substantial gap. A survey conducted among NewSpace industrial actors highlights the need and necessity for these actors to evolve their practices for better alignment with standards, gaining control over complexity and reproducibility. These studies underline the need for companies to have a pragmatic and well-guided engineering framework adapted to the dimensions, constraints of their organizations and projects, and the specificities of their industry, NewSpace. We make an initial framework proposal and explain how we developed it. This framework has been deployed in research projects at ExpleoGroup, providing initial user feedback. It will be crucial to submit this framework to a broader panel of NewSpace experts for validation and potential evolution. Contacts have been made with ESA, which is working on adapting ECSS for the quality of nanosatellite development. The results of this work should enable NewSpace companies to gain performance, control over processes and projects, and product quality control. Therefore, this work holds particular importance for industrial professionals, aiming to solve practical challenges and ensure the success of these new space missions.• Provide What the Audience Will Take Away from the Presentation – Outline Methods and Describe Expected ResultsThroughout the presentation, the audience will gain insight into the NewSpace domain and its constraints. They will discover and comprehend the extent and importance of current industrial issues in system engineering related to the specific context of NewSpace for the development of nanosatellites. They will also become familiar with specific requirements related to the space sector, as described in the ECSS standard (content, organization, requirements related to space missions).The presentation will elucidate the methodology built to develop an adapted engineering framework for NewSpace SMEs. This includes a thorough analysis of ECSS-E-ST-10C requirements, adaptation of ISO 29110 processes to consider space-specific requirements, presentation of the resulting framework, and a discussion on possible tools to support process execution in this framework.The

presentation will also highlight the experience of adapting ISO 29110 for CubeSat development. This encompasses a significant improvement in mission reliability, reduced failure risks, facilitated technological innovation, and the potential to transfer these methods to other small-scale space projects. These results aim to provide tangible solutions to specific challenges encountered in the field.• Background on the Presenter and Qualifications to Provide the TalkMamadou Lamine NDAO is a computer science and telecommunications engineer from the Polytechnic School of Thiès, Senegal, in 2020. He subsequently earned a master's degree in space systems development from the Polytechnic University of Engineers in Montpellier, France, in 2021. After a year of experience in space systems engineering in the NewSpace department at ExpleoGroup, he embarked on a Ph.D. in 2022 at the LAAS laboratory of the National Center for Scientific Research (CNRS) under the guidance of Professor Claude Baron, an INCOSE Fellow, focusing on improving system engineering processes for nanosatellite development, with a focus on SMEs in this sector.

Presentation#219

An holistic view of the implementation of the Open Architecture Approach in military systems

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Keywords. Open Systems Architecture;Military Systems;Systems Thinking;Soft Systems Methodology

Topics. 1.6. Systems Thinking; 2.4. System Architecture/Design Definition; 3.1. Acquisition and/or Supply; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Many military systems have long lifecycles, which brings challenges such as technological obsolescence management and the need to adapt to changes in the operational environment. Another growing challenge for military platforms is achieving interoperability within a system of systems context, as they are becoming more distributed and delivering new and expanded capabilities. This is reinforced by the view of data as an asset to provide operational advantage, which is one of the drives of the Digital Transformation. To address these engineering and integration issues, a persistent aspiration has been a move towards Open Architectures as part of the information structure of these complex systems. In the defence area, this is evidenced by the extensive number of existing Open Architecture standards and policies mandating the use of these approaches. But adoption of open architectures presents different challenges to different parts of the supply chain that must be overcome if the promised benefits are to be realisedThe fundamental assumption of this architecture strategy is that by adopting widely used standards for the key interfaces, as opposed to proprietary solutions, there would be more options of potential suppliers for the system. Consequently, a broader range of technological modifications across the lifecycle would be facilitated, and opportunities for innovation would thrive. Furthermore, it could avoid costs incurred from redundant equipment, in cases where the capability is confined to a particular application due to proprietary interfaces.Although the potential benefits of this approach are promising, accomplishment in its implementation has varied and the time taken to successfully adopt it has often proved longer than was originally anticipated. Potential reasons for that are difficulties in setting up a community of interest due to conflicting interests of suppliers and the government, time to agree and mature the implementation of the architectural standards, and necessary investments upfront. Furthermore, while the number of applications of Open Architectures is extensive, the procedures to achieve the intended benefits are still disparate and unclear, especially regarding the synergy of technical and commercial challenges. Moreover, these applications predominantly originate from governments such as the UK, the USA, and certain NATO members. Conversely, other governments either lack awareness, refrain from publicizing their initiatives, or are still unsure on how to move away from the traditional bolt-on, monolithic integration and are highly dependent on the primes. Hence, this presentation aims to explore how systems thinking tools can be applied to represent

the implementation of the Open Architecture approach from a holistic perspective and in a comprehensive manner. The goal is to offer the decision-makers a clearer understanding of the “big picture” of this approach, particularly those that haven’t started to address integration challenges in which open architecture may offer benefit. It will elaborate on how the presenters tackled this multifaceted problem by leveraging some aspects of the Soft Systems Methodology to build a comprehensive visualization of the issues. This methodology is particularly useful for capturing the issues from the perspectives of multiple stakeholders. The research began by reviewing the usage of the Open Architecture approach. More specifically, seeking the different perceptions on what the open architecture approach is, the motivations, enablers, challenges, and potential recommendations. This involved gathering data from publicly accessible literature and conducting interviews. The latter were performed with professionals that have worked with Open Architecture approaches for over ten years, from multiple domains (maritime, land, air, multidomain), and multiple perspectives (supplier and government). Next, the data were grouped and analyzed using thematic analysis, and the different perspectives were identified. Then, the CATWOE framework was used to represent these worldviews with the intended transformations and constraints. Finally, insights from the CATWOE models were used to build a causal map, demonstrating the relationship between the challenges and benefits of the Open Architecture approach. The contributions of this work are twofold. First, this CATWOE analysis provides valuable insights for effectively communicating this approach to various stakeholders. Secondly, although current literature covers some of the Open Architecture's challenges and benefits, our approach goes further by presenting a visualization of the relationships among these elements, from which practical insights can be derived. To conclude, from this presentation the participants should expect to obtain an holistic understanding of the implementation of the Open Architecture approach, and how systems thinking contributed to that.

Presentation#438

An MBSE group project challenge as a learning experience for Masters degree students

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Keywords. MBSE;Education;Engineering Management;Configuration Management;Case Study

Topics. 1. Academia (curricula, course life cycle, etc.); 2.4. System Architecture/Design Definition; 3.2. Configuration Management; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 5.9. Teaching and Training;

Abstract. This presentation will report on the author’s experience as a Visiting Lecturer in setting a group project challenge to multiple groups of students at Loughborough University, over a period of three years and planned for future years. The groups were predominantly part-time, on block release from employers interested in improving their pipeline of SE capability. More than half were participants in the UK’s Systems Engineering Level 7 Apprenticeship scheme, incorporating a Masters degree. The challenge set was a genuine leading-edge problem facing industry – how to keep multiple models of a system under development in step through joint configuration control of design changes in each model. At the outset, it was unclear whether this was a tractable problem for early-career engineers, but the results have been generally very good, and proved an excellent discriminator of student capability. It also enthused the participants into ‘selling’ MBSE into their enterprises.The preliminary brief for the challenge asks the students to create a meta-model system (MMS) representing the relationship between diverse models (including SysML, physics models, reliability, FMECA, CAD…), and the parametric flows between them. The ability to visualise this is not intuitive, and the module demonstrated the benefits of cross-disciplinary expertise and of ‘groupthink’.The groups illustrated their solutions using their own choice of ‘real-world’ case study, and a wide variety of examples ensued. In each case, the requirement was to present a configuration change of the case study system via dynamic update of the SysML MMS, triggering updates to the constituent physics (and other) models, and consequent configuration control updates. A surprising outcome was that the resulting SysML structures offered were widely different, and the presentation will illustrate this with examples. One conclusion drawn is therefore that MBSE does not reduce SE to following a recipe. Another is that a relatively untrained group can get an integrated solution working in under a week – an important outcome for those considering investment.The

students had undertaken a variety of modules in their first two years, including systems thinking, systems architecture, systems design, verification & validation (V&V), holistic engineering, and engineering and managing capability, plus a number of optional modules. Some had good introductory content on |MBSE, and Sys|ML in particular. This gave them a strong preparatory foundation, enabling rapid assimilation of the challenge, and methods to arrive at a successful solution.A “Challenge Specification” was written, approved, and issued to the students at the launch of the module. Extracts from the Challenge specification are reproduced below.“One of the greatest challenges in successfully realizing a complex, multidisciplinary system, where the optimum design is not initially known, is maintaining the integrity of the design: adapting to changing needs, integrating across the disciplines, and controlling the configuration for manufacture. Model-Based Systems Engineering (MBSE) is a great aid in keeping track of the coherence of a given design, and its evolution over time. However, there is more work to do, to incorporate models used by specialist disciplines to evaluate performance of the candidate architecture and designs, such as:• Reliability, Availability and Maintainability (RAM)• Failure Modes and Effects Criticality Analysis (FMECA) and safety analysis• Geospatial location, both static and dynamic, and physical structure• Security and cybersecurity analysis• Mechanical stresses• Thermal and aerodynamic flows• Technical (Parametric) performance, e.g. sensitivity, bandwidth, throughput or flow rate, speed, response time, accuracy, probability of mission success…• Cost estimation“The majority of these modelling techniques require different views of the system: differing levels of granularity, inclusion or exclusion of users and context from the modelling boundary, and diverse calculation methods with mostly non-linear relationships between the model elements. Thus, a multi-physics model may not be as efficient or effective as a set of linked models representing the same architecture. It is sometimes technically possible to assign attributes representing values derived from each model in a SysML model with links to the executed calculations, but this may not the most elegant or efficient way of proceeding. “It now becomes important to assure coherence between the models of the system architecture. How do we know that each model represents the same functional and physical design? How do we verify that each model simulates the system realistically? Is there any way of linking verification and validation evidence from the set of models, to add up to the required system-level evidence for acceptance?“The group project task is to create a design concept showing how models (SysML and the various performance models) may be linked together logically and coherently. The aim should be to animate sequences of actions on the linked models to show how the requirements below are met.“Groups may use any Case Study of their choice to illustrate the working demonstrator. The challenge is not to model the Case Study system itself, although this needs to be done to a limited extent to illustrate the satisfaction of the requirements. Rather, the challenge is to design, and ideally implement a working model of, the system of linked Case Study system models – in effect, a MetaModel System (MMS). The design concept should be treated as a competed feasibility study commissioned by an industrial enterprise. The customer’s Chief Engineer will run the competition, and will be role-played by the Course Tutor.”The presentation will show aspects of the most successful solutions provided by the groups, and comment on the challenges involved running the module. The most interesting features and the diversity of models offered will be shown. Finally, some analysis is offered on the team dynamics observed, plus the positive feedback on the learning experience from the students, and indeed from the external examiner for the course.

Presentation#156

Analytic Viewpoint for Information Normalization (AVIaN): A model-based analytic viewpoint to promote consistency in systems engineering practice

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Keywords. Model-Based Acquisition;Digital Engineering;Model-Based Systems;Unified Architecture Framework;Ontology;MOSA;Cyber Security;Architecture Assessment

Topics. 2.4. System Architecture/Design Definition; 3.1. Acquisition and/or Supply; 5.3. MBSE; 6. Defense;

Abstract. Overview. The DoD aims to digitally transform systems engineering practice through a technical

approach that uses models and other digital artifacts as the primary means of information exchange, rather than on document-based information exchange. This requires a foundation, a way to capture how certain data or information represents key aspects of a system and relates to other data or information in the semantic and structural forms necessary for effective synthesis or co-use with other data or information. This foundation of data, meaning, and relationships, will enable effective Model-Based Acquisition and Digital Engineering (DE) processes. Captured in a model-based framework, we can guide and promote consistent practice in addition to offering the capability to discover previously unseen gaps and relationships.How we represent and define data, concepts, and their relationships depends on the type of problem and the context of its associated activities. In the world of computing and the Semantic Web, linked data encompasses a principled approach to structured data representation, a method of connecting data coming from heterogeneous data sources that can be interlinked, combined, and shared. Many efforts in Semantic Web development have moved toward ontologies and ontological principles to help differentiate between entities and categorizations, above and beyond taxonomies. At a high level, ontologies provide a common vocabulary for representing and organizing data within a domain, defining relationships and the meaning of concepts. Currently, there are multiple ontology formalisms in existence, with a few in widespread use. As different ontologies express their commitment, or how they see the world, differently, which significantly impacts which ontologies may be best fits for further development and use in different domains, their compatibility or lack thereof with one another, and extensibility for future use. Yet, the value of ontologies lies in what they allow us to communicate, consistently and unambiguously. Development of a formal domain ontology takes time, commitment to a given upper-level ontology, and often presents interoperability challenges with Unified Modeling Language (UML) based modeling languages. Problem. In DE, a key challenge is that different bodies of information, such as standards, engineering domains, and acquisitions strategies, describe concepts differently, using different terms and at different levels of abstraction. The combination of these guidance artifacts can result in duplicative or contradictory applications as they are not necessarily complementary or cohesive. DoD stakeholders performing Model-Based Acquisition and modernization, sometimes informing each through technology capability gap assessment, need a harmonized foundation with the correct context for definition and use across their enterprise and its objectives. This foundation must be developed in a way that promotes a level of commonality and consistent application across development, incorporation, and modernization of systems and technologies. Further, we need to capture and represent the foundation in a way directly usable across Model-Based Acquisition and modernization. Beyond ontological principles, this requires a model-based framework be intrinsically compatible with Model-Based Systems Engineering (MBSE) languages and practice that: i. Describes the relevant entities and relations of a system,ii. Normalizes across different bodies of information that describe concepts differently, and iii. Thereby allows an enterprise to implement those descriptions and relationships consistently across activities that support their objectives. Approach and Methods. Through experience across multiple DoD programs, an approach has been developed that normalizes and unifies applicable concepts extracted from traditionally text-based artifacts such as consensus-based standards, policies, regulations, and high-level constraints and through the creation of a custom, fit-for-purpose Unified Architecture Framework (UAF) viewpoint. The resulting Analytic Viewpoint for Information Normalization (AVIaN) is an architectural viewpoint that frames stakeholder concerns related to the analysis and assessment of an architecture against an engineering domain, such as Modular Open Systems Approach (MOSA) or Cybersecurity. It provides a model-based method for representing and organizing data and information to define the meaning of concepts and relationships unique to a given problem area or domain. As such, it is directly analogous to the concept of a Domain Overlay now being fleshed out by the Model-Based Acquisition User Group in the Object Management Group (OMG).Specifically, AVIaN is a model-based analytic viewpoint; the approach enables organizations to define concepts; normalize how they classify, represent, and relate key development, modernization, and integration concepts and gaps; capture how they relate to each other; and allow for further granularity via attributes as necessary. AVIaN provides several capabilities for a stakeholder engaged in Model-Based Acquisition and DE activities, especially for increasingly complex systems:• Information normalization framework for normalizing potentially conflicting and duplicative policies, regulations, guidance, standards, constraints, rules, i.e., governance, applicable to the architecture as a result of the engineering domain into a common, unambiguous unified set• Architecture assessment metrics based on normalized governance• Methods for analysis and assessment of an architecture against the assessment metrics• Model kinds and views used to support analyses with respect to system development and modernization needs relevant to the text-based artifacts captured.This presentation will describe the concepts and methods underlying the development of an AVIaN viewpoint. Using UAF as its foundation, AVIaN is directly compatible with other systems engineering artifacts and system models expressed using SysML and thereby supports a stakeholder’s ability to share and understand data consistently and unambiguously across its digital enterprise. The presentation will describe tailoring the UAF grid to best support the specific dimensions of information and their relationships for a given stakeholder’s enterprise and concerns, and provide an example use. The result is a streamlined, fit-for-purpose framework, aligned with stakeholder objectives and yet extensible to future needs.

Presentation#35

ANDES, the high resolution spectrograph for the ELT: the adoption of Model-Based Systems Engineering approach

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Keywords. astronomy;ELT;ANDES

Topics. 5.3. MBSE;

Abstract. ANDES (ArmazoNes high Dispersion Echelle Spectrograph) is one of the second-phase instruments planned for the Extremely Large Telescope (ELT) of ESO. ANDES will provide high-resolution spectroscopy in the visible and near-infrared wavelengths, enabling a wide range of scientific investigations, such as characterizing exoplanet atmospheres, testing fundamental physics, and measuring the cosmic expansion. In this paper, we present the general strategy of the Model-Based Systems Engineering (MBSE) approach that we have used to design the instrument during the Phase B-One, which covers the system architecture review (SAR) successfully completed at end 2023. We describe how we have applied the Cameo Systems Modeler tool to create and manage the system model in compliance with the SysML standard to perform requirements and interfaces management, structure verification and validation, and trade-off analysis. We also emphasize that ANDES is used as a test case for the application of the MBSE methodology in the astronomical field, in order to create a standard of procedures to perform all the actions and tasks that serve to satisfy all the steps in the various design phases of an ESO project. In fact, the inital phases require specific tasks, such as the analysis of requirements, the flow-down of specifications to the subsystems, the tracing of interfaces, the analysis of budgets. Since there is no tool that specifically encompasses all these capabilities in the astronomical field, it is necessary to define a robust methodology that can be taken as an example for future astronomical instrumentation. We discuss the benefits and challenges of using MBSE for ANDES, as well as the lessons learned and best practices that can be useful for other astronomical instrument projects.

Presentation#309

Dealing with Emergence in Systems Engineering Models--Fewer Surprising Failures and more "Happy Little Accidents"

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Keywords. Emergence;Emergent behavior;Complex systems;Cynefin;Ergodicity;Decision making in uncertainty;Critical Thinking;Red Teaming

Topics. 1.1. Complexity; 2. Aerospace; 22. Social/Sociotechnical and Economic Systems; 4.4. Resilience; 5.4. Modeling/Simulation/Analysis; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Emergence is what happens when the whole is more than just the sum of the parts. It is both

something we count on and something we fear in product development. When we can confidently design an airplane capable of doing things that none of its constituent elements can do alone this is Weak Emergence. Our skill at creating intentional Weak Emergence is the basis for much of our technical success and many Systems Engineering decomposition and integration approaches. But, sometimes we are surprised by things that we didn't expect. That is unintentional emergence. It may be good or bad; an opportunity or a problem. The extreme case, Strong Emergence, cannot be predicted in advance by analysis. It is not simply engineering error or insufficient training. Even error free models created by experts will not be able to predict Strong Emergence. It nearly always shows up in the actual product and is often attributed to knowable causes, such as poor modeling, poor requirements, etc. But that conclusion implies "solutions" that may simply make things worse; like increasingly more complex models. As we move deeper into a world of Model Based Engineering and more and more models are connected, we face increasing risk that we will be unable to anticipate emergent behavior. This is particularly important for the field of Systems Engineering when we look at the details of INCOSE Vision 2035 and realize that a world of increasingly connected networks of increasingly complex models is very much a part of our vision. Emergence is found in multiple parts of Vision 2035 either by name or by implication. The highest value statement, found on page 8, is a statement of the greatest value of intentional emergence:"SYSTEMS ENGINEERING AIMS TO ENSURE THE PIECES WORK TOGETHER TO ACHIEVE THE OBJECTIVES OF THE WHOLE."It is found later as part of Architecting Flexible and Resilient Systems, Infusing Data Science Methods into Systems Engineering Practice to Understand Complex Systems Behavior, Understanding Socio-Technical Complex Systems with Human Systems Integration Methods, and Theoretical Foundations, for example. While the potential for unanticipated behavior is mentioned, the implication is primarily that the solution will come from better models and related analytical methods. But, will that work? The premise in this presentation is that it will not. Strong Emergence is not just unanticipated, it is not predictable by analytical models or Large Language Model variants of General Artificial Intelligence. Consequently, this presentation focuses on the risks we face with emergence, how our current approach to modelling and Model Based Engineering appears inadequate to address the risks, and recommendations for what we can do to gain the benefits of emergence and avoid the downside failures. The presentation differs from many past views of the topic by taking a more practical and less abstract and theoretical view of a solution approach. It draws on historical examples of emergence in design and engineering and looks to technological phase shifts of the past for clues as to what we can do today. It also addresses the issue of whether past emergent behavior could have been predicted by better or more complete models or whether it just appears so in hindsight. Among other things, improvement implies the need to develop a strong sense of Engineering Judgment in Systems Engineers so as to keep the human in the loop and why such a development focus is needed in Systems Engineering education. Recommended actions include a number of practices, such as:• The importance of documenting assumptions, limits to applicability of methods, and error bands of input parameters. • How known approaches, such as Machine Learning and simulations run under different conditions in a pseudo Design of Experiments or a Monte Carlo approach can improve prediction in domains of Weak Emergence but not Strong Emergence.• What we can learn from using past examples of technology and modeling changes as Reference Case comparisons. For example, the transition from slide rules to spreadsheets, the use of Wind Tunnels and Computational Fluid Dynamics models, etc. We faced, and resolved, similar issues in each, in part, by keeping the human in the system and relying on Engineering Judgment as a way to detect emergence. This solution is highly recommended.• How we can capitalize on our collective experience and sharing of successes, failures, and learning to more rapidly identify Weak and Strong Emergence, determine heuristics to help avoid negative outcomes, and speed up the time it takes to develop the ability to act appropriately.While emergence may often be categorized initially as "engineering error" we need to go past that perception and see it as a side effect of a phase change in Engineering and that gaining the benefits will come from systemic action of the types to be presented in order to increase our ability to successfully accomplish the intent of Vision 2035.

Presentation#68

Design for Future Mobility: Four-Wheel Independent Steering System Architecture Design and Technology Roadmapping Case Study

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Keywords. 4WIS (4 Wheel Independent Steering);Pareto Frontier;Technology Roadmap

Topics. 2.1. Business or Mission Analysis; 2.4. System Architecture/Design Definition; 21. Urban Transportation Systems; 3. Automotive; 3.3. Decision Analysis and/or Decision Management;

Abstract. The automotive industry, with established definition of mobility and vehicle architecture for the last hundred years, is going through fundamental changes. New breeds of vehicles, such as hybrid vehicles and electric vehicles are starting to gain market shares. Semi-autonomous and autonomous vehicles are actively being researched and developed to be the next game changers in the automotive industry. Also, with the rise of autonomous vehicle concepts, the definition of mobility is expanding. One concepts that stems from this expanding definition of mobility is called Purpose Built Vehicle (PBV). It is defined as “means of transport that is optimized for operational use and moves passengers or cargo safely and efficiently” (Hyundai Motor Group).PBV is gaining attention as the next generation of mobility device, with potential to expand into several mobility services sectors. It is envisioned to incorporate latest electrification and autonomous driving technologies, resulting in overall complexity increase due to increasing functionality. Architecting such system requires a rigorous and quantitative process, not only to establish the initial system architecture, but to plan for the technology infusion in the future. In this presentation, we present a case study of a newly developed four-wheel independent steering system (4WIS), which is a new type of steering system intended for future mobility vehicle. The case study utilized systems engineering process as well as the advanced roadmap architecture (ATRA) framework to design initial 4WIS architecture and to create its future technology roadmap.The first half of the presentation shows how the 4WIS architecture was designed following the traditional systems engineering approach. First, the concept of operation is established to facilitate a comprehensive understanding of the system among various stakeholders, and to define high level requirements. Next, detailed requirements are derived from stakeholder’s needs to define key functions for the 4WIS. To map these functions to forms, Object-Process Diagram (OPD) is used to create a system architecture model. Based on OPD and utilizing decision-option system architecting pattern, over 24,000 different 4WIS architectures are generated and plotted in the chart, with system torque and cost as two major values assessed. Pareto front is established, and candidate concepts are then evaluated using Pugh Matrix for selecting final concepts.The second half of the presentation shows that based on selected 4WIS architecture, how its technology roadmap is architected and proposed. First, the charter for the technology roadmap is created, followed by identifying the roadmap position within the company R&D portfolio. Using the system model and Pareto front from previous systems engineering process, in addition to information on Figure of Merit trend over time, the direction on how the 4WIS should proceed in the future is identified. Examining available R&D projects and funds, the R&D portfolio and technology infusion schedule, along with necessary budget, are established and documented in the technology roadmap statement.We hope that this case study will provide useful insights for both for academia and industry by presenting a new future mobility related system design case study, which follows both systems engineering process and ATRA framework.

Presentation#515

Designing for Resilience: Integrating Ecology into Engineered Systems

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Keywords. Biomimicry;Sustainability;Natural Systems;MBSE;Resilience

Topics. 1. Academia (curricula, course life cycle, etc.); 1.3. Natural Systems; 1.4. Systems Dynamics; 10. Environmental Systems & Sustainability; 17. Sustainment (legacy systems, re-engineering, etc.); 4.4. Resilience;

Abstract. Across industries, system resiliency is a foundational design goal. As both the economic and environmental landscape evolve, systems must adapt to emerging conditions. The emerging field of biomimicry presents engineers and ecologists with the opportunity to innovate while simultaneously operating within the constraints of a consumer-driven landscape. The intersection of engineering principles and ecological information empowers us to create systems capable of meeting human needs while synergizing designs with nature. The planet has been designing, testing, and evolving ecosystems for 3.8 billion years. The environment develops adaptive dynamics capable of changing to meet evolving conditions. These ecosystems present us with invaluable information on how to optimize our designs for unique environments, energy efficiency, and higher resilience. By comparing the mechanisms of ecosystems and the challenges faced in engineering resilient systems, we can discover novel solutions for resiliency-based innovation.Through the development of a technical engineering process harnessing the knowledge of ecology, systems thinking, and model-based systems engineering (MBSE), we demonstrate how ecological insights can be systematically integrated into design and development across industry scales and needs. With the intersection of engineering principles and ecological knowledge, we can enhance the adaptive dynamics, environmental specialization, and energy efficiency of a desired system.Through the development of predator-inspired models, we were able to synthesize the benefits of using nature as a blueprint for specialized system design. By analyzing the physiology and behavior of top-level trophic predators, we demonstrate how biological information can be integrated into the design of resilient and efficient systems. An adaptive methodology, the proposed process applies to diverse biomimetic design innovations. Through the development of a biomimetic design process, we also show the needed collaboration between the fields of engineering and ecology to optimize the resilience and success of biomimetic systems.

Presentation#282

Digital Engineering Capability Guidance and Maturity Assessment Framework

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Keywords. Digital Engineering Capability;DE Capability;Digital Engineering Maturity;DE Maturity;Digital

Engineering Guidance;DE Guidance;Capability Assessment;Digital Engineering Capability Assessment;DE Capability Assessment;Digital Engineering Enterprise Assessment;DE Enterprise Assessment;Digital Engineering Enterprise;DE Enterprise;DE Tooling;Digital Engineering Tooling;DE Environments;Digital Engineering Environments;DE Ecosystems;Digital Engineering Ecosystems;Digital Engineering Data Systems;DE Data Systems;Digital Engineering Workforce;DE Workforce;Digital Engineering Workforce Assessment;DE Workforce Assessment;Digital Engineering Roadmap;DE Roadmap;Roadmap;Maturity;Capability;Assessment;Digital Engineering;DE

Topics. 2. Aerospace; 3.6. Measurement and Metrics; 3.7. Project Planning, Project Assessment, and/or Project Control; 4.5. Competency/Resource Management; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Overview--------The DoD has embarked on digital engineering (DE) transformation in the pursuit of more rapid and modern capability development to keep up with near-peer adversaries. This pursuit is resulting in a both a rapid and massive evolution of the traditional engineering environment, requiring new capabilities, a new culture, a new set of infrastructure, and a new set of practitioner skills. Knowing if an organization has achieved sufficient maturity in areas of paramount importance to its effectiveness given its role and responsibilities in the product’s lifecycle is critical to all levels of the DoD, whether at the service-enterprise level, the support function level, or the individual program level. The small set of existing frameworks, requirement sets, and capability assessment methods in existence are each focused on key areas of digital engineering; none are comprehensive enough to cover the other key areas. An integrated capability guidance and maturity assessment framework (CG-MAF) that is both comprehensive across all aspects of DE and tailorable to an organization’s unique scope of influence and needs will provide these organizations with a clear means to identify investments that will transform their engineering practices and workforce, and further support how they procure their DE infrastructure and associated capabilities to meet their objectives.Problem-------Assessing Digital Engineering maturity is a large, complex endeavor, with multiple tools, requirements, and capability frameworks available. To be fully a comprehensive, a larger, unifying approach would be beneficial to harmonize the existing concepts into a tailorable, whole. This effort is focused on the DoD DE transformation problem space, and consequently started with very specific sources of guidance: :- The 2018 DoD Digital Engineering Strategy serves as the primary source to identify and delineate specific concepts of policy or guidance most relevant to DoD organizations. The strategy is comprehensive and includes concerns relating to communication, leadership, policy, workforce transformation, and enterprise-level activities. However, it contains no concept of maturity in terms of how well or to what degree an organization is achieving the objectives it puts forth. It is also light on DE ecosystem requirements related to tooling and interoperability that are explicit enough to be actionable guidance.- The INCOSE Model-Based Capability Maturity Matrix (MBCM) is well-vetted and comprehensive in its treatment of workflow, governance, model use, and especially systems engineering technical and management processes using a DE lens. Uniquely among these source documents, it defines maturity using a framework of defined levels that enable assessment of how well or to what degree an organization is doing these activities. However, it frequently requires reading through the maturity level descriptions to discern a specific DE capability an organization needs to achieve. The MBCM is also light on or lacking in its specification of enterprise concerns such as those related to policy, collaboration, and workforce transformation emphasized in the DoD DE Strategy. Like the DoD DE Strategy, it also lacks explicit DE ecosystem guidance from tooling capability and interoperability perspectives.- The DoD DE Ecosystem Requirements [Draft, 12/2022] document is a draft source of DoD guidance still undergoing its own maturation. While it lacks the coverage of either of the other two sources in terms of the full scope of what is necessary for DE transformation and does not include levels of maturity like the MBCM, it is the one source that offers solid detail with respect to specific capabilities needed to implement a DE ecosystem. It offers detail on all aspects of infrastructure, data, security, digitally-enabled collaboration and discovery, etc.Approach and Methods--------------------This presentation will describe the concepts and methods underlying the development of a digital capability guidance and maturity assessment framework and its accompanying model expressed in the Unified Architecture Framework (UAF). The concepts will be described first using a mapping ontology to show key concepts across the three sources and will serve as the basis of a meta-model for the accompanying UAF model. The DoD DE Strategy serves as the primary capability category basis using its decomposition of five primary goals into fourteen goal subcomponent areas and further specification using descriptions for each of the latter. The INCOSE MBCM is leveraged to flesh out vital aspects of systems engineering and technical processes as well as serve as the single basis for how to describe levels of maturity for each capability described. The DE Ecosystem Requirements draft is similarly used to augment the framework with tangible concepts to guide identification and assessment of DE ecosystem capabilities. Using UAF as its foundation, the model created from the CG-MAF description is directly compatible with other systems engineering artifacts and system models expressed using SysML. It is also compatible with concepts generally found in a Systems Engineering Plan, and thereby supports understanding DE maturity across all stakeholders in the organization’s evolving digital enterprise.

Presentation#455

Digital Engineering in Military Systems Integration

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Keywords. Digital Engineering;Military;Systems Integration;Acquisition;Digital Twin

Topics. 17. Sustainment (legacy systems, re-engineering, etc.); 2.5. System Integration; 3.1. Acquisition and/or Supply; 5.3. MBSE; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. With the rise of digital engineering (DE), many industries are looking for the best way to integrate these new methods into their systems development. For those with military interests, the Department of Defense (DoD) has provided guidance for implementing digital engineering practices throughout the acquisition process. The DoD's traditional process for development of complex systems is often linear and involves long cycle times, ending in products that are difficult to update and maintain. DE strategies and plans aim to transform DoD systems into more affordable, flexible, and effective versions of themselves. Through defining and maintaining the system architecture and using DE in system integration, testing and verification can be better streamlined to foster seamless transitions from early research and design to delivery. These implementations can be completed using a variety of methods such as Models Based Systems Engineering (MBSE) architectures, SysML, and Modular Open System Approach (MOSA) reference architecture. This presentation focuses on the creation of a digital twin environment built through a combination of these practices. A digital twin utilized during early integration and testing allows developers and acquisition professionals to assess the viability of the system design prior to conducting full system tests. Early development of digital twins in the systems engineering phase of the acquisition process allows developers to better understand customer expectations and integrate digital engineering into the systems. This presentation will explore the DoD guidance on DE and ways that this guidance impacts the acquisition process, specifically in systems integration labs. By exploring the impacts on system development, we can imply the ways that DE is capable of changing overall processes within military system acquisition. Exploring the impact of a digital twin environment on the acquisition process will be one of the main topics discussed. The benefits of incorporating DE include better design change impacts such as sensitivity studies and impact analyses while also increasing efficiency throughout the engineering process. We are specifically considering the impact of digital twins within a systems integration lab. These digital twins also allow flexibility with a modular capability between the subsystems and modeled system components. We will also explore the social impacts of DE on the traditional development processes and lab environments. Implementing fundamental change will receive resistance, so forecasting the social impacts of these changes will speed up adoption by a broader community. By exploring how DE can be utilized by the DoD, we can better understand how DE can change military acquisition and impact overall systems design.

Presentation#303

Enabling Systems Engineering at scale - the data asset management case

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Keywords. SE;MBSE;common language;common reference;ontology;semantic;model;concept;data;information;interoperability;at scale

Topics. 1.1. Complexity; 11. Information Technology/Telecommunication; 2. Aerospace; 3.4. Information Management Process; 5.2. Lean Systems Engineering; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The flagship projects of the world leading companies are multidisciplinary and engineered digitally in extended enterprise mode.That is why these companies are using Systems Engineering: “Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.” - INCOSEIn our digital era these projects integrate a huge number of data:- created by numerous enterprises,- coming from various disciplines,- using a wide set of digital applications and IT languages.At this scale, integration of data becomes a critical challenge, not to say “THE” critical challenge.None of the typical mitigations applied is solving the point:- reduce the number of players => still several companies involved,- reduce the number of IT solutions and languages => no IT solution nor language is dealing with all the project disciplines,- use semantic to describe data => far not enough ontology modelers are available,- … So they face exponential costs & time to connect billions of new & legacy data coming from authors having different backgrounds, in extended enterprise & across IT solutions.Why? Because they do not share the same meaning reference!This was before using a Common Language;The ambition of this language based on proven international standards is to value data by providing practical solutions to clarify, federate & query data, at marginal cost and time, even at scale.The vision is to use a common reference that is shared and recognized across disciplines and enterprises as a standard;This reference contains concepts and their explicit definition organized in domains, aspects, …In a word, the common reference is a framework that structures the representations of data.To be understood at scale by humans and machines these concepts are exposed in an ontology format: this is the foundation ontology containing 15000 concepts and relations.Then a metamodel describing the core concepts of System Engineering (e.g. functions, interfaces, …) is created and connected to this common reference.Thus any data created following the SE principles is easily connected to a foundation ontology concept; So its meaning is understandable by anyone even with no specific domain expertise;This data can be queried by machines across IT solutions and languages;And it is easy to federate data coming from various sources and disciplines.Concepts with no practical applications are useless, so a live demonstration will show how easy it is to:- create a domain ontology and connect data- federate models coming from different silos- query data This concrete application will highlight the main benefits of using a common reference:- interoperability enabler across silos,- robust & proven as based on standards providing the semantic for business concepts,- scalable as distributed, allowing incremental deployment, operable by humans & machines,- low footprint on IT, compatible with any IT language & software,- easy to learn and apply as no specialist knowledge or modeling experience are required.In short, a common reference is a key enabler of SE at scale!

Presentation#234

Enhancing Capabilities of Parametric Diagrams with Opaque Behaviors

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Keywords. MBSE;Advanced Tool Features;Scripting;Parametric Diagrams;Cost Analysis;Model Query;Model Based Systems Engineering;Cameo;Opaque Behaviors

Topics. 2. Aerospace; 5.12 Automation; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. In the Systems Modeling Language (SysML), there are multiple types of diagrams. One such diagram is the parametric diagram which is also a subtype of an Internal Block Diagram. The parametric diagram takes the internal properties of a block and allows the user to use mathematical analysis generally to show satisfaction of requirements. Most advanced modeling tools allow these parametric diagrams to use standard math and integrate with other tool sets suitable for complex analysis. However, whenever the properties of a system are dynamic and better suited for calculation by model query, there is a disconnect between the parametric diagram and the resulting query. This limits the usability of the parametric diagram and requires users to use other tool integrations for simple parametric analysis or manually transpose query results into the parametric analysis. In order to resolve this, opaque expressions are created which can parse the model to calculate the properties of a system dynamically. As the model changes, the calculations will update as a result. These opaque expressions cannot be used as a constraint directly, but using advanced MBSE tool features, a constraint can use a script that executes the opaque expression to query the model and returns the value to a constraint parameter of a constraint block. By binding the constraint parameter to a value property of the system or its components, the value can be populated real time based on the construction of the model.This presentation will provide details on how to bridge the gap and enhance parametric diagrams using Opaque Behaviors. The audience will learn how to reuse opaque behaviors to query the model, how to write scripts that express those opaque behaviors, how to use the scripts in a parametric diagram, and how to use a simulation configuration to tie it all together by using one button press to query the model and generate an analysis of the model automatically.

Presentation#189

Enhancing Data-Driven Decision Making through MBSE

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Keywords. mbse;decision analysis working group;digital transformation;decision;decision analysis;decision management;sysml;dodaf;uaf;architecture;management;project management;risk;configuration management;patterns;reuse

Topics. 1. Academia (curricula, course life cycle, etc.); 2.1. Business or Mission Analysis; 3.3. Decision Analysis and/or Decision Management; 5.3. MBSE; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. In today's fast-paced data-driven landscape, the capability to make swift, consistent, and accurate multi-factored decisions is not just advantageous – it's imperative. Increasing system complexity and diversifying stakeholder demands are necessitating a systematic approach to decision-making. This presentation introduces the Decision Analysis Data Model (DADM), an official model-based product developed by the INCOSE Decision Analysis Working Group (DAWG), to address several key SE challenges identified in the INCOSE Vision 2035, including:•5. Systems engineering provides the analytic framework to define, realize, and sustain increasingly complex systems•6. Systems engineering has widely adopted reuse practices such as product-line engineering, patterns, and composable design practices•7. Systems engineering tools and environments enable seamless, trusted collaboration and interactions as part of the digital ecosystemBy providing a model-based data model for conducting multi-factored decision analyses, the DADM enables reuse of prior analyses and decisions in future decisions and defines a framework for leveraging MBSE and digital ecosystems to establish a trusted source of truth for organizational decisions. The DADM transforms traditional decision management fundamentals into a practical aid that today's SE practitioners can apply to their projects' complex engineering decisions. INCOSE Fellow, Dr. Greg Parnell, will guide audience participants through the DADM's model-based structure and underlying methodology, its strategic alignment with real-world decision-making challenges, examples of DADM v.1 in action, and its significance in actualizing INCOSE's Vision 2035 to enhance the global impact of systems engineering. Participants will leave this session with an understanding of the DADM itself, the impact the model will have on decision-making moving forward, and practical guidance on leveraging this model to immediately elevate any organizations decision-making. Through the DADM, organizations across a multitude of industries can not only navigate the myriad challenges of contemporary decision-making but also champion a future where systems engineering is ubiquitously recognized and adopted for its transformative potential.

Presentation#425

Enhancing Industry 4.0 Transformation Success with a Solution Debt Playbook

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permission

Keywords. Solution Debt;Technical Debt;Industry 4.0

Topics. 2. Aerospace; 2.2. Manufacturing Systems and Operational Aspects; 20. Industry 4.0 & Society 5.0; 3.7. Project Planning, Project Assessment, and/or Project Control; 3.9. Risk and Opportunity Management; 6. Defense;

Abstract. As technology advances at an ever-accelerating speed and programs face urgent needs to field capabilities quickly, teams struggle to balance time constraints, cost constraints, quality, complexity, and evolving intent. Accumulation of technical debt is often the result. In the software engineering community, the term "technical debt" is the implied cost of future rework required when an easy but limited solution is chosen in the short-term. In previous work, the concept of "solution debt" was introduced. Building on the idea of technical debt from software engineering, solution debt is used in systems engineering to characterize a broader set of debt incurred in complex, socio-technical systems. This broader debt taxonomy includes technical, product, and business debt. Data debt is one example. Like other future obligations, there is interest to be paid when debt is incurred, which gets more expensive to fix later than now. Well-meaning Industry 4.0 digitization efforts can cause debt when larger system context is overlooked. This presentation expands on the earlier work to provide a solution debt playbook with actionable guidance to help programs and Industry 4.0 initiatives systematically avoid, manage, and retire debt across the lifecycle.The solution debt playbook provides a mechanism to identify and evaluate debt incurred, link the debt to program assets, develop a debt reduction plan, and execute the plan to enhance success. The first step is to identify current debt, which includes identifying the current program/initiative debt and characterizing the debt type. The second step is evaluating debt. This includes assessing the impact, fix cost, and contagion factor. In addition, this includes assessing the source and recipient of debt, who pays and who benefits, and the ability to impact the debt. The structural context and quadrant for improvement are determined. The third step links the debt to program assets. The evaluated debt is linked to program and enterprise risks and to guardrails. In the fourth step, the debt reduction plan is developed. This includes identifying debt reduction activities, assessing the timeline, identifying resources, and documenting the debt reduction plan. The fifth step is executing the debt reduction plan. Program and enterprise metrics are tracked, and a Plan-Do-Check-Act cycle is employed. The presentation includes Industry 4.0 examples for solution debt playbook use.Since solution debt incurred early in the lifecycle must often be "paid" in manufacturing and later lifecycle phases, an integrated approach to solution debt management is particularly relevant for discussions on better integrating engineering and manufacturing. Systems engineering and manufacturing often operate in different worlds, with separate conference venues and different cultures. There has always been a need to better integrate engineering and manufacturing, but what is different now is Industry 4.0, digital transformation, and digital mechanisms to bridge the gap efficiently. As the digital twin evolves from as-designed to as-built to as-delivered, more disciplines interact with a unified representation of the solution. An enabler of the digital twin, the engineering data fabric (EDF), connects tools and data between disciplines, providing unifying transparency and insight. As the EDF and digital twin persist through the lifecycle, solution debt can also be continuously managed through the lifecycle in the governance layer. These unifying mechanisms provide boundary objects to integrate systems engineering and manufacturing cultures.As digital transformation and digital engineering are implemented, the holistic system view is essential. "Random acts of digital" can incur debt. Ignored debt with a high contagion factor, when linked efficiently across a digital thread, may super-spread the effect of bad data. Grandiose plans for a model-based acquisition supply chain can be thwarted with a reality of small and medium manufacturers who just want a 2D drawing. Expensive licenses, cumbersome infrastructure, and complicated modelling may not be feasible for some small manufacturers. Based on systems engineering fundamentals, the solution debt playbook provides a mechanism to capture this context, characterize debt incurred, prioritize action, then track resolution. As a complement to traditional risk management, the solution debt playbook provides more specific characterization of risks introduced into the program. Just as data governance is a key part of data debt management, governance is a key part of solution debt management. Thus, the solution debt playbook presented is built into the governance layer. Benefits include a more holistic view of Industry 4.0 challenges, tighter engineering to manufacturing integration, more visibility into vulnerabilities, and a unified approach to debt management, resulting in enhanced success for Industry 4.0 digital transformation efforts.

Presentation#213

Exploration of SysML V2 Capabilities to bridge the gap from System Modeling to Network Design

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Keywords. SysML V2;Network Architecture Design;System Model;Complex Systems

Topics. 1.1. Complexity; 2. Aerospace; 2.4. System Architecture/Design Definition; 3. Automotive; 3.2. Configuration Management; 5.3. MBSE;

Abstract. The promise of SysML V2 is on the verge becoming reality. The new SysML V2 standard is being released in 2024 bringing a new world of interoperability to System Engineers. Making the promise a reality will require understanding problems and developing uniquely V2 enabled solution.This presentation will explore that new reality with a model. The problem to be explored is one that is common to many industries, it is the development of solutions using the ubiquitous CAN Bus. This simple bus used my many industries in their product networking architectures will be used to highlight how SysML V2 is a means to improve interoperability. This presentation will depict an operational and physical architecture model of how SysML V2 can bridge between network design to system modeling. The model will include a depiction the operational capabilities of various actors required to develop system models and network architecture. The capabilities will then be decomposed into a series of operational activities allocated to respective actors and entities of the problem. The solution will depict all the elements of a SysML V2 eco-system. Elements that can speak SysML V2 by library enabled adapters specific to tools that deliver system modeling, network architecture design and simulation. A repository element that supports a standard set V2 APIs to manage, query and manipulate the generated V2 content in the safety and security configuration management. SysML V2 authoring tools configured and extended by a SysML V2 Library allowing the modification of SysML V2 content regardless the source. SysML V2 visualization tools that can interact with a SysML V2 repository allowing selective browsing on the SysML V2 model. SysML V2 analysis and reporting tools that can query a SysML V2 repository and extract content from all the various source that feed the SysML V2 Eco-SystemThis model will show that we are entering a new world for System Engineers, where not only System Models can feed design, but that design can be leveraged to change and build new and more complex systems of tomorrow.

Presentation#527

Exploring the Notion of Verification Complexity

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Keywords. Verification;Modelling;knowledge graphs;complexity;verification complexity

Topics. 1.1. Complexity; 2.6. Verification/Validation; 3.6. Measurement and Metrics;

Abstract. There is a plethora of research delving into system complexity as it is believed to be one of the primary sources of adverse outcomes in complex system projects. From expanded budget to delayed schedule, ill-recognized system complexity often results in severe overruns. Measuring the system complexity throughout the development lifecycle has therefore been considered one of the core prerequisites of the system management. Non-subjective complexity measures would aid better communications between various designers and engineers resulting in better system alternative selection in the face of possible overruns. However, comparatively less attention was given to the complex verification strategies. Traditional mathematical approaches to informing the design of verification strategies were limited to toy problems significantly simplify the complexity of verification in real-life applications, both in terms of the size of the problem and the inter-dependencies between the different elements of a verification strategy. There has been no public research tackling the verification strategy complexity problem in terms of requirements that need to be verified, verification activities that are conducted, their interrelationships, in practical scale. As system complexity aids system design and management, we expect the verification complexity to improve the planning and execution of verification strategies.Graph quality features such as size, connectivity, or communicability (including graph energy) have been studied to correlate to systems complexity (SC). Based on the analogy of verification strategy complexity (VSC) inheriting the characteristics of SC, we proposed a possibility of building a mathematical measure for VSC independent from the system complexity in terms of requirements and their verification. Preliminary research showed the prospect of such a measure, identifying VSC indicators by ordinal comparison between knowledge graphs. Two industrial projects were drawn from the collected verification artifacts such as requirements traceability matrices and verification matrices representing the verification problems. This resulted in two knowledge graphs each with 404 and 8,922 nodes and 563 and 17,319 edges respectively. Their inherently different scale led to a consensus on their VSC differences even without any formal measure. Based on this established VSC order, 25 graph complexity measures ranging from simple property counts to graph centrality, communicability, and graph energy were tested on the full graphs as well as their various subsets. These subsets were the modified version of elemental patterns of verification strategy; six types of subgraphs from connected components, relevant elemental patterns, and (semi-)orthogonal groups were extracted to each represent a specific verification strategy snapshot. The ordinal comparison revealed six graph complexity measures signifying VSC differences between the two projects, while the subgraph snapshots provided additional information such as differences in orthogonality. There was enough evidence to claim that VSC is connected to graph complexity measures.With no agreed upon numerical VSC measure present, proposing the VSC measure requires a larger number of projects ranked by their VSC to act as a training base. The issue here is again the lack of known VSC measure; manually comparing VSC between industrial projects becomes resource and time intensive when they share a similar requirement counts. We tackled this issue in the previous research by employing two industrial projects with varying scales. While the lack of data points limited the research to only detect VSC indicators, it showcased the scalability and resource efficiency of the graph-based approach validating the feasibility of a quantitative measurement applicable to existing real-world applications and future system developments. With the scalability already shown, our current research is utilizing a list of previously modulated toy projects which are far easier for manual VSC ranking. Currently six such toy projects ranging from five to 50 nodes are being utilized, each having explicitly specified relationships in the referenced sources. We are adding manually created and curated projects to the dataset as well, aiming to get at least 18. Their inherent scales would be used to allocate them in rough VSC categories, where experts in verification strategies would make a consensus on intra-categorical VSC rankings. The ranking would be made three times by differentiating the materials given to experts; descriptive text only, text with graphical representation, and interactive knowledge graph. This is to measure the effect of data mediums on perceived VSC. Using these ranking as de-pendent variables, ensemble learning algorithm with regression models will be trained with ten graph complexity measures as independent variables. Four previously uncorrelated measures would be used again here in order to eliminate the possibility of false negatives. The smaller sizes in toy projects limit the utilization of subgraph types, therefore a series of synthetic data genera-tion algorithms and generative graph algorithms would be used to enhance their effectiveness. The experiment would include 20 verification strategies including two industry projects from the previous research, each having 70 features in total. Based on the previous findings, we expect this experiment to result in a regression formula with at least a medium quality, paving the way for mathematical VSC measure that can be calculated automatically and without human intervention.Once this research is successfully completed, a number of future research are planned as extensions of this research. Verification artifact quality assessment is planned to provide weights to the knowledge graph nodes, evaluating the degree of decision-making process embedded in each requirement and verification activity with the NLP processes. Cognitive science is planned to be incorporated in this research to view VSC from an engineer’s perspective as well as the innate structural complexity. Standardization of verification sources and knowledge graph generation processes would follow based on the detected differences in the perceived VSC. This is to allow a more effective and accurate method for graph generation. It is our intention to develop a working VSC measure and validate its performance to both academic and industrial experts in a series of publications.

Presentation#492

Food Transformation (FX): A Systems Engineering Approach to Elevate Value through Cooking Recipe Design with Alternative Proteins

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Keywords. Cooking recipe;Alternative proteins;Process Design;Systems Engineering

Topics. 10. Environmental Systems & Sustainability; 18. Service Systems; 2.4. System Architecture/Design Definition; 20. Industry 4.0 & Society 5.0; 5.4. Modeling/Simulation/Analysis;

Abstract. The issue of food supply and demand has emerged as an urgent challenge, as the conventional food supply system alone cannot meet the food demand of the growing population. In particular, to develop a sustainable food system it is necessary to take into account various preferences and restrictions on food, such as religious, historical, and regional food culture and history, as well as food taboos, and it is not sufficient to simply solve the quantitative problem of supply and demand balance to address climate change, population growth, and changing diets. It is necessary to reconstruct the entire system of food production and supply from a holistic view of the diverse demands for sustainable food production and supply in systems engineering approaches.Here, we focus on protein, which is one of the most important topics in sustainable food supply. The demand for protein ingredients has surged in the past few years. The global protein ingredients market is valued at US$38 billion in 2019 and is expected to grow at a rate of 9.1% between 2020 and 2027 (Grandview Research, 2020). Consumption of animal protein has increased considerably gradually, and the growing interest in protein as a whole is expected to fuel significant growth in the market for plant-based protein ingredients. New approaches to replace the conventional livestock-centered protein supply are being sought, and various research and development efforts are underway, including insect diets, cultured meat, and animal welfare (Liu, F., et al., 2022)(Fasolin, L.H., et al., 2019). One of these that is attracting attention is "alternative proteins". Alternative proteins are obtained from resources other than those derived from plants and animals, and are considered to have low environmental impact and high sustainability (Grossmann, L. and Jochen Weiss, 2021). An additional significant motivation to explore innovative plant protein ingredients lies in the aspect of protein allergenicity. Ismail et al mentioned "Food producers are seeking to understand how these plant proteins can partially or wholly replace traditional plant and animal protein ingredients in food or plant-based meat-alternative products to deliver optimal nutrition, flavor, and functionality. Furthermore, advancement in nonprotein ingredient options and functionality are also in demand as these ingredients are combined with plant and meat proteins to fulfill the recipe needs (e.g., color, palatability, and shelf life) in the development of these food products (Ismail, B.P., et al., 2020)". Hence, it is crucial to showcase that novel plant proteins possess can be designed architecture equivalent or superior functions compared to their existing proteins.Therefore, this research aims to develop a cooking recipe design method using systems engineering to realize same characteristics of conventional dishes using meat using plant-based foods. In particular, we aim to develop the method for FX (Food Transformation) in the context of value creation in DX (Digital Transformation). This presentation introduces an ongoing research project using a recipe for hamburgers made with plant-based meat as an example.Recipe design has long been studied in the fields of culinary science and nutrition. Food can be decomposed into elements at the level of ingredients and food components, and new approaches such as molecular cooking methods have been developed in recent years to decompose food into elements at a more detailed molecular level. Why is it beneficial to use systems engineering in the design of recipes using plant-based proteins? The reason is that the method of recreating a conventional dish using plant-based protein is not limited to mere substitution of ingredients. In the conventional cooking design process, while considering the combination of ingredients and cooking process to meet the requirements, the degree to which the dish satisfies the total amount of nutrients to be achieved in a meal is calculated, and the recipe and ingredient combination are determined by comparing them with other dishes on the same menu. This process can be considered to be very similar to

the design of "ilities" in systems engineering. The realization of a novel recipe design method, employing systems engineering techniques to delineate requirements from diverse perspectives and fundamentally redesigning the architecture, with cooking methods and ingredients serving as the means to attain newly established objectives, holds the potential to not only create recipes that are more flexible but also significantly elevate their value-added attributes.

Presentation#561

From Arizona to the World: From Education to Application in Community Engaged Engineering

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Keywords. community engaged engineering;science and engineering policy;engineering ethics

Topics. 1. Academia (curricula, course life cycle, etc.); 22. Social/Sociotechnical and Economic Systems; 3.7. Project Planning, Project Assessment, and/or Project Control; 4.1. Human-Systems Integration; 5.9. Teaching and Training; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Community-engaged learning has been recognized in recent years as an important tenet in engineering education, emphasizing the role of engineers in creating practical outcomes that impact people and groups across society. This presentation examines this tenet through the lens of a systems engineering student bringing diverse backgrounds to the field and seeking to apply engineering theory to address diverse challenges across other disciplines. This student was introduced to community engaged engineering through science and engineering policy, first in engineering coursework, then through a practical experiment involving interdisciplinary students in partnership with the United States government, and finally in the professional realm of engineering policymaking.Engineering policy is concerned with how engineering can inform policymaking, how policies can affect engineering constraints and outcomes, and ultimately enhancing communication between engineers and policymakers with the goal of streamlining collaborations to improve outcomes for all. Engineering diplomacy applies the same concerns to relationships across national borders for multinational collaborations, shared resource management, and modern international engineering challenges. In this example, coursework in science and engineering policy and diplomacy evolved into a public-private partnership between interdisciplinary students and the United States Department of State to develop recommendations for sustainable development in the Lower Mekong River Basin region. This project culminated with publication of a paper on community-engaged experiential learning in engineering curricula as a platform for professional preparation and student success. The case review concludes with description of an ongoing, multidisciplinary project in engineering policy in which professional and student scientists and engineers are collaborating to develop and implement a science and technology policy fellowship program in Arizona. This program aims to connect postgraduate scientists, engineers, and public health practitioners with lawmakers to inform policy creation on technical topics and elevate the benefits of science and engineering for communities across multiple arenas.This example serves as an illustration of how community engagement can serve engineering students in teaching engineering applications across diverse domains and enhancing interdisciplinary communication, and how the narrative within education leads to community engagement in professional applications. However, this is but one case in one arena. The audience will be asked to reflect upon the unique opportunities of the disparate systems engineering tracks and domains to contribute to improvement in functionality or efficacy of various areas, leading to improved wellbeing for specific communities. Beyond opportunity, this presentation seeks to spark discourse regarding ethics in engineering, and the responsibility of engineers as the world’s problem-solvers to apply engineering theory to applications in service of community.

Presentation#542

Full STEDE Ahead: Developing a Simulation Training Environment for Digital Engineering

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Keywords. digital engineering;training;education;case study

Topics. 1. Academia (curricula, course life cycle, etc.); 5.3. MBSE; 5.4. Modeling/Simulation/Analysis;

Abstract. To meet the challenges and realize the benefits of digital transformation, the systems engineering community must undergo significant transformation. This need stems from the growing use of digital/model-based engineering to represent complex systems throughout their lifecycle. Engineers, and perhaps in particular systems engineers, must be able to create, evaluate, and use digital engineering methods to specify, evaluate, and manage systems throughout the DoD acquisition process.INCOSE's Vision 2035 identifies a number of goals that are closely related to digital transformation, in particular:• Goal 4. Model-based systems engineering, integrated with simulation, multi-disciplinary analysis, and immersive visualization environments is standard practice.• Goal 7. Systems engineering tools and environments enable seamless, trusted collaboration and interactions as part of the digital ecosystem.• Goal 9. Systems engineering education is part of the standard engineering curriculum and is supported by a continuous learning environment.There is an adage that if you give a man a fish, he will eat for a day, but if you teach him to fish, he will eat for a lifetime. The systems engineering community must teach ourselves and our colleagues to fish in the digital ecosystem. As research has repeatedly shown (e.g. REF 1, REF 2, REF 3), we often learn best by doing. So to train ourselves and the rest of the broader workforce to be successful in a digital ecosystem, it is critically important that the community have resources that support the application of systems engineering principles in a data- and model-driven environment. This is the impetus for the creation of the Simulation Training Environment for Digital Engineering (STEDE).The vision for STEDE (supported by a number of subject matter experts (SMEs)) is to create an openly available resource that will provide individuals or organizations with the opportunity to directly apply the principles of systems engineering using realistic examples during training and/or education. This presentation will take the audience through the need for STEDE as well as the work that has been done by the [ORGANIZATION] to develop a STEDE. This will include:• Use cases• Architecture and• Case studies (realistic but fictitious systems models that can be used for training – what has been developed and is available will be described)The presentation will also discuss the future directions for STEDE and how the community as a whole can work together to build such critical resources that can provide a shared resource. Specifically, it will tie back to the INCOSE Vision 2035 goals:• Goal 4: Demonstration of what is possible, created in a way that supports training (i.e. everyone can have exposure)• Goal 7: Demonstration of what this sort of environment can look like• Goal 9: Standard engineering curricula are already using data- and model-driven approaches. But they are unlikely to incorporate SE practices into their work without an environment and examples like these being available to them. Otherwise, it becomes too heavy a lift for many organizations. SE curricula desperately need something like this as well..

Presentation#570

Hidden Beliefs in Verification Strategies

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Keywords. Verification;verification strategy;belief;AI;belief network

Topics. 1.6. Systems Thinking; 20. Industry 4.0 & Society 5.0; 3.3. Decision Analysis and/or Decision Management;

Abstract. The systems engineering process is divided into three main stages: problem definition, system architecture, and verification. While there has been significant progress made in the former areas, with theoretical rigor supporting heuristics, the process of designing and implementing verification strategies (VS) still seeks to bridge this gap. The problem is two-fold: selecting an optimal method for designing a VS, and accounting for the human factor in its implementation. A VS has both static and dynamic elements. The VS design itself is deterministic in nature and consists of defined elements mapping to a finite set of system requirements. This VS is a function of the complexity of the system architecture, number of requirements, coupling between sub-systems and components, and legal and contractual obligations. While the immediate deficiencies in this method of formulation are not apparent, it is more severely felt in the implementation phase. The implementation phase introduces an element of stochasticity to the VS and is a function of both the information gathered between the stages of implementation, and its interpretation by the verification engineer. The inclusion of the human factor is seldom considered while formulating a VS. Engineers resort to verification artifacts like analyses, test results, reports, drawings, etc. to make verification decisions. These artifacts shape their confidence of whether the system will meet certain characteristics and in turn meet the specified requirements. These sets of artifacts, providing information to the engineer, can be conceived as a network. Synchronous to a belief network, the nodes that provide information (such as tests or analyses) are directly accessible. Other nodes, such as system characteristics, are the modes we make predictions under uncertainty on, based on the information nodes. The VS is a function of the number of engineers working on verification activities, their familiarity with the system of interest, their experience level, their association with the organization, intrinsic biases, flawed judgement, disparate cognition, cognitive load, and belief. Of these factors, the belief of the engineer and its role in the implementation of the VS is the focus of this research. Information shapes belief and belief characterizes uncertainty. Here, we suggest that besides information from the former nodes, there is hidden information that the engineer also uses, albeit unconsciously, to make their verification decisions. Consequently, information in a verification matrix is inherently incomplete. A VS seeks to reduce uncertainty and ensure the system was built right. Thus, the consideration of belief is imperative in ensuring completeness. The challenge, however, arises from the lack of a codified methodology of quantifying and integrating belief in the formulation of a VS. Belief is a function of both information inputs and intrinsic knowledge. The challenge is binary: designing methods to incorporate belief and ensuring the completeness of elicited belief. Elicitation of belief and its translation allows its incorporation into the VS design. The challenge is determining the completeness of the beliefs elicited. Methods may be selected and employed to elicit known or popular belief, which can then be integrated into a VS. However, this study aims to establish the existence of hidden belief in the context of VS. This hidden belief may be understood as the ‘unknown unknown’ variable that must be accounted for. In this presentation we will share the results of an experimental study where we show (1) the existence of hidden belief networks when engineers make verification assessments and (2) the factors that surface such hidden beliefs into explicit information. The purpose of this study was to study the role of belief in engineering verification strategies and observe their impact on engineering design and the completeness of the aforementioned strategy in verifying the requirements related to a notional case. This was an empirical study, with data collected from test subjects satisfying pre-requisite inclusion and exclusion criteria. Participants were classified into control and experimental groups and asked to perform verification activities in two stages. Participants were presented with a list of requirements to be verified and corresponding verification artifacts, along with a verification matrix, which they were asked to fill in. In both stages, a single verification artifact corresponding to a single requirement was modified. The control group and experimental group received this artifact in an inverse sequence. The artifact contained an important consideration for the verification of its corresponding requirement, but this consideration was not explicitly codified. The experiment was aimed to reject the following null hypothesis “The control group and experimental group make identical selections of verification

artifacts that fulfill the verification success criteria." It was observed that one group failed to account for this artifact in the first stage but did so in the second stage. This established the existence of belief that was hidden and needed to be explicitly elicited. It was ensured that the artifacts were representative of those used in wider practice, and the population was representative of verification engineers typical to this context. Hidden belief can be attributed to factors like bias, lack of formalized quantification, implicit knowledge, and heuristic precedence. A lack of consideration of hidden belief may lead to gaps in both the static verification strategy design, and its dynamic implementation. The risk of failure arising from these gaps is high and is often retrospectively visible in several engineering failures. The significance of incorporating belief into VS design is not only present in discussions between a contractor and its customer but becomes critical as we rely on AI as part of a digital engineering ecosystem. If these beliefs are not codified and accounted for in VS design, the algorithms will be trained on an incomplete set of data. This exacerbates the possibility of error, and the cost of failure may be projected to be much higher. While determining the completeness and sufficiency of each verification activity, explicit elucidation of driving belief is essential. The future scope is to quantify factors influencing hidden belief and provide mathematical strategies to ensure completeness in elicitation. An extension into digital engineering with experimentation on existing AI and recommendations for mitigation and bridging future knowledge gaps is another focus area.

Presentation#87

How can INCOSE ensure SE's Future Relevance

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Keywords. Pursuing INCOSE's Vision;Evolving the SE Discipline;Sustainability;Global Problems;Transdisciplinarity

Topics. 1.1. Complexity; 1.5. Systems Science; 1.6. Systems Thinking; 10. Environmental Systems & Sustainability; 20. Industry 4.0 & Society 5.0; 22. Social/Sociotechnical and Economic Systems;

Abstract. As it pursues its vision of A better world through a systems approach, INCOSE will have to choose the types of systems problems SE should address, and consider the changes to SE practice and theory required for the discipline to continue to provide effective and lasting solutions. These are important considerations, since SE has traditionally been focussed on providing solutions to the technical problems it faced, and has refined its methods, processes, tools, heuristics, etc with this aim in mind. There is no guarantee, however, that our current knowledge will guide us reliably in resolving the new problems we might face as we broaden our horizons, and encounter new and unfamiliar complex systems behaviours. To remain relevant, INCOSE will – at a minimum – have to take more account of the wider systemic impact of the solutions it develops, even those that remain essentially technical in nature. For example, it might guide practitioners towards solutions which better conserve energy and raw materials during development, manufacture and operations, and encourage recycling and re-use at end of life. As our understanding grows, we might routinely consider the wider social impact of our technical solutions as we design them, and beyond that we might offer our expertise to those intervening directly in the socio- and eco-spheres to create more sustainable societies and a self-sustaining world. The capability to do this cannot be achieved in one step, and this presentation puts forward a model which INCOSE might adopt for how SE could evolve purposefully towards its vision, enhancing its knowledge and capability along the way, backed by heuristics and principles which are continually updated and organized – and scientifically grounded – all aimed at reinforcing SE’s ability to provide value as it widens its effective reach. We also argue that in taking on wider challenges outside the techno-sphere, SE will have to work closely with other disciplines, some of which are already adopting a Systems Approach, and learn from what they already know (and are still learning) about devising and implementing effective interventions. Such cooperation could result in an evolving, shared and transdisciplinary knowledge base. The vision we will present is of an SE discipline of the future which is self-confident, outward-facing and widely-valued, taking a leading position among others in the drive towards transdisciplinary and systemic approaches to resolving world problems. We conclude by suggesting some early steps which INCOSE might take to initiate desirable changes, from which others might grow. In putting forward this vision, the authors draw on insights they gained from developing a systemic model for how the SE discipline evolves - briefed at previous INCOSE ISs and IWs – and now becoming known familiarly as The Bridge. This presentation will expand on the one by the same authors which was presented at the INCOSE EMEA Workshop and SE Conference on ‘Engineering a Sustainable World’, Seville, May 2023.

Presentation#377

INCOSE and IEEE SMC Society Alliance: 5 Years In

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Keywords. INCOSE Alliance;IEEE SMC Society;joint activities;SE research and practice

Topics. 1. Academia (curricula, course life cycle, etc.); 1.2. Cybernetics; 1.5. Systems Science; 14. Autonomous Systems; 4.1. Human-Systems Integration;

Abstract. An outreach alliance between the International Council on Systems Engineering (INCOSE) and the IEEE Systems, Man, and Cybernetics Society (SMCS) began in 2019 following several prior years of dialog and interaction toward that end involving respective leadership. Prior to being formalized via an initial Memorandum of Understanding (MoU) in 2019, dialog began as early as 2011 regarding potential joint technical activity focused on topics of mutual interest – system of systems (SoS) and model-based systems engineering (MBSE). Synergies were ultimately leveraged in 2013 via the establishment of an IEEE SMCS Technical Committee on MBSE comprised of SMCS members and members of INCOSE who were already engaged in the INCOSE MBSE Working Group. That Technical Committee was chaired by members holding membership as well as Fellow status in both INCOSE and IEEE. At present, 5 years since establishment of the MoU, the alliance has grown and continues to expand. This presentation provides an overview of the INCOSE-SMCS alliance to date as well as current plans and prospects going forward toward the joint aim to develop and promote best practice processes and guidance, training, and supporting materials that can be used in projects and organizations in the field of systems engineering (SE) including human-systems integration.IEEE SMC SOCIETY OVERVIEWThe IEEE SMC Society is one of 39 technical activity-focused Societies within the IEEE, the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity. The SMCS mission is to serve the interests of its members and the community at large by promoting the theory, practice, and interdisciplinary aspects of systems science and engineering, human-machine systems, and cybernetics as accomplished via conferences, publications, and other activities that contribute to member professional needs. The SMCS aims to be recognized as the world leading society for the advancement of theory and application in each of these three technical pillars with particular emphasis on their integrative science, the human element within systems, and development of transdisciplinary approaches. The SMCS alliance with INCOSE is facilitated by an appointed SMCS member designated as INCOSE point of contact and liaison as well as interactions between respectively aligned technical groups.MUTUAL BENEFITSSMCS and INCOSE share interests in SE with respective strengths in academic/applied research and industry practice/development. The relationship was motivated by complementarity in that regard. SMCS is largely an academic society focused on systems science and systems engineering including an emphasis on human-systems, all involving the conception of analytical techniques and methodologies underpinned by cybernetics (i.e., including what is commonly referred to as AI and machine learning). INCOSE is focused on SE professionals and their practice of SE largely within the context of industry and government. This complementarity fed the impetus for the alliance and fosters reciprocal value. To areas of common interest, SMCS brings an academic strength while INCOSE brings a disciplined industrial practice. This has become essential as engineered systems increase in complexity while technological advances accelerate. Toward strengthening the SE toolbox, INCOSE benefits from applied theoretical systems science and development of new methodologies that SMCS brings, while SMCS benefits from the grounding in practical applications and emerging industry challenges along with participation of SE practitioners from industry that INCOSE brings. Such synergy is important toward enabling the SE research and practice communities to advance together to meet challenges of emerging complex systems.The scope of the INCOSE-SMCS alliance is both broad and evolving, currently including mutual promotion, technical collaboration between INCOSE Working Groups and SMCS Technical Committees, and joint publications,

webinars, conference panels/sessions, etc. The scope encompasses activities related to each of the four INCOSE Future of Systems Engineering (FuSE) Initiative streams including joint promotion of SE.JOINT ACTIVITYExamples of joint INCOSE-SMCS activity to date include sharing of SE perspectives, teaming on dissemination of technical ideas and thought leadership at conferences, and authoring academic products that inform and educate members. SMCS representatives have participated in FuSE monthly sessions and have provided review feedback and SMCS perspectives on the FuSE Charter, INCOSE SE Principles and Hypotheses formulation, and SE Vision 2035. Conference paper special sessions and listening sessions have been organized as well as joint panel discussions on MBSE and FuSE at SMCS annual flagship conferences (most recently IEEE SMC 2023 in October), covering respective insights from both development and research points of view. Joint webinars have been produced and made available to the systems community as have various publications including a handbook, edited book volume, and articles in respective member-/practitioner-focused periodicals (INCOSE INSIGHT magazine and IEEE SMC Magazine). Under current consideration is the formulation of joint technical projects related to the influence of context on system performance and to MBSE as an instance of transdisciplinary systems engineering.SUMMARYThis presentation highlights some of the INCOSE-SMCS activities over the past 5 years including some precursor interactions over the years prior to establishing the MoU formalizing the alliance. Also highlighted are technical areas of mutual interest to respective members, who are researchers and/or industry practitioners, as well as future outlooks on systems science and engineering that can offer foundations for ongoing collaborative efforts.This presentation responds to a call for interest in an “Alliance Track” planned by the INCOSE Events and Outreach Leadership. The focus is not on SE challenges of interest but rather on the complementary INCOSE-SMCS alliance through which various SE challenges could be addressed. The alliance’s activities relate to industries drawing INCOSE and SMCS attention, and span domains of application listed in the Call for Submissions. The alliance is of mutual strategic importance and can inform how important SE problems are addressed. The audience will take away a heightened awareness and appreciation of alliance activities to date. The presenter is the SMCS Senior Past President and former VP for Systems Science and Engineering, and a Fellow of IEEE who was instrumental in engaging INCOSE leadership since 2011 in dialog culminating in establishment of the alliance. Co-authors are current and recent SMCS officers or leaders who have been similarly instrumental and/or are current actively involved.

Presentation#65

Industrial DevOps and Digital Twins for Cyber-Physical Systems

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Keywords. digital twin;cyber-physical systems;agility;safety-critical;digital engineering

Topics. 20. Industry 4.0 & Society 5.0; 5.1. Agile Systems Engineering; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. Industrial DevOps applies Agile, Lean, DevOps, and digital transformation capabilities to the full lifecycle of cyber-physical systems. As we engineer and build the physical system, we also build its digital twin, the replication of the physical system. This digital twin is important as is it can provide real-time data and advanced analytics to improve decision-making, streamline operations, and create simulation environments to test changes before releasing to the physical instance. In this presentation we will discuss the importance of digital twins, the challenges they address, and the benefits to the organization. This will include how the factory that manufactures the cyber-physical system is also a cyber-physical system with a digital twin. In addition, we will discuss the importance of experimentation and validated learning, feedback loops, and how data is used for problem solving analysis for the product we are building and to the digital twin of the factory. Bringing this altogether we will demonstrate the relationship of digital twins for cyber-physical systems with DevOps for software to enable agility and speed of value delivery to the customer. We will highlight where these capabilities are being applied across industry and academia. Participants will receive recommendations for getting started and questions for their team to answer as they shape your organization’s technology roadmap.

Presentation#173

Integrating Arcadia and Capella with SysML v2

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Keywords. SysML v2;Arcadia;Capella;Interoperability;Model libraries;Model interchange

Topics. 2.4. System Architecture/Design Definition; 5.3. MBSE; 5.5. Processes;

Abstract. Arcadia is a Model-Based Systems Engineering (MBSE) method originally developed by Thales. It is supported by the open-source modeling tool Capella, which now has a wide user community. It was developed in response to issues with other methods and modeling languages at the time, such as the Systems Modeling Language (SysML).The original version of SysML (“SysML v1”) is a profile of the Unified Modeling Language (UML), meaning that it directly adopts a large subset of UML, which is then tailored and extended using stereotypes on UML model elements. This approach allowed the development of SysML tools based on existing UML tooling with support for a number of different methodological approaches. On the other hand, the grounding in UML makes it more difficult for SysML v1 to support certain critical features of

Arcadia.The second version of SysML (“SysML v2”), recently adopted as the successor to SysML v1, is no longer a UML profile. Instead, it is based on a new Kernel Modeling Language (KerML), which provides more freedom for the language design to directly address the issues with SysML v1. It is therefore of some interest to consider the relationship between Arcadia/Capella and SysML v2 and their respective approaches to resolving these issues.Components• In Capella, system modelers can develop models starting from specific components as used in a system, rather than first defining component types and then defining the use of the components in a system. In addition, component instances can easily be nested inside of other components in context of the system and updated in that context only.• The primary structural diagrams in SysML v1, the Block Definition Diagram (BDD) and Internal Block Diagram (IBD), both represent the decomposition of blocks (i.e., component types), rather than individual component instances. This makes it difficult to maintain nested parts with instance-specific properties.• SysML v2 replaces the v1 concepts of blocks and part properties with part definitions and part usages. However, unlike v1, part usages can be directly specialized and decomposed, similarly to component instances in Arcadia. This is an example of a very general pattern in SysML v2 allowing peer-level modeling of definitions and corresponding usages, including attribute definitions and usages, action definitions and usages, etc. This supports usage-focused modeling that was not possible in SysML v1.Functions• In Capella, functions and subfunctions can be modeled in the context of specific system instances, which can then be directly allocated to the components executing those functions. • SysML v1 supports the modeling of functional decomposition of behavior separately from the structural decomposition of blocks. It also provides notation for allocating behavior to blocks in the structural model, but this is not supported semantically in UML. As a result, it is difficult to represent functional models at multiple levels of decomposition, without physically replicating the model of allocated functionality within the blocks to which it is allocated.• SysML v2 provides syntactically and semantically consistent means for structural decomposition (e.g., of part definitions and usages) and behavioral decomposition (e.g., of action definitions and usages). Further, parts from the structural decomposition can be specified to perform certain actions from the behavioral. This provides a formal means for representing the allocation of the performed actions to the corresponding parts. Methodology• Capella provides tooling that directly supports methodological concepts from Arcadia, such as Operational Analysis, System Analysis, Logical Architecture and Physical Architecture layers, and realization links between components across layers.• SysML v1 is, by intent, method independent, but it still must be used within some methodological approach. Method-specific concepts are sometimes addressed by creating additional profiles on top of SysML v1. But the ability to extend the language in this way has often proven complicated to support in tooling.• Like SysML v1, SysML v2 is designed to be used across many different MBSE methods. However, SysML v2 is also designed to be highly adaptable and tailorable for use with specific methods. And, unlike UML and SysML v1 profiles, which are essentially syntactic extensions, SysML v2 also allows for formal semantic extension.InteroperabilityThe convergence of SysML v2 and Arcadia capabilities, along with the tailorability of SysML v2, provides an opportunity for interoperability that was not available with SysML v1. SysML v2 is built on KerML using semantic library models, written in SysML itself, that formally capture the semantic concepts of the language, based on kernel concepts from KerML. Similarly, a SysML library model of the key concepts embodied in Arcadia can be used to create SysML v2 models that are consistent with the Arcadia method.For example, the Arcadia concepts of “logical function”, “logical component” and “component functional allocation” can be modeled in SysML v2 as action, part and allocation definitions, respectively. As represented in the SysML v2 textual notation, these are (partially):action def LogicalFunction specializes Function { action ownedLogicalFunction[0..*] : LogicalFunction redefines ownedFunctions; }part def LogicalComponent specializes Component { part ownedLogicalComponents[0..*] : LogicalComponent redefines ownedComponents; perform action allocatedLogicalFunctions[0..*] : LogicalFunction redefines allocatedFunctions;}allocation def ComponentFunctionalAllocation { end allocatedFunction : Function subsets allocatingComponent.allocatedFunctions; end allocatingComponent : Component;}Note, in particular, that this simple model captures the semantics that a LogicalComponent performs the LogicalFunctions allocated to it, and that these allocations are established using ComponentFunctionalAllocation relationships.These library-model concept definitions can then be used to represent Arcadia concepts in SysML v2 models, interoperability with their representation in Capella. For example:action 'Condense Steam' : LogicalFunction;part 'Heat Exchanger' : LogicalComponent;allocation : ComponentFunctionalAllocation allocate 'Condense Steam' to 'Heat Exchanger';This technique can be used to support model exchange between Acadia models, created using Capella, and SysML v2 models, created natively in another authoring tool. Such model exchange generates a SysML v2 version of a Capella authored model or reads in a SysML v2 model that uses the SysML semantic library for Arcadia, without loss of methodological constraints. Further, other customer-specific extensions can also be seamlessly integrated with the Capella/SysML v2 models.

Presentation#74

Integrating IV&V into a generative AI Enterprise work culture

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Keywords. Chatgpt;AI;Generative AI;IV&V;Verification and Validation;Intelligence

Topics. 3.5. Technical Leadership; 4.1. Human-Systems Integration; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The technology landscape is being actively disrupted by the release of OpenAI’s large language model. Amtrak should seek to leverage the benefits of GPT models to generate code and narrative while ensuring that the technology is aligned with our goals and values. This requires a careful balance between human oversight and AI (Artificial Intelligence) capabilities. In this short briefing, we will explore how Amtrak can manage risk and optimize the use of GPT models by adopting a human-AI collaboration approach that leverages the strengths of both human editors and AI algorithms.The public version of OpenAI is fraught with risks to an enterprise, specifically when it comes to sensitive data and intellectual property. Whenever a user interacts with the model, that model will be updated and enhanced with human interactions and inputs.Because of the power of LLM’s to generate code and narrative text, it has never been more important to apply strong IV&V principles. Independent Verification and Validation (IV&V) is a critical process for ensuring that the results generated by GPT models are accurate, reliable, and meet the required standards. Enterprises must prioritize IV&V as an essential step in the development and deployment of GPT models. This can involve rigorous testing and validation, transparent and ethical use of data, and involving users in the design and development process.To ensure the accuracy and reliability of the generated content, technologists should adopt a journalistic mindset when checking for accuracy. This means being diligent, thorough, and skeptical in analyzing and interpreting the generated text. It involves asking questions like "Is the information presented accurate, reliable, and supported by evidence?" and "Are there any biases or inconsistencies in the generated text that could affect its accuracy or credibility?" By adopting a journalistic mindset, technology executives can help ensure GPT models

Presentation#514

Integrating Model-Based and Loss-Driven Systems Engineering

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Keywords. MBSE;Specialty;Loss-Driven Systems Engineering;Reliability;Safety;Human System Integration;Aerospace;Defense

Topics. 2. Aerospace; 4.1. Human-Systems Integration; 4.3. Reliability, Availability, and/or Maintainability; 4.6. System Safety; 5.3. MBSE; 6. Defense;

Abstract. Systems Engineering has many specialty disciplines which include safety, reliability, availability, maintainability, system health, electromagnetic environmental effects, human factors, and security. The engineering tasks performed by these disciplines are often complex, resulting in a loose integration with the conventional system engineering tasks. This loose integration is also evident in industry standards and best practices. The presentation will begin with an overview of this problem space along with a brief review of the relevant aerospace industry standards to provide context. A discussion on the emerging idea of Loss-Driven Systems Engineering (LDSE) will follow. The INCOSE SEBoK defines LDSE as “an area of systems engineering that holistically addresses the quality characteristics concerned with loss (such as resilience, safety, and security).The focus of the presentation will be an example from the aerospace industry using model-based engineering to integrate traditional systems engineering with LDSE. This example addresses the multi-faceted integration of people, standard-driven processes, and tools, seeking to answer the following key questions:• What are the data inputs and outputs for a specific specialty analysis?• Where is that data coming from and going to?• How is that data transferred?• Who is responsible for that data at a given point in the process?• What are the data handoff points?• What engineering tools are used?The presentation concludes with lessons learned about the integration process and observations on potential improvements to industry standards. An outlook on future work will also be provided.

Presentation#90

Is the Journey to the End of the Project Rainbow a Minimal Viable Capability (MVC)?

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Keywords. Minimal Viable Capability (MVC);Minimal Viable Product (MVP);Agility;Lean;Iterative;Incremental;Digital Engineering;Digital Transformation

Topics. 11. Information Technology/Telecommunication; 2.4. System Architecture/Design Definition; 20. Industry 4.0 & Society 5.0; 3.7. Project Planning, Project Assessment, and/or Project Control; 5.1. Agile Systems Engineering; 6. Defense;

Abstract. Often in the past we have strove to deliver a “perfect solution”. Sometimes this was warranted, particularly dependent on the intended operational domain. But often it was not necessary, and led to many cost and/or schedule overruns, and sometimes the introduction, or the appearance of, poor quality systems, at least for the initial deployment. With the growing interwoven dynamics of the world from climate change initiatives to political instability, from health concerns to resource restrictions, from economic upheavals to global operations, the speed to deployment is becoming more and more crucial. Thus, the balance to achieve perfection and the speed to deploy are in conflict.A means to address this challenge is to employ a Minimal Viable Capability (MVC). MVC is “the capability that can successfully achieve the lowest acceptable level of the directed effect in the required time, able to be acquired, introduced into service and sustained effectively” (quote from Australian Vice Chief of the Defence Force (VCDF) Group). This approach supports the delivery of needed capability as soon as possible with further capabilities being incrementally incorporated. The MVC can be considered the threshold of performance. But does the MVC journey lead to the pot of gold at the end of the rainbow? Is MVC “the buried treasurer” as some customers are hoping it to be?The answer is questionable. MVC requires a lot of change and flexibility both in acquisition and in-service support. Based on many workshops and meetings with customers, discussions with peers globally, and personal research, the author is creating a guidance document for her organization on MVC. This presentation will make use of this material.The presentation will discuss and illustrate the relationship between the value offered to stakeholders, and the blockers stopping the value from being realized. In turn, the tailoring of SE practices, including Model-Based Systems Engineering (MBSE) approaches to address these blockers will be identified. In doing so, the presentation will address – • The impact of MVC across different development lifecycles such as incremental, evolutionary (iterative), agile and lean.• The impact on different contracting models such as fixed price, cost plus, early contractor engagement. • The relationship between agile methods and MVC, including the Agile SE approach developed by the Agile SE Working Group, (namely Rick Dove, Kerry Lunney, Michael Orosz, and Michael Yokell).• The changes required by different stakeholders to realize capability using MVC.• The changes required to SE practices to embrace MVC at each phase of development and support.• The use of digital transformations to facilitate the MVC approach.The presentation will provide a number of graphics illustrating the journey to implementing MVC, cumulating in a single graphic that summaries the relationships and influencing factors between the necessary tailoring of practices across all stakeholders, in different phases of the development and support lifecycle, and the variations of such tailoring across different development lifecycles. By using the guidance provided by the author in this presentation, there is a greater likelihood that MVC will address complexity and the speed to deployment for such projects. The presentation is applicable to all domains, where large projects and long timelines to deployment are common. Participants should become familiar, firstly with the difference between MVP and MVC, followed by the realization challenges in successfully executing MVC. They will be presented with examples of real, experienced challenges and blockers, in providing the value to stakeholders implementing MVC, and the means to address such challenges and blockers. The graphics and guidance will add to a Systems Engineer’s toolkit for use, adaptation and adoption.

Presentation#143

Lessons learnt about the management of a Systems Engineering trainings framework: A Safran Group return on experience

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Keywords. Trainings;Competency;Feedback;Framework;Lessons learnt;Safran

Topics. 2. Aerospace; 4.5. Competency/Resource Management; 5.9. Teaching and Training; 6. Defense;

Abstract. The Safran Group is – as the rest of the aerospace industry – in the middle of the transformation journey described in the INCOSE vision, from traditional engineering to model based systems engineering.This transformation cannot happen without a strong effort in updating, transforming and improving the skills & competencies of the Safran employees.During the last decades, a significant effort was made to build the trainings framework.The initial steps – beginning of the century – were done with local initiatives, few internal competencies, external help, and with trainings of a very classical format (slideware).During the 2nd decade of the century, a central sponsoring emerged, along with a Safran university and stronger partnerships with consultants such as CESAMES. Experts networks were created, and internal trainers were trained for animation and development of the trainings. The different trainings formats progressed, to include some MOOCs and on the job trainings, and also more interactive trainings.Since 2020, the situation is stronger and more stable. The sponsorship is stronger, centralized at the exec level of Safran, and the deployment is followed by KPIs. The central and local entities of the group are coordinated. The internal experts network are productive, and the trainings formats are various and more and more adapted to both the people to train, and the current context within Safran. The entire framework is in continuous improvement, based on the trainees feedbacks.The lessons learnt are on many aspects on the training framework:• About the management on the framework, a complete process was defined. The communication is improved, as well as the planning of the sessions. Some tailoring is applied if necessary, depending on the context of the need.• About the design of the trainings, the best format is used for each objective, among MOOCs, interactive trainings, videos, etc. Many tools are now available at Safran to develop and manage the training offer. Moreover, the trainings are considered within a whole, with a systemic approach and training paths, so as to ensure the completeness of the offer and its consistency. Practitioners can go from awareness to intensive trainings, through methodological and tools trainings. All this framework is continuously improved, both on the format, contents, and offer.• The lessons learnt also improved our selection and training of trainers, so as to have the adequate profiles and competencies to provide quality trainings.The results over the past years are positive. A virtuous loop is now engaged, with more and more people trained and an overall progress on the projects, bringing new business opportunities. The critical size of trained people and experts is now reached, even if some challenges remain since the target is still not reached.As a conclusion, Safran really learnt these years that provide trainings of good quality shall not be improvised. It requires both a good approach (big picture, open and humble mindset, specific competencies, profile of trainers) and a significant effort and time (both initialization effort and continuous improvement, with a good level of sponsorship).The way forward for Safran it to ensure the standardization of trainings for the entire group. The sponsoring shall remain high, the monitoring at a good level and constant, the organization optimized between the Safran university and the Safran entities to ensure a full convergence. The experts network will be in cruise mode for trainings continuous improvements, with many trainings formats, each of them adapted to the pedagogic objectives and the project needs. The full coverage of the INCOSE Competency framework as also in the roadmap, since some parts of the framework are still not correctly covered.

Presentation#126

MBSE Methodology: Risk Analysis and Requirements Management

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Keywords. MBSE;Model-Based Systems Engineering;Risk;Requirements;Verification Techniques;System of Systems Architecture

Topics. 17. Sustainment (legacy systems, re-engineering, etc.); 2.6. Verification/Validation; 3.9. Risk and Opportunity Management; 5.3. MBSE;

Abstract. To ensure a system of interest (SOI) will maintain functionality through the range of all operating environments, including undesirable conditions, it must be verified against bounding environmental requirements. Verifying SOI functionality through a formal engineering qualification or certification process is an essential step that proves that a system complies with its requirements. Although the qualification process has traditionally been document-based, we have found the capability of verifying requirements to be a strong suit of model-based systems engineering (MBSE); therefore, our Systems Engineering team at the Los Alamos National Laboratory is actively developing a methodology and implementation strategy for MBSE-assisted requirements verification.In our work, the application of one or more verification methods (e.g., inspection, analysis, demonstration) used to qualify a system integrates with the system architecture to build a consistent and fully traceable set of hierarchical system requirements. Tying verification requirements from the system performance requirements to both structural and behavioral elements within a verification activity architecture maintains the distinction between parameters (or attributes) which must be maintained for system verification and localized requirements bounding the execution of the verification activity. This differentiation creates integrated verification techniques that translate from developmental testing configurations to full system qualification testing, enabling localized trade-studies at the testing team level while minimizing concern for affecting the test's ability to verify system level requirements. Additionally, the implementation of an MBSE-enabled System-of-Systems (SoS) approach allows for the application of established verification activities for future systems that require similar qualification processes. By defining each verification technique's capabilities and attributes as self-contained MBSE models in an SoS architecture, trade studies between verification techniques to satisfy system verification needs also becomes more efficient and effective. By leveraging the capabilities of MBSE to expedite the administrative steps of systems engineering, system realization can be accelerated without adding risk to the program or system.
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Presentation#362

Mission Engineering – Extending Systems of Systems Engineering to Mission

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Keywords. Systems engineering;Systems of systems;Mission;mission engineering;digital engineering

Topics. 5.4. Modeling/Simulation/Analysis; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 6. Defense;

Abstract. As the INCOSE Visions 2020 and 2035 have emphasized, the application of systems engineering continues to expand to provide the same discipline and systems approaches to capabilities beyond technical systems. Mission engineering is one example of this type of expansion, now an area of emphasis for the Defense community, but with clear potential across a broader set of domains. This presentation discusses the origins and motivations for mission engineering, the current mission engineering methodology and how it leverages systems engineering approaches and tools to address the unique challenges posed by mission engineering, and the relationship of mission engineering to systems and systems of systems engineering. It provides several examples to illustrate the application of mission engineering. Finally, the presentation explores opportunities for applying mission engineering beyond defense.Mission engineering is applying systems engineering to missions – that is, engineering a system of systems, (including organizations, people and technical systems) to provide desired impact on mission or capability outcomes. Traditionally, systems of systems engineering focused on designing systems or systems of systems to achieve specified technical performance. Mission engineering goes one step further to assess whether the system of systems, when deployed in a realistic user environment, achieves the user mission or capability objectives. Mission engineering applies digital model-based engineering approaches to describe the sets of activities in the form of ‘mission threads’ (or activity models) needed to execute the mission and then adds information on players and systems used to implement these activities in the form of ‘mission engineering threads.’ These digital ‘mission models’ are then implemented in operational simulations to assess how well they achieve user capability objectives. Gaps are identified and models are updated to reflect proposed changes, including reorientation of systems and insertion of new candidate solutions, and which are assessed relative to changes in overall mission effectiveness. The presentation will provide examples to illustrate this approach to mission engineering and highlight the benefits and challenges experienced to date. It will highlight systems engineering capabilities from across several INCOSE working groups (particularly SoS, MBSE, Complexity, Socio-Technical Systems, Education and Training) which are relevant to addressing the challenges. Finally, while mission engineering has been largely focused on defense, examples of ways this approach can be applied to domains beyond defense will be explored.

Presentation#244

Mission Possible: Deploying MBSE Model Libraries for Optimal Systems Development

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Keywords. Library;Development;Reuse;Sharing;Governance;Training;Model Based Systems Engineering (MBSE)

Topics. 2. Aerospace; 2.4. System Architecture/Design Definition; 3.7. Project Planning, Project Assessment, and/or Project Control; 5.3. MBSE; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Setting out on the journey of deploying a Model-Based Systems Engineering (MBSE) model library is like diving headfirst into an exhilarating adventure, rife with challenges and opportunities for growth. Careful planning and execution are needed to ensure effective integration into workflows and the necessary support for the development of complex systems. In this presentation, we will be discussing methods and considerations for deploying a MBSE model library within an industry platform focused on systems architecture, with practical examples at each stage.First step in deploying an MBSE model library is to identify the team's needs and how the library will be taught to engineers who are utilizing it. This includes understanding the team's experience level, technical capabilities, and the type of projects they typically work on. Scope of the library should also be clearly defined and identify the specific models and templates that will be included in the library. Defining the scope of the library ensures that it is focused on meeting the needs of the team and is not overwhelming with unnecessary information. Training on the use of the MBSE model library is critical to ensure that the team is able to effectively use it. Additionally, library developers may also bake training into the model itself, using navigators, comments, and other tools provided by modeling languages to document their thoughts and instructions. This training can include hands-on exercises, webinars, and on-site training. The training should be designed to match the experience level of the team members.Establishing governance is also critical in ensuring that the use of the library was consistent across the company. This can include guidelines for naming conventions, data entry, and model structure. This governance is often in the form of a board, consisting of those who developed the library and users, which laid out intended use cases, developed training, provided guidelines for model development, and conducted knowledge sharing (through presentations, etc.). Governance ensures that the library is used effectively and can be easily shared and reused. Through knowledge sharing, encouragement of collaboration across teams is also essential to ensure that the library is used to its fullest potential.Finally, planning for the integration of the MBSE model library into the team's workflow is crucial. Integrating the library into existing tools or developing custom integrations to support the team's specific needs can help provide visible value to the team. Planning for integration ensures that the library is effectively used and provides the necessary support for the development of complex systems architecture.In conclusion, deploying an MBSE model library requires careful planning and execution. Identifying the team's needs, defining the scope of the library, providing training, establishing governance, encouraging collaboration, and planning for integration are all important factors to the success of deployment efforts. With these considerations in mind, library developers can effectively deploy MBSE model libraries to support the development of complex systems architecture as well as improve efficiency and effectiveness.

Presentation#279

Modeling of Uncertainty in System and Enterprise Models

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Keywords. Uncertainty Modeling;System Architecture;Enterprise Architecture;Modeling Standards

Topics. 1.1. Complexity; 2. Aerospace; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Modelers typically create models of their systems assuming some degree of certainty in what they are describing. However, there is a need to understand how much uncertainty there is in their projections of what the system will do and how well it can do this. There needs to be a standardized way to model this uncertainty to ensure a greater understanding of what is actually feasible to implement to solve our most challenging problems. A new standard from OMG called Precise Semantics for Uncertainty Modeling (PSUM) specifies concepts of uncertainty, accuracy, precision, and related concepts. The PSUM concepts are specified as a metamodel, but this approach lacks integration with the commonly used modeling approaches, such as SysML, AADL, UAFML, and others. We will discuss why modeling precision and uncertainty is important to the Systems Engineering discipline, and we will propose extensions to the UAFML and SysML standards with examples and discuss possibilities for SysML V2.In this presentation you will learn why uncertainty is an important concept to model as part of MBSE and how to do so with extensions of SysML. We will see how uncertainty isn't just about measurements and precision but should also be part of our design process and integral to the operation of the systems we design. We will explore how uncertainty can be modeled, talk about the standards it is based on, and look at examples of using this approach. Systems engineering in part was created to help us understand complex interactions and behaviors in the operation of systems. As part of this endeavor, understanding precision and uncertainties of the system is necessary as these affect the system capabilities and performance. The measures of the system need to be identified and these measures need to be characterized with respect to desired level of precision and an understanding of the underlying uncertainties. For example, a self-driving vehicle may have several sources of uncertainty due to its imaging systems, image recognition algorithms, control parameters variations, and the differing operational conditions. Such uncertainties are driven by capabilities and precision of its parts. For example, this could involve a sensor's resolution or a machine learning algorithm's confidence level with regard to a recognized object. Uncertainty can also be related to risks like that of a potential collision if a system fails to recognize a vehicle before changing lanes. Uncertainty can also change over time or conditions like rain reducing visibility and thus increasing the uncertainty.Systems Engineers, enterprise architects, and stakeholders can all benefit from a better model of uncertainty. By associating uncertainty to measurements of the system and relating it to risks, precision of measurements, beliefs related to the uncertainty, causes, and other concepts we can reduce the unknowns about a design or even understand better when the design causes an uncertainty. Understanding precision and uncertainties of systems is critical to proper operation and reducing risks. If engineers could better model uncertainty, its origins, precision of measures, and related concepts like beliefs, facts, unknowns (including our evidence of such), sources of belief of our designs, such as for example how sensors and processing can be executed within operational bounds. We therefore need a capability to model uncertainty in our system and of our designs of those systems. PSUM defines several core concepts in its metamodel, such as uncertainty, belief, evidence, precision, etc. It leverages two other metamodels: Structured Metrics Metamodel (SMM) for modeling measures and measurements, and the Structured Assurance Case Metamodel (SACM) for representing structured assurance cases. An Assurance Case is a set of auditable claims, arguments, and evidence created to support the claim that a defined system will satisfy particular requirements.PSUM and its related DMM and SACM are only metamodels, so we need to map these onto SysML and where applicable to UAFML. UAFML, used for enterprise architecture modeling, already has many similar concepts of PSUM. For example, the UAF metamodel contains concepts for opportunity, risk, measurement, effects, outcomes, etc. We have also made allowances for modeling with SysML since PSUM modeling is likely to be more relevant and useful as details of a system design evolve.Extending SysML with PSUM is our first step (as a side benefit of this presentation is a tutorial on creating extensions to SysML). Most concepts in PSUM benefit from elevating the concepts in similar ways to how we distinguish a Block from a Requirement. For example, we use stereotypes to distinguish an Uncertainty from a value property that we are relating to the uncertainty. In some cases, additional stereotypes are used to represent relationships

between concepts. For example, in PSUM a Belief is associated with its Belief Agent (source of the belief like an image sensor or a person), in this case by using a stereotype called SourceOfBelief. As a measure of success, the end result should produce a specialized modeling language and syntax that can be readily validated by modeling tools. There needs to be enumerations for some of the concepts like EvidenceType, UncertaintyType, UncertaintyNature, and many others. These enumerations aid the modeler in narrowing the prescribed choices to the domain. We plan to test the PSUM language with realistic examples. We will duplicate examples provided with the PSUM specification and add information as needed to prove that the concepts can be modeled properly.As discussed, modeling uncertainty, especially as a formal model when doing MBSE, will be a useful tool to improve our understanding and design of systems. There are many use cases such as, for example, understanding what parts of a design have significant uncertainty. When using this new modeling capability, it will help us better understand what we do not know and the associated risks, as well as helping us determine what are the uncertainties of the system under a variety of scenarios and conditions. We can then describe the nature of our uncertainty and more readily find solutions to reduce that uncertainty. Our goal is to know what we know and how certain we know it, and to eventually avoid that eternal problem of thinking we are right.

Presentation#392

MOSA Implementation Challenges and Opportunities; Perspectives from the NDIA Architecture Committee

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Keywords. MOSA;Modular Open Systems Approach;open architecture;open interface;intellectual property;IP;data rights;system architecture;architecture;DoD;interoperability

Topics. 11. Information Technology/Telecommunication; 2. Aerospace; 2.1. Business or Mission Analysis; 2.4. System Architecture/Design Definition; 3.3. Decision Analysis and/or Decision Management; 6. Defense;

Abstract. The Modular Open Systems Approach (MOSA) has been implemented in US defense acquisition for several years, initially during the time of the NDIA's acclaimed 2020 white paper "MOSA: Considerations Impacting Both Acquirer and Supplier Adoption". With the experiences of the US defense industrial base and acquisition community MOSA engagement over the three years since, the (National Defense Industrial Association (NDIA) SE Division's Architecture Committee developed a subsequent report "MOSA Implementation Challenges and Opportunities 2023". Findings disclosed in the report are centered around three primary implementation matters: 1) Integration of Government and industry interests and efforts; 2) Management of concerns and related risks of contractors and suppliers in MOSA-involved solutions; and 3) Successful solicitation and selection of MOSA contract partners. This presentation shares the findings of that report on lessons learned through implementation of MOSA on development programs to date. It further makes updated recommendations to facilitate successful enablement and application of the MOSA objectives by all stakeholders over the long term.

Presentation#372

Navigating Organizational Acceptance: Leveraging the Overton Window as a Systems Thinking Tool for Radical Project Ideas Approval

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Keywords. Systems Thinking;Overton Window;Context Diagram;Larger Systems;Sociotechnical Systems

Topics. 1. Academia (curricula, course life cycle, etc.); 1.5. Systems Science; 1.6. Systems Thinking; 2.1. Business or Mission Analysis; 22. Social/Sociotechnical and Economic Systems; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. In the dynamic landscape of organizational decision-making, the notion that "the best ideas win" often collides with the reality of bureaucratic hurdles. This presentation explores the application of the Overton Window as a powerful Systems Thinking tool to address the challenge of gaining approval for radical project ideas within large corporations.The Overton Window, a political theory depicting the range of socially acceptable ideas in a given time period, serves as a lens through which employees can view their project proposals. By adopting a holistic approach, employees can consider their project idea as constituent part of a larger system encompassing organizational stakeholders and its strategic priorities, instead of just focusing on the idea itself.This presentation outlines how the Overton Window can be employed to increase the likelihood of stakeholder support for seemingly radical concepts. Employees can understand the range of ideas that are considered acceptable in the industry, organization and target stakeholders and categorize the stakeholders who see the project idea as sensible, acceptable, radical and unthinkable. Through system engineering tools such as context diagram and matrices for this larger system at hand, and analyzing the beliefs shaping these perceptions, employees can craft effective strategies for engaging stakeholders, conveying project goals/benefits, and securing essential buy-in.This proactive approach, grounded in Systems Thinking, enhances the prospects of obtaining approval from senior leadership. The absence of such holistic system analysis often leads to employee frustration, as their innovative ideas sit on the shelf just because the idea was outside of the Overton window.Learning Outcomes for Audience:1. Embrace a holistic Systems Thinking approach with the help of Overton Window and by considering project idea proposals as integral parts of a larger organizational system.2. Learn how to use system engineering tools such as context diagrams and matrices to analyze the larger system at hand.3. By the end of the presentation, the audience will be equipped with practical insights, tools, and strategies to navigate organizational acceptance successfully, for radical project ideas.

Presentation#245

On a Recursive Methodology for the Analysis of System Requirement Tolerances

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Keywords. Digital Engineering;Statistical Analysis;Verification & Validation;Test Coverage Evaluation;System Behavior

Topics. 1.6. Systems Thinking; 17. Sustainment (legacy systems, re-engineering, etc.); 2. Aerospace; 2.6. Verification/Validation; 5.5. Processes; 6. Defense;

Abstract. he performance of a system can only be quantified once the amount of variability in its requirements is allocated. This presentation proposes a methodology whose purpose is to improve system test suites, determine test coverage, and predict future system performance. This method showed that data analysis and systems theory can be used to truncate requirement tolerances, increasing system and test precision. Test activities are optimized, throughput is increased, and rework activities are abated. The methods described have also been used to quantify confounding variables' effect and determine intra-system dependencies within opaque behaviors. In addition, this method can support analysis of propagation of Type I error that can be thus calculated and capped, ensuring V&V activities are accurate in measuring true system performance outcomes.

Presentation#315

Optimizing MBSE adoption: Identifying and prioritizing forces

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Keywords. Model-Based Systems Engineering;MBSE adoption;Force Field Analysis;Organisational change;Adoption strategy

Topics. 5.3. MBSE;

Abstract. Model-Based Systems Engineering (MBSE) has been a topic of interest within the INCOSE network, since it was introduced as the next paradigm during the INCOSE symposium in 2007 (Friedenthal et al., 2007). Many organisations have shown interest in the potential benefits of MBSE, have applied it in pilot projects, and have tried to adopt it organization-wide (Huldt & Stenius, 2018). However, MBSE adoption presents a wide variety of challenges for organizations seeking to implement the methodology in their organization. Due to the many different challenges, formulating a fitting starting point and adoption strategy for MBSE is challenging for practitioners and organizations. This presentation aims to address this gap in current MBSE adoption research and practice. Current research has identified various restraining forces

impeding MBSE adoption (Huldt & Stenius, 2018), identified restraining and driving forces (McDermott et al., 2020; Vogelsang et al., 2017), studied the magnitude of restraining forces (Cloutier & Bone, 2010), and studied the dependency between restraining forces (Chami & Bruel, 2018). However, these studies mainly focus on the restraining forces, overlooking the driving forces and the interdependencies between both the driving and restraining forces. This limits the comprehensive understanding of MBSE adoption, leaving practitioners without a clear starting point and strategy for adoption. This study proposes a methodology that can be used to quantify the magnitude of both the restraining and driving forces and identify the interdependencies between the forces. The results support practitioners in formulating strategies for successful adoption. To analyse the potential dependencies between barriers and drivers of adoption, the research draws on Kurt Lewin's Field Theory (Burnes & Cooke, 2012; Endrejat & Burnes, 2022; Swanson & Creed, 2013). Field theory assumes a (psychological) system is influenced by external interdependent forces, the force field, originating from its surrounding systems. To achieve a specific change, the force field has to be understood and analysed from a holistic perspective including quantified magnitudes and interdependencies between driving and restraining forces from its surroundings. Based on Field Theory, Force Field Analysis (FFA) technique is commonly applied to identify driving and restraining forces moving a system away from adoption, closer to adoption, or resulting in inertia. However, FFA does not support quantification of the magnitude or dependencies of the forces (Burnes & Cooke, 2012; Lewin, 1951). To overcome this limitation, FFA is combined with the Decision-Making Trail and Evaluation Laboratory (DEMATEL) and with the Analytical Network Process (ANP). The DEMATEL is used to quantify the dependency between the forces, while ANP is used to quantify the magnitude of the forces. Therefore, by combining FFA with DEMATEL and ANP, this presentation proposes a comprehensive and quantifiable approach for analysing the force field, as suggested by Kurt Lewin (Lewin, 1951). The methodology follows four steps of FFA, namely define desired situation, identify forces, quantify force strength, and prioritize forces. The DEMATEL and ANP is integrated in the quantification step. Initially, a comprehensive list of driving and restraining forces has been compiled based on extensive literature review and expert interviews. This comprehensive list can be used by practitioners to rate the magnitude of the forces and identify the most influential forces based on their experience and expertise. Subsequently, the practitioners can determine the dependency between the highly rated forces by performing pair-wise comparisons. The result is a causal diagram showing the dependency between the forces. In the causal diagram, the nodes represents the forces, the arrows show the direction of influence, and the thickness represent the strength of the influence. The causal diagram and quantified force magnitudes support practitioners to formulate fitting MBSE adoption strategies for their organization. To validate the practicality of this methodology, it was applied in a high-tech organization. The application in industry showed the methodology's effectiveness in identifying and prioritizing the forces influencing MBSE adoption. This approach proved beneficial in guiding the high-tech organization in understanding the complexity of MBSE adoption in their organization. The main contributions of the presentation to the INCOSE network are twofold. Firstly, it introduces a practical method combining FFA, DEMATEL and ANP, which supports practitioners to identify, understand, and prioritise forces restraining and driving MBSE adoption in their organizations. Secondly, it demonstrates the methodology's application in a high-tech organizational context. In summary, it offers a valuable framework for organizations to identify key influential forces, prioritise the forces, and support formulation of fitting strategies and processes for MBSE adoption.

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Presentation#271

Optimizing Systems Engineering Workflows through Novel Applications of Large Language Models

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Keywords. Large Language Models;Machine Learning;MBSE;Model Based Systems Engineering;Systems Engineering;mbX;Automation;Artificial Intelligence;System Architecture

Topics. 2. Aerospace; 2.4. System Architecture/Design Definition; 5.11 Artificial Intelligence, Machine Learning; 5.3. MBSE; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Recent advancements in Large Language Models (LLMs) have showcased considerable potential in the realm of generative design, offering a capacity that can be leveraged to optimize Systems Engineering (SE) workflows. This presentation presents two novel approaches, accompanied by practical examples, that utilize LLMs to assist and enhance SE workflows. These approaches integrate well-established software engineering design techniques to mitigate risks. The first novel approach has been implemented in the mbX application (U.S. Air Force Phase II SBIR). mbX extracts specific, measurable facts from unstructured documents using a pre-trained LLM model. To ensure the correctness and reproducibility of LLM responses, several layers are wrapped around the use of the LLM - a deterministic layer, an automated validation layer, and a human validation layer. After extraction, the human validation layer can assign labels to the data; this labeled data is then stored and can be designated as an Authoritative Source of Truth (ASoT) or used to fine-tune the LLM. The second novel approach employs a generative design process in which the LLM aids in contextualizing text into a format representing a system model. This approach has been implemented as a proof of concept by taking natural language input from users, generating a representation in JSON, and subsequently converting that representation into the likeness of a SysML Block Definition Diagram (BDD). In conclusion, these two approaches demonstrate the potential of employing Large Language Models alongside established software engineering techniques to enhance productivity during the system design process while mitigating associated risks.

Presentation#471

Perspective and Influence and Leverage, Oh My! Leadership for Systems Engineers

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Keywords. Technical Leadership;Facilitation;Collaboration;Influence;Perspectives

Topics. 3.5. Technical Leadership;

Abstract. “Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems” (Systems Engineering and Systems Definitions, INCOSE, 2019). It spans problem and solution, requires a diverse team thinking broad and deep, and

demands that we think across the entire lifecycle. Within a systems engineering team, the systems engineer plays a unique role serving as the technical connective tissue that binds together the greater team as they work to deliver the needed capability within schedule and budget and free of unintended consequences. Doing so requires that the systems engineer lead but not by position or power. For systems engineers, at the heart of leadership are the more challenging concepts of perspective, influence, and leverage.Systems engineers are familiar with the concept of perspective in the technical domain using viewpoints to explore, analyze, and specify their solution. But embracing perspectives from the human dimension is the starting point for systems engineering leadership. It begins not with self nor team but with customer, users, and stakeholders. To satisfy and delight, the systems engineer must see the world, the challenges, and the opportunities from the perspective of others as they look at the problem and solution space. This requires the social dimension, emotion, interest, and empathy.The systems engineer must also apply the power of perspectives to the team. Fundamental to systems engineering is the idea that many are wiser than the one, but to achieve this requires that we connect individuals, their insights, and their concerns. Again, this requires seeing from their perspective and helping to convey their perspective to others. Each perspective is imperfect, neither right nor wrong. The last perspective that the systems engineer must understand, position, and honor is their own. Systems engineering teaches us to see differently than others – not better nor worse, but simply different. The systems engineer must successfully integrate the deep subject matter expertise of the team with their own insights seeking the big picture and looking across the lifecycle. Doing so requires that systems engineers embrace their unique role and responsibilities without elevating themselves above those of others. If done correctly, as systems engineers help to connect and integrate these diverse perspectives together, they advance the collective intelligence of the team facilitating a shared understanding of problem and solution. For the systems engineer, it is not enough to apply perspectives and help the team to collectively see the big picture. Systems engineering is interventional, seeking not simply to understand but to create a better future. Frequently operating without positional power, the systems engineer must lead through influence. This means positioning themselves correctly within the team – not above as the superior nor below as a service function but alongside enhancing team performance as they connect perspectives, concerns, and concepts. It requires connecting through motivation and belief, keeping the why of the project at the forefront as the team develops the how and what of solution. Throughout, the systems engineer must practice humility, seeking to understand before seeking to be understood, engaging others in their language to fully unlock their insights. The final aspect the systems engineer must embrace is leverage – not leverage over people but points of leverage unlocked by systems principles and approaches. In fully embracing transdisciplinarity, the systems engineer helps the team gain leverage through an inclusive, holistic mindset. In adopting a lifecycle perspective, the systems engineer identifies unique points in time where the right investment, action, or decision can drastically influence project outcome. Looking across complexity and across scale, the systems engineer exposes different methods and tools for project success. The leverage lies in identifying and exploiting specific intervention points as we look upstream, downstream, and outward at the product, enterprise, and societal levels.As systems engineers, we often ask ourselves what we can do to create a better tomorrow. The answer goes far beyond our systems engineering processes, methods, and tools. Leveraging our principles and positions, we can have a unique and positive impact. But we must look beyond our technical contributions and embrace our leadership responsibilities. Doing so requires that we apply perspective, influence, and leverage to unlock our strengths in combination with those around us and lead for a better future.

Presentation#67

PLE Digital Thread: Now and the Future

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Keywords. PLE;Product Line Engineering;PLM;Product Lifecycle Management;Digital Thread;Interoperability;Component-Based Design;Modularity;MOSA;Reuse

Topics. 1.6. Systems Thinking; 2. Aerospace; 5.6. Product Line Engineering; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. When it comes to balancing cost and schedule with developing innovative and highly capable systems, product lines can be a decisive advantage in a competitive market. At Northrop Grumman, digital transformation is allowing a product line approach to be seamlessly applied across proposals, development, production, and sustainment. This is already resulting in faster times to market and reduced costs, but there is even greater potential still to unlock through digital threads. All this promise is contingent on one central question: Can our tools pass data across all disciplines from engineering to business to production and supply chain?Previous discussions in Product Line Engineering have mainly focused on closing the gap between variation management and systems/software tools. This presentation focuses on pulling the digital thread further and explores the need to tie business, engineering, and manufacturing tools closer into our product line tool environment. The goal is to illustrate the values in efficiencies that could be unlocked. In doing so, this will influence the industry to prioritize these new requirements and drive tool vendors to meet these needs. There are three main areas that will be discussed. First, that we need our business capture, investment, funding, order management, and production planning tools to be configured for use by product lines. Second, engineering needs to leverage product line repositories and account for the benefits of reuse when assessing optimal solutions. Third, to reap the benefits of alignment across disciplines and provide additional cost avoidance, our product lifecycle management (PLM) tools must align with variation management strategies. Ultimately, the significance of these findings is that the digital thread has a lot of untapped benefits that we can elevate from single products to product lines (family of similar products). Within the defense industry, this promises immense savings and within the commercial industry an undeniable competitive advantage for adopters. Implementing these approaches would be a monumental task for a single company, therefore a concerted effort across the industry, tool vendors, and the customer base must be pursued.Background on Presenters:Matthew Reilly is a Product Line Coach with Northrop Grumman's Product Line Center of Excellence within the Mission Systems sector. He works with product lines at various stages of maturity supporting them in the areas of business strategy, technical approach, and governance. Matt's professional experience spans across mechanical design, model-based systems engineering, and software engineering. Matt holds an MS in Aerospace Engineering and an MBA from the Georgia Institute of Technology. Paul Kepinski is working Product Line Digital Thread and Integration for Northrop Grumman's Product Line Center of Excellence within the Mission Systems sector. He works on evaluating and road mapping out potential integrations with product line ideology and existing systems across engineering disciplines. Paul holds an MS in Mechanical Engineering from Florida Institute of Technology. June Kobayashi is the Space Vehicle & Payload Products Digital Transformation and Product Line Engineering (PLE) Lead at Northrop Grumman Space Systems, where she stood up the processes and technology infrastructure to support PLE since 2015. She has trained and guided the team members for many product lines across the enterprise and advised best practices for across NG. Prior to this, she managed and developed RF and Mixed Signal electronics for Northrop Grumman and other defense and commercial companies for over 37 years. She has BSEE and MSEE degrees from the University of California in Los Angeles.

Presentation#209

Practice to adapt MBSE as agility enabler to the agile software development for mobility platforms

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Keywords. MBSE;Agile Software Development;Agile Systems Engineering;Boeing MBE Diamond Process;SysML;Ontology;Software Defined Vehicle;Mobility Platform

Topics. 14. Autonomous Systems; 3. Automotive; 5.1. Agile Systems Engineering; 5.3. MBSE; 5.7. Software-Intensive Systems;

Abstract. Background:Woven by Toyota, it develops a mobility platform encompassing in-vehicle software, software development tools, and cloud systems to aim to enable the development of integrated, software-driven experiences for Original Equipment Manufacturers (OEMs). The company was established in 2021 and dedicated to research and development (R&D) projects for the software-centric platform, also most developers come from the software industry and do not have working experience with systems engineers. Now, the company is transforming its development phase from the R&D to a production phase that requires more harmonized work to ensure quality, costs, delivery, and risks. Also, it is required to meet customers' needs appropriately. That means the time has come for systems engineering for this young company, but there are SE challenges as described below.SE Challenges in our context:The company is young and its culture has focused on modern software engineering customs. They have adopted agile software development and Scrum framework that conducts one-month iterations and three-month releases since they conducted R&D projects. There are 2 challenges in our context. The first one is to integrate systems engineering into agile software development. The second one is organizing terminologies that are used frequently by developers but tend to be used differently by different people.Regarding the 1st challenge, there are generally gaps between agile software development and traditional systems engineering. In addition, there is a valley of death between R&D and systems engineering in terms of engineering cultural differences or misconception that SE is a heavy process, as reported in the INCOSE INSIGHT volume 26, Issue 3 [1]. Therefore, to transform the organization from the R&D to the production phase, our 1st SE challenge is integrating systems engineering and agile software development to harmonize different software engineering teams' activities while overcoming the gaps and valley of death between SE and agile software development culture that were grown in the R&D phase.About the 2nd challenge, our company has several software development teams. They often use the words "product," "system," "software," "feature," and "function. " However, these words are used with ambiguous terminology and relationships. Unfortunately, when they consider the integration of their different teams' products, these ambiguous concepts cause problems and confuse software engineers. To get rid of confusing things, our 2nd SE challenge is letting all developers have the same understanding of the concepts of "product," "system," "software," "feature," and "function. " Why is the problem important, and what is it worth?The automotive industry is entering an era of change toward new mobility, such as software-defined vehicles (SDV). As the term SDV describes, mobility is changing from hardware to software-centric. As represented by autonomous driving (AD) and advanced driver-assistance systems (ADAS), software-centric technology advances rapidly in the automotive industry, and the demand for early adoption of R&D technologies and agile software development has been raised. On the other hand, the difficulty in ensuring quality and harmonizing R&D technologies and existing systems is increasing more and more. To overcome the difficulty, systems engineering is more in demand, but there seem to be similar challenges with us, such as:There are gaps between systems engineering and agile software developmentThere are barriers for developers who work in R&D or agile software projects to introduce systems engineering because SE seems to be a heavy process and additional work for them.Traditional V-model tends to be refused by agile software developers in terms of development style differences and the possibility of sacrificing agility.The words "product," "system," "software," "feature," and "function " are widely used in both systems engineering and software engineering, but there is no ontology to describe them and their relationship to each other.Outline methods:To overcome the 1st SE challenge, we are tailoring the "Boeing MBE Diamond" process methodology consisting of the traditional V processes for the physical system and the digital engineering processes presented by the Boeing company at the INCOSE International Workshop 2020 [2]. In our tailored diamond process, the bottom half of the diamond focuses on software

development processes, and the top half focuses on the virtual systems realized by SysML system models. This tailored diamond does not add extra work, i.e., systems engineering activities, to the current software development processes on the bottom-half side. Systems engineering activities are simultaneously conducted on the top-half side. This practice tries to keep the original agility and harmonization between agile software development as a whole system. The top-half side provides system models with SysML as a single source of truth, and it enables all stakeholders to get a common understanding of the whole system.To overcome the 2nd SE challenge, we developed the ontology with SysML metamodels to provide the definition and represent the relationship between “system,” “software,” “product,” “feature,” and “function.” This ontology has already enabled all developers to obtain the same understanding of these concepts and enhance the productivity for cross-functional activities. Also, this ontology has been used to develop system architecture models for our company's different products, and it succeeded in integrating different products as a single system at the design level.Expected Results:The author expected to succeed in integrating systems engineering and agile software development without sacrificing agility and establish the following achievements:Derive the tailored diamond processes for vehicle platform developmentPublished the ontology with SysML metamodels to organize the relationship between buzzwords that are used in the agile software development culture: “system,” “software,” “product,” “feature,” and “function.”These would be helpful for SE practitioners in the automotive industry who are trying to adopt systems engineering to their agile software development.References:[1] https://incose.onlinelibrary.wiley.com/toc/21564868/2023/26/3[2] https://www.omgwiki.org/MBSE/doku.php?id=mbse:incose_mbse_iw_2020

Presentation#347

Product Assurance in the Model-Based System Engineering Ecosystem: Learning from Various Vertical Lift Platforms

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Keywords. System Safety;Reliability;Product Support;Product Assurance

Topics. 2. Aerospace; 4.3. Reliability, Availability, and/or Maintainability; 4.6. System Safety; 5.3. MBSE; 6. Defense;

Abstract. Model-Based System Engineering (MBSE) represents a paradigm shift in countless engineering disciplines across multiple industries, including Product Assurance (PA) in the aerospace industry. Even though the returns on investment and ease of implementation for MBSE are both highest earlier in the product/service lifecycle, MBSE can still be used effectively at any stage of the lifecycle on a broad spectrum of products and services. This presentation kicks off a multi-part series to explore what could be learned from the application of MBSE for PA on platforms at various stages of their respective lifecycles. The scope of this research series includes hardware and software contexts on both civilian and military product/service platforms and spans the lifecycle from initial conceptual development to retirement/disposal. For this series, PA is centered mainly on Reliability/Availability/Maintainability (RAM), Product Support (PS), and System Safety (SS) (collectively RAMPSSS). Being the introduction of the series, this presentation primarily focuses on SS in civilian and military rotorcraft contexts up to the conclusion of the Detailed Design (DD) stage of the product/service lifecycle. Disciplines beyond SS, additional product/service platforms beyond rotorcraft, and stages beyond DD will be explored in future work, but parts of the foundation for some of these future works are included here.The general program structure for the civilian and military rotorcraft examples is described before both platforms are used to demonstrate key lessons in the application of MBSE to the SS discipline. The lessons are briefly summarized below.First, the fundamentals of Systems Engineering (SE) are still vital in an MBSE ecosystem. MBSE tools do not absolve a program from the responsibility of executing solid SE fundamentals, such as the development of baselined and synchronized requirement, functional, logical, and physical element trees. The Civilian Rotorcraft Platform (CRP) is presented first as an example to illustrate the pitfalls of trying to begin Preliminary Design (PD) without these trees in place. Fortunately, this CRP recognized the need for these trees and subsequently implemented such a structure, in the process becoming an example of successful SE.Second, once the initial requirement, functional, logical, and physical

element trees are established, the MBSE tools enable extremely powerful linkages to be established in a single central repository. The linkages between requirements, functions, and architectures have already been shown in the CRP example and the Military Rotorcraft Platform (MRP) is presented to expand these linkages into SS contexts. Prior to expanding this discussion, an overview of the applicable SS standards and artifacts is presented for the MRP. Note that all of these details were captured in the System Safety Program Plan (SSPP) delivered in report form to the customer. Furthermore, note that both military standards like MIL-STD-882E and commercial standards like SAE ARP 4754A and 4761 were used for the MRP.The use of a MBSE tool to provide a single central repository of SE data (DESE-CAMEO, in the case of the MRP) created opportunities that would not have been previously feasible in traditional SE ecosystems. In the realm of SS, hazards from Aircraft/System Functional Hazard Assessments (AFHA/SFHA) could be represented as elements in the MBSE ecosystem. These hazard elements can then be linked within the MBSE tool to the other previously-mentioned elements of the MBSE ecosystem, including requirement elements, function elements, logical elements, and physical elements, allowing an analyst to quickly see all of the related elements in a single central repository, more easily understand the connections between them, and analyze for change impact. Also, the hazard elements can be easily expanded beyond FHA linkages and content to include other relevant SS deliverables, such as System/Subsystem Hazard Analysis (SHA/SSHA). Additionally, once hazard elements are established with their initial severities and linked to functional and physical elements, an initial Development Assurance Level (DAL) could be assigned to functions and items. Subsequent design maturation and partitioning could be used to manually adjust the initial DALs and capture the substantiation for any adjustments. Note that all of these were delivered to the customer directly in the MBSE model. Additional SS analyses were also delivered directly in the model, including Systems Requirements Hazard Analysis (SRHA) and System-Theoretic Process Analysis (STPA). Third, despite the very powerful linkages made possible by MBSE, not everything can be easily captured, analyzed, and delivered via a MBSE model at this time. Other tools are still required, particularly as the context shifts from SS to SS's interactions with other aspects of PA, namely RAM and PS. In the SS-RAM context, Aircraft/System Fault Tree Analysis (AFTA/SFTA) would require a separate delivery outside the MBSE model, as would Failure Modes, Effects, and Criticality Analysis (FMECA) and Critical Safety Items (CSI) or equivalent. In the SS-PS context, the Operating and Support Hazard Analysis (O&SHA) for the MRP was not delivered in the MBSE model, but very easily could be imported in later and would likely resemble the AFHA/SFHA already in the MBSE ecosystem, which would lay the foundation for the inclusion of RAM's maintainability analysis elements and PS's publication ecosystem elements into the broader MBSE ecosystem.Finally, the presentation closes with a collection of other relevant lessons from both platforms beyond what was discussed above and a conclusion to summarize everything that was discussed.

Presentation#226

Projects Doomed to fail before they start - Early Lifecycle Activities are missing

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Keywords.
Lifecycle;Infrastructure;Transportation;Needs;Requirements;Risk;Planning;Organization;Society;Stakeholder

Topics. 12. Infrastructure (construction, maintenance, etc.); 2.3. Needs and Requirements Definition; 21. Urban Transportation Systems; 3.1. Acquisition and/or Supply; 3.7. Project Planning, Project Assessment, and/or Project Control; 5. City Planning (smart cities, urban planning, etc.);

Abstract. NOTE: This presentation was accepted for IS2023 as Easychair ID 115. The presenting author was taken seriously ill just after arrival in Honolulu and was unable to present. The presentation can be refreshed, if needed.Infrastructure has an enormous impact on civilization. Infrastructure presents a multi-trillion-dollar opportunity around the globe to better deploy Systems Engineering and mitigate the many "normalized failures" seen throughout the infrastructure domains. The general public is jaded and cynical about any large infrastructure project finishing on time or on budget or functioning or performing as expected. This represents a tremendous societal waste of resources in aggregate.A key root cause is represented by the early lifecycle activities that are not being executed. Infrastructure projects are too often led by very large construction companies who are not motivated during the acquisition process to invest in activities such as stakeholder analysis, needs and requirements analysis, design of projects, concepts of operations and early risk or priority analysis. Those activities (if considered at all) are subcontracted to other firms to execute after construction is completed.This presentation will present the root causes and effects in the first part - looking at the problem. The second part of the presentation presents a plausible and pragmatic solution approach for the industry.

Presentation#295

Right-sizing risk management approaches using lessons learned from Transportation and Infrastructure Industries

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Keywords. Organizational competency assessment;Requirements-driven risk management;Contractor-Supplier risk requirements

Topics. 12. Infrastructure (construction, maintenance, etc.); 2. Aerospace; 2.3. Needs and Requirements Definition; 3.9. Risk and Opportunity Management; 4. Biomed/Healthcare/Social Services; 4.5. Competency/Resource Management;

Abstract. Problem: Managing risk is often misconstrued as a highly complex activity to which only

quantitative analysts can add value. The results of such analyses are often considered highly subjective, based on a vast array of known and hypothetical factors. This perception increases when organization, program, or project leadership have different understandings of meaningful risk management approaches. Differences in the definition of risk or how risks are to be managed compound when critical project efforts are subcontracted to independent teams constructed of representatives from multiple sub-subcontractors. With each cascading layer of participation, the expectation for an effective risk management approach may become diluted. Further, segregating risk management into separate, non-interrelated processes working within narrow silos reduces opportunities to harvest information useful for continuous improvement and achieving greater economies of scale. A tremendous amount of information and data is accumulated in most any risk management system. Not using that information to proactively improve organizational processes reduces the key benefit provided by these systems to increase operational effectiveness and efficiency over time. Thus, hoped-for gains are lost without a rethink of this approach. When differences arise in how risk is managed, whether between the project owner and its contracting teams or subcontractors, not only are opportunities lost to increase positive outcomes, but jobs can be lost, programs derailed, or organizations decommissioned. The challenge for leadership wanting any risk management system is to ensure that the key objectives and requirements for the system are clearly defined, communicated, and supported throughout the entire owner-contractor relationship, whether the owner is a public agency or a large airplane manufacturer, and the contractor is a construction design-build organization or a large supplier of high-precision titanium components. While considerable focus has been spent on the mechanics of risk management systems, how objectives and requirements are defined remains an area needing additional focus as evidenced by the continued struggles witnessed in many organizations tackling this essential prerequisite for success.Approach and Methods: Risk management is more than identifying potential issues that may present threats or opportunities to an entity and is far more significant than performing quantitative analysis on risk impact to provide leadership with a rough estimate of the likelihood of finishing a project on schedule or on budget. Effective risk management requires a holistic system-wide definition and agreed-upon approach so that it can be sustained over the life of the effort, whether that is the entirety of the organization’s existence or through fulfillment of a team goal or project objective. A first step in establishing a holistic system-wide definition of risk is for an organization to assess its core competencies around risk and then identify and fill gaps between current and target competency levels. Capability or competency assessments such as a Capability Maturity Model Integration (CMMI) self-assessment helps organizations take this first step. Once baseline capabilities are understood, the organization can then obtain additional capabilities needed and then draw from this collective knowledge base to define risk in meaningful terms relevant to the specific and unique needs of the entity. With a cohesive, shared understanding of risk, how the commitment to risk is socialized through all levels of the organization and between the organization and its customers and suppliers can be fully determined.To address challenges facing entities embarking on the delegation of multi-tiered risk management system implementation, it’s critical to use established, proven methods to define clear, concise, and traceable requirements for risk management and all supporting processes. ISO 31000:2018 provides a possible framework of requirements that can help any entity get a jump-start on the minimal requirements for managing risk applicable to any industry or organization size. Once the requirements for the risk management system are clearly defined, these must then be translated for the right audience. Keeping the focus on the purpose of risk management to systematically address and reduce uncertainty throughout the organization, program, or project lifecycle enables flexibility in establishing right-sized approaches. Setting expectations to use a process-based approach designed to address the requirements of ISO 15288:2023 ensures the focus remains on fulfilling key objectives for risk management and avoids overly prescriptive, nonvalue-added activities that consume valuable resources with little obvious gain of knowledge or lessons learned. Too often, enterprise risk management expectations are captured in policies and procedures written for the contracting entity and then directly passed down to subcontractors through procurement documents. These approaches can miss critical components of an effective risk management system such as establishing mechanisms for closed-loop communication that respects and leverages the bi-directional nature of risk communication using methods scaled to the needs of all stakeholders in the communication exchange. Rarely are the needs of the subcontractor the same as those for the enterprise thus this approach often leaves subcontractors attempting to implement inappropriate enterprise-equivalent risk management systems when a more compact solution would suffice. Defining requirements focused on key objectives and desired outcomes from managing risk increases the likelihood of developing a risk management system that is right-sized for the intended users.This process assumes that organization, program, and project teams maintain the required capabilities to effectively define risk and that the “right” requirements are identified for both the organization (enterprise) and the subcontractor/supplier. In this presentation, how an understanding of organizational risk competencies ties to defining appropriate risk management requirements for all participants in the buyer-supplier relationship is explored using case studies from industry. Strategies for defining risk management requirements for all participants in that relationship are presented. Attendees will leave with a conceptual list of criteria for “right-sizing” a risk management system based on the specific needs of the entity wanting that system and which is appropriately scaled to the supplier/subcontractor’s abilities to support throughout the contractual relationship.

Presentation#430

Safer Complex Systems

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Keywords. Safety;Complexity;Complex Systems;Socio-technical Systems

Topics. 1.1. Complexity; 22. Social/Sociotechnical and Economic Systems; 4.6. System Safety;

Abstract. We live in an increasingly connected and technology-led world. We rely on a growing number of safety critical complex systems (SCCS). These include our communication, transportation, energy, healthcare and more. SCCS are ubiquitous and they are becoming more complex. Complexity is leading to safety risks that are not anticipated or understood. Achieving safer complex systems require us to think, act, and intervene differently.We can typically understand and predict the future behaviour of simple systems. As complexity grows, these systems become complicated, and a variety of specialised experts are required to analyse, predict, and manage their future behaviour. As complexity increases further, we face complex systems, which pose increased safety challenges because they:• cannot be fully analysed and understood• have unpredictable and often non-linear behaviour• are dynamic; they are ever changing• stakeholders have various, conflicting perspectives on purpose, goals, boundaries These attributes lead to unanticipated and unmanaged hazards, with major safety implications. Systemic hazards increase the potential for catastrophic and widespread harm to people, property, and the environment, disproportionally affecting the most vulnerable.This presentation will include a summary report of recent activities with in INCOSE and supported by INCOSE to further raise the awareness of practices to enable safer complex systems. This will include an overview of activities conducted by the Safer Complex System Initiative of Engineering X. Engineering X is an international collaboration founded by the Royal Academy of Engineering (RAE) and the Lloyd’s Register Foundation. In 2019, Engineering X launched Safer Complex Systems. Safer Complex Systems (SCS) is a visionary multi-year initiative aimed at enhancing the safety of complex global socio-technical systems. Earlier SCS work identified governance is an important factor in enabling safer complex systems. This includes the September 2020 University of York report exploring approaches for analysing complex systems. This report provides an initial framework for analysing safety in complex systems. In the next phase, 18 SCS case studies were published covering safety challenges in a wide range of application. These case studies posed fundamental questions on accountability, responsibility, and decision-making processes (governance mechanisms). INCOSE has provided technical experts who have provided input and served as mentors/critical friend advisors. The initiative also identified poor governance as a major source of risk. The SCS Govern workstream was created to explore pressing contemporary governance challenges for safer complex systems. This includes investigating the mechanisms intended to influence, direct or control behaviour through formal means (e.g., explicit rules, laws) or informal (e.g., social norms, ad hoc actions). New publications are due to be released in 2024. Finally, this presentation will close on a summary of the findings that emerge from the IW Safer Complex System Workshop crosscutting initiative. An overview of the learnings as well as proposed next steps will include a call to arms to the INCOSE membership to consider their individual contribution and role in ensuring safer systems (of all complexity) are realised.

Presentation#202

Seeing the bigger picture with the Unified Architecture Framework (UAF) - Offshore Wind to Hydrogen Enterprise

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Keywords. MBSE;UAF;System of Systems;SoS;Offshore Wind;Green Hydrogen;Wind Power;Sustainable;Simulation

Topics. 10. Environmental Systems & Sustainability; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 8. Energy (renewable, nuclear, etc.); 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Offshore wind to hydrogen generation and distribution represents a ground-breaking enterprise, intricately weaving together multiple independent systems to mitigate global challenges related to climate change and energy security. This complex yet vital endeavour is not merely a response to the urgent need for clean, renewable energy but also a multifaceted exploration fraught with technical, economic, and social barriers. As such, a holistic and systemic approach to design and analysis becomes not only preferable but imperative.This presentation delves into the utilization of the Unified Architecture Framework (UAF) to model an enterprise strategically incorporating offshore wind and hydrogen systems. UAF, a standardized representation of enterprise architecture through a Model-Based Systems Engineering (MBSE) approach, stands as a robust tool for evaluating various design choices and scenarios within the offshore wind to hydrogen enterprise. The UAF model embraces diverse views, capturing strategic vision, operational processes, resources, services, projects, and security controls.The system of systems within this enterprise consists of offshore wind farms, hydrogen production through to hydrogen storage along with integration to the power grid. Leveraging offshore wind, a renewable energy source, this enterprise aspires to produce green hydrogen, contributing significantly to the decarbonization of various sectors. This system of systems is not without its set of challenges, ranging from determining optimal configurations for systems to grappling with the variable and intermittent nature of offshore wind, in tandem with the demand and supply of hydrogen. The challenges extend to the enterprise too; needing to ensure the economic feasibility within an unknown market, along with conducting comprehensive environmental and social impact assessments and engaging with a wide variety of stakeholders to garner public acceptance and support.Addressing these multifaceted challenges necessitates not only technical prowess but also multidisciplinary research and innovation, demanding collaboration across industries, academia, government, and society. While the enterprise holds promise as a key solution in achieving net-zero emissions, it must traverse barriers and risks that may impede its development and deployment.By skilfully utilizing UAF, the presentation seeks to propel the knowledge and practice in the realm of the energy industry, illustrating how this framework empowers systems engineers to comprehend the complexity of their challenges on a grand scale. The presentation endeavours to equip the audience with an understanding of the Offshore Wind to Hydrogen enterprise, underscoring the significance of Model Based Systems Engineering (MBSE) in addressing its challenges and steering sustainable energy solutions. The UAF model is used in conjunction with Trade Analysis Simulation (TAS) and Monte Carlo simulation to help evaluate design alternatives, ensure coherence and consistency, and paving the way for future applications in concrete energy enterprise case studies.To enhance the learning experience, the presentation will include a live demonstration of the tools and techniques discussed, providing attendees with a first-hand insight into the practical application of UAF, MBSE, TAS, and Monte Carlo simulation.The presentation will be given by Joseph Hughes and Matti Koskipää, both esteemed experts at Dassault Systèmes. Joseph, an INCOSE Certified Systems Engineering Professional, leverages over a decade of experience as an MBSE Senior Specialist in the UK, specializing in SysML and UAF. With a background in Computing and Electronics, Joseph's global impact spans high-speed rail and renewable energy projects, embodying a commitment to excellence in shaping the future of systems engineering. Meanwhile, Matti, with over 15 years at Dassault Systèmes, manages the Model-Based Systems Engineering expert team, showcasing versatility across various industries and processes. His influential role in spreading MBSE knowledge includes serving as a visiting lecturer at Oulu University. Together, Joseph and Matti bring a wealth of knowledge and practical insights to the forefront of the presentation, offering a comprehensive view of advancements in Model-Based Systems Engineering.

Presentation#547

Spares Strategy for Programs in Development Phases: Quantifying Hardware Needs Prior to Production

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Keywords. Verification and Validation;Integration and Test;Development;Systems Engineering;Spares;Project Management

Topics. 2. Aerospace; 2.6. Verification/Validation; 3. Automotive; 3.7. Project Planning, Project Assessment, and/or Project Control; 4.2. Life-Cycle Costing and/or Economic Evaluation; 6. Defense;

Abstract. A sparing strategy is method to determine what parts and how many of each are needed as spares. Sparing strategies are widely employed for systems in production or operation where the system has completed development/certification and has a statistically significant set of failure data. The sparing strategy is closely tied to reliability analyses and considers delivery time and cost, downtime, lost production costs, and failure and repair data to calculate the quantity of spare parts needed at any specific time. The purpose of a sparing strategy is to ensure the necessary spare parts are available for unplanned failures, while also ensuring there is not a surplus of unneeded parts. These sparing strategies use the failure data to calculate a ‘cost VS risk of failure’ approach for the system. Risk and cost thresholds are established for each program and the cost/risk equations are used to identify spares.The literature provides no quantitative approach for a sparing strategy supporting a program in development phases. A system in development, which must be subjected to a series of tests and analyses in order to define the final design and achieve a certified status, also requires spares if the test and analysis activities are to complete within a reasonable time frame. Pedigree and configuration of parts change as the development cycle progresses. How many spares are needed and for which parts and of which pedigree? The purpose of a sparing strategy during the development phases is to facilitate replacement of parts so that development activities can continue should a part fail.The quantitative sparing strategy used for the production/operation phases does not directly apply to the development phase because the calculation of cost and risk is more difficult. In the development phase, failure data may be limited or non-existent and the failure observed in a test may not be resolved by replacing a part of the same design (i.e., both the original part and the spare may need modification or redesign). While this drives to a different sparing strategy than in a production scenario, the strategy is still based on a ‘cost VS risk of failure’ assessment. The purpose remains the same – ensure the necessary spare parts are available for unplanned failures, but also ensure there is not a surplus of unneeded parts. Therefore, when comparing the ‘cost VS risk of failure’, this sparing strategy will consider not only the ability of the spare to buy down the risk of failure and resulting consequence (downtime/damage to system) but also the potential reuse of the spares should they not be needed (risk is not realized but cost has been realized) as well as any remaining, or residual risk, the sparing strategy does not address.This research proposes a modified set of equations for calculating Cost VS Risk to create a quantitative sparing strategy for a system in the development phase. The equations cannot be based on a calculated risk with failure data as the failure data does not exist for parts in development until the design solidifies and test/analysis data is available. The ‘consequence of a failure’ in the equations is changed to reflect the unique constraints of the program and the design: the criticality of the part, the redundancy in the system, the state of the design of the part and the resulting impact on the program as the result of a failure (such as duration for unplanned part replacement and potentially damage to other hardware).The research applies the sparing strategy to a case study – focusing on the electronics components and cables for a system in the development phase. The modified equations are used to define the sparing strategy and considers the phase of the program, the limited test data to inform failure rates and mode and the assumptions unique to the program. The case study indicates that the use of a quantitative sparing strategy for a program in the development phase is possible. This presentation will frame the unique constraints of programs in the development phase and describe the difficulty and impacts of defining spares. The presentation will walk through the process and equations – using the case study as an example. The presentation will include observations on the difficulty of the process, the required data to effectively use the process and some thoughts on uncertainty as well as updates to the sparing strategy through the program development phases. The presentation will conclude with thoughts on the ability of Systems Engineers to execute the sparing strategy and the required skillset or experience.

Presentation#379

Spreading the word: How the Brazilian INCOSE Chapter is Contributing to the Growth of the Local Systems Engineering Community

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Keywords. systems thinking;community;social media

Topics. 1. Academia (curricula, course life cycle, etc.); 1.6. Systems Thinking; 19. Very Small Enterprises; 22. Social/Sociotechnical and Economic Systems; 3.5. Technical Leadership; 5.9. Teaching and Training;

Abstract. Not every organization shares a consistent appreciation for the value of applying systems engineering in their processes. Beyond the United States and Europe, implementing systems engineering processes, methods, and tools poses a greater challenge since they are not widely spread or entirely understood. In the South American context, more specifically in Brazil, a lack of understanding regarding the roles of systems engineers leads the majority to consider them as IT professionals or software developers.Recognizing that this misunderstanding can jeopardize the success of initiatives aimed at implementing systems engineering in several industry branches in our country, it becomes imperative to promote systems knowledge dissemination. Despite the large number of industries from different sectors in the region, systems engineers are almost exclusively demanded by the defense and aerospace sectors. These are among the main reasons why INCOSE Brasil has implemented several marketing initiatives in the last two years.Another reason is that, since we do not have any INCOSE publications translated into Portuguese, there is an additional barrier to popularizing these systems engineering concepts. Therefore, we understood that the first step was to produce technical content on our social media to teach the fundamentals of systems thinking and systems engineering to engineers who had no access to that kind of content in their undergraduate and graduate courses. This content is produced in various formats and published on different platforms. Among the produced content is a podcast where we invite professionals to share their experiences and expertise related to systems engineering in different industries. Being real-world stories, these talks are very beneficial not only for encouraging junior professionals to pursue a career in systems engineering but also for making seniors aware of new possibilities. Besides, the chapter is always promoting webinars and conferences to discuss more technical subjects related to the INCOSE Handbook content. Being the only INCOSE chapter in South America, we believe that this presentation can benefit systems engineering leadership in other countries that want to found a chapter or seek guidance for successful initiatives to strengthen the understanding of systems engineering fundamentals. The Brazilian chapter is composed of volunteers who genuinely believe that systems thinking and systems engineering can improve the world. Despite not having social media managers on our team, we were able to increase the relevance of our social networks, which is already reflected in the growing number of certified professionals and chapter members.The presentation was prepared by Diego Rangel and Bruno Soares, both volunteers in the chapter's Communications Directorate and who have a solid academic and professional background in systems engineering. In this presentation, they will share their strategies and best practices for conducting the marketing activities of the Brazilian Chapter.

Presentation#445

Survey of LLM Applications for Systems Engineering

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Keywords. Large Language Model;Artificial Intelligence;Systems Engineering

Topics. 11. Information Technology/Telecommunication; 5.11 Artificial Intelligence, Machine Learning;

Abstract. Much of systems engineering work is carried out through the use of text, in the form of requirements, specifications, architecture documents, use cases, test cases, change order, and all kinds of plans and reports. Generative AI, especially Large language models are a natural fit to support many aspects of systems engineering. In this presentation, we survey how large language models (LLMs) are being used in systems engineering applications, and how techniques and tools such as retrieval-augmented generation with vector databases, and iterative prompting of LLMs are being employed. Live demonstrations of many of the techniques will be included.

Presentation#175

Sustainably Designing Products / Designing Sustainable Products

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Keywords. Sustainability;Sustainability Technologies;Requirements Management;Compliance;Systems Engineering;Sustainable Design

Topics. 1.6. Systems Thinking; 10. Environmental Systems & Sustainability; 12. Infrastructure (construction, maintenance, etc.); 2.3. Needs and Requirements Definition; 2.4. System Architecture/Design Definition; 3. Automotive;

Abstract. Sustainability is an outcome of two interrelated product engineering dimensions:1. Sustainably Designing Products - becoming more efficient in the actual development, building, creation of products.2. Designing Sustainable Products - building a product that meets our efficiency goals to consume less row materials, less energy, provide new efficiency methods, involve reusable products.Meeting an organization’s sustainability goals doesn’t just happen. It must be planned. Or in other words, it must be designed and engineered.Numerous government entities are writing sustainability mandates (both forced and voluntary). How does an organization ensure they are compliant to those directives?Let’s take the European Union Taxonomy Regulation as an example. “The EU Taxonomy is a green classification system that translates the EU’s climate and environmental objectives into criteria for specific economic activities for investment purposes”.“It is a transparency tool that will introduce mandatory disclosure obligations on some companies and investors, requiring them to disclose their share of Taxonomy-aligned activities.” ec.europa.eu, 2023.How

do we consume this directive? How do we confirm or validate that we are meeting those obligations?We employ Systems Engineering standards and more directly, Requirements Management practices. Sustainability regulation is really another type of requirement:o Single view of truth across all parties o Managing compliance and sustainability through coverage analysiso Tracking and controlling and mitigating riskso Managing verification and validation of requirements o Change management as updates occur.o “Always ready” for an auditSustainability By Design - EngineeringAgain, these goals don’t just happen, they must be designed and engineered.If you want to make sustainable products today, dabbling at the edges no longer suffices. You must start at the design phase. For example, “80% of a product’s lifetime emissions is determined by product design”. Fuchs, 2022.Achieving sustainability demands a transformation of thought. While 86% of companies have a sustainability strategy—with 73% of those set on a net-zero carbon emissions goal—only 35% act on that strategy. Backward-looking initiatives, like retrofitting products or alternate maintenance schedules, can make a dent in the collective footprint, but it’s forward-looking initiatives that make lasting change.Designing for sustainability (D4S) will never practically deliver a net-zero environmental impact, but there are five principles that can help companies make a meaningful impact on their sustainability strategies:1. Reduction in material: the least complex of the five, this looks at improvements in technologies to reduce the amount of material and energy used in production.2. Modular design: subdividing sophisticated systems into simple modules to organize complex processes more efficiently.3. Design for longevity: extending the use phase of a product by integrating business knowledge, market conditions, company capabilities, technical possibilities, and user needs into product concepts to make better strategic decisions.4. Investing in simulation: making computer-generated models and simulated environments to model, manipulate, and test parts/assemblies before spending time and money on production.5. Design for recycling: encouraging manufacturers to account for the end of a product’s useful life by considering what else it can become during the design-stage of a product’s development.Example, in March, the 10th 2022, the European Parliament approved the new directive on battery management.This report aims to govern the entire product lifecycle, from design to consumption and all the way to recycling into new products."...propose stronger requirements on sustainability, performance, and labelling, including the introduction of a new category of “batteries for ‘light means of transport’ (LMT)”, such as electric scooters and bikes, and rules on a carbon footprint declaration and label..." Consilium, 2022.Sustainability Steps in Systems EngineeringStep 1. Requirement allocations (to department/owner) and traceability coverage. More importantly, establish methods such that the final product can be evaluated against business goals (example, Environmental, Social, Governance ESG). Step 2. Develop the design requirements and show compliance to the ESG corporate goals. From a Systems Engineering perspective, environmental constraints (such as CO2 emissions) should be captured as part of the non-functional requirements (realized by using attributes, tags, traceability).Step 3. Validate the requirements (analyze different approaches/architecture) using MBSE (Model Based Systems Engineering) and model validation (e.g., when excess CO2 level is detected, how should the system behave) – prevent rework. Test the design to the environmental requirements. ConclusionSystems Engineering and Requirements Management methodologies are purpose built to manage new and changing mandates. The 4R Strategy designs for a circular economy of built products – Refurbish, Reuse, Remanufacture, Recycle. All of which contribute to less waste and a cleaner environment.Successful development of increasingly complex products demanded today is only possible by adopting an integrated development lifecycle management approach. This approach frees up development resources from repetitive and mundane tasks to focus more of novel solutions, provides more data insight that will open new design opportunities and improves the collaboration within and between teams to explore alternative approaches.It’s important for industries to adopt a key metric of sustainability in their design and development efforts. This metric must have the same weight as time-to-market, cost, and profitability.How can IBM help companies achieve these sustainable goals?IBM is committed to helping clients adopt and leverage best-practices of integrated development lifecycle management. Offering IBM ELM – Engineering Lifecycle Management, an integrate portfolio for managing requirements, workflow and testing, as well as systems design modeling. This toolset offers a federated data approach which optimizes information sharing and leveraging across the entire development lifecycle, makes data and processes transparent and traceable, enables better regulatory and compliance adherence, and provides better data currency to improve critical business and development decisions.References:Fuchs, Stephan, et al. “Product Sustainability: Back to the Drawing Board.” McKinsey & Company, McKinsey & Company, 7 Feb. 2022, www.mckinsey.com/capabilities/operations/our-insights/product-sustainability-back-to-the-drawing-board. Council Adopts New Regulation on Batteries and Waste Batteries, www.consilium.europa.eu/en/press/press-releases/2023/07/10/council-adopts-new-regulation-on-batteries-and-waste
Commission Notice on the Interpretation and Implementation of Certain ..., eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C_202300305.

Presentation#300

Symbiotic relationship between neurodiversity and systems thinking

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Keywords. • Diversity;• Systems thinking;• Inclusion

Topics. 1.6. Systems Thinking; 3.5. Technical Leadership; 4.5. Competency/Resource Management;

Abstract. Studies have shown that teams and organisations that excel in diversity, equity and inclusion drive better outcomes. It is crucial for building engaged and motivated team members thereby in the process creating a competitive advantage.Addressing diversity, inclusion and equity is important to innovation in engineering. It is about creating opportunities to adapt and to find creative approaches to the engineering challenges we are facing. Diversity is not limited to differences that are only visible. It is also about creating teams with diverse thinking achieved through team members with diverse personalities, thinking styles, working styles, age, background, area of expertise, and experience to name a few. The benefit is team members being exposed to multiple points of view, have their own views and contributions challenged and in the process, formulate sustainable solutions that achieves better results for the future of the world. This will only work if the environment is also inclusive. Inclusion is about creating the space where team members, customers and communities in which we work and live in have a sense of belonging. As such, people are their authentic selves in the workplace and feel valued. They are willing to put themselves out there in sharing their thoughts and ideas. In both instances, research shows that diversity and inclusion encourages better creativity and innovation.Neurodivergent is a non-medical umbrella term that describes people with variation in their cognitive functions, and can include conditions such as autism spectrum disorder (ASD) and attention-deficit/hyperactivity disorder (ADHD).Neurodivergence, a concept originally attributed to sociologist Judy Singer, defined neurodiversity as:- A state of nature to be respected- An analytical tool for examining social issues- An argument for the conservation and facilitation of human diversityAccording to Harvard Health and Laura Boxley, Ph.D, neurodiversity is “the idea that people experience or interact with the world around them in many ways – some that may not be considered typical. It is based on the framework that “different” is not the same as “deficient”.”Within the vast neurodivergent umbrella, ADHD is an area that both presenters have personal experience in and have spent time understanding how it fits within systems engineering.ADHD, despite its challenges, can offer unique perspectives and strengths that are conducive to systems thinking. Here's how ADHD traits can be beneficial for systems thinking:1. Divergent Thinking: People with ADHD often have highly creative and divergent thinking abilities. They can see unconventional connections between ideas and think "outside the box." This creative approach is valuable in systems thinking, where unconventional solutions and the ability to connect seemingly unrelated elements are crucial for understanding complex systems.2. Hyperfocus: While individuals with ADHD may struggle with maintaining focus in certain situations, they can also experience periods of hyperfocus, during which they become intensely absorbed in a specific task or topic. This intense focus can lead to deep exploration and understanding of specific aspects of a system, allowing for in-depth analysis and problem-solving within that particular area.3. Multitasking Skills: People with ADHD often develop strong multitasking skills as a way to cope with their symptoms. While multitasking has its limitations, individuals with ADHD can manage multiple streams of information and inputs simultaneously. In systems thinking, the ability to juggle different variables and factors is valuable for understanding the interconnectedness of elements within a system.4. Ability to Embrace Complexity: ADHD individuals can sometimes tolerate ambiguity and complexity better than neurotypical individuals. Their minds are naturally inclined to handle a multitude of thoughts, ideas, and inputs simultaneously. This tolerance for complexity aligns with the systems thinking approach, which involves dealing with intricate relationships and interdependencies within a system.5. Innovative Problem-Solving: The creative and unconventional thinking style of individuals with ADHD can lead to innovative problem-solving approaches within systems. Their ability to see patterns, make unique connections, and generate novel ideas can be instrumental in finding innovative solutions to complex problems.6. Risk-Taking Propensity: Some individuals with ADHD have a higher tolerance for risk and are more willing to explore unconventional solutions. While this trait needs to be managed carefully, a healthy

level of risk-taking can lead to breakthroughs in systems thinking, encouraging the exploration of uncharted territories and unconventional interventions within complex systems.It's important to note that the benefits of ADHD traits for systems thinking may vary from person to person. Not all individuals with ADHD will possess these specific strengths, and the impact of ADHD on an individual's thinking style can be influenced by various factors. For those who do exhibit these traits, embracing and harnessing them can lead to valuable contributions in the field of systems thinking.The presenters look to create greater awareness and a better informed engineering community to enable inclusiveness. This experience will provide greater insight for the presenters to develop a paper on the subject.

Presentation#436

System Engineering Challenges at Los Alamos National Laboratory: Modernizing the System's Thinking Approach

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Keywords. System Engineering;DOE;NNSA;Defense;Energy

Topics. 1.6. Systems Thinking; 2.3. Needs and Requirements Definition; 2.5. System Integration; 2.6. Verification/Validation; 6. Defense; 8. Energy (renewable, nuclear, etc.);

Abstract. Los Alamos National Laboratory (LANL) is one of the United States premiere research institutions with a wide research and development scope spanning foundational science to complex System of Systems. One of the major mission assignments from the National Nuclear Security Administration (NNSA) is the development and stewardship of the nation's deterrent system. As a design agency organization, LANL follows a specific engineering process to support NNSA, the Department of Energy (DOE), and the Department of Defense (DoD) as its main stakeholders. LANL is responsible for requirements during all lifecycle stages, design standards, management and traceability of design inputs, control of design interfaces, design verification, validation, qualification, and certification, design configuration management, design change control, and design records. These responsibilities are managed by systems engineering groups using the Phase X process, analogous to the INCOSE defined Vee Lifecycle Processes. The Phase X process is defined as: Phase 1) Concept Assessment Phase 2) Feasibility Study and Design OptionsPhase 2a) Design Definition and Cost StudyPhase 3) Development EngineeringPhase 4) Production EngineeringPhase 5) First ProductionPhase 6) Full Scale Production and SustainmentPhase 7) Retirement, Dismantlement, and DisposalLANL's is regulated by the Code of Federal Regulations, Prime Contract clauses, DOE Orders, and program specific constraints. These regulations lead LANL to create specialized systems for managing large and complex programs. LANL is responsible for the stewardship of a significant number of the stockpiled systems. However, LANL is also responsible for exploration of new technologies for applications in new systems to address a known or perceived Department of Defense (DOD) needs.New technologies/system testing does not follow the same level of rigor as stockpile systems, although, the level of rigor is appropriately applied to the system's most important aspects and reduced for less important aspects at the experimentalist's judgment. Rigor within a test design and test object is specified through the application of design tolerances, specification of acceptance requirements, requirements for independent inspections or machinists' checks, establishment of hold points for independent reviews, diagnostics selection, and data collection requirements.LANL's approach to systems engineering diverges from conventional industry practices in several key aspects. While industry often prioritizes rapid development and commercial viability, LANL places paramount importance on the meticulous stewardship of the nation's deterrent system. Unlike industry, LANL operates within a highly regulated framework, adhering to the Code of Federal Regulations, Prime Contract clauses, DOE Orders, and program-specific constraints. Industry typically emphasizes product commercialization, but LANL's responsibilities extend beyond production, encompassing the full lifecycle stages, from concept assessment to retirement and disposal. Additionally, LANL's focus on national security requires specialized systems to manage large and complex programs, a departure from industry's more generalized approach. This presentation will delve into differences between industry and LANL practices,

shedding light on how LANL's distinct systems engineering processes respond to the unique challenges posed by scientific research and national security initiatives.This includes integrating advanced technologies using the Digital Thread, to enhance data processing and decision-making capabilities. LANL faces the challenge of ensuring system reliability and security in an increasingly interconnected and digitized environment. Another challenge presented is addressing an aging workforce nearing retirement and what emerging challenges are presenting with the next generation of systems engineers. Ensuring a smooth transition in systems engineering involves addressing critical issues such as knowledge transfer through mentorship programs. The evolving nature of the field requires continuous learning, adaptability to emerging technologies, and fostering a positive work environment for recruitment and retention.

Presentation#399

System Product Line Cost and Investment Modeling Applied to UUVs

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Keywords. product lines;economics;COPLIMO;COSYSMO;cost modeling;ROI;UUV;systems engineering

Topics. 1. Academia (curricula, course life cycle, etc.); 2. Aerospace; 4.2. Life-Cycle Costing and/or Economic Evaluation; 5.4. Modeling/Simulation/Analysis; 5.6. Product Line Engineering; 6. Defense;

Abstract. AbstractIntegrated cost and product modeling applied to the acquisition of Unmanned Underwater Vehicles (UUVs) demonstrated the economic benefits of a product line strategy. The modeling framework includes System Modeling Language (SysML) for product modeling and a constructive cost model set. The Constructive Product Line Investment Model (COPLIMO) framework was used for ROI analysis with the Constructive Systems Engineering Cost Model (COSYSMO) for single system investment and reuse costs. Cost model inputs were extracted directly from the SysML requirements and executable activity models for the UUVs. The model integration reduces effort since only product modeling is performed without the need for independent cost modeling expertise.The case study research investigated the reduction of acquisition costs applying the integrated product line acquisition model for UUV missions with overlapping requirements. The key research question focused on the return on investment (ROI) of a product line approach for UUV systems developing a baseline architecture for reuse. Supporting questions addressed the reuse savings for individual UUV systems, the size and complexity of the resulting system, and their estimated effort. Results indicate a strong ROI when using a product line approach for UUV systems.UUV Product ModelingThe US Navy requires nine primary missions: Intelligence, Surveillance, and Reconnaissance (ISR), Mine Countermeasures (MCM), Anti-Submarine Warfare (ASW), Inspection and Identification (INID), Oceanography (OO), Communication or Navigation Network Node (CN3), Payload Delivery (PD), Information Operations (IO) and Time Critical Strike (TCS).Detailed analyses for the UUV mission types were used to develop the SysML models that encapsulated system size and complexity measures. Analysis and comparison of the defined UUV missions identified ISR as having the most commonality across the set and chosen as the reference architecture. Development of the ISR UUV constituted the investment costs.Requirements models were generated and provided enumeration of system requirements by reuse type and complexity. Detailed executable activity models of mission operations were used to quantify interfaces with their complexities for inputs to the cost models. Cost ModelingThe COSYSMO model inputs for system size include requirements and interfaces classified by reuse category and complexity. It uses size weights to account for the relative effort for the reuse categories: New, Designed for Reuse, Modified, Deleted, Adopted and Managed. The complexity levels also have equivalent size weights for Easy, Nominal and Difficult ratings.COPLIMO provides a trade space for determining initial investment and future ROI for product line systems versus non-product line systems. Product line investment models must address two sources of cost investment or savings which were afforded by COSYSMO in this approach. The relative cost of developing for product lines is the added effort of developing flexible product line architectures to be most cost-effectively reused across a product line family of applications, relative to the cost of developing a single system. In COSYSMO, this investment cost is captured in the Designed for

Reuse category.The relative cost of reuse is the cost of reusing system architecture in a new product line family application relative to developing new systems. COSYSMO has the categories for Reuse, Modified, Deleted, Adopted, and Managed to quantify the relative costs compared to the New category.The model size inputs were extracted from the product models for each mission type. Each requirement and interface in the models were further tagged for reuse category and complexity level. The reuse categories are assessed with respect to the ISR baseline from which it is reused from. The COSYSMO size weights are then applied in the estimation tools.Model outputs provide decision makers with essential information on product line savings, investment, ROI, cost per mission type, and savings per mission type. It supports the initial investment decision as well as a starting point for planning the individual system developments. The cost and schedule of each system is already estimated and can be planned over time per the mission needs.Conclusions and Future WorkThe case study outcome was a substantial ROI over five for the product line approach over the single system approach for the UUV systems. This result corroborates previous product line economic analyses, demonstrating that many DoD systems and other types of system families would benefit from a product line strategy. System architectures for unmanned systems should focus on the product line, instead of mission specific systems. The product line modeling approach has a broader application for acquiring systems that are based on similar functions and will be applied to future case studies. The model integration is being further streamlined. We are developing improved tools for SysML 2 to automate the product and cost model integration. With this, we can also include a richer set of system attributes for costing from activity models, use case models and sequence models.

Presentation#27

Systematically Pulverised EARS - Improvements in requirements authoring and presentation

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Keywords. Requirements;Presentation;Syntax;Authoring

Topics. 2.3. Needs and Requirements Definition; 5.5. Processes;

Abstract. Although innovative work is ongoing into graphical representation of requirements, the vast majority of requirements are still textual. Standard INCOSE guidelines provide a basis for characteristics of a good requirement, but what more could be done to ensure that requirement statements are properly captured, transmitted, and understood? This presentation investigates a set of innovative approaches to writing and presenting requirements that may be used, either independently or in combination, to convey the intent of a requirement statement more clearly.We start by building upon the formal ‘Easy Approach to Requirements Syntax’ (EARS) and investigate a simple mechanism for tying this into a Model-Based Systems Engineering approach. We also look at extending the EARS syntax to deal specifically with interface type requirements. We then improve the presentation of requirements following this extended syntax by using syntax highlighting to separate different parts of the requirement statement. Syntax highlighting has been used in code editing software for many years and can be used to clearly separate the syntactical parts of a requirement statement.With this requirement visual presentation in place we then investigate complex statement structures, including how to deal with grammatical conjunctions in requirements, and how they are better thought of as logical connectives. We also consider the difficulty introduced by statements that are about a potentially empty set. We formalise these as a set of proposed rules for requirement authoring that can easily supplement standard INCOSE guidelines.Throughout the presentation we provide examples of poor requirements and how they can be improved. We draw inspiration from current New Zealand major infrastructure project requirements, but also from a 1957 paper on drafting legal documents (using a ‘systematically pulverised form’), a viral social media maths puzzle, and the rules of the Road Runner and Wile E. Coyote cartoons.

Presentation#404

Systems and Software Engineering Cost Modeling of AI Assistance

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Keywords. Artificial Intelligence (AI);Generative Artificial Intelligence;Cost Modeling;COSYSMO;COCOMO;Systems Engineering;software engineering;Large Language Models (LLMs);Parametric Cost Modeling

Topics. 1. Academia (curricula, course life cycle, etc.); 2. Aerospace; 3.7. Project Planning, Project

Assessment, and/or Project Control; 4.2. Life-Cycle Costing and/or Economic Evaluation; 5.11 Artificial Intelligence, Machine Learning; 6. Defense;

Abstract. Abstract Artificial Intelligence (AI) based tools that assist in generating system artifacts are transforming systems and software engineering lifecycles. Drastic reductions in effort are possible using tools that use large language models (LLMs). This research addresses the new challenges in systems and software cost modeling with the introduction of cost factors and size measures to incorporate into existing parametric cost models. A research goal is to better understand and codify the advantages and pitfalls of integrating AI into systems and software processes. We consider the benefits, challenges, and dangers of over-reliance and potential inefficiencies. AI tools can support virtually all non-hardware lifecycle aspects from concept, AoA, architecture, requirements, design, software, V&V, testing, etc. The research initiative examines the quantitative AI impacts by lifecycle phase and activity since their effects may vary greatly. The cost modeling and measurement framework incorporates a new factor for “AI Assistance Usage” with a defined rating scale, and data analysis process to calibrate it. An online data collection and Delphi survey to improve the model with expert judgment has been developed for the community. A new measure “query points” is being refined to quantify the size and complexity of the AI generated solutions. We will highlight systems and software engineering case studies providing empirical data on generated solution sizes, actual effort, and effort estimates without AI assistance. Subsequent case studies will address larger scale team and enterprise processes assisted with AI. Preliminary findings will be presented, and a road map for the systems and software engineering community in furthering the cost models. Background and ObjectivesLLMs are a type of generative AI that utilize a deep learning algorithm to generate human-like text based on natural language prompts. One typically interfaces with a chatbot such as ChatGPT, Bard, Claude, Copilot and many others. They are well suited for tasks such as language translation, text summarization, and question answering. Some LLMs are exceptionally good at generating code and text-based system models like SysML 2. Already there is very strong convincing data that substantial labor can be saved in steady-state AI tool usage by individuals and teams. To address the cost impacts we have developed a road map for advancing the cost models by leveraging existing modeling and measurement frameworks. We are using the Constructive Cost Model (COCOMO) framework and calibration procedures.Parametric ModelingThe initial rating scale for “AI Assistance Usage” has been defined using the COCOMO framework. It consists of six ratings from Very Low to Very High corresponding to the degree of AI usage on a project. The default setting is Nominal in the middle of the rating scale corresponding a typical project. The data collection will be used to calibrate the effort multipliers for each rating level. Effort multipliers for each rating represent the relative effort to Nominal.We have also identified other affected cost factors and parameters for using generative AI. For example, the relative cost of achieving reliability may change and AI may help reduce impacts of experience and capability. Overall cost model coefficients will change. Usage of AI will become an assumed skillset of engineer. Subsequent data collection will help us assess these impacts as well.The initial definition is oriented to software. The factor definition and its data collection are setting the stage for further exploration into systems engineering process impacts. We are defining an analogous usage factor for systems engineering to incorporate in the Constructive System Engineering (COSYSMO) model. In our research we are generating SysML 2 artifacts and capturing data on effort, solution accuracy, size and complexity. In additional case studies we will collect similar data from large projects.We are also investigating phase sensitive effort multipliers to account for different AI tool impacts across the lifecycle. We are codifying the practices by phase and activity, and empirical data collection is being aligned with those in the ISO/IEC/IEEE 15288 lifecycle.Data Collection and Analysis A variety of data sources are being drawn from to support model calibration and provide insights. Multi-project data collection in conjunction with other cost factors is going forward for the COCOMO III model. Small-scale empirical case studies and controlled group experiments are being performed. We are also collecting classroom data. We have developed an online Delphi survey form to capture both expert judgment and actuals data to help calibrate the model. It is available at http://softwarecost.org/data/ai/. The data collection is being supported by the Boehm Center for Systems and Software Engineering.Since project data will have the effects of other individual factors, a method is needed to normalize out those contaminating effects to isolate the contribution of the AI tool usage factor on productivity. The Ideal Effort Multiplier (IEM) method will be used to determine calibrated multipliers for each project and perform regression across the rating scale to attain global effort multipliers for the model.A chatbot output incorporated in a system baseline constitutes a process output to be measured as part of development productivity. In our research also we need to normalize correctness and defect density measures, for example to measure scale effects on generated solutions. There is clear initial evidence that AI assistants do not scale. We are refining a measure termed “query points” as an adaption from function points to quantify the size and complexity of the AI generated solutions.Current and Future WorkWe are early in the initiative and the community is highly encouraged to provide feedback on the model definitions, submit data and feedback on the data collection. Community support is imperative to develop the new models. We are instituting the Delphi data collection and will continue iterative analysis with COCOMO III research to update the models. For this we will provide open source tools with new factor(s) in the models for public usage.A current research focus is on how query task complexity impacts AI correctness and effort impact. We are elaborating of query points as a complexity measure for this to measure SysML 2 model artifacts. We will perform further analysis of AI tool impacts across lifecycle aligning artifacts and effort data with ISO/IEC/IEEE

15288 systems and software engineering phases and activities. This harmonization will also help address large scale team and enterprise processes assisted with AI.

Presentation#91

The A to Z for Implementing a Digital Transformation on a Systems Project

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Keywords. Digital Transformation;Digital Engineering;Agile;System Modernization;Systems of Systems (SoS);Engineering Management;Digital culture;Digital thread;SE Toolkit

Topics. 11. Information Technology/Telecommunication; 5.12 Automation; 5.3. MBSE; 5.5. Processes; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Digital transformations are and will continue to change our products, systems, services, as well as the way we work and the way we operate our solutions. However, will we, the Engineers, be ready for this future? In a global context, we will be moving towards model-based approaches. Knowledge sharing will be exponentially increasing, including good and not so good information. Digital technologies, such as AI, autonomy and digital twinning, will be increasingly incorporated into the various engineering disciplines as they evolve to better adjust to a dynamic world within increasing complexity. If an organization does not start operating as a digital enterprise, will it be left behind?Collaborations and interactions will be paramount, largely through the management of the digital thread, enabled through the tools and environments of the digital ecosystem. To do this, the workforce of a digital enterprise will need to be diverse, agile, efficient, possibly distributed, and more strongly recognize knowledge as an asset. Will this be possible based on where we currently are positioned?This presentation will outline the challenges of such a systemic transformation through a digital perspective. The presentation will examine and present – • The current Engineering “State of Readiness” by how the formal standards regulations and guidance documents are addressing (or not) the digital challenges.• The foundational elements of the digital transformation including the data, the workforce skills and competencies, the MBSE approach, the need of the customer (acquirer), as well as the need of the organization (supplier).• A subset of key engineering disciplines/practices that are currently lagging in the readiness for a digital transformation (e.g. at present, ecodesign, resilience, data analytics, to name a few), and what is proposed to address this.• The strength and weaknesses of an integrated digital engineering workbench, including an example.• The dependency of a successful digital transformation requiring more than technology and engineering digitalization. Topics such as digital culture/mindset, delivery and support changes, including development paradigms, lifecycles, and supply chain, will be addressed.Throughout the presentation real industry examples will be given to illustrate the topic. Lastly, as a takeaway, a brief “A to Z” guidance will be given to address the digitalization of SE practices. These “26 tips” can be readily applied across any domain. Participants should walk away with some practical guidance on implementing a digital transformation at a project level through systems engineering. They should be more aware of the challenges ahead of them and the possible means of addressing such challenges. Likewise, they should be able to tailor a digital transformation for one organization or one project to apply to another organization or project. And by applying the “A to Z for the Digitalization of SE practices”, participants will be adding to their toolkit of SE practices, applications and tools.

Presentation#85

The Contextual Metadata Layer (CoML) concept - unlocking collaboration in an uncertain/ BANI world

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Keywords. CoML;MoSSEC;Complexity;Uncertainty;BANI;Nonlinear

Topics. 1.1. Complexity; 2.4. System Architecture/Design Definition; 5.4. Modeling/Simulation/Analysis;

Abstract. The Contextual Metadata Layer (CoML) is a concept often undervalued in industry but intrinsically apparent in the way we collaborate as organizations. Within the field of Systems Engineering there is a common appreciation of the need to share the context behind the decisions we make, to provide clarity to our partners and even to remind ourselves of the processes we followed when coming to some determination. This context informs others on the next possible steps they can take, which areas have already been covered and can provide a feedback loop where it becomes apparent more information is necessary. There is therefore value in recording and sharing the “Who”, “What”, “When”, “Where”, “Why” and “How”.Across industries there is also a need to accept and embrace the fact we live today and indeed have always lived in a Brittle, Anxious, Non-linear and Incomprehensible (BANI) world. The future success of products and services provided by industry will rely on an appreciation of this fact. Systems Engineering principles have a key role to play in helping to produce products in a way that can quantify uncertainty and mitigate against the unforeseen.The Contextual Metadata Layer, in conjunction with the concepts, processes and methods proposed in the INCOSE SE Handbook provide the needed clarity on how we may realize complex products through effective collaboration in an uncertain BANI world. This presentation aims to; introduce the Contextual Metadata Layer concept; discuss the management and quantification of uncertainties; provide the linkages to appropriate processes and methodologies, from the INCOSE SE Handbook and finally examine how this manifests in supporting complex product development according to interpretations of each term within the BANI definition.Brittle - Through the use of an agile mindset to manage change and a combination of life cycle approaches, the presenters will demonstrate how a resilient development system’s architecture can be supported in a fragile environment.Anxious - A discussion of how the proposed capabilities enable those within an organization to make sense of the information overload cascade and empower them to make rational and well informed decisions.Non-linear - Managed through the effective quantification and management of uncertainties and an understanding/ appreciation of non-linearity in both mechanical and human behaviors.Incomprehensible - Demonstrating that local centers of expertise within an organization can, through the CoML, share the context behind their decisions, across product development silos and hierarchies. The globally incomprehensible can therefore be understood locally and the knowledge gained appropriately shared.

Presentation#69

The Latest on the INCOSE-PMI Alliance and integration between Program Management and Systems Engineering

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Keywords. PMI;Project management;Roles and responsibilities;Project tension

Topics. 1.4. Systems Dynamics; 3.7. Project Planning, Project Assessment, and/or Project Control; 5.5. Processes;

Abstract. A decade into INCOSE's Alliance with PMI, the Project Management Institute, this presentation will share highlights from the past decade and how we are forging the path forward together. The disciplines of Program Management and Systems Engineering are inherently intertwined. To develop and deliver complex systems, all three sides of the "iron triangle" (cost, schedule, and scope) must be known, traded, and evolved in consideration of the others. When there is tension and confusion over the roles of program managers versus systems engineers, programs suffer from deadline overruns and failures. This presentation will discuss project roles performed by program managers, systems engineers, and those performed jointly. Success in these roles depends on strong collaboration. Sources of tension will be identified and ways to manage this tension discussed. This presentation will also dive into the new PM-related sections that are included in the latest edition of the SE Handbook.

Presentation#511

Think Like an Ecosystem: Deploying MBSE Within Your Organization

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Keywords. MBSE;CATIA;Biomimicry;Sustainability;MBSE Deployment;Systems Design;Systems Thinking

Topics. 1. Academia (curricula, course life cycle, etc.); 1.6. Systems Thinking; 10. Environmental Systems & Sustainability; 17. Sustainment (legacy systems, re-engineering, etc.); 5.3. MBSE; 5.7. Software-Intensive Systems;

Abstract. The systems we design are inherently natural. Every ecosystem on this planet operates within the laws of physics and subsequently the laws of ecology. All systems undergo change. These disruptions to the status quo may be unexpected or introduced intentionally. Fortunately, we can leverage the sophistication of our ever-changing and adaptive natural ecosystems to better understand how we can manage change within our human and engineered systems. We propose that an organization can improve and accelerate the deployment of a new initiative by looking to nature and taking cues from ecosystem succession principles. Specifically, we translate characteristics of each stage of ecosystem succession and apply them to the stages of deployment of MBSE within an organization. We draw on analogies from ecosystem disruption to develop resilient processes, leverage patterns, utilize resources, and advance the system model and modeling ecosystem. We offer practical tools for organizational leaders, program managers and MBSE practitioners involved in both small and large-scale technological transformations. We discuss where to start when introducing your team to MBSE and how to evolve your MBSE practice over time and with growing system complexity. We offer guidance to modelers on how to build efficiency into the modeling endeavor with reusable model elements and libraries. Finally, we will use nature as a guide to better understand the concept of integration and modeling system interfaces. We will perform a live demonstration using CATIA to illustrate these constructs.The adoption of a metaphorical biomimetic model enriches the discourse surrounding MBSE adoption, recognizes the complexities of the organizational ecosystem, and provides a foundation for developing an adaptive organizational strategy. Natural systems are not stagnant, and an MBSE initiative should not be either. With a diverse span of stakeholders, approaching MBSE deployment with an adaptive process facilitates resilience and success.

Presentation#552

Three Dimensions of Precision Digital Engineering

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Keywords. Digital Engineering;Digital Thread;Model-based Systems Engineering;System Family Engineering;Feature-based Product Line Engineering;Variation Management;Temporal Management;Configuration Management

Topics. 1.6. Systems Thinking; 3.2. Configuration Management; 5.3. MBSE; 5.6. Product Line Engineering;

Abstract. Engineering enterprises are steadfastly advancing into the new digital age of Digital Engineering. At the heart of this new paradigm are the precise digital representations of engineering and operations information, integrated end-to-end throughout the enterprise in ways that can be comprehended, communicated, analyzed, and processed by both humans and advanced computer systems. The justification for transitioning to this new paradigm is faster, more predictable, and more reliable solutions to the largest societal, enterprise, and mission challenges, needs, and audacious aspirations, which have heretofore been beyond our technological and human limits.While the foundational digital representation for digital twins, digital threads, model-based systems engineering (MBSE), and digital simulations is the central concern for a Digital Engineering approach, there are two additional engineering concerns that must be addressed for a successful holistic, practical, production-ready Digital Engineering solution. We refer to these three concerns as the three dimensions of Precision Digital Engineering:Multi-discipline dimension. This is central concern of Digital Engineering, where digital artifacts from across the Systems Engineering lifecycle — requirements, architecture design, mechanical, electrical, software, verification, validation, documentation, and more — are connected by digital threads to express the cross-discipline, full-lifecycle relationships and dependencies.Multi-product dimension. In Digital Engineering, virtually all engineering is performed in the context of a product line — a family of similar systems with variations in features and functions. Hardly anyone builds just one edition, just one flavor, just one point solution of anything. Traditional techniques such as clone-and-own, branch-and-merge, and siloed variant management schemes are intractable due to the sophistication and intricate interconnectivity of the digital threads, where for example managing and coordinating multiple copies is infeasible. Feature-based PLE enables a single, consolidated, authoritative model-based source of truth for the multi-product dimension.Multi-baseline dimension. In Digital Engineering, change is still the norm. In fact DE is intended to enable faster evolution based on better understanding of the impact of change across the digital threads among all the disciplines in the lifecycle. Temporal Management enables consistent configuration management across the full engineering lifecycle, for versions, branches, baselines of digital assets and most importantly the digital threads.Carefully separating and cleanly supporting each of these concerns enables a precise holistic solution for advanced DE. However, they are not fully orthogonal. The interdependencies among these three dimensions are key to combining them into a complete, consistent and effective DE solution.Feature-based PLE according to ISO 26580 provides the interface and interactions between the multi-product and multi-discipline dimensions. Fundamental DE for a single product is extended with “variation points” in the digital artifacts, models, relationships, and digital threads. For example, SysMLv2 includes a variation point specification that is compatible with ISO 26580.Managing versions, branches, baselines of digital assets and intricate digital threads for all assets in all products in a large evolving product line has the potential to overwhelm an engineering organization, so the approach is critical. ISO 26580 specifies that supersets are CM’ed rather than the individual products. The tools and assets in each of the multi-disciplines may have their own CM solution, these CM systems must be integrated as a system-of-systems (or CM-system-of-CM-systems) to form the intersection dimension of Multi-baseline and Multi-discipline. This is referred to as Temporal Management and is the subject of ISO 26581, which is current in the initial stages of drafting.In summary, a successful holistic, practical, production-ready Precision Digital Engineering solution requires more than the precise digital representations of multi-discipline digital assets and cross-discipline digital threads. Two additional engineering concerns, or dimensions, are required. The multi-product dimension supports product line engineering, or system family engineering, without clones, copies, duplication, divergence, or dissonance across multi-discipline dimension. The multi-baseline dimension supports the temporal evolution over time, for all of the digital artifacts in all of the engineering disciplines as well as the digital threads, for the entire product line. The key is keeping a clear separation of these three concerns, while carefully managing the interfaces and interactions among them.

Presentation#270

Towards a Reusable Model Based Systems Integration Framework

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Keywords. System of Systems;Emergence;Interoperability;Model-Based Systems Integration;Element of definition;Element of usage

Topics. 12. Infrastructure (construction, maintenance, etc.); 16. Rail; 2.4. System Architecture/Design Definition; 2.5. System Integration; 5.3. MBSE; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. Challenge: Many of today's transportation programs – due to its size and complexity – require their procurement using multiple specialized contracts over an extended period of time in a staggered contract formation. As those contracts are executed, they are to a large degree managed and operated independently, effectively creating a system of system (SoS), resulting in numerous SoS engineering and integration challenges, such as:1. SoS Architecture: Owners often prefer to delegate the risk of program (system) integration to contractors, typically the last contractor which is most often the systems contractor. The initial contracts are commonly infrastructure contracts, and managed as such without creating a holistic program (SoS) architecture. The result is often a program that that runs into substantial integration challenges during integration, testing, and commissioning.2. SoS Collaboration & Integration: The state of the industry is such that it treats systems integration frequently as a program-specific ("re-inventing the wheel") discovery process on an as-you-go basis. Interfaces are considered between stakeholders that can be resolved by coordinating (talking about them) in interface working groups. The process is very reactive, results in late discovery of interfaces and associated requirements, and frequently leads to additional work order claims by contractors.3. SoS Autonomy & Emergence: The relative independence (autonomy) of contracts leads to self-optimization of individual projects, with the strong potential to negatively affect the future program integration efforts (emergence).Approach & Takeaway: This presentation builds on a prior paper on achieving systems integration in large system of systems though interoperability, addressing the SoS challenges described above. The focus of the presentation will be on transitioning the interoperability concept towards a model-based systems integration framework ("element of definition") in form of a model library that can be tailored and re-used in various transportation programs ("element of usage"). The presented MBSI framework will include various examples of common contract types and associated interfaces, e.g., infrastructure, facilities, track, systems, vehicles, operations, etc. The audience will be able to follow the transition from a traditional documents-based towards a model-based approach presenting various viewpoints and views with structure, key interfaces, interface requirements and interoperability standards "in the loop".

Presentation#479

Towards an Ontology of Digital Engineering Terminology to Support Digital Information Exchange

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Keywords. digital engineering;digital transformation;systems engineering;ontology;standards

Topics. 22. Social/Sociotechnical and Economic Systems; 5.3. MBSE; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. As more disciplines and organizations move toward a model-based engineering (MBE) approach, there is a growing need to represent multiple aspects of the system lifecycle – from requirements through to operation and across organizational boundaries – in a digital environment. To support this, Digital Engineering (DE) and the digital thread have received significant attention in recent years. Today's industry leaders consider digital thread initiatives to be a top priority. In particular, data integration, exchange and management technologies are crucial to support tool and data interoperability. Despite this, there is a lack of consensus regarding the definitions of much of the widely used terminology.To address this, the Digital Engineering Information Exchange Working Group (DEIX WG) is leading an effort to create a framework for official standards related to digital information exchanges. This effort incorporates the following activities: searching for and reviewing relevant standards and frameworks that support information exchange; surveying DE practitioners to elicit existing knowledge with regards to relevant terminology; identifying the need for standards through the definition of use cases; creating a model that contains definitions of relevant terms and the relations between them in the domain of digital engineering.The DEIX Taxonomy WG is primarily involved with the latter of these activities. Complexity is inherent in DE. DE is required to manage data concerning complex structures and organizations and is conducted across multiple domains and product lifecycle phases. Terminology can vary significantly between these organizations, domains, and phases. The objective of the DEIX Taxonomy WG, therefore, is to consolidate digital-engineering-related terminology into a consistent, unambiguous ontology that can be used to support interoperability across the system lifecycle. To achieve this, the DEIX Taxonomy WG have been following Noy’s approach to ontology development. Our first task has been to scope the problem and to identify relevant domains. We have established several use cases that we intend for the DE ontology to support. These initial use cases are within the scope of the DEIX WG – e.g., to provide definitions for the DE Guide, to support the Digital Viewpoint Model (DVM). The identification of relevant domains enables us to identify the relevant domain standards. Relevant DE terminology can then be extracted from these standards and organized.In this presentation, we describe the current status of the DE ontology under development by the DEIX Taxonomy WG. We highlight the standards from which terminology has been extracted, and discuss decisions that have been made regarding the classification of this terminology. We show how the outcomes from the DE Taxonomy session at the INCOSE International Workshop (IW) have influenced those decisions. Through example use cases, we demonstrate how this ontology can be used to support digital information exchange.

Presentation#233

Unlocking Value in MBSE – Consistent Data Extraction & Visualisation from SysML Models with Rule-based Analysis

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Keywords. MBSE;Data Analytics;Visualisation;Metrics;Dashboard

Topics. 13. Maritime (surface and sub-surface); 3.3. Decision Analysis and/or Decision Management; 3.6. Measurement and Metrics; 5.3. MBSE; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The increasing popularity of SysML and Model Based Systems Engineering has highlighted the need for a more efficient method of data extraction from the models to gain insights into projects. The lack of a systematic approach to monitor and compare project progress causes challenges to engineering management and governance. To address these challenges, this presentation applies a set of standardised, tool-agnostic queries on SysML model databases. These queries have been developed using a defect-driven methodology and provide metrics which will be visualised during the presentation on an open-source dashboard tool, Grafana. These metrics allow engineers and other stakeholders to make more informed data-driven decisions by tracking metrics derived directly from model data.Organisations aiming to shift from a ‘model-aware’ or ‘model-enabled’ to a ‘model-based’ approach need to possess the capability to extract data from SysML models. With substantial literature available on creating models, systems engineers can find it easy to generate data and construct well-formed models, however extracting value from these models (especially for non-systems engineer stakeholders) remains a challenge. In cases where proprietary tools already offer visualisation capabilities, there is often a lack of a systematic process to develop specific metrics and dashboards for monitoring and comparing projects.Projects which utilise queries and metrics often do so in an ad-hoc and isolated manner. Whilst this approach highlights and resolves project specific issues, it does not allow for the comparison of projects. This can lead to engineering governance and process issues being overlooked, causing organisational inefficiencies. Using SysML with a suitable tool and framework provides a foundation for comparing projects. All that is required in addition to this is the development of a method for creating queries and visualising relative metrics on a dashboard.To present this method, the modelling domain is broken down into key areas of analysis. These areas correspond to Requirement, Use Case, Structural, and Behavioural models. Defect-driven testing, a (software test technique) is then applied by creating rules to check for defects in the model artefacts. The hypothesis is that by tracking and reporting on rules regularly, modellers will be enabled to take proactive action prior to engineering lifecycle reviews. If any defects remain at review, then additional rules can be defined. To increase the effectiveness of this approach, an open-source visualisation and querying tool is connected to the model database. This allows for the rules to be reported on in real-time, as well as tracked over time. This approach fulfils the same role as code linting or static code analysis.The expectation is that providing access to these rules will achieve the same benefits to systems engineers that software engineers enjoy from unit testing. Each rule provides rapid feedback to the systems modeller to ensure that any business, framework, or process rule is applied consistently. This has the natural benefit of improving the consistency of work products and allows for reviews to focus on the actual engineering content rather than syntactic or style errors. These rules have been applied to a small example Hybrid SUV system model, which has been created to demonstrate how model itself can automatically create this data.

Presentation#161

Using Systems Engineering and Decision Analysis in Descriptive, Predictive, and Prescriptive Analytics

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Keywords. Analytics;Data Analytics;System Engineering;Decision Analysis;AI;Machine Learning

Topics. 10. Environmental Systems & Sustainability; 3.3. Decision Analysis and/or Decision Management; 5. City Planning (smart cities, urban planning, etc.); 5.1. Agile Systems Engineering; 5.7. Software-Intensive Systems; 6. Defense;

Abstract. Analytics is a growing field that uses math, statistics, and AI/machine learning to find meaningful patterns to make data driven decisions to meet organizational objectives. Analytics involves sifting through large data sets to discover, interpret, and share new insights and knowledge. Our research uses data analytics to provide data driven insights to Army installation management decisions in three areas: severe weather alerts, avoiding heat related injuries in training, and evaluating the financial return on investment of installation resilience options to reduce the impact of severe weather influenced by climate change. Our research team involves installation managers, Engineer Research and Development Center project managers, contractors, and university researchers. We describe how we have used systems engineering and decision analysis techniques to define the decision problems, identify the data sources, identify system objectives, capture the system requirements, define the system interfaces, evaluate the system solutions, verify the system solutions, and validate the solutions.

Key Reserve Papers

Key Reserve Paper#441

A Configuration Management Strategy for Model-based Product Line Engineering in Aircraft Systems Development

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Keywords. model-based systems engineering;model-based product line engineering;change and configuration management

Topics. 3.2. Configuration Management; 5.3. MBSE; 5.6. Product Line Engineering;

Abstract. Aircraft systems development is complex and time-consuming. Model-based Product Line Engineering (MBPLE) aims to reuse assets between projects to accelerate the development of systems at their early stage. Despite guidance from standards, MBPLE practitioners still face the challenge of deploying an appropriate configuration management strategy. This paper presents and demonstrates a configuration management strategy to support practitioners deploying MBPLE for aircraft systems development. We developed this strategy to comply with ISO/IEC 26580 and address pending standard ambiguities using best practices from product lines for systems, software, business processes, and systems of systems. The proposed strategy supports long-term product line evolution, management of different asset types, and independent product environments

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Key Reserve Paper#548

A Framework to use Bifurcation Analysis for Insight into Complex Systems Resilience

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Keywords. Critical Transitions;Bifurcation Analysis;Resilience Engineering;Complex Systems

Topics. 1.1. Complexity; 1.3. Natural Systems; 12. Infrastructure (construction, maintenance, etc.); 14. Autonomous Systems; 22. Social/Sociotechnical and Economic Systems; 4.4. Resilience;

Abstract. The increasing complexity and integration of systems present challenges in understanding and managing these systems, as highlighted by the INCOSE Systems Engineering Vision for 2035. The complexity in systems can be a cause of system failures as it complicates their operation and un-derstanding. Resilience Engineering is a field that focuses on system behavior in the face of disrup-tions. However, existing methods to measure resilience, such as probability-based measures and linear recovery models, are limited by the non-linear and dynamic nature of modern systems. bi-furcation analysis, a mathematical system dynamics technique, offers a different perspective by examining how systems behave under changing conditions. This approach, developed in ecology and traditionally applied in fields including power systems and neural networks, can provide insights into the resilient characteristics of non-linear systems. Despite its promise, bifurcation analysis is not usually associated with Resilience Engineering. Thus, the hypothesis of this work is: if Bifurcation analysis is performed to a nonlinear system, then it is possible to get insight on the resilient char-acteristics of the system. This paper proposes using Bifurcation analysis to understand system resil-ience better and support RE practitioners. It aims to bridge the gap between bifurcation analysis and Resilience Engineering, offering a framework for integrating both approaches. This framework is then applied to a model system to demonstrate its potential in enhancing the understanding of system resilience. Contributions are an overview of current Resilience Engineering and bifurcation analysis, a general-use framework for practitioners, and an application of this framework. Future work will focus on applying the new framework to more cases, allowing for improved Resilience Engineering, and improving the framework to make it more accessible, versatile, and reliable.

Key Reserve Paper#563

A Model Based System Engineering Approach for Trucking Fleet Replacement

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Keywords. transportation;heavy vehicle;fleet management;environment;model-based systems engineering;sustainability

Topics. 17. Sustainment (legacy systems, re-engineering, etc.); 21. Urban Transportation Systems; 3. Automotive; 3.1. Acquisition and/or Supply; 4.2. Life-Cycle Costing and/or Economic Evaluation;

Abstract. Heavy vehicles operating for less than truckload (LTL) carriers are utilized to the maximum extent possible for the operator to maximize vehicle return on investment. However, the decision to purchase new vehicles, reallocate the vehicle, or retire the vehicle is based on complex and interacting factors like performance degradation, total cost of ownership, new regulatory pressures, and maintenance costs. The problem of optimizing fleet capacity is well suited to a model-based systems engineering approach. Using SysML as the language and MagicGrid as the method, a model for fleet vehicle replacement and utilization was built to understand the best way to maximize and grow shipping capacity. The process started with identifying stakeholders and their needs and ended with system parametric models capable of computing costs. This model has the potential to optimize operating costs for fleets and maximize the use of the vehicle assets. Not only do these optimizations improve company financial performance, they reduce the need to unnecessarily replace expensive equipment, which is a more sustainable business practice.

Key Reserve Paper#556

A modular simulation-based MBSE approach applied to a cloud-based system

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Keywords. cloud-based system estimation;model-based systems engineering;time-base simulation;modular modeling approach

Topics. 1. Academia (curricula, course life cycle, etc.); 11. Information Technology/Telecommunication; 2. Aerospace; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 5.7. Software-Intensive Systems;

Abstract. Data systems consist of a network of communication channels, applications that trans-mit data across these channels, and the hardware running these applications or generating the data. Most modern data systems include cloud storage or compute which has unpredictable or stochastic properties making estimations of cloud behavior and performance difficult. Resource usage is function of behavior and performance on software/hardware. Cloud cost is a function of resource usage and hardware used. Public cloud spend was over budget by an average 18% for 2022 with organizations reporting an estimated 28% public cloud waste. The scale of this problem is a measure of the difficulty of accurate cloud-based system performance and cost predictions. The goal of this paper is to develop and demonstrate a modular and scalable Model-Based Systems Engineering (MBSE) approach for designing, updating, and managing cloud-based data systems. Our use-case based Agile MBSE approach is developed to integrate with commonly used Agile software development processes to increase collaboration between system engineers and developers. We embed simulation behaviors within the lowest level of system specification activities to produce a modular andreusable set of simulation-ready system activities. Our approach uses a combination of languages (SysML, fUML, Apache Groovy, and the Action Language Helper (ALH)) to develop these modular system activities for scalability and speed. We applied this approach to the simulation of a cloud-based data system. The results show that our approach produces a modular, time-dependent, executable system model that can estimate cloud-based system performance and storage cost as a function of time. Emergent behavior observed from the simulation results indicate that the systemmodel is capable of providing system engineers and management teams valuable insight into the behavior of the system they are designing or upgrading.

Key Reserve Paper#507

A Proposed Approach for the Digital Thread

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Keywords. Digital Thread;Authoritative Source;MBSE;Digital Twin

Topics. 1.6. Systems Thinking; 11. Information Technology/Telecommunication; 3.4. Information Management Process; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 6. Defense;

Abstract. This whitepaper presents a notional digital thread concept as seen by the Digital Engineering Strategy group at Los Alamos National Laboratory. The paper presents these thoughts in hope of facilitating feedback, correction, and debate rather than presenting an absolute approach intended for a final implementation. We talk through a conceptual implementation as it crosses requirements, design, test, manufacturing and maintenance domains, then break down our current guiding principles to consider when building a digital thread. Terms are then established to govern maturity levels of thread implementations and ideal data/information objects for connection to the digital thread. Next we take a high level look at four different types of digital thread implementations and present a basic anatomy for one of the thread types. Finally, we address significant concerns for implementation regarding the ways to leverage the thread, the role of MBSE inside of the digital thread environment, and close by looking at two relevant open standards/specifications that support digital thread implementation.

Key Reserve Paper#524

A Rapid Review of How Model-based Systems Engineering is Used in Healthcare Systems

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Keywords. Model-based systems engineering (MBSE);healthcare systems;sociotechnical systems;human-in-the-loop systems

Topics. 18. Service Systems; 4. Biomed/Healthcare/Social Services; 4.1. Human-Systems Integration; 5.3. MBSE;

Abstract. This study presents the results from rapid review of how model-based systems engineering (MBSE) is utilized in healthcare systems (HSs). We conduct a review of the last twelve years and find that MBSE adoption in HSs is accelerating, with use of various MBSE languages and tools, as well as their integration with other simulation and modeling techniques. We find that similar to engineered systems, the most common MBSE language is systems modeling language (SysML), followed by unified modeling language (UML) and others such as OPM. Additionally, we observe that MBSE methods are frequently used in conjunction with other analytical techniques, such as simulation and co-simulations, to analyze and enhance various HS operations, or to assist with making tradeoffs between HS attributes such as quality and cost. Moreover, we provide a non-exhaustive classification of current research based on two dimensions: healthcare applications and MBSE use cases. Notably, MBSE is being implemented generally with patient-centric objectives in various HS domains, including IoT-enabled smart healthcare, clinical medicine, medical device development, healthcare process enhancement, and healthcare facilities management. While the primary MBSE use case involves modeling different aspects of healthcare operations, there is a significant number of studies that pursue requirements engineering, systems analysis, integration, verification and validation, as well as risk analysis and management. Furthermore, we identify two promising research gaps. First, there is a need for the integration of MBSE with state-of-the-art data-driven analytical methodologies such as hybrid simulation and artificial intelligence techniques. Second, HSs could greatly benefit from representing the cognitive functions and processes of human decision-makers in the loop, such as healthcare providers (e.g., doctors and nurses), who are instrumental in sustaining the HS performance and functionality. We contend that MBSE and other SE methods and techniques could improve HSs design, operations, and management; while fostering resilience and long-term sustainability.

Key Reserve Paper#139

A Technical Approach to the Digital Signature of MBSE Models

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Keywords. Model-Based Systems Engineering (MBSE);Digital Signature;Authoritative Sources of Truth (ASOTs)

Topics. 11. Information Technology/Telecommunication; 3.2. Configuration Management; 3.4. Information Management Process; 5.3. MBSE; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. To fully realize the benefits of Model-Based Systems Engineering (MBSE), users of an MBSE model need to be able to verify its authenticity and integrity. A digital signature is a common cryptographic technique that enables users to sign digital content and verify the integrity of the signed content. This enables users to verify that the signed content is truly from the author who signed the content and is a common practice in digital documentation. MBSE models have unique qualities that separate themselves from other digital documentation, thus specific digital signature approaches need to be implemented for MBSE models.This paper describes an approach to apply digital signatures to MBSE models. The approach explores some characteristics of MBSE models and enables the digital signing of a portion of a model using a signer’s digital certificate. The approach allows for the verification of the signed model content against the signature and indicates if information is altered from what the signer intended. This paper captures the technical challenges and lessons learned applying this approach as a prototype to an existing MBSE modeling tool. These findings from this paper can be used to guide the development of a digital signature capability in MBSE modeling tools.

Key Reserve Paper#120

Ability of the OSLC Standard to Improve Data Traceability in the Development of Systems

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Keywords. Open Services for Lifecycle Collaboration OSLC;Traceability;Digital Thred;MBSE

Topics. 1.6. Systems Thinking; 2.5. System Integration; 5.3. MBSE; 5.5. Processes; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The development of systems offers a particular challenge for the interoperability of different tools used by collaborating developers like requirements management, design, or simulation tools. The difficult and time-consuming process to integrate and exchange data between different systems can lead to data inconsistencies and reduced efficiency in the development process. The integration standard Open Services for Lifecycle Collaboration (OSLC) targets the integration of engineering software applica-tions. Its approach supports loose tool coupling, in which each application autonomously manages its own product data, while providing RESTful web services through which other applications can interact. This paper aims to analyze the suitability of OSLC as an overarching integration mechanism for the complete set of engineering artifacts created during system development. This paper presents use cases for the application of OSLC at the company MAHLE. For these use cases, the employed OSLC based toolchain is assessed. The analysis in this paper confirms that OSLC's capabilities allow users to support traceability and can support the exchange and integrate data according to the defined re-quirements, but it is not sufficient for sophisticated data processing functionalities, such as safety analysis or simulation. The OSLC integration does correspondingly compare favorably to integration technologies already in use regarding traceability, while transformation of data in domain specific tools is needed to achieve deeper levels of integration.

Key Reserve Paper#375

Addressing Cross-Domain Interoperability between Automotive and Smart Grid Architecture Models

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Keywords. Model-Based Systems Engineering;Domain Specific Languages;Cross-Domain Interoperability

Topics. 1.1. Complexity; 3. Automotive; 5. City Planning (smart cities, urban planning, etc.); 5.3. MBSE; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 8. Energy (renewable, nuclear, etc.);

Abstract. The rapid advancement and diversification of technical domains, particularly in automotive and smart grid sectors, are pivotal in driving the emerging energy revolution. This evolution is instrumental in governing the future of smart cities, characterized by escalating complexity and diversity within these domains. Such a landscape necessitates seamless collaboration among various domain experts, a task often complicated by the prevalent use of domain-specific languages and tools tailored to specific engineering needs. This poses a significant challenge towards cross-domain interoperability.Addressing this challenge, our research introduces a novel approach leveraging abstraction layers inspired by the Software Platform Embedded Systems (SPES) methodology. This approach aims to enhance the compatibility of domain-specific frameworks, with a focus on the Smart Grid Architecture Model (SGAM) and the Automotive Reference Architecture Model (ARAM). By applying these SPES-inspired abstraction layers, our work facilitates the reconciliation of varying levels of detail across different domains.The paper culminates in a proof of concept that demonstrates the practical implementation of this approach, showcasing a method to achieve effective cross-domain interoperability. This implementation not only underscores the feasibility of our proposed solution but also illuminates a pathway for managing the intricate interplay of systems in the rapidly evolving landscape of smart cities.

Key Reserve Paper#236

An ontology example in Configuration Management at Airbus

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Keywords. Ontology;Configuration Management;Digital

Topics. 2. Aerospace; 3.2. Configuration Management; 5.12 Automation;

Abstract. Today data is increasingly available in our engineering domains but without an ontology to structure it, one might get drowned in the data lake. Configuration Management data being central to maintaining the configuration of the aircraft throughout its life cycle, need to be well described, understood and interpreted appropriately. This paper presents the effort performed at Airbus in the configuration management domain to structure the data through abstract ontology models of processes, tools and workflows. The ontology objects are then implemented and exposed as a data product to be used in digital transformation initiatives. This ontology based approach has encouraged harmonization of digital initiatives across different aircraft programs, and the associated graph style implementation ensures a more efficient exploration of Configuration Management data, leading to shorter lead time for development of data driven initiatives and knowledge ramp up.

Key Reserve Paper#384

Application of Model Based Systems Engineering within the Automotive Industry – a Current State

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Keywords. Model-Based Systems Engineering;MBSE;Automotive;Survey

Topics. 3. Automotive; 5.3. MBSE;

Abstract. Model-Based Systems Engineering (MBSE) has been utilized within the automotive industry for several years. Increasing complexity due to highly automated, connected vehicles demand more than ever methods to cope with this complexity. In most cases, currently only specific partial aspects or single methods of MBSE are used, which even varies across different companies. This paper aims to examine the current implementation of MBSE based on samples collected from various automotive suppliers (referred to as "Tier 1"). Various aspects are explored, including the scope of application throughout the product lifecycle, the use of simulation methods and the collaboration with other disciplines within product development. In the end an evaluation dis-cusses reasons for the current state and recommendations are given.

Key Reserve Paper#314

Application of SysMLv1 vs SysMLv2 in the Scope of the MagicGrid Framework

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Keywords. Model-Based Systems Engineering (MBSE);Systems Modeling Language (SysML);SysMLv1;SysMLv2;MBSE methodology;MagicGrid

Topics. 2.3. Needs and Requirements Definition; 2.4. System Architecture/Design Definition; 5.3. MBSE;

Abstract. This paper aims to assess the impact of the next generation Systems Modeling Language, SysMLv2, on MagicGrid, the established framework for the model-based systems engineering (MBSE). The research involves the parallel application of SysMLv1 and SysMLv2 to build two models of the problem domain definition by following the steps defined by the framework. The paper compares the modeling concepts of both languages used to create the model, discloses differences, and assesses advantages and disadvantages over each other. While SysMLv2 offers both textual and graphical notations, this study primarily focuses on the graphical representation. The paper concludes with a comprehensive summary of distinctions observed in the application of SysMLv2 versus SysMLv1. As anticipated, SysMLv2 was found a completely fresh modeling language. Significant alterations has been observed in the use case specification and functional analysis. Additionally, the absence of explicit guidelines on the utilization of definitions and usages was identified.

Key Reserve Paper#117

Are Electric Vehicles Always Better for the Environment?

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Keywords. carbon emissions;electric vehicles;environmental impact;life cycle assessment

Topics. 1.6. Systems Thinking; 10. Environmental Systems & Sustainability; 3. Automotive; 4.2. Life-Cycle Costing and/or Economic Evaluation; 5.4. Modeling/Simulation/Analysis; 8. Energy (renewable, nuclear, etc.);

Abstract. Electric vehicles have been touted for their environmental friendliness, as their carbon emissions are significantly reduced during the usage phase compared to traditional petrol vehicles. However, from a lifecycle perspective, it is necessary to examine how the components of electric vehicles are obtained, constructed, operated, maintained, and disposed to better inform of their impact on the environment. Moreover, the environment's focus is often on the impact of carbon emissions but less on other forms of environmental impact such as ecotoxicity to marine life.To better study the carbon emission reduction effect of electric vehicles throughout their entire lifecycle and their other environmental impacts, the petrol and electric versions of the SAIC Roewe i6 MAX vehicles in China will be compared throughout their entire lifecycles, including raw material collection, transportation, manufacturing, usage, and disposal processes. The results for the diesel and hybrid vehicles will also be briefly covered for comparisons purposes. The study showed that the breakeven point for carbon emission between petrol vehicles and electric vehicles is at about 2.8 years of use in China. This means that electric vehicles produce more carbon emission in the manufacturing/ assembly and only after 2.8 years of usage, that they emit less carbon emissions than petrol cars. As expected, the carbon emissions of diesel and hybrid cars fell in between these two, with hybrid vehicles performing better than diesel vehicles. However, electric vehicles produced the worst marine toxicity, with hybrid cars being second.

Key Reserve Paper#568

Automating Rule-Checking to Identify SysML Modeling Errors: A Preliminary Study in a Classroom Environment

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Keywords. Model-Based Systems Engineering (MBSE);System Modeling Language (SysML);verification and validation;systems engineering education

Topics. 1. Academia (curricula, course life cycle, etc.); 2.6. Verification/Validation; 5.3. MBSE; 5.9. Teaching and Training;

Abstract. Among other benefits, the adoption of Model-Based Systems Engineering (MBSE) or Dig-ital Engineering (DE) is expected to decrease the number of escaped errors in a project by enabling early errors detection within the modeling environment. This contributes to reducing the cost associated with corrective activities, which are generally costly in late phases of the development. This paper pro-vides an empirical insight into this benefit through a study of models developed by students in a grad-uate MBSE course, where they leveraged the use of automated rule checking within the modeling tool. The dataset covers 10 editions of the course, spanning 2016-2023, and contains 601 models. The study shows that the term project models resulted in nearly zero latent errors when non-stylistic rules are concerned, with most of the latent errors categorized stylistic rather than fundamental violations.

Key Reserve Paper#415

Configuration Management of Sets of Links in a Federated Tool Environment

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Keywords. Configuration management;model-based systems engineering;traceability

Topics. 2. Aerospace; 3.2. Configuration Management; 5.1. Agile Systems Engineering; 5.3. MBSE; 5.6. Product Line Engineering;

Abstract. In the era of document-centric systems engineering, large organizations developing complex sys-tems had practical methods of associating drawings, specifications, requirements and other infor-mation with each other. Mostly these evolved methods involved part numbers and drawing num-bers, although sometimes the methods included mundane techniques such as storing drawings in specific drawers in specific filing cabinets. These manual methods were very labor intensive, did not handle changes gracefully, and were somewhat error prone. As computer software and model-ing tools began to displace paper drawings and filing cabinets, a “connect and forget” style of link-ing evolved. We can see this sort of thinking in the relationships in UML and SysML, but also in other places such as the use of Universally unique identifiers (UUIDs) in the XMI file format un-derlying UML/SysML, the relationships in DOORS and related requirements tools, as well as the original architecture of OSLC which depended on URIs embedded in design artifacts to establish relationships. While these “click to connect” features provided increased convenience compared to the previous manual numbering approaches, these “hard-coded” links have introduced a new set of problems. The root of most of the new problems comes in the difficulty of managing this sort of extremely large set of direct links as configuration items in their own right. In a larger system, this sort of link set quickly grows to thousands or even millions of links. Managing change, modularity, variants, subsystem reuse, and so on all become very difficult in the presence of such a large, un-planned, and uncontrolled link set. In this paper, we will review the different approaches to creating and managing such sets of links and provide a concise best practices recommendation for the con-figuration management of such sets of links.

Key Reserve Paper#460

Context-Based Systems Engineering

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Keywords. Requirements;Decomposition;Context-Based;Processes

Topics. 2. Aerospace; 2.3. Needs and Requirements Definition; 2.4. System Architecture/Design Definition; 3. Automotive; 5.5. Processes; 6. Defense;

Abstract. This paper explores a new problem/system decomposition approach. Instead of the traditional way, where stakeholder requirements are transformed into system requirements on the sys-tem-of-interest, stakeholder requirements are decomposed into requirements for modified context subsystems. The subsystems will consist of system elements from both the system-of-interest and its context. The main benefit of the new approach is that the functionality at all levels can be defined and not only declared. Consequently, it will be possible to write executable requirements which enables system simulation on all system levels, which in turn makes very early integration, verification and validation possible.

Key Reserve Paper#513

DATA ELEMENT MAPPING AND ANALYSIS (DEMA) TO ENABLE SYSTEMATIC MODEL CREATION USING SYSML

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Keywords. Data Element Mapping and Analysis (DEMA);Model-Based Systems Engineering (MBSE);System Verification;System Modeling Language (SysML);Digital Engineering;Data Mapping

Topics. 2. Aerospace; 2.4. System Architecture/Design Definition; 2.6. Verification/Validation; 5.3. MBSE; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.)

Abstract. Data Element Mapping and Analysis (DEMA) represents a new and systematic methodology for the standardized capture, mapping, and analysis of data threads essential for comprehending digital systems and their architecture. This research studies the synergies between DEMA and Systems Modeling Language (SysML). The results of this research show that DEMA can serve as a complementary tool, enhancing the creation of SysML models by improving knowledge capture and verification processes.

Key Reserve Paper#469

Developing a Model-Based Systems Engineering Tool for Cybersecurity Risk Management of Micro-Electronic Devices

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Keywords. Model-Based Systems Engineering;Cybersecurity;Risk Management

Topics. 2. Aerospace; 4.7. System Security (cyber-attack, anti-tamper, etc.); 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense

Abstract. This presentation outlines a method to quantify cyber threats associated with micro-electronics. The method utilizes MBSE as a tool to implement a cyber-threat assessment model. The model integrates a mathematical quantification of these threats to produce a visualization of the results in a 5x5 risk matrix. This tool will help users identify unique threat vectors and analyze counter-measure strategies to mitigate the effects on system performance, safety, and security.

Key Reserve Paper#78

Do Algorithms Dream of Electric Requirements? Leveraging AI-Based Approaches for Automated Allocation and Classification of Requirements in Railway Engineering

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Keywords. Artificial Intelligence;Requirements Classification;Systems Engineering;Railway Engineering;Machine Learning

Topics. 12. Infrastructure (construction, maintenance, etc.); 16. Rail; 2.3. Needs and Requirements Definition; 2.6. Verification/Validation; 21. Urban Transportation Systems; 5.11 Artificial Intelligence, Machine Learning;

Abstract. In recent years, Artificial Intelligence has experienced an extraordinary growth, and it is being implemented in almost every aspect of engineering. Systems Engineering is a discipline where the implementation of AI can be challenging, but that could immensely benefit from its capabilities. This paper presents one of the many implementations that AI can have within the Systems Engineering field. In particular, this paper shows how the power of AI has been leveraged to create an algorithm that allows for the automatic classification of requirements within a specific engineering sector: large railway projects. While text classification algorithms are well stablished, the key to a successful implementation of a requirements classifi-cation algorithm lays on the effective structurization of the data, as well as the high quality of the training datasets. This paper describes how an AI-based requirements classification algorithm has been planned and trained to effectively classify requirements based on systems and subsystems from a System Breakdown Structure (SBS), as well as to identify the adequate method of verification for both the Design and Testing and Commissioning stages of a project.Finally, the paper showcases how the use of this AI-based requirements classifier does not only lowers the probability of human error, but also reduces ~75% human workload per project. Additionally, overall ~30% cost savings to organizations are expected in a 10-year period in the task of classifying requirements with respect to manual classification performed by subject matter experts.

Key Reserve Paper#344

Early Validation of SysML Architectures by Extending MBSE with Co-Simulation using FMI and SSP

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Keywords. MBSE;System Architecture;Simulation;Co-simulation;SysML;FMI;SSP

Topics. 2.4. System Architecture/Design Definition; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis;

Abstract. Due to complexity increases in modern systems and the digitalization paradigm shift, industrial development requires the integration of new technologies and methods to keep customer satisfaction high while reducing time to market. One emerging paradigm in the Systems Engineering (SE) discipline is Model-Based methods and technologies, and correspondingly Model-Based Systems Engineering (MBSE) is seeing increased adoption. With mature MBSE application, several benefits can be expected from the availability of models, even from the very early stages of development, enabling increased communication clarity, cross-domain collaboration, traceability, and analysis. Notably, MBSE enables (Co-)simulation even at the early stage of architecture/design by leveraging model-based capabilities. Co-simulation specifically enables a smooth and seamless integration of different models defined across layers of abstraction, for example, system logical architecture and system physical architecture. However, while MBSE is assisting with many aspects of development it is still a predominantly isolated set of activities throughout the development, especially on the left-hand side of the traditional V-model. In this work we discuss the status of Co-simulation in industrial MBSE and list several existing challenges, then we propose a novel framework for implementing Co-simulation and exemplify using a real scenario how we might address the observed challenges. Finally, we propose a set of recommendations for future investigations to strengthen Co-simulation in industrial MBSE.

Key Reserve Paper#71

Excuse me Sir/Madam, which Model?

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Keywords. MBSE;Modelling and Simulation;Systems Architecting;Virtual integration

Topics. 2. Aerospace; 2.4. System Architecture/Design Definition; 5.3. MBSE;

Abstract. Development of complex systems through the application of Model-Based Systems Engineering will require the creation and maintenance of multiple models, created using multiple languages. Struc-turing the models such that there is efficient support for incremental development require some foresight. Having models with multiple or unclear purposes may introduce situations where parts of the organisation will ask for modification for representing a desired future system state whereas other part require it to unchanged in order to represent the present state. This paper introduces structure with associated terms and characteristics of the different model types to provide guidance to the devel-oping organisation. In particular, it extends previous work on model tenses capturing different time-perspectives/purposes on the models, to also include model usage for keeping track of the actual state of a realised system instance, i.e., the concepts of Digital twin and Digital shadow are discussed and conceptualised. As such, the contributions made in the paper allows an organisation to reason about the completeness of their modelling methodology and its applicability to support incremental development. Above all, the paper spells out clearly that for a complex heterogeneous system, any request for an update to “the model” will prompt the response “Excuse me Sir/Madam, which mod-el?”.

Key Reserve Paper#60

Exploring the Executable SysML Capabilities to Integrate and Operate Hardware in the Loop

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Keywords. SysML;Digital Twin of Weapon System;Lego Mindstorms;Executable Model;Hardware in the Loop

Topics. 1. Academia (curricula, course life cycle, etc.); 2.6. Verification/Validation; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. Effective modeling and integration are critical systems engineering capabilities. They involve breaking down complex systems into simpler, less complicated parts that are easier to understand. Systems engineers can use advanced software tools and standardized modeling methods to perform these tasks. CATIA Magic, the new portfolio name we will use from this point, is software that allows for systems architecture, as well as more in-depth SysML modeling and simulation. The goal of this paper is to explore the capabilities of SysML to model and control hardware in the loop (HIL). The model of a weapon system was created using several different diagrams commonly used in the Systems Modeling Language (SysML). When these diagrams are used together with the CATIA Magic simulation toolkit (Magic Model Analyzer), they can be made executable and used for simulation purposes. While CATIA Magic was selected to provide a digital model of the weapon system, a LEGO Mindstorms EV3 development kit was selected to create a mockup of a physical system. LEGO infrared sensors can receive inputs and send data to the model made in CATIA Magic. The model reacts based on changing inputs and sends control signals to motors built into the model. In general, the integration between the LEGO Mindstorms and CATIA Magic can be done successfully, however, this study revealed certain limitations pertinent to the current capability of CATIA Magic to make connections between the SysML model and LEGO hardware. While these limitations did not allow for a full integration and in-depth testing of the created dynamic model, as intended, the paper presents the current state of the project discussing what is involved in integrating CATIA Magic and LEGO Mindstorms kits and what functionality could be achieved by doing this. The paper pursues both the educational aspect that allows a deeper exploration of the modern system modeling tools, and the practical aspect ,showing how a SysML model can be integrated with HIL to provide opportunities to better understand the design space at earlier stages of system development.

Key Reserve Paper#40

Extending SysML Model Federation to Support Systems of Systems Multilevel Security Development

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Keywords. Model Based Systems Engineering (MBSE);SysML Model Federation;Digital Engineering;Systems of Systems (SoS)

Topics. 13. Maritime (surface and sub-surface); 2. Aerospace; 2.4. System Architecture/Design Definition; 5.3. MBSE; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 6. Defense;

Abstract. Practitioners of modern systems engineering within the defense industry and intelligence community often find themselves being pulled in diametrically opposed directions. On the one hand, systems engineering is quickly evolving into a digital practice, strategically connecting heterogeneous sets of models to form digital threads and digital twins capable of providing insights more valuable than the sum of their parts. On the other hand, the inherent nature of working within the national security space necessitates information be held a multiple levels of classification, safeguarded from release, and compartmentalized. This paper focuses on Model Based Systems Engineering (MBSE) development to introduce methods and tools to aid in overcoming these challenges. The work presented here builds on previously published works in SysML Model Federation for Systems of Systems (SoS) Architecting, the experience of applying this methodology on real world programs. Furthermore, it lever-ages freely available MBSE tools, processes, and methods in the construction of System Architecture Models (SAMs). This paper culminates in a call to action for additional published research and development to address residual challenges and gaps with respect to executing MBSE for Multilevel Security (MLS) development.

Key Reserve Paper#100

Hardware-in-the-Loop with SysML and Cameo Systems Modeler

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Keywords. MBSE;SysML;Hardware-in-the-Loop

Topics. 2. Aerospace; 20. Industry 4.0 & Society 5.0; 3. Automotive; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis;

Abstract. This paper describes an approach for Hardware-in-the-Loop simulations with SysML models in the Cameo Systems Modeler tool. It is based on a plugin called MQTT Simulation Connector that enables bidirectional communication between the tool and hardware components using the MQTT protocol. The paper presents the applicable requirements and constraints that were considered, describes the MQTT Simulation Connector in detail and shows an example of its use in the form of a Smart Home demonstrator.

Key Reserve Paper#505

Impact Analysis of using Natural Language Processing and Large Language Model on Automated Correction of Systems Engineering Requirements

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Keywords. Requirements;Systems Engineering;Large Language Models;Natural Language Processing

Topics. 2.3. Needs and Requirements Definition; 3. Automotive; 5.11 Artificial Intelligence, Machine Learning; 5.12 Automation; 9. Enterprise SE (organization, policies, knowledge, etc.); Other domain;

Abstract. The increasing complexity of Electronic Control Units (ECUs) in the Automotive Industry due to the integration of more sophisticated vehicle features led to a greater need for robust Systems Engineering (SE) to define and implement efficient solutions. In this context, requirements emerge as a critical part of the communication between cross-functional teams. The more complex systems become, the more requirements are needed to define them. Misalignment, lack of information and ambiguity on requirements impact the entire development process, resulting in issues later, harder to be fixed. Some studies are being applied to evaluate techniques using Natural Language Processing (NLP) and how it can replace extensive peer reviews, identifying weaknesses in requirements earlier in the process, avoiding wasted time and large financial losses. Normally, NLP is combined with templates such as Easy Approach Requirements to Syntax (EARS), or other techniques based on rules like the INCOSE rules to define metrics and evaluate the quality of requirements in automated way. The focus of this study is to enhance the requirements evaluation algorithm by combining NLP with Large Language Models (LLMs) and adding the ability to provide corrected requirements to Systems Engineers.

Key Reserve Paper#407

Implementation of a Technical Peer Review Process: Principles, Policy, and Cultural Change

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Keywords. design process;technical review;peer review;continuous improvement;engineering process

Topics. 2. Aerospace; 3.7. Project Planning, Project Assessment, and/or Project Control; 5.2. Lean Systems Engineering; 5.5. Processes; 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The complex scientific and engineering work performed at Sandia National Laboratories is supported by a comprehensive system of reviews that include design, gate, and peer reviews. A recent exercise revealed a need to change how technical peer reviews are conducted. Building on industry standards, best practices, current standard internal practices and other previous work, Sandia has developed a continuous improvement process to institutionalize technical peer review in the design lifecycle of products. The approach focuses on translating customer and leadership expectations, utilizing current established practices, simplifying planning and execution, and providing resources to engineering teams to guide them and ensure that rigorous and consistent technical peer reviews are performed. This paper presents the process used by Sandia to improve the technical peer review process, the factors that affect implementation of a peer review process, the simplified three-step process implemented, the tools and resources generated, and the sustainment plan adopted to increase the institution-wide use of peer review as a tool to improve product delivery.

Key Reserve Paper#37

INCOSE Systems Engineering Competency Assessment Guide Systems Modeling Language (SysML) Model Description

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Keywords. Systems Engineering Competency Model;Competency;Competence;Model Based Systems Engineering (MBSE);Systems Modeling Language (SysML)

Topics. 1. Academia (curricula, course life cycle, etc.); 4.5. Competency/Resource Management; 5.3. MBSE; 9. Enterprise SE (organization, policies, knowledge, etc.); Other domain;

Abstract. The INCOSE Systems Engineering Competency Framework (SECF) and INCOSE Systems Engineering Competency Assessment Guide (SECAG), published in 2018 and 2023 respectively, provide a definition for 37 systems engineering competencies and the evaluation criteria against these. This paper describes the development, use, and plans for a Systems Modeling Language (SysML) Model Based Systems Engineering (MBSE) model. A description of the metamodel and data structure is presented as well as a series of evolving use cases for this model.

Key Reserve Paper#381

Introducing a Three-Layer Model Taxonomy to Facilitate System-of-Systems Co-Simulation

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Keywords. model-based systems engineering;power systems;cyber-physical systems;digital twin;modeling and simulation

Topics. 12. Infrastructure (construction, maintenance, etc.); 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 8. Energy (renewable, nuclear, etc.);

Abstract. The growing demand for efficient, resilient, and sustainable electricity infrastructure has led to the emergence of smart grids as cyber-physical systems of systems. Co-simulation has proven an effective tool for their analysis and validation by coordinating independent subsystem simulations. However, the reuse and integration of diverse models in co-simulation poses challenges, requiring compatibility and integration efforts. In response, this paper proposes a model taxonomy with the purpose of facilitating co-simulation; it comprises three layers: concrete-instance models, abstract-instance models, and type models. The taxonomy contributes to the creation of independently developed models that can be seamlessly integrated into a coupled co-simulation. Furthermore, it reflects the emergence of digital twins in smart grid engineering by the explicit distinction of abstract and concrete instances. The three-layer taxonomy was derived and validated through a case study on co-simulation of elec-tric-vehicle charging infrastructure. The research further analyzes and formalizes three model-ing-and-simulation challenges framed through the lens of the taxonomy: the integration of models across all three layers, the merging of layers, and the consolidation of instance models to craft joint co-simulation scenarios. Finally, three concrete recommendations for industrial practice and research are given. Thereby, the study contributes to the efficient and effective model-based validation of cyber-physical systems of systems using co-simulation.

Key Reserve Paper#132

Introduction of Systems Engineering Practices in a Product Lifecycle Management (PLM) course for master students

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Keywords. Product Lifecycle Management;Model-Based Systems Engineering;graduate course

Topics. 1. Academia (curricula, course life cycle, etc.); 5.3. MBSE; 5.9. Teaching and Training;

Abstract. This paper presents how a model-based system engineering approach was used to introduce to master students the strength of and the challenges with a Product Lifecycle Management (PLM) system. The students were introduced to use various authoring applications to build the product content to be managed by a PLM system.

Key Reserve Paper#171

Leading in Uncertainty: A Framework to Improve Performance

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Keywords. Uncertainty;Leadership;Technical Leadership;Framework

Topics. 1. Academia (curricula, course life cycle, etc.); 3.5. Technical Leadership

Abstract. We are all leaders in our organizations in some form. As leaders, we often face elements outside our control. As systems engineers, we think of technical uncertainties, which we attempt to predict, manage, and mitigate. As leaders many of the uncertainties experienced are not technical. They involve elements, such as people, and incorporate unknown and known unknowns. We propose a framework to provide leaders with a tool to help achieve their goals with the uncertainties they face as leaders.

Key Reserve Paper#361

Leveraging Large Language Models for Direct Interaction with SysML v2

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Keywords. API;Assistant;Large Language Model;LLM;SysMLv2

Topics. 5.11 Artificial Intelligence, Machine Learning; 5.12 Automation; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis;

Abstract. This paper examines the potential integration of Large Language Models (LLMs) with the Systems Modeling Language version 2 (SysML v2), proposing a novel methodology for systems engineering by capitalizing on the enhanced readability and human-friendly syntax of SysML v2. Given the emergent sophistication of LLMs and the coincidental development of SysML v2—an endeavor that presents a pivot toward naturally articulated model interaction—we explore the possibilities and implications of such an intersection. Our investigation posits that LLMs can serve not only as an interpretive layer, allowing for the syntactically simplified manipulation of system models, but also as a catalyst for a knowledge-driven design approach. We highlight the efficiencies gained by deploying LLMs for SysML v2 interactions, which reduce the dependency on technical expertise traditionally needed for API navigation and model management. Through case studies and analysis, we demonstrate that the conversational engagement with system models facilitated by LLMs can lead to a democratized and accelerated design process. However, this advent is tempered by a critical awareness of potential pitfalls, such as automation bias and overre-liance on automated systems—underscoring the need for continued human oversight and the ex-amination of ethical considerations. Emphasizing the chance of SysML v2 being inherently English-based and the parallel maturation of LLMs, this paper suggests that the collaborative utilization of these concurrent advancements may offer an opportune fusion, potentially revolutionizing the way systems are modeled and managed. Future work involves the empirical validation of these approaches and a deeper investigation into interoperability with existing and future systems engineering ecosystems. The ultimate goal is to ensure that this fusion not only complements human expertise but also propels systems engineering into a new era of innovation and holistic design.

Key Reserve Paper#228

LEVERAGING MBSE USAGE THROUGH MODEL CHECKERS

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Keywords. Model checkers;correctness;completeness;consistency;static analysis

Topics. 2.4. System Architecture/Design Definition; 2.6. Verification/Validation; 5.3. MBSE

Abstract. System modeling is an essential part of the systems engineering process, helping with the design, analysis, and communication of complex systems. The usage of modeling languages like SysML and UML has become increasingly prevalent in this domain. To ensure the Holy Trinity of validation of these models (correctness, completeness and consistency), model checkers play an important aspect.This paper discusses the role of model checkers in the validation of system models, and their im-portance in adopting MBSE approach with a quick benefit to system engineers. Different possible implementations are presented including one based on an ontology able to take advantage of semantic analyses. Finally, in order to deal with the number of issues due to the complexity of our models, we suggest correcting them regarding the goal of the model and the project milestones. This last point implies the need of an issue acknowledgement feature making it possible to justify the temporary or definitive rejection of these issues.

Key Reserve Paper#267

LEVERAGING MISSION SOLUTION CONFIGURATION THROUGH MBSE AND TRADESPACE EXPLORATION

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Keywords. Systems Engineering;Tradespace Exploration;Variants Management;Pareto-Optimization;Product Management

Topics. 13. Maritime (surface and sub-surface); 2.4. System Architecture/Design Definition; 3.3. Decision Analysis and/or Decision Management; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. is a worldwide leader in innovative radar and mission solution systems used by naval ships. As the demand for personalized products increased through the time, shifted from a project-oriented to a product-oriented approach, so that it can exploit variants and reuse to create diversity and, at the same time, reduce the occurrence of specific tailoring, which needs to be performed by projects. In this context, established a mission solution configuration process (SCP) to facilitate the selection of product variants to compose a system during the bidding phase. The SCP's current state, thought, limits the solution space exploration to predefined system solutions with have limited freedom for choosing variants. Furthermore, the SCP is not directly integrated to engineering process and the actual systems information. As a consequence, the proposed systems sometimes fall short from the most optimal solution the client could get. Therefore, the objective of this work is to develop and validate an improved mission solution configuration process that facilitates the efficient creation and selection of product variants/mission solutions, aligning them more effectively with the client's needs and operational requirements, particularly within the bidding phase at . The developed method combines Model-Based Systems Engineering (MBSE) and Tradespace Exploration (TSE). In the MBSE part, ARCADIA (ARChitecture Analysis and Design Integrated Approach) is used as the method and the language, and MELODY is the used tool. A descriptive model is created, which includes the relevant information to create an analytical model to be used during the TSE, where the Multi-Attribute-Utility-Theory (MAUT) and Pareto-Optimization were used in evaluating and selecting between the most optimal mission solution variants. The method was validated through a coast guard mission case study closely resembling a real scenario of 125 solution variants. The results revealed the Pareto-optimal solution variants achieved through optimization for overall performance versus total cost. We conclude that the proposed method enhances that current configuration process by harmonizing client and operational needs with 's sales and product teams, thereby ensuring accurate interpretation of operational requirements and mitigating the potential for information inconsistencies in creating and selecting the most optimal solution variants. Using the case study results to pinpoint technological gaps in the variant designs to channel their research and development efforts towards sub-systems or components that exhibit heightened competitiveness and wield substantial influence over the overall system's performance.

Key Reserve Paper#98

LLM-based Approach to Automatically Establish Traceability between Requirements and MBSE

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Keywords. Large Language Model (LLM);Requirement Engineering;MBSE;Semantic Web;Knowledge Graph

Topics. 1.1. Complexity; 3. Automotive; 5.11 Artificial Intelligence, Machine Learning; 5.12 Automation; 5.3. MBSE;

Abstract. Tracing requirements specification to design and implementation is an essential part of safety standards, as it allows to ensure that safety goals are met throughout the development process. Manual tracing numerous artifacts produced throughout the development process is error-prone and takes much time. To address these problems, we proposed a tool (Anonymous, 2023), which allows to establish links between requirements and Model-Based Systems Engineering (MBSE) in a semi-automatic way. The underlying algorithms of our tool are embedding similarity computation and classification approaches based on Large Language Models (LLMs). To assess the performance of underlying algorithm we propose an evaluation, where we compare the recall, the precision, and the F_2 score of different approaches applied to our datasets. The goal of our evaluation is to understand how well LLMs perform in automatically generating trace links on different datasets. Our evaluation shows that it is worth to invest time in preprocessing the data and fine-tuning the LLMs to achieve the better recommendations for engineers, which improved the traceability process.

Key Reserve Paper#360

LOGICAL ARCHITECTURE OPTIMIZATION METHOD FOR THE AEROSPACE DOMAIN

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Keywords. Architecture optimization;clustering algorithm;DSM;DAL

Topics. 16. Rail; 2. Aerospace; 2.4. System Architecture/Design Definition; 3. Automotive; 4.2. Life-Cycle Costing and/or Economic Evaluation; 8. Energy (renewable, nuclear, etc.);

Abstract. Due to the growing complexity of engineering systems, the need for an optimized decomposition and clustering of functions to achieve a better level of modularization is becoming fundamental in the economy of the Systems Engineering process. The Design Structure Matrix (DSM) has been frequently used as input for algorithms to optimize logical architecture. The objective is usually to create clusters of functions with a high level of interaction among them, while minimizing de-pendencies across modules. The method has been developed in the field of multi-agent systems control for the reformulation of a mixed integer linear program and adapted to the problem at hand. It does not require any prior knowledge of system structure (e.g. the number of clusters), and it is computationally less demanding than multi-run stochastic optimization algorithms. The aim is to discover the hidden block-diagonal structure with single or double border of the DSM, if any. The detection of borders in the hidden structure of the DSM corresponds to the detection of bus elements. The method reformulates a matrix manipulation problem into a graph partitioning problem, using Agglomerative Hierarchical Clustering to group together nodes with similar evo-lutions of probability distribution vectors. This paper shows how this method could be applied in the optimization of logical architecture for Systems Engineering activities and in the future ex-tended to include Design Assurance Level considerations as per ARP4754A guidelines.

Key Reserve Paper#285

MBSE Analysis and Update of the U.S. Infrastructure Data Taxonomy (IDT) Using the U.S. National Critical Functions (NCFs)

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Keywords. MBSE;Critical Infrastructure;Functional Analysis;National Critical Functions;Cybersecurity Infrastructure Security Agency

Topics. 1.1. Complexity; 2.4. System Architecture/Design Definition; 4.7. System Security (cyber-attack, anti-tamper, etc.); 5. City Planning (smart cities, urban planning, etc.); 5.3. MBSE; Other domain;

Abstract. In this paper, we will demonstrate the application of Model-Based Systems Engineering (MBSE) tools and techniques we have used to assist the US Department of Homeland Security (DHS) /Cybersecurity Infrastructure Security Agency (CISA) in analysis of open-source IDT data to analyze and contribute to the update of their 2011 Infrastructure Data Taxonomy (IDT). We will show how we have successfully used Functional Analysis and MBSE tools and methodologies to analyze the IDT alongside the DHS described National Critical Functions (NCFs), and recommend updates to the IDT, as well as potential updates to the NCFs themselves. Our future recommendations are to continue this effort as a team of INCOSE Critical Infrastructure Protection and Recovery (CIPR) team members along with other INCOSE Working Groups (WGs), and to explore other use cases based on this model data, as well as inviting others to assist as well. This effort demonstrated the use of these MBSE tools while working together with other organizations to contribute to the Critical Infrastructure (CI) space leveraging systems theory & thought leadership. We will also outline further avenues for exploration using this provided MBSE capability in multiple areas that could be useful to the DHS, and will discuss a potential longer-term engagement with DHS in an annual challenge, as well as multiple other projects to include collaborations with universities and other entities interested in this modeling of CI space, as well as model extensions to include, but not limited to a cybersecurity model Use Case, involving Industrial Control Systems (ICS), etc. We have shown how these tools are effective in the Water/Wastewater sector, but will also yield similar benefits when applied in other sectors as well (i.e., Transportation, Telecommunications, etc.).

Key Reserve Paper#493

MBSE for Real World Teams

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Keywords. MBSE barriers to adoption;SysML;Arcadia;Denso Create;Thales;Obeo;functional analysis

Topics. 16. Rail; 2.3. Needs and Requirements Definition; 2.4. System Architecture/Design Definition; 3. Automotive; 3.4. Information Management Process; 5.3. MBSE;

Abstract. With the release of the OMG Systems Modeling Language (Object Management Group, 2007) there was a surge of enthusiasm for model-based systems engineering (MBSE). Expectations were high. Cumbersome, fragmented documents would be completely replaced by coherent, fully integrated models. The models would serve as the “Single Version of the Truth” (later transitioning to models being part of the “Authoratative Source of Truth”). All concepts in the system design would be smoothly integrated into one or more master ontologies. Messy duplication of terms and incoherent relationships would be replaced with a perfect, abstract, fully coherent, hierarchy of concepts defined in the computer-parsable ontologies. Data and information would move effortlessly along the “digital thread”, system development would accelerate dramatically. Mistakes and misunderstandings would fade into a distant memory of a primitive past. While progress has been made, this utopian vision has largely failed to materialize. Certainly tool and language limitations have been a factor. However, the bigger factor in many communities has been human factors challenges. In our enthusiasm to propagate the MBSE vision, we forgot to perform the most basic systems engineering task: stakeholder analysis. This paper will introduce some of the basic human factors issues that were overlooked. The paper will then discuss three concrete cases in which a community was struggling with the abstract, radical change approach and how the teams involved have modified this approach and tooling to make it more practical and successful for those communities. Finally, the paper will conclude with some recommendations to consider when undertaking the introduction of MBSE methods in a new community.

Key Reserve Paper#359

MIGRATING TO ARP4754A: TAILORING OF ARCHITECTURE AND SYSTEMS REQUIREMENTS DEFINITION PROCESSES IN THE ROTORCRAFT INDUSTRY

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Keywords. ARP4754A;Requirements;Architecture;Tailoring;Rotorcrafts;Function Based Systems Engineering

Topics. 2. Aerospace; 2.3. Needs and Requirements Definition; 2.4. System Architecture/Design Definition; 3.5. Technical Leadership; 5.3. MBSE; 5.5. Processes;

Abstract. Rotorcrafts are very complex systems that require a huge systems engineering effort to design, implement and integrate. A successful aircraft design is a matter of good integration between engineering disciplines and suppliers just as much as it is about finding a good technical solution to the customers' expectations. This issue is well understood within the industry and competent authorities. Companies now face the challenge of transitioning from integrating complex systems to make an aircraft (as per ARP4754) to engineering and collating a complex aircraft system as per ARP4754A, a game changer in all respects. Leonardo Helicopters is tailoring its internal processes to reflect this change and challenge. While the ideal process can be defined today, the transition takes time and a significant change in culture and organization needs to take place. To support the transition, the authors have developed a hybrid rationale to the aircraft architecture and system requirements definition process. This new approach leverages existing expertise at system level to facilitate the integration between systems and the subsequent migration to bridge the gap with the aircraft engineering activities required by the ARP4754A.

Key Reserve Paper#472

Model-Based Architectural Patterns for Teaching Systems Engineering

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Keywords. model-based patterns;pattern language;pattern library;SysML patterns

Topics. 1. Academia (curricula, course life cycle, etc.); 2. Aerospace; 2.4. System Architecture/Design Definition; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 5.9. Teaching and Training;

Abstract. Systems Engineering may be one of the fastest evolving engineering disciplines today. With each new technology introduction, the practice of systems engineering is challenged to adapt in order to apply systems engineering to the new technology. Two such practices that have been appearing in university curricula are Model-Based Systems Engineering (MBSE) and systems engineering patterns. The combination of MBSE and patterns has proven to be a powerful construct. This paper looks at the use of a space-based patterns library (language) in a graduate level system engineering to teach MBSE.

Key Reserve Paper#427

Model-Based Cybertronics Systems Engineering (MBCSE)

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Keywords. MBSE;Cybertronics;MBCSE;Arcadia;Microelectronics;Embedded Software;System of Systems;Subsystem;SysML V2;SysMD;PMM

Topics. 2. Aerospace; 2.4. System Architecture/Design Definition; 3. Automotive; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. The cybertronics challenges evolved around the complexity of systems and increase in detail and data involved. Existing methods and tools are able to master some of the rising challenges, but a method being able to handle the challenges as a whole had not yet been introduced. MBSE is a potential approach to solve these problems, but the available methods were developed for modeling physical systems and software, not cybertronics. Because of the diversity of implementation domains participating in cybertronics systems, the modeling methodology must support the holistic management of requirements, properties and design data. This paper introduces some promising emerging technologies like Arcadia, SysML V2, SysMD and PMM, that have the potential to interact with other methods and tools, closing the gaps in requirements tracing, system modeling, documentation and verification. One potential methodology is introduced through a design example from requirements to implementation interface.

Key Reserve Paper#192

Model-Based Switching Costs

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Keywords. Switching cost;MBSE;Model-Based Systems Engineering

Topics. 2. Aerospace; 3.7. Project Planning, Project Assessment, and/or Project Control; 4.2. Life-Cycle Costing and/or Economic Evaluation; 6. Defense;

Abstract. In product development, rarely a product is developed from scratch. In most cases, a product is developed from a prior design or several prior designs. The associated development cost is actually a switching cost (or some called reuse cost), representing the additional cost on developing the product from prior designs. Prior works in this area were developed without considering the MBSE (Model-Based Systems Engineering). Today, MBSE is being widely adopted. It is important to develop switching cost development methods that leverage models and support model-based development needs. This paper, for the first time per the best of our knowledge, discusses switching cost development method for MBSE. Our work identifies different use case scenarios/phases in an MBSE development cycle, and provides corresponding switching cost estimation methods, to support various certification needs, laying down the fundamental methodology for the model-based switching cost estimations. Using SysML language, an example use case of derivative airplane electrical power system is used to demonstrate the effectiveness of our methods.

Key Reserve Paper#534

Model-Based Systems Engineering Approach for Designing an Artificial Magnetic Field Generator System for Spacecraft Radiation Protection

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Keywords. Model Based Engineering;Artificial Magnetic Field;Spacecraft Radiation Protection;System Design

Topics. 2. Aerospace; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis;

Abstract. The hazardous environment of space, dominated by cosmic and solar radiation, poses a significant threat to spacecraft and their occupants. Traditional radiation shielding methods, like passive materials, have limitations in weight and effectiveness. An artificial magnetic field generator system emerges as a promising solution to replicate Earth's magnetosphere, providing a protective magnetic shield against harmful radiation. This paper presents a Model-Based Systems Engineering (MBSE) approach to the holistic modeling and design of such a system. Utilizing the MBSE approach, this study models the system's components, their interactions, and the offered services, incorporating Radiation Monitoring, Magnetic Shielding, Power Management, System Health & Diagnostics, and Crew Communication services. The conceptual data model captures key entities and their relationships, ensuring a coherent integration of the system's parts. The activity diagram illustrates the operational flow, providing clarity on the system's dynamic behavior under varying radiation conditions and power reserves. A services taxonomy is developed to hierarchically categorize and ensure the comprehensive functionality of the system.The application of MBSE methodology provides numerous advantages, including a unified visualization of the system's complexities, enhanced stakeholder communication, and a streamlined validation and verification process. Furthermore, the flexibility inherent in the MBSE approach ensures that the system can be easily updated or scaled based on advancements in technology or changing mission requirements. The MBSE approach's application to the design of an artificial magnetic field generator system for spacecraft presents a robust and systematic method to ensure optimal performance, safety, and adaptability in the perilous realm of space.

Key Reserve Paper#565

Modeling Enterprise Software with UAF

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Keywords. Enterprise Architecture;Software;UAF;MBSE;Frameworks;SysML

Topics. 17. Sustainment (legacy systems, re-engineering, etc.); 2.2. Manufacturing Systems and Operational Aspects; 20. Industry 4.0 & Society 5.0; 5.3. MBSE; 5.7. Software-Intensive Systems; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Systems and Software Engineers often have an uneasy relationship. The job of the systems engineer is to work with the stakeholders to define a set of requirements that meet their needs. These are then allocated to various solution spaces such as electronic hardware, mechanical, procedural, and software among others. For many systems, the functional requirements are almost exclusively software requirements. Correspondingly, as an increasing amount of project manpower, schedule time, and budget are allocated to software, it becomes increasingly important that systems and software engineers communicate effectively. The Systems Modeling Language (SysML) has helped in this regard in that it can provide executable behavioral models with precise semantics to express software requirements in a model. These models define “What is required” without overly constraining the implementation.. In addition, SysML can be used to define performance constraints, required concurrency, hardware memory and processor budgets, interfaces, safety critical requirements, etc. These aspects are essential for software engineers to understand the constraints and limitations of their environment. At the System of Systems (SoS)/Enterprise level, defining software/systems employs a similar pattern, but at a higher level of abstraction. In the Unified Architecture Framework, capabilities are defined for the enterprise, with systems and software allocated to realize the capabilities. In the same way that capabilities depend on one another, the implementing systems and software interact to support each other. In the past, enterprise software would be modeled as residing in mainframes in a federated software pattern. Modern software can be modeled throughout the enterprise in a distributed network that can adapt to the changing needs of the enterprise to do load leveling, dynamic and late binding, reconfiguration, and reallocation of hardware resources as necessary. If the domain includes the Industrial Internet of Things (IIOT), then deployment could include edge devices, embedded software, Programmable Logic Controllers (PLC), PCs, servers, cloud computing, and of course main-frames. The Object management Group (OMG) Data Distribution Services (DDS) standard enables these capabilities across these devices in a universal format implemented by multiple vendors. However, before this complex system of systems can be implemented, it must first be architected and designed to ensure that it will be fit for purpose both now and as the complex system of systems expands. This paper will examine the aspects of modeling software in the UAF, and how it can help guide enterprise and system and software architecture.

Key Reserve Paper#49

Models Models Everywhere! A practitioners view on the reality of modeling

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Keywords. Model Based Systems Engineering;Modeling;Simulation;Digital Engineering;Practice

Topics. 3.3. Decision Analysis and/or Decision Management; 3.5. Technical Leadership; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis;

Abstract. This paper addresses three of the most common real-world challenges to modeling. The INCOSE Vision 2035 correctly states that the future of SE is Digital and Model Based. Achieving this requires significant development of the state of the art in Digital Engineering and Modeling. The focus of this paper is, however, the significant gap between the current potential of today's models and the actual practice. Based on over 80 years of industrial experience, the authors describe problems that plague poor modeling. The paper: describes the different types of models and their uses; provides a high-level generic model development approach; and addresses some of the real-world challenges that modelers and their managers need to address.

Key Reserve Paper#557

OMG Standard to Extend SysML to Reliability Block Diagrams

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Keywords. SysML;Reliability;RAAML;Reliability Block Diagrams;MBSE

Topics. 2. Aerospace; 3. Automotive; 4.3. Reliability, Availability, and/or Maintainability; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. This paper describes a Reliability Block Diagram (RBD) Library that has been added to the Risk Analysis and Assessment Modeling Language (RAAML) version 1.1, the Object Management Group (OMG) standard for safety and reliability extensions for SysML. A discussion of relevant reliability concepts is provided followed by a description of the RBD library. An demonstration of the library using an example system is described, followed by plans for further reliability enhancements in future versions of RAAML.

Key Reserve Paper#555

One model to rule them all and through emergence bind them

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Keywords. Systems Models;Systems Thinking;Iceberg Model;MBSE;Engineering of Systems;Model of Systems Model

Topics. 1. Academia (curricula, course life cycle, etc.); 1.5. Systems Science; 1.6. Systems Thinking; 5.3. MBSE; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Models are central to understanding Systems and to the Engineering of Systems. Systems Engineers employ various types of models, such as conceptual, functional and physical models of a system to communicate shared understanding, through systems life-cycle models that enables the transformation of the functional to physical models, that are then realized in tangible systems of benefit to society. The recognition of the central nature of models to the engineering of systems resulted in the coining of the term Model Based Systems Engineering (MBSE), in contrast to traditional document-based approaches. However, the identification of model-types employed, both to understand and to engineer systems, appears to largely have been an emergent bottom-up construct. This paper briefly examines the extant approaches to understanding systems models and considers the question of whether there is a suitable top-down “meta-model” perspective that naturally “contains” all types of systems models. It explores this question, building on the metaphor of the Iceberg, as a reference systems model architecture, in conjunction and comparatively with concepts on mental models from biology and philosophy, and a proposition that all (systems) models may take on two-forms, to propose a possible evolutionary, binding, emergent “model of systems models” for consideration and refinement by the Systems community.

Key Reserve Paper#354

Outcomes and Perspectives from a Model-Based Space Systems Engineering Workshop on reducing the gap between model-based systems engineering and domain-specific approaches.

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Keywords. Model-Based Systems Engineering;Space Systems;System Architecture;Inter-domain Data Exchange;SysML v2;Artificial Intelligence;Digital Engineering;Model-Driven Engineering;World Café;Workshop;Facilitation;Creativity

Topics. 1.6. Systems Thinking; 2. Aerospace; 2.4. System Architecture/Design Definition; 5.3. MBSE;

Abstract. In the context of its initiative to promote the adoption of model-based approaches in the development of present and upcoming missions, our organization held this year a workshop on Model-Based Space Systems Engineering. The aim of this year's workshop was to investigate how the model-based systems engineering community could contribute to bridging the gap with do-main-specific model-based approaches used in subsystem design. The World Café Method was used to facilitate the group discussions, the outcomes of which are summarized and presented in this paper.

Key Reserve Paper#419

Process as a System I: Evaluating Automotive SPICE® as Process Requirements

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Keywords. Automotive;Standard;Automotive Spice;ASPICE;Systems engineering;Requirement;Process

Topics. 1.6. Systems Thinking; 2.1. Business or Mission Analysis; 2.3. Needs and Requirements Definition; 3. Automotive; 5.5. Processes;

Abstract. Software and Systems engineering projects in the Automotive industry are often mandated to develop according to the Automotive SPICE® standard. Despite a highly qualified workforce, many projects or organizations fail to implement compliant processes. This paper reinterprets the Automotive SPICE® standard, viewing its base practices as process requirements. Using a set of derived quality criteria for requirements, the subsequent evaluation of base practices for quality results in an aggregate and individual analysis of the ASPICE base practices. The analyses reveal, amongst others, deficiencies in the aspects of atomicity, detail, unambiguity, and origin. The paper proposes a public, collaborative effort to enrich the requirements with purpose, detail and structure.

Key Reserve Paper#251

Requirement Discovery Using Embedded Knowledge Graph with ChatGPT

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Keywords. Large Language Models;OpenAI;ChatGPT;Urban Airspace Mobility;Requirements;Advance Air Mobility;Digital Assistant;Machine Learning;Artificial Intelligence;Graph Database;Link Prediction

Topics. 2. Aerospace; 2.3. Needs and Requirements Definition; 21. Urban Transportation Systems; 5.11 Artificial Intelligence, Machine Learning; 5.12 Automation; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The field of Advanced Air Mobility (AAM) is witnessing a transformation with innovations such as electric aircraft and increasingly automated airspace operations. Within AAM, the Urban Air Mobility (UAM) concept focuses on providing air-taxi services in densely populated urban areas. This research introduces the utilization of Large Language Models (LLMs), such as OpenAI's GPT-4, to enhance the UAM Requirement discovery process. LLMs are deep neural networks trained on vast datasets from a wide variety of sources, capable of generating human-like text in response to input prompts. These models have proven to be powerful tools in various natural language processing (NLP) tasks. As rapid innovation of these models continues, it is becoming possible to apply LLMs to use cases outside those associated with traditional NLP tasks.This study explores two distinct approaches to leverage LLMs in the context of UAM Requirement discovery. The first approach evaluates the LLM's ability to provide responses without relying on additional outside systems, such as a relational or graph database. Instead, a vector store provides relevant information to the LLM based on the user’s question, a process known as Retrieval Augmented Generation (RAG). The second approach integrates the LLM with a Neo4j graph database. The LLM acts as an intermediary between the user and the database, translating user questions into cypher queries for the database and database responses into human-readable answers for the user. Our team implemented and tested both solutions to analyze requirements within a UAM dataset. This paper will talk about our approaches, implementations, and findings related to both approaches.Future goals include expanding the scope of our system to encompass all nodes and links within the knowledge graph ontology and potentially utilizing a hybrid approach combining several databases and vector stores. Additionally, the feasibility of deploying open-source models is being explored for use cases beyond UAM Research.

Key Reserve Paper#26

Requirements Digitalization Cost Analysis Leveraging Machine Learning

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Keywords. Digital Transformation;Requirements Engineering;Machine Learning;Cost Analysis

Topics. 3.6. Measurement and Metrics; 3.7. Project Planning, Project Assessment, and/or Project Control; 5.11 Artificial Intelligence, Machine Learning;

Abstract. A requirements digital transformation project is a significant endeavor that involves changing business operations, engineering life cycle processes, vendor interfaces, contracts, standards conformance, as well as IT infrastructure among others. A project of this magnitude includes a many unknowns and significant uncertainty involving the extent and scope, software tools, number of engineering documents, type of documents, document quality, and length of documents. Understanding time to completion and level of effort required is essential to organizations planning these initiatives. The challenge the authors were faced with was to be able to accurately predict the number of systems engineers and subject matter experts that would be required over the course of the project. We developed a methodology to automatically extract key data from hundreds of documents and process the parameters through our machine learning model to provide insight into complexity and scope of the project. The model results provide valuable prediction of the short and long-term schedule and resource needs on a set of requirements across a discipline.

Key Reserve Paper#508

Risk and Systems Analysis for Renewable Power Generation with Environmental and Other Stressors

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Keywords. Risk management;Scenario identification;Infrastructure resilience;Climate change;Water scarcity;Sustainability

Topics. 1.5. Systems Science; 10. Environmental Systems & Sustainability; 12. Infrastructure (construction, maintenance, etc.); 3.9. Risk and Opportunity Management; 4.4. Resilience; 8. Energy (renewable, nuclear, etc.);

Abstract. The effects of climate change and water scarcity threaten the stability and resilience of critical infra-structure systems in developing regions. In particular, the interconnectedness of energy systems, natural resources, economic growth, and social welfare requires a systems-level framework to adequately address scenarios which compromise system functionality. This paper evaluates and quantifies infrastructure system risk, defined as the influence of scenarios on system priorities. A scenario-based multi-criteria preferences model assesses system component priorities for a baseline scenario and other climate and related scenarios. The methods are demonstrated for the case of the emerging renewable energy sector of Iraq. Twenty-five renewable energy system assets are prioritized by an assessment of system success criteria, which include economic, social, political, and climate considerations. The system prioritization is reevaluated in the case of each disruptive scenario, identifying the scenarios which most affect system order. This paper advances methods of the Systems Engineering Body of Knowledge (SEBoK) Part 3: Engineering and Management, by defining system risk and proposing methods for risk identification and risk analysis.

Key Reserve Paper#144

Risk Management in Project Planning for Life Science R&D: An Integration of the NTCP Framework

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Keywords. Risk Management;Project Planning;NTCP;Life Science

Topics. 3.7. Project Planning, Project Assessment, and/or Project Control; 3.9. Risk and Opportunity Management; 4. Biomed/Healthcare/Social Services;

Abstract. As with most other industries, the early life science R&D drug discovery sector is facing cost-pressure and increasingly higher demands to the products in terms of cost, quality, and time-to-market. Addi-tionally, the complexity of involved targets and systems, requirements for rapid, safe, and developable candidates are increasing. The drug discovery market, often regarded as rather conservative, relies more and more on advanced technologies. It is therefore a significant task for suppliers to create good solu-tions that meet customer requirements. The life science industry has a long tradition of using projects as the preferred method to manage these complex systems developments, such as the production of target proteins, screening of compounds, and follow up of hit compounds. When applying the project ap-proach, the level of uncertainty is usually high, and the risk of those uncertainties must be managed starting in the early planning phase. Thus, this paper focuses on the issue how to manage risks in the early project planning phase. We firstly review state of the art practices in risk management for complex systems project management, and identify an important framework, NTCP, and apply it to successful risk management for early life science projects. Through an in-depth case study in the life science in-dustry, we further demonstrate a systemic integration of the NTPC framework into project planning.

Key Reserve Paper#185

Role-Based Structuring of Systems Engineering Teams

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Keywords. Structuring;Organizing;SE Roles;Teams;Growth;Management;Leadership

Topics. 3.5. Technical Leadership; 5.5. Processes; 5.9. Teaching and Training;

Abstract. There is little documented information on how Systems Engineering (SE) teams are structured with respect to the various SE subdisciplines. This paper provides five possible role-based structures to aid in filling this knowledge gap and in helping projects structure their own SE teams for success. The five structures range from a simple, single-role structure to an advanced embedded SE with lead. The paper defines, illustrates, and presents key advantages and disadvantages for the structures. It also presents two real-world examples to show the value of organizing or reorganizing SE teams to these structures. One focuses on large-sized and complex waterfall project with a separate SE team restructuring for efficiency and growth opportunities and the other focuses on a medium-sized and complex Agile project where the SE team restructures for better design definition and schedule efficiencies. Both show how a restructuring helped improve the overall quality of work, the integration with others in the project, and the overall understanding of the systems.

Key Reserve Paper#59

Security Interpretations and Elaborations on Systems Engineering Principles

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Keywords. systems engineering principles;security;system security;systems security;cybersecurity;resilience;safety

Topics. 1.5. Systems Science; 4.7. System Security (cyber-attack, anti-tamper, etc.); 5.9. Teaching and Training;

Abstract. INCOSE's Systems Engineering Vision 2035 includes thirty-one mentions of security as part of the vision, including security to become as foundational perspective to system design as performance and safety. INCOSE's Systems Engineering Principles technical product published a "first set of systems principles" (Watson, et al., 2022). This paper examines interpretations of these principles for security as captured in the vision and suggests modifications and possible additional principles to see security more integrated into the systems engineering process.

Key Reserve Paper#550

SoS - Global Solutions to Global Problems Using UAF

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Keywords. System of Systems(SoS);Unified Architecture Framework (UAF);Model-Based Systems Engineering (MBSE);Circular Economy;Global Environmental Sustainment;Socio-economic Sustainment

Topics. 10. Environmental Systems & Sustainability; 17. Sustainment (legacy systems, re-engineering, etc.); 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. This paper applies Unified Architecture Framework (UAF) to a case study which defines the global copper market as an enterprise comprising a diverse set of stakeholders and independently operating businesses and industries, with the goal to understand how they might evaluate, execute, or modify their behaviors in response to the diminishing global copper supply. Specifically, we sought to determine if the framework viewpoints, modeling language, and workflow guidance provided in the UAF specification could support the analysis. In a true System of Systems(SoS), the solution (or any improvement) relies on the cooperation of a multitude of independent and unrelated businesses and industries. Several viewpoints of UAF were evaluated to model the SoS, which reveal how certain entities may be motivated to implement solutions, and how those decisions may impact others within the SoS. We also provide observations from the analysis which may serve to improve the utility of UAF in other applications.

Key Reserve Paper#97

Systems Architecture Meta-Model for the MagicGrid Framework

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Keywords. MBSE;SysML;MagicGrid;meta-model;MBSE enablers

Topics. 2. Aerospace; 2.3. Needs and Requirements Definition; 2.4. System Architecture/Design Definition; 3. Automotive; 5.3. MBSE; 6. Defense;

Abstract. Although Model-Based Systems Engineering (MBSE) might be understood and applied across diverse communities and industries differently, its fundamental principles and practices de- scribed in INCOSE Systems Engineering Handbook, are common. It is known that successful applica- tion of MBSE is impossible without a tool, language, and method as well as harmony among these three. The de-facto standard modeling language for MBSE is Systems Modeling Language (SysML). However, SysML is only a language, and it is not aligned with terminology systems engineers use daily in their work. This paper studies SysML as the standard language to model systems, and MagicGrid as the framework to bridge the gap between Systems Engineering (SE) terminology described in the INCOSE Systems Engineering Handbook and SysML specification. It proposes a new systems engi- neering meta-model to describe a common SE terminology and bind it to the SysML concepts.

Key Reserve Paper#483

Systems Perspective Outcomes from Aerospace Failure Investigations

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Keywords. Complexity;Systems Thinking;Systems Perspectives;Aerospace;Collaboration;Failure Case Studies

Topics. 1.1. Complexity; 1.6. Systems Thinking; 2. Aerospace; 5.1. Agile Systems Engineering;

Abstract. Many tools are available for managing complexity in the development of large aerospace systems. Complexity manifests in components, software and so many possible human interactions that all of the operational states of the system can't be predicted ahead of time. In other words, system behaviors are seemingly unexpected, unpredictable, and often unwanted. However, finding these failure modes before they happen can be done in a variety of ways. These techniques can be qualitative, quantitative, or mixed methods, and all can be used situationally, as needed for each particular circumstance. Through studies of failure investigations from NASA and the aerospace industry, recommendations coalesce on using a systems perspective to increase communication and reduce the risk of failure. Overall, a consistent outcome of these investigations is the suggestion to listen to as many value-added perspectives as possible. Preventing failures in operation is managed by improving collaboration within and among teams, which is an effective way to reveal those perspectives, through both formal and informal communication techniques.

Key Reserve Paper#41

Tactical Network Bandwidth Analysis: Application of the Wearables Model-Based Systems Engineering - System Architecture (MBSE-SA)

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Keywords. Model-based systems engineering (MBSE);network bandwidth analysis;wearable sensor systems

Topics. 1.6. Systems Thinking; 4. Biomed/Healthcare/Social Services; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. Warfighters are often exposed to harsh environmental conditions, and experience high rates of physical and cognitive stress, fatigue, and infections, resulting in the degradation of their health and physical performance. This degradation can have a profound effect on the readiness of military forces. Wearable sensor systems can be used to monitor warfighter physiological and cognitive data, providing insight into their health status during routine military training and deployed operations; however, to enable a real-time, tactical health and performance monitoring capability, wearable sensor systems must integrate into existing tactical military information networks without compromising network function. We extended our existing Wearables Model-Based System Engineering – System Architecture (MBSE-SA) to include a bandwidth simulation to analyze the effects wearable sensor systems have on overall network function specifically for military use cases. Our Wearables MBSE-SA enabled us to model many notional and existing architectures, which represent the wide range of wearable sensor devices, communication protocols, end user devices, and tactical network nodes typically present in operational environments. By taking advantage of the existing Wearables MBSE-SA framework and architectures, the resulting bandwidth simulation rapidly assessed several existing military network architectures for wearable sensor system integration and identified where network changes were required. Validating the flexibility of the Wearables MBSE-SA to incorporate new analyses was critical for the military's ability to explore wearable sensor system trades and evaluate architectures in the quickly changing wearable systems technology domain.

Key Reserve Paper#484

The Digital Engineering Factory: Considerations, Current Status, and Lessons Learned

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Keywords. model-based systems engineering;digital engineering;digital thread;education;semantic web technologies

Topics. 1. Academia (curricula, course life cycle, etc.); 3.4. Information Management Process; 5.3. MBSE; 5.9. Teaching and Training; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. In industry, the advancement of digital engineering and the digital thread aims to reduce the impact of knowledge 'siloes' by providing a way to integrate data across the entire system lifecycle and across multiple domains. In a typical engineering curriculum, however, courses are still treated as 'siloes', and students often do not have the opportunity to experience this industrially relevant approach to engineering. The Digital Engineering Factory (DEF) is a digital engineering environment under development at the University of XXXXX to support engineering students. The DEF supports students by providing access to multiple engineering tools and is structured using a 'hub-and-spoke' approach to consolidate data from these tools. Through this connected architecture, students can transfer data generated in a particular course to tools for use in other courses. Connecting course activities in this way enables students to experience a complete end-to-end system lifecycle. At its 'hub', the DEF uses Violet to integrate data from multiple sources, create a digital thread, and generate a graph representation of the dataset. This knowledge graph, written in the Ontological Modeling Language (OML), can be viewed in OML Rosetta and is structured according to the University of XXXXX Ontology Stack (UXOS). The use of the UXOS and OML Rosetta allows instructors to leverage semantic web technologies to support teaching activities such as grading. In this paper, the authors review the objectives of the DEF, discuss the status of the project, and highlight current limitations and lessons learned with regards to its deployment. These may be useful to inform similar developments in industrial settings.

Key Reserve Paper#57

The Electric Revolution: Fully Electric Transportation System On An Urban College Campus

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Keywords. electric;transportation;college;campus;implementation;systemigram

Topics. 1.6. Systems Thinking; 10. Environmental Systems & Sustainability; 21. Urban Transportation Systems; 4.6. System Safety; 5. City Planning (smart cities, urban planning, etc.);

Abstract. Abstract— This paper offers a comprehensive exploration of the implementation of fully electric transportation systems within urban college campuses. Urbanization and environmental concerns have intensified the need for sustainable transportation solutions, and college campuses serve as ideal testbeds for innovative mobility initiatives. The paper begins by establishing the context through background research, which highlights the adverse effects of urban air pollution and the role of electric vehicles (EVs) in mitigating these issues. The driving forces behind the adoption of fully electric transportation systems are discussed, Benefits, challenges, and implications of implementing electric transportation systems are meticulously examined. The anticipated benefits encompass improvements in air and noise pollution, reduced operational costs, and enhanced campus reputation. Nevertheless, the challenges of infrastructure costs, charging management, and operational intricacies are acknowledged. The paper underscores that successful implementation goes beyond immediate advantages, positioning campus electric transportation systems as living laboratories for research and innovation in sustainable mobility. Additionally, these systems serve as models for neighboring communities and influence regional transportation policies.The paper concludes by laying the groundwork for forthcoming discussions. It highlights the subsequent sections' focus on planning, stakeholder engagement, technological integration, and operational management, which collectively shape the implementation. The paper will employ the application of Systems Thinking approaches, tools, and techniques in order to properly analyze and tackle the problem statement at hand.

Key Reserve Paper#310

The Organization MBSE Methodology

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Keywords. MBSE;methodology;space

Topics. 2. Aerospace; 5.3. MBSE;

Abstract. The Organization (organization name removed for double-blind review process) has been developing an MBSE Methodology to address the increased digitalization of systems engineering and facilitate the complex system development in European space projects. The methodology is based on the European Cooperation for Space Standardization (ECSS) standards for Systems Engineering, and feedback from projects using the methodology. By using the ECSS standards as the starting point, the processes, terminology and expected outputs are familiar to the engineers, lowering the usage barrier within the Organization. This paper describes the background of and effort for establishing the MBSE methodology and a description of the methodology. The paper also reports on the current efforts at the Organization for deploying MBSE and the way forward regarding the methodology.

Key Reserve Paper#348

Towards UAF Implementation in SysML V2

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Keywords. MBSE;UAF;SysML;SysMLV2;Enterprise Systems Engineering

Topics. 5.3. MBSE; 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.); 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. The ongoing transformation in the industry from a document-based systems engineering to a model-based systems engineering appro¬ach reveals gaps in existing modeling standards. Evolution of standards is inevitable. A de facto standard modeling language, SysML (Systems Modeling Language), is undergoing a major transformation in its evolution, with the introduction of SysML version 2, which is a complete redesign of the language architecture. With the major update of SysML, all related standards need to be redesigned. The Unified Architecture Framework (UAF) is not an exception. UAF version 2 is a future version of the standard to be based on SysML V2. Currently, the development of UAF based on SysML V2 is in the very early stages, and various organizations involved in its development are independently researching the way forward. This paper describes one of the research projects to test the feasibility of SysML V2 to address UAF community needs.

Key Reserve Paper#176

Translating the STPA-Sec security method into a model-based engineering approach

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Keywords. STPA-Sec;Systems engineering;Cybersecurity;Metamodel;Model-driven engineering

Topics. 22. Social/Sociotechnical and Economic Systems; 4.7. System Security (cyber-attack, anti-tamper, etc.); 5.4. Modeling/Simulation/Analysis; 6. Defense; Other domain;

Abstract. In today's interconnected digital ecosystem, protecting cyber-physical systems is critical. STPA-Sec is a systematic method that allows to analyze system designs and identify vulnerabilities in those designs from the onset and throughout the system lifecycle. In this article, we describe a carefully designed metamodel that accommodates the concepts and steps of the method. We translate key concepts from STPA-Sec into a metamodel, with the intention of facilitating a more structured and disciplined application of STPA-Sec. We demonstrate the advantage of using the metamodel in two case studies.

Key Reserve Paper#432

Truly Modular and Open System Design is Difficult

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Keywords. MOSA;modularity;open systems;Littoral Combat Ship;blade servers;Carrier Grade Linux

Topics. 11. Information Technology/Telecommunication; 2.3. Needs and Requirements Definition; 2.4. System Architecture/Design Definition; 4.2. Life-Cycle Costing and/or Economic Evaluation; 6. Defense;

Abstract. In the United States, major defense acquisition programs must implement a modular open systems approach (MOSA) as required by U.S. law. (Defense Standardization Program, 2016). Some in the defense community have focused on MOSA as a checklist compliance activity. However, designing economically and operationally competitive system platforms that are truly modular is extremely challenging. Many such modular system platform efforts fail to meet early expectations for convenience, cost, and community uptake. Open standards are challenging as well. If a highly successful, stable, well-documented, appropriate open standard is available for an interface, then leveraging such a standard can be fairly straightforward. However, often there is no obvious or adequate open standard available and the system platform owners have to organize a community to bring such a standard into existence. This paper will review three concrete examples of such MOSA efforts. The three cases cover both commercial and defense applications as well as covering both hardware and software. The two systems that focused on hardware modularity did eventually go into production but did not completely fulfill early expectations for their programs. The software system used an out-of-the-box approach and achieved a best-in-class result in terms of economic effectiveness, time to market, and stakeholder satisfaction. This paper will discuss underlying challenges that seem to be common to all such efforts, review the results of the three cases, and offer some simple guidelines for increasing the probability of success for such a program.

Key Reserve Paper#102

Unlocking Synergy: Leveraging SysML and Modelica with Bi-Directional Transformation and Simulation Integration Standards

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Keywords. SysML;Modelica;Integration;Model Transformation;Modelica Command;Simulation

Topics. 2.4. System Architecture/Design Definition; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis;

Abstract. Both the SysML and Modelica standards are used in the field of Systems Engineering (SE) to model systems from different perspectives, on different abstraction levels. SysML is strong when modeling systems on the functional level; also, because it provides different views. With the capabilities of other simulation specifications, the engineers can simulate the system architecture. On the other hand, an open standard, such as Modelica is a key enabler for representing multi-physical systems described by differential, algebraic, and discrete equations. With the symbolic manipulation, the dynamics of the systems are represented in state space form and solved by the numerical integration methods fixed or variable step. However, it is clear that the connection between systems engineering and system simulation, with their respective domain knowledge of the actual equipment in their system, is missing. By seeing these complementary values, the authors demonstrate both languages' interaction to integrate SysML and Modelica to achieve complimentary values through bi-directional transformation and simulation.

Key Reserve Paper#544

Validation Framework of a Digital Twin: A System Identification Approach

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Keywords. System Validation;AI-enabled systems;Model;Digital Twins;System Identification

Topics. 2.6. Verification/Validation; 20. Industry 4.0 & Society 5.0; 5.11 Artificial Intelligence, Machine Learning; 5.4. Modeling/Simulation/Analysis; 8. Energy (renewable, nuclear, etc.)

Abstract. The constant improvement and developments in Artificial Intelligence/Machine learning models coupled with increased computing power have led to the incorporation of AI/ML for simulating learning and problem-solving in simple and complex engineering systems. However, the advent of AI/ML-enabled systems possesses latent uncertainty and unpredictable characteristics compared to traditional systems. This reality challenges engineers and industry stakeholders who care about ensuring the right AI-enabled systems are built (system validation). Digital Twins is an excellent example of such AI-enabled systems whose system validation has not been well-researched. This study delves into existing research and frameworks for validating Digital Twins and proposes a novel model-centric validation framework based on system identification techniques. Since Digital Twins are data-centric, system identification offers an intuitive approach to uncovering the system dynamics of physical assets' data, which Digital Twins aim to replicate, monitor, and update for structural health monitoring and control, which can further help validate Digital Twins. As a case study, we apply this model-centric validation framework towards partially validating a Digital Twin for a single-heat-pipe test article in a Microreactor Agile Non-nuclear Experimental Testbed demonstrated at a national laboratory last year. The system identification method helped identify the best mathematical process model that best represents the dynamics of the heat pipe and provides a pathway towards improving future digital twin ML prediction capabilities with a promise of finally validating future ML forecast datasets for this heat pipe on the identified process model to complete the system validation process. The outcomes of this study will help improve trust and system-level assertion for Digital Twins in practice towards sustaining the operational health of physical assets for various industry applications.

Panels

Panel#397

Building Cultural Intelligence: The Role of Organizational Culture in Nurturing Leaders in Systems Engineering

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Keywords. Nurturing Leaders;Cultural Intelligence;Systems Engineering Leadership;DEI

Topics. 3.5. Technical Leadership; 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.); 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. In the dynamic field of systems engineering, fostering an inclusive and supportive organizational culture is critical for unlocking the full potential of systems engineers’ role. This panel discussion will delve into the intricate relationship between organizational culture and the success of leaders in systems engineering. The panel will explore the challenges faced in technical leadership roles, examine the impact of organizational culture on their professional journeys, and provide actionable strategies for creating a more supportive and inclusive workplace environment. The key discussion points would include understanding the current landscape, the crucial role of organizational culture, success stories of fostered inclusive cultures in systems engineering and insights into how evolving technologies and industry dynamics may shape the future of inclusivity.

Biography

Stueti Gupta (BlueKei Solutions Pvt Ltd) - stueti.gupta@gmail.com

Stueti Gupta is the co-founder and director at BlueKei Solutions, and provides consultancy and customized training services for Enterprises and Startups looking for integrated digital engineering solutioning to solve engineering problems, embrace emerging technologies and achieve operational excellence. Over her 15+ years’ experience in industry and academia she has led SE research projects and co-led SE competency development, largely around MBSE and system dynamics modeling. Stueti has a Mechanical Engineering degree from BITS Pilani, India, a second masters from Cornell University, USA. and a certificate in Systems Design and Management from MIT, USA. She is actively involved in INCOSE.

Position Paper

Stueti Gupta is honored to serve as the moderator for this insightful panel on Building Cultural Intelligence within the realm of Systems Engineering Leadership. In today's interconnected and diverse global landscape, the significance of cultural intelligence cannot be overstated. As we explore the vital role of organizational culture in shaping leaders in systems engineering, my aim is to facilitate a dynamic and enriching discussion that delves into the intersection of cultural intelligence and effective Systems Engineering leadership. Even Department of Defence emphasizes Transform the culture and workforce to adopt and support digital engineering across the lifecycle as one of its five strategic goals for digital engineering.

We will address points such as:
The symbiotic relationship between organizational culture and effective leadership in systems engineering.
What strategies can leaders employ to foster cultural intelligence among their teams?
How can organizations create a culture that embraces diversity and inclusion in systems engineering?
The role of communication and collaboration in fostering a culturally intelligent systems engineering environment.

Alice Squires (International Council on Systems Engineering) - alice.squires@incose.net

Dr. Alice Squires has served as author, editor, manager, Professor, and systems engineer with 40 years of combined experience in industry and academia. She has served as keynote speaker, delivered workshops, and participated in peer-reviewed panels and paper presentations for the past two decades. She is Founder of the INCOSE Empowering Women Leaders in Systems Engineering (EWLSE) and is an INCOSE Expert Systems Engineering Practitioner with Acquisition (ESEP-ACQ). She wrote an ebook for IEEE-USA that describes her engineering journey: Dandelion Wishes: A World Where We Collaborate as Equals (Book 21) (2018). She is co-editor and co-author of the 2019 INCOSE Insight Diversity in Systems Engineering themed edition, the 2022 INCOSE published Letters To My Younger Self: How Systems Engineering Changed My Life ebook and the 2022 Springer Emerging Trends in Systems Engineering Leadership: Practical Research from Women Leaders book written by 26 women from around the world.

Position Paper

An organization’s culture often starts at the top. To understand how the organizational culture nurtures members to become organizational leaders, one first must understand how the culture prevents members from becoming leaders. That is, what is it about the organization’s culture that creates obstacles and challenges for a member to achieve their full potential? And for whom? Several years ago, I was running a workshop on enablers and inhibitors for leadership in one’s organization, and as the group discussions started, I heard one young woman share with her group: “They are all inhibitors.” Organizations interested in establishing cultures that allow a diverse set of members to progress into leadership positions, need to take a hard look at the impact of the established culture. Is mentoring encouraged, supported, and rewarded? Do the team’s norms include communication equity and psychological safety? To what extent does the culture promote hiring members that represent diverse demographics? How does the organization’s promotion process ensure an unbiased performance appraisal? In what ways does leadership require open and transparent communications? And finally, how do the organization’s policies enable the creation of an inclusive and diverse leadership culture?

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Anabel Fraga is a Systems Engineer & Computer Science professional. She obtained her Master's Degree in E-Commerce and Networks and her Diploma in Advanced Studies at Carlos III University in Madrid (UC3M). She researches at the Knowledge Reuse Group. She is an Associate Tenured Professor at UC3M, the Treasurer, and President of the Spanish Association of Systems Engineering (AEIS). She is EWLSE and DEI EMEA representative, EMEA Events representative, and Cohort 6 inducted member of the INCOSE Technical Leadership Institute. She coordinates the financial management activities of the Knowledge Reuse research group. Certified in ITIL, ININ, ISO20000, and ISO15288. She has several publications in knowledge management, systems engineering, requirements engineering, software engineering, and ethics; two patents in exploitation; and she led several projects, including two EU research projects. She was the recipient of the SWE Distinguished Educator Engineering Award 2023.

Position Paper

As I stated in a publication related to this topic, keeping in mind that a leader shall grow and provide the team with an environment appropriate to develop their best, guidance, influence, inspiration, and mentoring when needed. It is stated that theory and practical sides of engineering ethics are necessary for the proper education of engineers as knowledge of differential questions, diversity, or any other technical matter. Said that inspiring diversity is required for a leader and, as a consequence, for the leadership practice.

Diversity directly relates to ethics, leadership, and how diversity improves the organization's behavior. Three indicators of inclusion in organizations are equality, belonging, and openness. Diversity aids organizations in connecting with customers and leading new opportunities in the interrelated world.

Javier Calvo-Amodio (Oregon State University) - Javier.Calvo@oregonstate.edu

Javier Calvo-Amodio is an associate professor of Industrial and Manufacturing Engineering at Oregon State University, where he directs the Change and Reliable Systems Engineering and Management Research Group (CaRSEM). His research focus is on developing a fundamental understanding of how to integrate systems science into industrial and systems engineering research and practice to enable better engineering of organizations. At INCOSE, he serves as the chair of the Systems Science Working Group, is a member of the Bridge Team, and is the Technical Program Director for IS24. He is also a Fellow of the American Society for Engineering Management and serves as Deputy Editor of Systems Research and Behavioral Science Journal.

Position Paper

Organizations are complex systems that arise from the arrangement of various components, such as people, information, technology, and more. They not only consist of these individual constituents but also encompass how these components interact with each other. As a result, organizations can be defined as purposeful human activity systems. Organizations are a special kind of system as they are aware of their purpose and pursue it intentionally. But for organizations to be successful at pursuing their purpose they must possess 1) persistent structures -how all its individual constituents are arranged, 2) persistent processes -how flows of causal powers are managed. From the interaction between structures and processes, meanings emerge, creating a set of foundational ideas, feelings, and beliefs that form the basis for an organizational culture. The interaction between structures, processes, and meanings guides behaviors that shape what the organization can do. From a systems science perspective, culture emerges from the interactions of an organization's persistent structures, processes, meanings, and behaviors, thus making it possible to design each of these elements to influence organizational culture.

Panel#288

Empowering real world complex problem solving: Socio-technical Applications of Model-Based Systems Thinking (MBST)

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Keywords. Model-Based Systems Thinking (MBST);System Dynamics;Systems Thinking Principles;Patterns of Behavior;Causal Loop Diagrams;Stocks and Flows;Modeling and Simulation;Model-Based Systems Engineering (MBSE);Systems Science

Topics. 1. Academia (curricula, course life cycle, etc.); 1.4. Systems Dynamics; 1.6. Systems Thinking; 2. Aerospace; 22. Social/Sociotechnical and Economic Systems; 5.4. Modeling/Simulation/Analysis

Abstract. Model-Based Systems Thinking (MBST) refers to using rigorous modeling frameworks, languages and tools that help us understand and potentially influence complex emergent behavior of socio-technical systems. MBST enforces systems principles and identifies leverage points within the structure and mental models driving the behavior of complex systems in order to increase predictability, controllability, reliability, profitability, and other significant figure of merits of our solutions and policies.Systems thinking texts (e.g. Dana Meadows, Peter Senge, John Sterman etc.) appear to imply that System Dynamics is the "de-facto" framework, language and tool for systems thinking. System Dynamics is already taught at many schools so

that at least hundreds of graduates are getting exposed to great tools such as Vensim, Stella, iThink etc every year in the US. Worldwide, this is a much larger number. Yet, despite the education, many textbooks with “systems thinking” in the title and availability of tools, System Dynamics has been largely ignored by industries delivering safety critical complex systems & components (e.g. aerospace, automotive and energy) is near zero. The fact that there was only one paper at INCOSE IS 2023 with any System Dynamics content, or papers that specifically recognized rigorous tools for systems thinking speaks volumes. This panel explores real world rigorous modeling frameworks, languages and tools that enforce systems thinking and discusses what is hindering their broader adoption beyond boutique management consulting firms. Here are the specific questions in particular:1. What are the rigorous frameworks, languages and tools for MBST?2. What are some examples of real-world applications of MBST ?3. Is System Dynamics almost synonymous with MBST ?4. Is MBSE rigorously enabling Systems Thinking?5. Shall MBST be discipline agnostic or discipline specific ?6. Why is the adoption of System Dynamics or MBST so low in mature industries?

Biography

Golam Bokhtier (Northrop Grumman and Colorado State University) - gbokhtier@gmail.com

Golam M. Bokhtier. A Systems Engineer by profession, Golam M. Bokhtier has been affiliated with several renowned aerospace companies since 2004 including Collins Aerospace/Raytheon, L3-Harris, Woodward, Northrop Grumman and several Aerospace Start-ups. He has occupied numerous management and engineering leadership roles in the aerospace and defense sectors. He earned his BS in Electrical & Computer Engineering and Mathematics from Rutgers-New Brunswick in 2004, obtained his Master's in Electrical Engineering from Iowa State University in 2009, and is presently pursuing a PhD in Systems Engineering at CSU, Fort Collins, CO. His current research interests encompass eVTOL, UAVs, and wildfire detection. He has expertise in the systems engineering domain, specifically for communication and navigation systems, RF systems, and flight control systems for aerospace platforms

Position Paper

The Framework of Model-Based Systems Thinking (MBST) integrates the utilization of mental models, a cornerstone of Systems Thinking, exemplified by the iceberg model. This integration facilitates the identification of patterns of behaviors. From these discerned patterns, it is possible to construct causal loop diagrams, which serve as a foundational step towards developing comprehensive stocks and flows dynamics models. Subsequently, these stocks and flows models form the basis for System Dynamics modeling and simulation. This sequential progression from mental models to dynamic simulations embodies the essence of MBST framework. The elements in the MBST framework aid in identifying leverage points within complex systems.

Model-Based Systems Thinking (MBST) proves highly effective in the conceptual systemic design and development of aircraft or Unmanned Aerial Vehicles (UAVs), especially for specific purposes like wildfire detection and communication. This approach begins with analyzing flight control strategies, deployment, and trajectory control using tools like Vensim, before progressing to detailed airframe design. Employing Systems Thinking within a model-based environment can lead to significant time savings during the development process. For example, by identifying flight controls and deployment strategies as leverage points in the design process of a wildfire UAV, we can make critical design decisions supported by Systems Thinking. This leads to more targeted designs, utilizing tools such as ANSYS, Cameo/MBSE, and Monte Carlo. Utilizing this framework ensures the integration of Systems Thinking in our wildfire UAV design process.

The concepts of Systems Dynamics and MBST, while closely related and frequently used interchangeably, are not identical. The term “Model-Based Systems Thinking” (MBST) was coined and extensively discussed by Dr. Kamran Shahroudi in the 2015s. System Dynamics, potentially a subset of MBST, was originally developed by Dr. Jay W. Forrester in the 1950s. MBST integrates various model types, including systems dynamics models, combining Systems Thinking principles with System Dynamics and model-based approaches. Both MBST and System Dynamics emphasize the importance of feedback loops. MBST is acutely aware of the mental model and leverage points within a complex system. In contrast, System Dynamics does not explicitly identify the mental model.

Integration of Systems Thinking and Model-Base Systems Engineering (MBSE) is still a challenge that has not been fully discovered but it is an opportunity for the MBST and make MBSE approaches to be more Systemic instead of it being a linear approach only. MBSE automatically does not guarantee Systems Thinking but MBST increases the odds if MBSE and MBST integrated together. Furthermore, MBST plays a crucial role in addressing systemic gaps that have been identified in the development of Model-Based Systems Engineering

(MBSE), Systems Dynamics, and Systems Thinking. This enhanced Model-Based Systems Thinking (MBST) approach facilitates a more comprehensive and nuanced understanding and analysis of complex systems.

Kamran Eftekhari-Shahroudi (Woodward and Colorado State University) - Kamran.EftekhariShahroudi@Woodward.com

Kamran Eftekhari Shahroudi. Kamran is a Systems Fellow at the Corporate Technology Office of Woodward, Inc. working on Aerospace, Energy and Power Actuation Systems in technical lead and managerial roles since 1997.

Kamran is a Professor of Systems Engineering and a founding member of the CSU-SE program teaching and researching application of Systems Thinking and System Dynamics to Socio-Technical problems since 2009.

Position Paper

Systems Thinking (science, principles, applications) has so many facets, perspectives and dimension that we cannot claim that Systems Dynamics is the end-all rigorous method for it.

However, System Dynamics is probably the most useful rigorous framework, language and tool for MBST at this time.

A short demo of using SD to understand the impact of schedule priority versus cost priority resource decision on the complex dynamic behaviour of agile projects shows insights that years of professional practice does not!

Other rigorous methods that have great potential to boost MBST are DSMs, Data Science/Machine Learning and MBSE. However realizing this potential does not automatically come with buying and using these tools separately without a parallel integrated focus on systems science, systems principles and systems thinking.

SD has not penetrated because of many practical hurdles in the path of creating a validated model. Another speaker in this panel Kirk Reinholtz will discuss how these practical hurdles shall be overcome providing a glimpse of future SD capability that is beyond current tools.

Sarwat Chappell (Department of Defense (DoD) and Colorado State University) - Sarwat.chappell@colostate.edu

Sarwat Chappell is a PhD student in Systems Engineering at Colorado State University. Thesis work “A Systems Thinking Approach to Eliminating the DOD Science and Technology Valley of Death”.

Sarwat Chappell works for the Department of Navy at the Office of Naval Research where she leads the research and development of novel technologies for the Navy. Sarwat started her career at ONR in 2008 as Program Officer for Directed Energy. She directs critical investments for Science and Technology (S&T) efforts leading to research development for Directed Energy (DE) Weapon Systems for the Navy. Sarwat was the Deputy Program Manager and the Lead Program Manager for the Free Electron Laser Innovative Naval Prototype (INP) program. Prior to joining ONR, Sarwat was Chief Scientist for Naval Gunnery at Program Executive Office Integrated Warfare Systems (PEO IWS) and the PEO IWS Advanced Technology Director for all Surface Ship Weapons. Ms. Chappell was responsible for the Surface Ship Technology Master Plan. Sarwat has published and presented on a variety of topics ranging from guidance and navigation to power and thermal management and directed energy and has received numerous awards for science and technology excellence throughout her career. Sarwat has extensive experience leading international collaborative research programs with complex, technical objectives. Sarwat has a B.S. and M.S. in Electrical Engineering from Tennessee Technological University in Cookeville, TN.

Position Paper

Systems Thinking is a framework to solve complex problems in a holistic manner. Model Based Systems Thinking is a model-based framework for Systems Thinking to solve complex problems using the seven Shahroudi Systems Thinking Principles using models that can be communicated across a wide breadth of disciplines.

Model Based Systems Thinking can be used to solve problems ranging from prediction of weather patterns, species extinction, marathon race performance, traffic flow problems, escaping the technology transition valley of death to optimizing the operation of an innovation ecosystem.

Model Based Systems Thinking uses Systems Dynamics(SD) for probabilistic inferences of future behaviors based on historical patterns and data. SD modeling is a complex problem-solving framework used to solve dynamical problems that are governed by nonlinear feedback behaviors.

Systems Thinking is an enabler of Systems Engineering and Model-based systems engineering (MBSE). Some notable differences between MBSE and MBST is that Model Based Systems Thinking uses a holistic approach and is well suited to dealing with systems evolution whereas Model Based Systems Engineering is used to build models of complex systems from requirements to specific performance specifications.

Difference between Model Based Systems Thinking(MBST) and Systems Engineering(SE) is that SE follows a document centric, linear approach to solving problems whereas MBST is suited for interconnected, diverse elements which exhibit nonlinear, emergent behaviors as a complex system.

Model Based Systems Thinking is a mental model framework that governs MBSE, SD, SE, and ST. This framework can be thought of as an underlying methodology that connects different systems engineering disciplines to solve complex, dynamical problems.

Model Based Systems Thinking is agnostic to profession or discipline because it can be applied to any phenomena and disciplines such as social, biological, economic, political, and technical.

The adoption of System Dynamics or Model Based Systems Thinking is so low in mature industries because its only taught in technical disciplines or using technical jargon which non-technical students cannot relate to. To promote adoption of Model Based Systems Thinking, teachers must use examples related to the student’s field of study along with non-technical terminology which will increase their understanding of the subject matter.

Quentin Saulter (Department of Defense (DoD) and Colorado State University) - Qesaulte@colostate.edu

Quentin Saulter is a PhD student in Systems Engineering at Colorado State University. Thesis work is “A Dynamical Approach to Understanding the DoD Innovation Ecosystem.

Quentin Saulter works for the Department of Navy at the Office of Naval Research he is directing critical investments for research, development, test, and evaluation for the Navy. Mr. Saulter specializes in fostering innovative technologies for Navy stakeholders. Mr. Saulter is coordinating several research, development, and testing programs.

In 2006 Mr. Saulter was selected for the position of the Chief Engineer for the Air Force Research Laboratory for Directed Energy (AFRL/DE) in Albuquerque, New Mexico. Quentin also managed AFRL/DET, Directed Energy Technology division consisting of 3 departments with 30 direct reports.

Mr. Saulter served as operational crew chief at the Continuous Electron Beam Accelerator Facility (CEBAF) now called Thomas Jefferson National Accelerator Facility (TJNAF) or JLAB. Mr. Saulter also performed research cutting edge new accelerator physics topics while at Jefferson Laboratory.

Quentin E. Saulter was the first African American recipient of the Patricia Roberts Harris Fellowship Award and the first African American to graduate from Appalachian State University, Boone, NC with a master’s degree in Applied Physics. At the university, Quentin focused on thin film electron beam evaporation, high vacuum technologies, cryogenics, plasmonic oscillation theory, laser physics, and electro-optics.

Position Paper

Model Based Systems Thinking is the use of models to gain understanding and behavioural prediction of complex systems in science, engineering, political, economics, and any complex phenomena that is difficult to understand or explain. Model Based Systems Thinking encourages a holistic view of complex phenomenon instead of focusing solely on individual components. Model Based Systems Thinking considers how elements within a system interact and influence each other. This holistic understanding helps to uncover hidden connections and dynamics. Model Based Systems Thinking is a conceptual framework that could be used to encompass and bring together the separate disciplines of Systems Dynamics, System Thinking, Model Based System Engineering, and System Engineering in general. The conceptual framework of Model Based Systems Thinking can be used as a holistic framework that can be applied to science, business, academic, or social disciplines. The increasing complexity of many of today's systems make using Model Based Systems thinking necessary to explain systems operations, systems evolution, and possible systems behaviours. The explosion of the availability of mass quantities of data is an enabler to using Model Based Systems Thinking by analysing patterns and causal relationships to understand and predict complex systems structures and behaviours. Model Based Systems Thinking gives a framework of how to correlate data into information to be used by dynamical models to gain probabilistic inference of future events. Model Based Systems Thinking provides a logical and structured framework for understanding complex systems feedback. Model Based Systems Thinking can help in identifying, incorporating, and modelling variables with linear and non-linear relationships too help contribute to a clearer understanding of the underlying systemic mechanisms. Most complex systems often involve feedback loops, where the output of a process feeds back into the system. This influences subsequent behaviour. Recognizing, understanding, and modelling feedback loops is essential for predicting system behaviour over time. With this knowledge, Model Based Systems Thinking can facilitate the formulation and testing of hypotheses. By adjusting model parameters and examining their impact on predictions, one can explore various scenarios and assess the validity of different assumptions. Model Based Systems Thinking may also be used to predict and prevent complex problems by understanding the root causes and systemic structures. Model Based Systems Thinking could allow for interventions that address underlying systemic issues before they become detrimental to an organization, technology, or process. Model Based Systems Thinking has the advantage of serving as a visual or conceptual representation that can be easily shared amongst a diverse group of individuals. Model Based Systems Thinking can help distil complex information into manageable and understandable forms by simplifying and abstracting key elements and variables that make it easier for diverse groups of individuals to grasp essential features of systems or concepts.

Kirk Reinholtz (Colorado State University) - Kirk.Reinholtz@colostate.edu

Kirk Reinholtz was a Principal Engineer at the California Institute of Technology/Jet Propulsion Laboratory. He left that position in early 2023 to focus full-time on aligning with 21st-century advancements by pursuing a PhD in Systems Engineering at Colorado State University. He holds an MSCS from the University of Southern California

Position Paper

Systems Thinking is an essential concept: structures lead to behaviors, and actions have consequences, which in turn have their own repercussions. Everything is interconnected. However, the very need for Systems Thinking highlights a critical point: if it were easy and intuitive, we wouldn't be writing books about it or discussing it in panels like this one. The crux of the matter is that complexity, when truly complex, is irreducible. It's not merely a matter of perspective; some behaviors are unpredictable regardless of how we view them. Fortunately, we can glean insights through simulations, approximations, heuristics, regressions, and various other technical methods. This leads to my stance: the efficacy of Systems Thinking would be significantly bolstered if it were taught and implemented alongside key technical tools and practices. The 21st century is ushering us into a realm of tighter constraints, with previously externalized factors re-entering our System-of-Interest (SOIs). Let's learn and teach Model-Based Systems Thinking (MBST) as a core practice of Systems Engineering to better understand and optimize the outcomes of our engineering decisions.

Panel#129

Participatory Methods in SE

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Randall Iliff (Project Performance International) - riliff@ppi-int.com
Dale Brown (Hatch) - dale.brown@hatch.com

Keywords. Stakeholder engagement;Problem resolution;Collaboration techniques

Topics. 2.1. Business or Mission Analysis; 2.3. Needs and Requirements Definition; 22. Social/Sociotechnical and Economic Systems; 3.5. Technical Leadership; 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.); 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Based on the success of last year's INCOSE Invited Content, this panel is offered to extend the discussion with our systems engineers. Stakeholder engagement is a valuable resource for systems engineers. The methods, effectiveness, and lessons learned related to a project or initiative can vary widely. This panel will share and practice several stakeholder engagement tools and review their effectiveness. Attendees will be active participants in this session; experience and knowledge sharing is valued! Attendees will leave with a practical technique for engagement and a new way to think about stakeholder engagement and its relationship to systems engineering. Outcome goals: 1) Audience takes away something to use at work. 2) Also learn a new way to think about something or a concept you hadn't realized previously.

Biography

Jennnifer Russell (Garver) - JLRussell@GarverUSA.com

Jennifer Russell, EISE, CSEP is the Program and Management Support Leader on Garver's Water team. Over the past 25 years, she honed her West Point leadership motto of being a "Leader of Character." From strategic planning to tactical logistics, Jennifer has invested in public service and infrastructure. Currently, Jennifer is the Chair of the INCOSE Smart Cities Initiative, and has been the Outreach Director for the Transportation Working Group. At the International Symposia, Jennifer has presented several papers, on a panel, and lead several Roundtables. Jennifer holds a B.S. in Engineering Psychology from the United States Military Academy and an M.S. (2003) and Engineer Degree (2007) in Industrial and Systems Engineering from the University of Southern California.

Position Paper

As moderator for the INCOSE Invited Content Panel last year, this session is a unique opportunity for knowledge and experience sharing for a common, yet un-discussed role of systems engineers. This panel will expand the efforts from IS2023, which would allow renewal of vibrant discussions that happened during the panel session. As moderator, I'd be able leverage the themes of last year and enhance with the panelists' perspectives. I know each of the panelists and will be able to ask questions that are likely to engage the audience and motivate participation.

As moderator and experienced infrastructure domain practicing systems engineer, stakeholder engagement and participation in planning and design is a critical part of my job. These panelists have been brought together for their depth and breadth of experience. As moderator, I will engage with the panelists, support them to draw out their root messages, and surveille the audience for ideas that spur interest.

Dana Polojarvi (Maine Maritime Academy) - Dana.Polojarvi@mma.edu

Dana Polojärvi is Co-chair of the Social Systems Working Group at INCOSE. He is also a professor at the Maine

Maritime Academy, where he teaches courses that focus on large-scale societal transformation over time. As part of that process, he regularly runs participatory modeling sessions with stakeholders on a wide range of societal problems.

Position Paper

Theme: Managing stakeholder engagement to minimize political divisiveness

Position: Every complex, socio-technical problem involves people. All people have mental models about their surroundings that effect the way they perceive their world and determine how they interact with it. This is both a source of innovation (there are many perspectives) and a source of problems (people don't all agree, and they often turn disagreement into conflict). Holistic stakeholder engagement helps all of us develop empathy for each other, so that we can see the value in what other people have to say.

In short:

• Community building is the heart of participatory modeling.

• There are no right views.

• All views are limited.

• All views have value if you know how to look for it, and the value can often be found in your groups' hopes and fears.

Engagement

Poll questions:

• How does diversity affect stakeholder engagement?

• How do you manage this diversity?

• Where you do see applying these stakeholder management tools in your organization?

• How do you manage your own views when engaging with stakeholders?

Randall Iliff (Project Performance International) - riliff@ppi-int.com

Randy Iliff has over 45 years' of PM and SE experience on developmental efforts ranging in size from a few thousand to billions of dollars, and has built a solid record of disruptive innovation in aerospace, medical, commercial and consumer markets.

o Randy is a charter member of INCOSE and has been a steady contributor ever since. He works with Project Performance International as a Course Presenter / Principal Consultant and is also founder of his own consulting company - Eclectic Intellect.

o Prior to that he was Vice President at the award-winning product development firm bb7, served as Systems Engineering Manager for IceCube, an Engineering Manager at Motorola Government Electronics Group, a Program Manager / Senior Systems Engineer at Martin Marietta Denver Aerospace, and a junior member of the "skunkworks" Advanced Development Group at McDonnell-Douglas Astronautics.

o Mr. Iliff holds a BS in Engineering / Industrial Design from Michigan State University, and an MS in Systems Management, Research and Development from the University of Southern California.

Position Paper

Theme: Systems Engineering derives its power not from the terminology or details, but instead by delivering the emergent property of fully coordinated development.

Position: Extremely modest applications of SE can be highly successful, while well-funded but partial applications often fail to deliver on the promise of SE.

Engagement

• Which is the greater barrier to your ability to contribute to the goals of your organization?

o Your knowledge of SE practices and tools?

o Your organization's understanding of applying SE?

I can then share that I've asked a similar question of course audiences throughout the last 35 years - that's now over 12,000 people worldwide - and the answer is overwhelmingly that "SE is good enough to be widely used today, the problem is marketing of methods."

Dale Brown (Hatch) - dale.brown@hatch.com

Dale Brown is a licensed professional engineer with 40+ years of experience and multiple design patents. Dale is co-chair of the INCOSE Transportation Working Group and Configuration Management Working Group. Dale is also the relationship manager for the APTA/INCOSE cooperative agreement and is the technical lead / project manager for the proposed APTA Systems Lifecycle Engineering Standard currently under development. Dale is the current Chair of the APTA Systems Lifecycle Engineering (SLE) Subcommittee.

Position Paper

Theme: Perspective on civil infrastructure – how can systems engineers engage stakeholders who have performed their functions for decades and "know their trade" very well? Why are we not effectively convincing these stakeholders to deploy some level of SE?

Position: Within industry segments where Systems Engineering is emerging there is a high level of psychological and practical inertia that resists brute force methods to include Systems Engineering – the result being zero to poor Systems Engineering deployment and repeated large project failure which has become an accepted "norm" in our society.

Audience engagement will begin with a set of questions: Do you face this problem? What techniques do you use to engage your stakeholders?

Discussion Questions or Poll:

How did you approach change based on your audience?

Have you ever participated in formal approaches to Stakeholder engagement?

What were your lessons learned? (What worked, what didn't?)

After audience engagement panelist will discuss the technique of having team members create stakeholder impact statements to practice building empathy for stakeholder positions. The engagement technique could follow a FMEA process.

Panel#448

Peace, Love, and Digital Understanding: How system models will bring us all together

Kirsten McCane (MathWorks) - kmccane@mathworks.com
Alan Moore (MathWorks) - amoore@mathworks.com
Carol Erikson (Northrop Grumman) - carol.erikson@ngc.com
Cristina Valera Munoz (Airbus) - cristina.valera@airbus.com
Joseph Pack (Naval Sea Systems Command (NAVSEA)) - joseph.n.pack.civ@us.navy.mil

Keywords. Digital Transformation;Digital Engineering;Standards;Interoperability;Model-based;Tooling ecosystem;Collaboration;Culture

Topics. 2. Aerospace; 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.); 5.3. MBSE; 5.5. Processes; 6. Defense;

Abstract. Aerospace and defense organizations are on the brink of a transformative era, where the rapid evolution of technology demands a shift in their approach to developing complex systems. There’s consensus that models are fundamental to digital transformation, but wide variability in the implementation of model-based strategies presents a formidable challenge in defining and attaining this vision. The central role of system models requires that they be easily accessible and transferrable across the system development lifecycle. Embracing this imperative, our expert panel seeks to unravel the complexities of the Digital Engineering (DE) ecosystem to help us reach digital unity.Join us for an in-depth exploration of:• Challenges and Transformation: Discover the hurdles faced by AeroDef organizations as they strive to make system models central to their processes and collaboration. From overcoming organizational frictions in multi-group collaboration to redefining work methodologies, we'll delve into the transformative journey ahead.• Interconnected Teams and Models: Learn how the industry is moving from isolated to interconnected teams and models, driving the rise of methodologies like standards to ensure consensus and interoperability. Understand the evolving nature of collaboration and the tools, infrastructure, and resources needed to support this shift.Meet Our Diverse Panel: Our panel comprises leaders in various roles, each addressing multiple facets of this paradigm. Gain valuable insights into the challenges and opportunities inherent in the pursuit of a unified and efficient Digital Engineering ecosystem.

Biography

Kirsten McCane (MathWorks) - kmccane@mathworks.com

Kirsten McCane is an Industry Manager at MathWorks in Washington D.C. He works with defense industry customers on strategies and solutions to accelerate the realization of their digital transformation objectives such as digital engineering, DevOps, and MOSA.

Kirsten graduated from the University of Pittsburgh with a B.S. in Computer Engineering in 2007 and M.S. in Electrical Engineering in 2009. He joined Northrop Grumman Mission Systems upon graduation where he worked for 12 years on solutions for Multi-function Sensor Systems. While at Northrop Grumman, he received his MBA from the University of Maryland in 2017.

Position Paper

Digital transformation can deliver greater efficiencies, reduce costs, and drive competitiveness. However, implementation of the advanced workflows, tools, and processes to make digital transformation a reality varies widely within the industry. The push toward digital transformation has gained momentum recently, and aerospace organizations are aligning around a common vision for the goals of digital transformation and digital engineering. Three fundamental objectives are emerging – investment in enterprise digital engineering environments, workflow streamlining, and workforce reskilling.

First, investment in enterprise digital engineering environments requires incorporating technologies like modeling, cloud computing, and artificial intelligence. This means creating accessible platforms that better equip engineering workforces and improve overall business practices.

Second, streamlining workflows is possible by introducing tools and processes that alleviate administrative burdens, foster collaboration among engineering groups, and enhance overall workflow efficiency.

Third, reskilling the workforce is necessary for success and includes training employees on aspects like communication techniques for digital models replacing conventional presentations. Reskilling initiatives also helps to ensure more decisions are made based on data, incorporating new data insights as support for existing subject matter expertise.

Despite this common vision, we see aerospace and defense organizations facing significant adoption challenges around the integration of new digital tools and processes, business challenges, significant cultural resistance, and how to achieve the required workforce skilling.

Today, at the root of many of these challenges is how organizations are leveraging, utilizing, and integrating system models to achieve the promise of a wider model-based approach. Most organizations have invested in creating system models with the hope of them becoming the central artifact that can drive the rest of the development process. However, we see these organizations being frustrated by an inability to move the modeling data across the lifecycle, misalignments around model specification, fidelity, purpose, as well as business impediments to how to share across organizations in a consistent and useful way. To overcome this, there is promise in popular industry approaches that enable a data centric approaches like standards and ontologies as well as new contracting frameworks that help enable collaboration and protection of intellectual property. My hope is that information exchanges that highlight the lessons learned from growing pains towards this vision, combined with these new approaches will help us go from promoting the promise to standardizing the practice.

Alan Moore (MathWorks) - amoore@mathworks.com

Alan Moore is an architecture modelling expert at MathWorks and has extensive experience in the development of real-time and object-oriented methodologies and their application in a variety of system domains. Alan served as the language architect for version 1 of the SysML language and is a co-author with Sandy Friedenthal and Rick Steiner of “A Practical Guide to SysML.”

Position Paper

Despite ever increasing interest in and use of MBSE, system models are still often the poor relation when compared to other engineering artefacts. Requirements have high importance because they represent the contract with customer, often with financial implications. Source artefacts that drive the implementation process and any artefacts that are used to verify them must de facto be maintained. System models on the other hand are mostly used to facilitate design discussions or support design decisions by predicting some system characteristic which can limit their useful life.

System engineers are becoming increasingly interested, with reason, in modern workflows like DevOps that promise more flexible system development approaches. Unlike traditional systems engineering projects, a key concept in DevOps is the never-ending develop/operate cycle as opposed to a more staged delivery of functionality. This focus on repeated deployment reinforces the central importance of implementation sources, because fundamentally they are all that is needed to drive the process along, and of course the systems that are used to verify them. In this context, system models and even requirements have a reduced role.

In the light of these trends, what role should system models play? Least ambitious is the use of system models for invention and collaboration, so called descriptive modelling. What is required here is an appropriate modelling language and a fast on-ramp.

A more ambitious goal is the use of system models to support decision-making by predicting system characteristics, so-called analytic models. This goal requires relevant language semantics and the tools to interpret them.

Today, analytic models typically have a narrow focus, oriented on supporting a specific goal. One can imagine extending the scope of these models to detail the whole system. These would be akin to digital twins and would offer modelled content that could be shared between analysis. Achieving this goal requires more emphasis on model verification and ongoing model curation.

Arguably, the most ambitious goal is to use the system model as the integrating source for system implementation. The enormous additional step here is to envisage a federated ecosystem that embodies digital engineering principles across many disciplines. That in turn depends on effective collaboration between different tool vendors, connected via a common system modelling language.

The design aims for SysML2 are consistent with the requirements I have listed above, although it is still too early to tell whether the language as delivered will meet those aims and way too early to know whether a critical mass of supporting tools will emerge.

Carol Erikson (Northrop Grumman) - carol.erikson@ngc.com

Carol Erikson is Vice President of Digital Transformation at Northrop Grumman. She is responsible for leading digital transformation initiatives that will enable the Space Systems team to leverage capabilities to ensure effective execution across the full program life cycle, from concept through sustainment. Most recently, Carol served as vice president and enterprise program manager for the Ground Based Strategic Deterrent program. She established and led the nationwide team responsible for capturing and executing the Technical Maturation and Risk Reduction program and for developing innovative engineering and digital environment solutions critical to preparing for the Engineering, Manufacturing and Development program.

Carol joined Northrop Grumman in 1987 as a systems engineer and has technical, supply chain, functional and program management experience in Space Systems. Carol earned a bachelor’s degree in engineering and computer science from Stonehill College and a bachelor’s degree in electrical engineering from the University of Notre Dame. She earned a Master of Science degree in electrical engineering from the University of Southern California and completed the Executive Management Program at the University of California Los Angeles. Carol contributed as an author to the book Flight Paths to Success, providing career insight from 33 successful women in aerospace and academia.

Position Paper

By uniting teams from various silos, Northrop Grumman aims to harness the power of collaboration to redefine our approach to system engineering. This involves discussing specialized needs for different products and fostering cross-fertilization across teams to leverage industry best practices and innovation.

Emphasizing the importance of interoperability, we seek to establish common language and understanding at interfaces, while also recognizing the need for specialization across different product lines. We rely on our system engineering roots to develop an enterprise architecture that illuminates organizational and product handoffs, as well as tool and data exchanges.

This approach aims to provide clarity on the necessary commonalities and standards, while allowing for necessary specialization. One size does not fit all. Our approach centers around enterprise architecture, collaboration, and a focus on interfaces and interoperability.

Cristina Valera Munoz (Airbus) - cristina.valera@airbus.com

Cristina Valera, holding an MSc in Aerospace Engineering and CSEP certification, based in Madrid, Spain, brings over a decade of expertise in aerospace engineering and systems engineering. As the FCAS Common Working Environment Chief Engineer at Airbus, Cristina plays a decisive role in providing a secure international digital ecosystem for the Future Combat Air System (FCAS) program, transforming the digital landscape and ensuring digital continuity and collaboration across international engineering teams in a secure system. In her previous role as Digital Architect, she contributed to the development of Eurodrone digital engineering solutions, navigating similar challenges. As both Technical Lead Engineer and Dynamic Simulation Engineer, Cristina managed projects focused on the development of flight controls and landing gear systems, demonstrating a deep understanding of developing safety-critical systems within the aerospace defense sector. Her experience spans across an array of systems engineering disciplines, including requirements management, technical management, systems architecture, configuration management and various technology domains. Her commitment to delivering innovative solutions exemplified her role at the foreground of the digital transformation of aerospace defense developments.

Position Paper

In the landscape of aerospace and defense, the imperative shift towards digital transformation demands a thoughtful exploration of key elements—digital continuity, model-based development, digital engineering processes, interoperability, secure ecosystems and cross-functional collaboration.

Digital continuity emerges as the key player in the pursuit of operational excellence. Facilitating a seamless flow of information throughout the product lifecycle, it ensures a holistic understanding of complex systems. My professional journey has emphasized the critical role of digital continuity in promoting efficiency, reducing redundancies, and fostering a unified vision across development phases.

The paradigm shift towards model-based development has been transformative. Embracing models as central artifacts fosters efficiency, precision, and collaborative decision-making. Models serve as a universal language, promoting a shared understanding across diverse teams. The panel's focus on model-based strategies resonates with the transformative impact witnessed in real-world applications.

The evolution of engineering processes underpins the transformation towards a digital future. My engagements have emphasized the need for clearly defined, standardized processes that traverse the entire development lifecycle. From requirements specification to validation and verification, an integrated and transparent process framework is crucial for successful model-based development.

Interoperability, an indispensable in this digital ecosystem, ensures that diverse systems and teams can seamlessly communicate and share information. The effective design and implementation of digital interfaces become instrumental in achieving interoperability, enabling a cohesive and interconnected environment. The discussion on requisite tooling, infrastructure, and resources aligns with the pivotal role that digital interfaces play in shaping the future of aerospace and defense.

Navigating within a restricted ecosystem, safeguarding sensitive information demands a comprehensive and nuanced approach. Establishing rigorous data governance and access controls is paramount. My experiences underscore the challenges and opportunities within a restricted ecosystem, emphasizing the delicate balance between fostering collaboration and maintaining the security of sensitive data in a digital ecosystem.

Multi-group collaboration introduces a layer of complexity that demands a harmonized approach to processes, interfaces, and data governance. Achieving accessibility and transferability of system models across teams and borders imposes a shared understanding of international engineering standards. My engagements underscore the multifaceted nature of collaborations, emphasizing the need for a unified approach to overcome technical, cultural, and regulatory challenges.

In summary, the path towards excellence in aerospace and defense requires a holistic integration of digital continuity, meticulous adherence to model-based development, adherence to standardized-digital engineering processes, assurance of interoperability, meticulous management of secure ecosystems combined with multi-group collaboration. As we collectively navigate this transformative era, these concepts converge to sculpt a future marked by innovation, collaborative synergy, and sustained advancements in the aerodef sector.

Joseph Pack (Naval Sea Systems Command (NAVSEA)) - joseph.n.pack.civ@us.navy.mil

Joseph Pack is a Department of the Navy (DoN) mission architect and engineer who utilizes integrated models to define technical-to-tactical engineering relationships in military capabilities. Mr. Pack leverages architecture models to define DOTMLPF problems and aid in the evaluation of holistic solutions. Joseph's work has been published and featured at multiple conferences and industry workshops. His mission engineering activities have sent him aboard multiple deployed vessels in support of exercises, live operations, and training events. In 2021 Joseph received a Meritorious Civilian Service Award for work in establishing and maturing mission engineering activities. He was later selected to lead the NAVSEA Warfare Centers as the Digital Engineering Lead to advocate for enterprise-level engineering needs and drive digital evolution across the NAVSEA divisions.

Joseph received his Bachelor's of Science in Aerospace Engineering from North Carolina State University in 2009 and later attended George Mason University where he received a Master's of Science in Systems Engineering. In 2010 he earned his certification as a federal enterprise architect from the Federal Enterprise Architecture Certification Institute based out of California State University at East Bay and currently maintains certifications in defense acquisitions and engineering from the Defense Acquisition University.

Position Paper

Joseph Pack's role at NAVSEA Warfare Center Headquarters requires that he consider both idealistic desires for a future digital state and the pragmatic considerations which drive currently-planned DOD acquisitions. As the Digital Engineering Lead for 10 divisions covering a wide spectrum of engineering activities across the systems engineering lifecycle, Mr. Pack maintains an awareness of the varied needs and risks that overly aggressive digital transformation may pose. Instead of focusing on a desired end-state for transformation activities, Mr. Pack has taken a "meet people where they are" approach to digital engineering. This means identifying where current momentum is already moving towards embracing digital engineering and working to remove obstacles from organic growth. Concurrently, it requires that he aid organizations more deeply entrenched in legacy engineering practices in understanding the inevitable nature of digital change.

The NAVSEA Warfare Centers represent scientists, engineers, and analysts working a diverse portfolio of capabilities across many phases of the engineering lifecycle. Some entities support legacy systems nearing their end-of-life while others are defining requirements for capabilities over a decade in the future. Individuals attempting to advance digital engineering across such an intellectually dispersed community are forced to embrace diversity rather than enforce conformity. Working with the diversity each center and community of interest forces Mr. Pack to acknowledge that digital transformation means unification, or commonality, only where it is beneficial towards the mission of delivering greater naval capability. While the goal of any digital engineering should be the continuous transformation and evolution of all technical activities, taking a pragmatic perspective towards transformation activities helps ensure greatest likelihood of total-enterprise participation and enthusiasm.

Panel#382

Smart Cities from architecture to application: A socialization of industry best practices

Jennnifer Russell (Garver) - JLRussell@GarverUSA.com
Christian Neureiter (Head of Josef Ressel Center for Dependable System-of-Systems Engineering Salzburg University of Applied Sciences) - Christian.neureiter@fh-salzburg.ac.at
Cecilia Haskins (Norwegian University of Science and Technology (NTNU) and the University of Southeastern Norway (USN)) - ceciliahskins25@gmail.com
Michael Dunaway (National Institute of Standards and Technology (NIST)) - michael.dunaway@nist.gov

Keywords. Smart City;Systems Thinking;Society 5.0

Topics. 1.6. Systems Thinking; 20. Industry 4.0 & Society 5.0; 22. Social/Sociotechnical and Economic Systems; 3.5. Technical Leadership; 5. City Planning (smart cities, urban planning, etc.); 5.8. Systems of Systems (Internet of Things, cyber physical systems, etc.);

Abstract. The realm of smart cities includes considerations and implications for technology developers, policy makers, and sustainability practitioners. While each of these is focused on their practice, each is creating tomorrow’s smart cities. A key enabler in this case is the establishment of a common understanding between the different stakeholders. Factors such as system architectures, policy guidance, and sustainability are foundational to enable the development of smart cities. For technologists, reference architectures and corresponding architecture modelling concepts are involved which require a broad understanding of the stakeholders and their corresponding concerns. Policy maker (the U.S. National Institute of Standards and Technology (NIST)) is leading an effort to create appropriate standards for smart cities that conform to the U.S. approach that standards be voluntary, consensus-based and led by the cities and communities themselves. For sustainability practitioners, the business of smart cities can lead to unintended negative environmental consequences, which creates a need for to define the roles of sustainability and systems engineering in the solutions. The panel will seek to reveal similarities and differences between these practice areas. Audience engagement will consider the role of systems engineers and systems engineering to bring these areas together for improved interfaces and application.

Biography

Jennnifer Russell (Garver) - JLRussell@GarverUSA.com

Jennifer Russell, EISE, CSEP is the Program and Management Support Leader on Garver's Water team. Over the past 25 years +, she honed her West Point leadership motto of being a "Leader of Character." Currently, Jennifer is the Chair of the INCOSE Smart Cities Initiative and has been the Outreach Director for the Transportation Working Group. At the International Symposia, Jennifer has presented several papers, on a panel, and lead several Roundtables. Jennifer holds a B.S. in Engineering Psychology from the United States Military Academy and an M.S. (2003) and Engineer Degree (2007) in Industrial and Systems Engineering from the University of Southern California.

Position Paper

The scope of effort from the INCOSE Smart Cities Initiative and the relationships between outside partners has been collaborative and informative. Yet, there are still many opportunities for continued knowledge sharing and best practice sharing between practitioners. Cross-collaboration is imperative as areas like MBSE, sustainability, and smart city policies mature. There is a broadening of the understanding, communication on the topics, and desire for cross-collaboration that is inspiring. Each of the practitioners invited to this panel have refined their cross-collaboration techniques and will provide valuable insight for systems engineers in any domain, and especially those working on aspects of smart cities.

Christian Neureiter (Head of Josef Ressel Center for Dependable System-of-Systems Engineering Salzburg University of Applied Sciences) - Christian.neureiter@fh-salzburg.ac.at

Christian Neureiter is a Professor at Salzburg University of Applied Sciences where he is leading the Josef Ressel Center of Dependable System-of-Systems Engineering. His main research interest is put on the development of dependable Cyber-Physical Systems.

Position Paper

Corresponding to Christian's research interests he argues that Model Based Systems Engineering is a key enabler for the development of Smart City System Architectures. Based on experiences made in the application domains of Automotive, Industry 4.0 and Smart Grids, Christian's position is that Model Based Systems Engineering approaches need to be centered around the individual user's perspective and needs. The proposed concepts of "Domain Specific Systems Engineering" (DSSE) focus on providing a domain-specific perspective on the one hand while maintaining interoperability and compatibility of architectural models between different domains (e.g., electric vehicles and the power grid) on the other hand. On this basis, understanding of the nature of System-of-Systems is supported and designing of dependable solutions is enabled.

Cecilia Haskins (Norwegian University of Science and Technology (NTNU) and the University of Southeastern Norway (USN)) - ceciliahskins25@gmail.com

Cecilia Haskins, PhD is recently retired and continues in emeritus status with the Norwegian University of Science and Technology (NTNU) and the University of Southeastern Norway (USN). Her career included over 30 years as a practicing systems engineer and over 20 years educating the next generation of engineers on the importance of systems approaches. She joined INCOSE in 1993 where she held a variety of leadership and other volunteer positions, was recognized as an INCOSE Founder, and continues to be active as a mentor and author. Her educational background includes degrees in chemistry, business, and eventually a PhD for application of systems engineering to sustainable development from NTNU.

Position Paper

Smart cities rely on providing jobs and services making industry an important contributor to value creation in today's' society. But business is also the source of undesired social impacts such as environmental degradation and exploitation of workers. Traditionally, society's response to the most severe impacts, has been to establish laws and regulations. However, negative consequences persist even when firms operate within established limits. This creates a dilemma in defining the role of industry to sustainable development as outlined in the UN SDG and considering the role of systems engineering in addressing this dilemma. This presentation offers frameworks and a toolset supported by systems engineering principles and practices to assist the business transition to sustainability drawing on recent research and cases of successful transitions.

Michael Dunaway (National Institute of Standards and Technology (NIST)) - michael.dunaway@nist.gov

Michael Dunaway is Associate Director for Innovation in the Smart Connected Systems Division at the National Institute of Standards and Technology (NIST) and program lead for the Global Community Technology Challenge (GCTC), a federal Smart City program within the U.S. Department of Commerce.

Dr. Dunaway previously served as Executive Director of the Digital Future Resilience initiative at the University of Cincinnati, as Director of the National Incident Management Systems and Technologies Institute at the University of Louisiana at Lafayette and Director of the Louisiana Business Emergency Operations Center. Earlier assignments included Senior Director for Preparedness and Resilience Programs at the National Headquarters of the American Red Cross; Chief for Risk Management and Program Manager for Community Resilience at the Science & Technology Directorate, U.S. Department of Homeland Security; and as a project manager in the Cognitive, Neural, and Social Science Division of the Office of Naval Research.

A graduate of the United States Naval Academy, he is a career veteran of the U.S. Navy and holds an M.A. from the Fletcher School of Law and Diplomacy at Tufts University, and Ph.D. (Systems Engineering) from George Washington University.

Position Paper

The Global Community Technology Challenge (GCTC) is a U.S. smart cities program led by the National Institute of Standards and Technology (NIST) within the U.S. Department of Commerce. The GCTC is a partnership of cities and communities, local and state government agencies, business enterprises, non-governmental organizations, universities, and research institutes dedicated to improving the urban environment through the integration of advanced technologies. The NIST Smart Cities Infrastructure (SCI) program serves as coordinator for both national and international dimensions of this partnership, in collaboration with other federal agencies and offices that sponsor smart city-related projects and research.

The GCTC is based on the concept that a “smart city” is a community ecosystem in which advanced technologies are adopted in order to increase the efficiency, availability, and accessibility of city services with the goals of improving city operations, enhancing public safety and community resilience, equitably distributing economic and social benefits, and improving overall quality of life for residents. The principal goal of the NIST program on Smart Cities is to support collaboration among innovative local governments and agencies, nonprofits, private companies, and university research centers to overcome challenges and develop solutions in collaboration with leaders in the smart city and IoT fields.

The National Institute of Standards and Technology (NIST) is the research institute of the U.S. Department of Commerce and serves as the lead authority on standards within the federal government. NIST coordinates policies and regulations to create an environment that reduces barriers to standards adoption for U.S. industry, while facilitating U.S. private and public sector engagement in international standards development organizations and activities.

Generally, NIST does not develop standards on its own. Rather, NIST produces frameworks and guidelines facilitating the efforts of U.S. standards development organizations and private sector firms to adopt standards to achieve efficiencies in their processes, products, and services. These frameworks and guidelines function to reduce the complexity and cost of innovation for businesses, big and small.

Standards development in the U.S. is guided by the principle that standards be developed through a transparent process that is voluntary, consensus-based, and contains provisions for the non-discriminatory, royalty-free, or reasonably compensated availability of relevant intellectual property to all. To reinforce this principle, federal agencies are required to use voluntary, consensus-based standards developed through private sector initiative rather than through government direction of procurement and regulatory activities, except where impractical or inconsistent with law. This approach is consistent with the U.S. Government commitment to the World Trade Organization’s Technical Barriers to Trade Committee principles of transparency, openness, impartiality and consensus, effectiveness and relevance, and coherence.

While the complexity brought by this scale of effort and diversity of participants can seem antithetical to the efficiency of a top-down standards process, the U.S. approach of voluntary and consensus-based participation in standards development generates mutual interest and open competition among parties who have both vested interests in outcomes and the technical knowledge and capability to contribute meaningfully to the process.

Panel#281

What works and what does not work in teaching non-Systems Engineers about systems thinking

Jill Speece (California Polytechnic State University San Luis Obispo) - jespeece@calpoly.edu
Kamran Eftekhari Shahroudi (Woodward Inc.) - keftek@woodward.com
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Keywords. Systems Thinking;Socio-Technical Systems;Penetration of Systems Thinking

Topics. 1. Academia (curricula, course life cycle, etc.); 1.6. Systems Thinking; 22. Social/Sociotechnical and Economic Systems; 5.9. Teaching and Training; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Real-world complex challenges often do not fall neatly inside purely technical fields. This has driven the increasing recognition of the importance of practicing systems thinking as we approach diverse socio-technical and non-technical problems. Systems Engineers are required to have systems thinking skills, but these have not been easily transferrable or teachable to non-engineering roles. For example, an experienced contract manager, sales or marketing professional working on customer negotiations may be fully unaware of the circular impact of her decisions on the engineering team and vice versa. The assumption that only systems engineers require systems thinking skills will not help this situation as every major role that has a circular interaction with the technical team needs to exercise systems thinking to improve the odds of success of the whole team. Furthermore, the assumption that industry tailored Systems Engineering tools and processes naturally lead to greater penetration of systems thinking into the whole organization is also debatable. This panel aims to both discuss and debate these assumptions, sharing best practices and lessons learned from their experiences in teaching systems thinking. The following key questions will guide the discussion: Are systems engineers consistently practicing systems thinking? Will adoption of SE Processes and Tools naturally lead to greater adoption of systems thinking in non-technical roles? How do you differentiate between systems thinking and systems engineering? What elements or tools of systems thinking have the highest leverage in different industries or professions? Who should teach systems thinking?What teaching approaches have worked effectively, and what have been less successful in teaching systems thinking?

Biography

Jill Speece (California Polytechnic State University San Luis Obispo) - jespeece@calpoly.edu

Jill Speece is an Assistant Professor of Industrial and Manufacturing Engineering at California Polytechnic State University in San Luis Obispo. She is also currently an adjunct professor in Healthcare Administration at Pacific University and a continuous improvement consultant with Ridgerunner Engineering. Prior to her academic career, Jill worked in the manufacturing industry as an Industrial Engineer at Raytheon (2004 – 2009), Abound Solar (2009 – 2012), and Terumo BCT (2013 – 2014). She received her Lean Six Sigma Expert certification through Raytheon in 2008. She then transitioned to working in the healthcare industry and served as both a Process Improvement Consultant and the Director of Business Optimization at Radiology Associates from 2015 – 2021. She has her BS in Industrial Engineering from Cal Poly, SLO, an MS in Engineering Management from USC, and a PhD in Systems Engineering from Colorado State.

Position Paper

Systems thinking is an intentional mental practice wherein you gather and analyze all stakeholder input, understand existing systems for context, and thoroughly research the history of the problem from various angles. Anyone can become a proficient systems thinker, but not everyone is willing to put in the effort. Systems Engineers should arguably be the experts in systems thinking, just as the media should arguably present an unbiased view of current events. Despite our awareness that neither always occurs, I believe Systems Engineers are still the most qualified to teach systems thinking. Systems Engineering is a discipline, while systems thinking is a mental habit that spans all disciplines. Just like any new habit, it requires a considerable initial effort before it becomes effortless. In my experience, this aspect has been the tough sell in training non-Systems Engineers to become systems thinkers. What has proven most effective in teaching healthcare workers about systems thinking is guiding them through the creation of various artifacts from the Systems Engineering discipline (such as context diagrams, use case diagrams, requirements writing, stakeholder analysis, trade-off studies, etc.) specific to a problem that interests them. For undergraduate students, what has been most successful thus far is presenting them with a lofty challenge, such as "how would you change the world," and forming cross-discipline teams (comprising, for example, a history major, a soil science major, a marketing major, and an industrial engineering major) mentored by various faculty members to propose an idea for solving a wicked problem. What has not worked in both environments is a theoretical overview of systems (i.e., death by PowerPoint) that is not combined with hands-on, relevant practice. Systems thinking games and exercises are also helpful but remain ineffective unless the individual can begin developing the systems thinking mental habit by working on a problem of special interest to themselves.

Kamran Eftekhari Shahroudi (Woodward Inc.) - keftek@woodward.com

Kamran is a Systems Fellow at the Corporate Technology Office of Woodward, Inc. working on Aerospace, Energy and Power Actuation Systems in technical lead and managerial roles since 1997. Kamran is a Professor of Systems Engineering and a founding member of the CSU-SE program teaching and researching application of Systems Thinking and System Dynamics to Socio-Technical problems since 2009.

Position Paper

Systems engineers can become disconnected and forget that the primary raison d'être for systems engineering frameworks, tools, language, and processes is to apply systems thinking and principles to enhance the team's (not solely their own) chances of success when handling complex socio-technical challenges. Many within INCOSE still equate Systems Thinking and Systems Engineering, which is counterproductive to fostering greater adoption of a systems thinking mindset in corporate culture. Presently, practical, experience- and observation-based universally applicable systems principles constitute the most leverageable and teachable aspect of the body of knowledge on systems thinking for non-systems engineering and non-technical roles. Systems science, the source of Systems Principles, is presently not ideally positioned for broadening the teaching of systems thinking, as highlighted in the INCOSE-IS 2023 Panel discussion where this challenge of instructing non-systems engineers was raised without a clear solution. It is imperative to formulate a set of SMART requirements for generic Systems Principles that are applicable across ANY discipline, not solely for systems engineers, to promote the broader adoption of systems thinking beyond the SE discipline. The aforementioned stances or perspectives are rooted in teaching systems thinking classes to over 80 industry professionals engaged in delivering complex actuation system products to the aerospace and energy industries, alongside instructing more than 500 mature student professionals at CSU, holding diverse technical to administrative roles since 2009. These viewpoints are supported by references to the SEBOK, standard systems engineering texts, prior INCOSE IS Panels/Publications on Systems Science and Systems Thinking, and data derived from previous instructional experiences.

Trae Span (United States Air Force) - Trae.Span@colostate.edu

Martin (Trae) Span, III is currently a PhD Candidate in Systems Engineering at Colorado State University. He is also commissioned as a Major in the United States Air Force (USAF). He has served the USAF as a Developmental Test Engineer responsible for planning and executing complex weapon system tests and evaluation. Additionally, he served as Deputy Director for the US Air Force Academy systems engineering program teaching multiple courses in systems engineering and project management. He serves as a developmental engineer and holds the Department of Defense certifications in systems engineering, science and technology management, test and evaluation, and program management. His PhD work is focused on cybersecurity requirements elicitation for complex cyber-physical systems.

Position Paper

Are systems engineers consistently practicing systems thinking? Not to its fullest...I believe systems thinking education is not a consistent part of systems thinking education and training. By default, most systems engineers are applying some tenets of systems thinking as its engrained in systems engineering processes, but there is certainly room for improvement in educating systems engineers on additional considerations and perspective gained through a systems thinking approach to understanding the complexity of their system operation and its environment. How do you differentiate between systems thinking and systems engineering?

Systems thinking is a way of viewing the world in which we understand that the most challenging problems we encounter are not decomposable and solvable by traditional engineering methods. Even a well-designed system, if not designed considering the complexity of its dynamic interactions in its operating environment (including the human element), will likely have large shortcomings throughout its lifecycle. What elements or tools of systems thinking have the highest leverage in different industries or professions? A holistic perspective -- the combination of parts does not equal the whole. Understanding that elements have dynamic relationships in the dynamic environment of the world we live in. Teaching non engineers to appreciate the implications their solutions may have (both intended and intended) is particularly powerful (Cats in Borneo Example). Who should teach systems thinking? The simplest answer is a systems thinker. I believe that an engineering degree specifically is not a requirement to teach systems thinking, but the instructor should have experience with either system design or project management. So, I would expect this course to be taught by someone from an engineering or management department. What teaching approaches have worked effectively, and what have been less successful in teaching systems thinking? A case study focused approach that highlights the failures of a lack of systems thinking has proven successful at the US Air Force Academy in introducing systems principles. Guest speakers who can speak to their own involvement in a systems thinking problem or success story are also particularly effective in conveying the complexity of interactions in our complex system design and operational challenges.

Kirk Reinholtz (Colorado State University) - Kirk.Reinholtz@colostate.edu

Kirk Reinholtz was a Principal Engineer with California Institute of Technology/Jet Propulsion Laboratory. He left that position in early 2023 to focus full-time on catching up with the 21st century by pursuing a PhD in SE. He has an MSCS from USC.

Position Paper

The challenge is much more than a lack of systems thinking. If there’s money or power to be had or lost, then there are lots of people doing systems thinking. The crux of the situation is that they are often using systems thinking to achieve their own ends, not necessarily fully aligned with success of the system at hand. When the system was just a spacecraft, we systems engineers could pretty much stay out of the fray. But now we are dealing with planetary-scale systems and existential challenges. We Systems Engineers are trained and experienced in systematically solving engineering issues of any scale. Should we join the fray? If so, how do we educate ourselves on the human behaviors that tend to thwart our most well-intentioned efforts?

Quentin Saulter (Department of Defense) - Quentin.Saulter@colostate.edu

Quentin Saulter is a PhD student in Systems Engineering at Colorado State University. Thesis work is “A Dynamical Approach to Understanding the DoD Innovation Ecosystem. Quentin Saulter works for the Department of Navy at the Office of Naval Research he is directing critical investments for research, development, test, and evaluation for the Navy. Mr. Saulter specializes in fostering innovative technologies for Navy stakeholders. Mr. Saulter is coordinating several research, development, and testing programs.

Position Paper

Systems Thinking is a discipline generally taught in Systems Engineering curricula throughout the United States. It is typically myopically applied to complex technical systems. A general application of systems thinking in social, environmental, economic, and medical disciplines is not usually taught in academic institutions. One rarely hears of Systems Thinking being taught in Law School. Systems Thinking, as taught by engineering professors is usually in terms of technical jargon of Thinking in Systems that cannot be understood by non-engineering students. Systems Thinking can be broadly applied to many different phenomena to solve complex dynamical problems. As an example, gathering data to formulate information and build models is using Systems Thinking to analyze the spread of diseases. Another example is using the historical patterns of behavior to build models to deduce whether a person possibly committed a crime. Even though these examples use some of the tools of Systems Thinking their adoption does not lead to using Systems Thinking principles.

Both classical Systems Engineering and Model Based Systems Engineering have traditionally been applied to solve problems without full application of Systems Thinking. For example, Systems Engineering is typically used to design complex systems such as ships, planes, rockets, and satellites whereas Systems Thinking can be used to predict the behavior of the system and deal with emergent behavior of the system such as stock markets, forest fires and civil unrest. The element of Systems Thinking that is agnostic to profession or discipline and has the most leverage is the ability to change mental models. A practitioner of Systems Thinking who understands systemic structures, diverse entity interactions, positive and negative feedback and emergent behaviors should teach Systems Thinking. In our experience, conducting Systems Thinking Workshops for both technical and non-technical persons, we learned that anyone could learn and apply basic systems thinking principles. This will lead to an understanding of the complexity of an enterprise culture and improve productivity. Teaching Systems Thinking using non-engineering jargon and using examples related to the student's field of study will increase their understanding and promote adoption of Systems Thinking.

Sarwat Chappell (Department of Defense) - Sarwat.Chappell@colostate.edu

Sarwat Chappell is a PhD student in Systems Engineering at Colorado State University. Thesis work "A Systems Thinking Approach to Eliminating the DOD Science and Technology Valley of Death". Sarwat Chappell works for the Department of Navy at the Office of Naval Research where she leads the research and development of novel technologies for the Navy. Sarwat has extensive experience leading domestic and international collaborative research programs with complex, technical objectives. Sarwat has a B.S. and M.S. in Electrical Engineering from Tennessee Technological University in Cookeville, TN.

Position Paper

Systems Thinking is a discipline generally taught in Systems Engineering curricula throughout the United States. It is typically myopically applied to complex technical systems. A general application of systems thinking in social, environmental, economic, and medical disciplines is not usually taught in academic institutions. One rarely hears of Systems Thinking being taught in Law School. Systems Thinking, as taught by engineering professors is usually in terms of technical jargon of Thinking in Systems that cannot be understood by non-engineering students. Systems Thinking can be broadly applied to many different phenomena to solve complex dynamical problems. As an example, gathering data to formulate information and build models is using Systems Thinking to analyze the spread of diseases. Another example is using the historical patterns of behavior to build models to deduce whether a person possibly committed a crime. Even though these examples use some of the tools of Systems Thinking their adoption does not lead to using Systems Thinking principles.

Both classical Systems Engineering and Model Based Systems Engineering have traditionally been applied to solve problems without full application of Systems Thinking. For example, Systems Engineering is typically used to design complex systems such as ships, planes, rockets, and satellites whereas Systems Thinking can be used to predict the behavior of the system and deal with emergent behavior of the system such as stock markets, forest fires and civil unrest. The element of Systems Thinking that is agnostic to profession or discipline and has the most leverage is the ability to change mental models. A practitioner of Systems Thinking who understands systemic structures, diverse entity interactions, positive and negative feedback and emergent behaviors should teach Systems Thinking. In our experience, conducting Systems Thinking Workshops for both technical and non-technical persons, we learned that anyone could learn and apply basic systems thinking principles. This will lead to an understanding of the complexity of an enterprise culture and improve productivity. Teaching Systems Thinking using non-engineering jargon and using examples related to the student's field of study will increase their understanding and promote adoption of Systems Thinking.

Tutorials

Tutorial#205

Dimensional Analysis. A helpful practice for identifying constraints on a system model developed using ISE&PPOOA MBSE methodology

Jose Luis Fernandez (Independent MBSE trainer) - joselfernandez@telefonica.net
Juan Antonio Martinez (Department of Signal Theory and Communications, Escuela Politécnica. Universidad de Alcala de Henares.) - juanan.martinez@uah.es

Keywords. Dimensional analysis;MBSE;Physical constraints;Interfaces

Topics. 11. Information Technology/Telecommunication; 17. Sustainment (legacy systems, re-engineering, etc.); 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 5.5. Processes; 8. Energy (renewable, nuclear, etc.);

Abstract. MBSE methodologies application ends with the physical architecture of the system, but a physical model is clearly incomplete without the study of its associated physical laws and phenomena related to the whole system or its parts. However, the computational demands could be excessive even for modest projects. Dimensional Analysis is common in fluid dynamics and chemical engineering, but its application to systems engineering is still limited. We describe an engineering methodological process, which incorporates Dimensional Analysis as a helpful best practice to understand the physical constraints of the system without the burden of complex analytical or numerical calculations. An illustrative example describing showing the benefits of this approach will be used. The selected example describes a problem rarely covered in modern expositions of Dimensional Analysis in order to show the wide benefit of these techniques. The information provided by this analysis is very useful to select the best physically realizable architectures, testing design and conduct trade-off studies. The complexity of modern systems and systems of systems demands new testing procedures in order to comply with increasingly stringent requirements and regulations. This can be accomplished through research in new Dimensional Analysis methods. Finally, this tutorial serves as a fairly comprehensive guide to the use of Dimensional Analysis in the context of MBSE, detailing its strengths, limitations and controversial issues.

Biography

Jose Luis Fernandez (Independent MBSE trainer) - joselfernandez@telefonica.net

Primary instructor was tenure associate professor during 18 years teaching project management and systems engineering to students and professionals. Currently is an independent trainer for MBSE and requirements engineering. He collaborates as well as MBSE mento for research projects in aerospace and medical devices.

PhD in Computer Science, and an Engineering Degree in Aeronautical Engineering. Universidad Politecnica de Madrid. Second instructor.PhD in Physics by the Universidad Complutense de Madrid and a Psychology Degree in Educational and Developmental Psychology by the Universidad Nacional de Educación a Distancia.

First instructor is the main author of the ISE&PPOOA MBSE methodology he developed the last years. This methodology is described in the book “Practical Model-Based Systems Engineering,” Artech House 2019.

ISE&PPOOA was presented in diverse INCOSE webinars and tutorials to universities and industry mainly in Europe and the US.

Juan Antonio Martinez (Department of Signal Theory and Communications, Escuela Politécnica. Universidad de Alcala de Henares.) - juanan.martinez@uah.es

Secondary instructor is tenure associate professor and expert in sensors, complex systems, computational physics, modeling and dimensional analysis, as can be seen in his scientific papers. His research span from plasma spectroscopy to optical and acoustical sensing of biological matter.

Second instructor is mainly interested in extending dimensional analysis and similarity techniques to complex systems as a foundational basis of modeling in systems engineering.

Tutorial#317

Embracing the Social Dimension of Systems Engineering

David Long (Blue Holon) - david@blueholon.com
Suja Joseph-Malherbe (Letter27) - suja@letter27.co.za

Keywords. Leadership;Interpersonal skills;Elicitation;Communication;Facilitation;Teams;Collaboration

Topics. 3.5. Technical Leadership;

Abstract. Through education, training, and on-the-job experience, the technical dimension in engineering is sufficiently understood, from exploring and defining the problem, appreciating the solution space, and conceiving, developing, and producing the system-of-interest. But the transdisciplinary nature of systems engineering requires far more than the technical dimension. It requires that we properly understand the problem and identify concerns across a diverse set of stakeholders. It requires that we elicit, connect, and leverage the insights from a diverse set of subject matter experts. Success in the transdisciplinary domain requires both technical and social dimensions. In this practical tutorial, we will explore our role in supporting the social dimension for enhanced collaboration and team performance. We will identify the challenges we face in systems engineering and explore how to better achieve shared understanding across diverse teams through effective elicitation, communication, and facilitation. We will look at how our engagements with one another – both 1:1 and group interactions – influence outcomes as well as developing an awareness and understanding of emotions, behaviors, and attitudes in context of self and others. This will be achieved through hands-on activities and facilitated small group and plenary activities. Suitable for all experience levels, this tutorial offers an opportunity for lifelong learners to either start embarking on a journey of discovery on this topic or an opportunity for fresh engagement and insights advancing their knowledge.

Biography

David Long (Blue Holon) - david@blueholon.com

For over 30 years, David Long has helped organizations increase their systems engineering proficiency while simultaneously working to advance the state of the art. David was the founder and president of Vitech where he led the development of innovative, industry-leading methods and software to help organizations engineer next-generation systems.

Throughout his career, David has played a key technical and leadership role in advancing and expanding the practice of systems engineering around the world. He advises government and commercial organizations as they assess, adopt, and deploy new methods and tools to enhance their engineering enterprise. David successfully led Vitech from initial start-up to mature organization through acquisition. David has served INCOSE since 1997 including a term as the Washington Metropolitan Area chapter president and international roles including Member Board Chair, Director for Communications, Director for Strategy, and President (2014 & 2015). An INCOSE Fellow and Expert Systems Engineering Professional (ESEP), David is considered the grandfather of INCOSE's Technical Leadership Institute and has served as a coach since 2019.

David is a frequent presenter at industry events worldwide delivering keynotes, presentations, and workshops spanning introductory systems engineering, the advanced application of MBSE, digital engineering, the future of engineering systems, and leadership.

Position Paper

David is an internationally recognized leader within INCOSE and the greater systems engineering community. David has developed his leadership philosophy and behaviors based upon a unique blend of commercial experience (founding and leading a systems engineering company) and volunteer experience (leading INCOSE at the local, regional, and international level). This has positioned David to advise diverse organizations around the world as well as coach the next generation of systems engineering leaders as part of INCOSE's Technical Leadership Institute.

Suja Joseph-Malherbe (Letter27) - suja@letter27.co.za

Suja has a passion for leadership and systems engineering and as such she is quite active in INCOSE in various roles. She is a coach at INCOSE Technical Leadership Institute since December 2020. She served as the President of INCOSE South Africa from January 2017 to December 2018.

She provides training and consulting services in systems engineering and leadership development to individuals and organizations through Letter27. She is also a sessional lecturer at the Faculty of Engineering and the Built Environment at the University of the Witwatersrand, delivering post-graduate courses on systems engineering. Her prior experience includes delivering training world-wide in systems engineering through Certification Training International (course presenter); managing software releases, including the testing, deployment, and support of new software for first-of-its-kind outdoor and fitness products at Garmin Stellenbosch (senior systems engineer); and substantial experience in modelling and simulation, image processing, and development of technology systems for the defense industry.

She is an INCOSE Certified Systems Engineering Professional (CSEP) and a Solution-focused Brief Coach (ICF-ACSTHs training).

Position Paper

Suja has a passion for leadership and prolifically engages in aspects of it in various ways. Over the years, she has delivered talks and keynotes on this topic (at local, regional, and international levels), most recently at the meeting of the International Society for the Systems Sciences (June 2023). She is a coach at the INCOSE Technical Leadership Institute and has had the privilege of being actively involved in the learning journey of about 80 systems leaders. She is registered for a PhD exploring leadership. In addition to being a practicing systems engineer, she offers coaching and leadership development to professionals.

Tutorial#374

Hands-on Journey on Variant Modelling with SysML: Features Models, Methods, SysML v2, and AI Insights

Marco Forlingieri (IBM Engineering) - marco.forlingieri@gmail.com
Tim Weilkiens (Oose) - tim.weilkiens@oose.de

Keywords. Variant Modelling in SysML;Model Based Product Line Engineering (MBPLE);Variant Modelling and SysML v2;AI-assistance for Variant Modelling

Topics. 16. Rail; 2. Aerospace; 3. Automotive; 5.11 Artificial Intelligence, Machine Learning; 5.3. MBSE; 5.6. Product Line Engineering;

Abstract. This comprehensive tutorial aims to equip participants with practical insights and skills in variant modelling with SysMLThe tutorial begins with an overview of what variant modelling is, covering the basics of Product Line Engineering (PLE), industry norms, and the historical evolution of the discipline.Following this, we dive into the creation of Feature Models with SysML, providing hands-on experience with profiles, dependencies, by using IBM Rhapsody.The journey continues with a detailed session on two possible variant modelling Approaches in SysML, where participants will gain practical understanding by exploring two modelling methods based on the best paper of IS 2022, "Two Variant Modelling Approaches for MBPLE at Airbus."The tutorial then shifts to the future of variant modelling with SysML v2, offering a dedicated session on SysML v2 for variability. This session includes both theoretical and practical insights based on the latest version of SysML and using the IBM SysML v2 prototype.Finally, it concludes with a session on AI-assistance for Feature Modelling and variant modelling, covering insights from IBM Watsonx.ai and OpenAi. This segment showcases how artificial intelligence can enhance, and in some cases, pose challenges to variant modelling practices.The objective of this immersive tutorial is to share the trainers'experience and practical insights on the subject, providing a comprehensive understanding of variant modelling in SysML, from foundational concepts to cutting-edge AI integration.

Biography

Marco Forlingieri (IBM Engineering) - marco.forlingieri@gmail.com

Marco Forlingieri, currently serving as the Technical Representative of IBM Engineering in Southeast Asia, has gathered more than 10 years in MBSE and PLE. His expertise extends across aerospace, defense, automotive, and railway industries in Europe, North America, and Asia Pacific. Marco holds key roles as co-chair of the INCOSE PLE Working Group and Assistant Director for the INCOSE Asia & Oceania Sector.

As Associate Faculty at the Singapore Institute of Technology (SIT), Marco teaches MBSE. His primary focus centers on Model-Based Product Line Engineering, where he played a pivotal role in implementing a significant PLE initiative at Bombardier Transportation in the railways sector. Additionally, during his previous role at Airbus within the Digital Design Manufacturing and Services program, he led the MB-PLE initiative.

As author, Marco has contributed to various publications focused on PLE and MBSE. His works includes "The four dimensions of Variability at Airbus", “Variability on System Architecture using Airbus MBPLE for MOFLT Framework” and "Two variants Modelling Approaches for MBPLE at Airbus," that was recognized with the "Best Paper" award at the INCOSE IS 2022 in Detroit. Marco remains dedicated to advancing the field and continues to shape the future of MBSE and PLE globally.

Position Paper

Marco Forlingieri, a leading MB-PLE expert globally, brings practical know-how from industry, consulting, and tool development to the tutorial. His rich experience in MBSE and PLE, evident in publications and PLE WG involvement, offers valuable insights. With a decade dedicated to Variant Modelling in SysML, Marco's expertise is a key asset for tutorial preparation and execution. Attendees can benefit from his simplified, hands-on approach, making complex concepts more accessible. With Marco's help, the tutorial becomes a key opportunity to improve the audience's skills in MB-PLE.

Tim Weilkiens (Oose) - tim.weilkiens@oose.de

Tim Weilkiens is a member of the executive board of the German consulting company oose, an MBSE coach, and an active member of the OMG and INCOSE communities.

Tim was a co-developer of the SysML v1 specification, was a co-lead of the last SysML v1 revision task forces, and is a co-chair of the SysML v2 finalization task force.

Additionally, Tim was also involved in the development of UML, BPMN, and the OMG certification programs.

Tim has written more than 15 books about modeling including "Model-Based System Architecture" (Wiley), and "Variant Modeling with SysML" (MBSE4U). Regarding AI, Tim currently works as a co-author on the book "AI Assisted MBSE with SysML".

Position Paper

Tim Weilkiens has deep knowledge about SysML, and the modelling of variability (see biography).

As an MBSE consultant and trainer for more than 20 years, he has a lot of experience in leading workshops and tutorials..

Tutorial#393

Open Source System Modeling with Python

Raymond Madachy (Naval Postgraduate School) - rjmadach@nps.edu
Ryan Longshore (Naval Postgraduate School) - ryan.longshore@nps.edu

Keywords. System modeling;digital engineering;open source;open source libraries;open-source tools;Python

Topics. 1. Academia (curricula, course life cycle, etc.); 2. Aerospace; 5.1. Agile Systems Engineering; 5.3. MBSE; 5.4. Modeling/Simulation/Analysis; 6. Defense;

Abstract. The tutorial will cover open-source system modeling capabilities using Python, and immediately enable participants to implement them. Participants will rapidly model, analyze, and automatically document systems with naturally integrated models even without prior Python experience. The exercises can be performed online or offline on a laptop or other device.The extensive Python scientific computing ecosystem lowers barriers to system modeling. It is the predominant language for systems engineering applications and serves as modeling glue. The open-source environment provides integrated capabilities for system modeling, analysis, and automatic documentation. Modeling will include SysML v.1 and v.2, continuous and discrete event simulation, reliability, network, risk, cost, project management, and others. Models and data are integrated with a few lines of code.Numerous examples, templates, and case studies will be provided using domain specific libraries and general utilities for computational system models and diagrams. The interoperable libraries include Systems Engineering Library (se-lib), NumPy, NetworkX, SciPy, Pandas, Matplotlib, and more. Model and data interchange with other external SysML and simulation tools will be covered.New guidance and examples using AI assistant chatbots to support the modeling process will be presented. Participants will also learn how to incorporate open source modeling in system engineering processes and toolsets. They will understand how open source tools support rapid iterative processes and automate round-trip digital engineering while reconciling single-source truth models.Students only need basic computer skills to modify the examples or create new models. Exercises will be simple short code statements based on self-evident and highly readable examples.

Biography

Raymond Madachy (Naval Postgraduate School) - rjmadach@nps.edu

Raymond Madachy, Ph.D., is a Professor in the Systems Engineering Department at the Naval Postgraduate School. His research interests include system and software cost modeling; affordability and tradespace analysis; modeling and simulation of systems and software engineering processes; integrating systems engineering and software engineering disciplines; and systems engineering tool environments. His research has been funded by diverse agencies across the DoD, National Security Agency, NASA, and several companies. Previously he was a Research Assistant Professor in the Industrial and Systems Department at the University of Southern California, and has over 20 years of management and technical experience in industry.

He has developed widely used tools for systems and software cost estimation, and is leading development of the open-source Systems Engineering Library (se-lib). He received the USC Center for Systems and Software Engineering Lifetime Achievement Award for “Innovative Development of a Wide Variety of Cost, Schedule and Quality Models and Simulations” in 2016.

His books include Software Process Dynamics, What Every Engineer Should Know about Modeling and Simulation; co-author of Software Cost Estimation with COCOMO II, and Software Cost Estimation Metrics Manual for Defense Systems. He is writing Systems Engineering Principles for Software Engineers and What Every Engineer Should Know about Python.

Position Paper

Dr. Madachy is a full tenured Professor at NPS teaching modeling and simulation, system software engineering, engineering economics and cost estimation (also course coordinator for these). He has developed full courses, short courses, and tutorials on system modeling and simulation for academia, conferences, and industry (internally and as consultant). His many publications are in these areas.

He has presented conference tutorials at IS and others for system and software cost modeling, process simulation and system dynamics.

He recently created and is lead developer for the open-source Systems Engineering Library (se-lib). He is also finishing the textbook What Every Engineer Should Know About Python.

Ryan Longshore (Naval Postgraduate School) - ryan.longshore@nps.edu

Ryan Longshore is an 18 year veteran of both the defense and electric utility industries. In his current role at Naval Information Warfare Center Atlantic (NIWC LANT), Ryan leads a diverse team of engineers and scientists developing and integrating new technologies into command and operations centers. Ryan is heavily involved in the Navy’s digital engineering transformation and leads multiple efforts in the model based systems engineering and model based engineering realms.

Ryan earned a BS in Electrical Engineering from Clemson University, a MS in Systems Engineering from Southern Methodist University, and is currently pursuing his PhD in Systems Engineering from the Naval Postrgraduate School. He is a South Carolina registered Professional Engineer (PE), an INCOSE Certified Systems Engineering Professional (CSEP), and has achieved the OMG SysML Model Builder Fundamental Certification.

Position Paper

Mr. Longshore is a practicing engineer mentoring a multitude of junior engineers in systems, electrical, and mechanical engineering. Additionally, he developed and led several sessions of a Fundamentals of Engineering (FE) review course for power systems and has contributed electrical, power systems, and engineering economics chapters to three FE and Professional Engineer (PE) exam preparation books.

He contributes to the Systems Engineering Library (se-lib) and is also conducting research into incorporating Artificial Intelligence (AI) into systems engineering practices.

Tutorial#47

Security as a Foundational Perspective in Systems Engineering: Engineering Trustworthy Secure Systems

Mark Winstead (The MITRE Corporation) - mwinstead@mitre.org

Keywords. Systems Security Engineering;Assurance;Trustworthy Systems;Systems Principles;Loss Driven Engineering;System Design;Trustworthy Secure Systems;Secure and Resilient Systems;Secure Design;NIST SP 800-160 Volume 1

Topics. 12. Infrastructure (construction, maintenance, etc.); 2.3. Needs and Requirements Definition; 2.4. System Architecture/Design Definition; 4.7. System Security (cyber-attack, anti-tamper, etc.); 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Security should be as foundational a perspective as system performance and safety (INCOSE SE

Vision 2035), as engineering of systems cannot assume benign environments for development, operations, maintenance, and support. Systems engineering must think and execute to properly employ principles, concepts, and methods to coordinate, orchestrate, and direct the activities to deliver assured trustworthy secure systems in and for contested environments. This tutorial overviews the needed security proficiency elements for systems engineering with alignment to many of the concepts of INCOSE's security in the future of systems engineering efforts (INCOSE Insight June 2022).Meeting stakeholder needs within constraints of cost, schedule, and performance must include meeting the security protection needs derived from those stakeholder needs. Activities address loss concerns associated with the system-of-interest throughout its lifecycle, considering potential adversities. This includes developing an inherently assured trustworthy secure design that 1) avoids loss from occurring, 2) minimizes effects of loss that does occur and 3) is intrinsically easier to analyze for vulnerabilities and hazards during upgrades.The tutorial presents a principled strategic approach focused on designing an intrinsically assured trustworthy design. This approach aids in realizing an intrinsically trustworthy secure system to help in prioritizations, reduce workload, and mitigate concerns of "unknowns" with assurance and thus producing trustworthiness in the system. This approach contrasts with widespread tactical risk-based approaches.This tutorial targets the experienced systems engineer who is a novice in Systems Security Engineering as a specialty discipline of systems engineering.

Biography

Mark Winstead (The MITRE Corporation) - mwinstead@mitre.org

Mark is the Systems Security Engineering department chief engineer in MITRE's Systems Engineering Innovation Center. He had over twenty-five years' STEM experience before joining MITRE in 2014, including stints as a crypto-mathematician, software engineer, systems architect, and systems engineer as well as occasionally working systems security engineering. Past employers include defense contractors, an EPA contractor, a Facebook-like start-up, a semi-conductor manufacturer, and a network performance management solutions company.

At MITRE, Mark has worked/works with various sponsors, helping programs with security engineering and teaming on integrating security into systems engineering for acquisitions and program offices. Recently, he has worked on advancing the systems engineering practice for security and resilience, working on Department of Defense (DoD) engineering standardization of practice and recently was asked to aid with an international effort in support of the US DoD.

With INCOSE, Mark serves as a co-chair of the INCOSE Systems Security Working Group, and at INCOSE IS 2023, was recognized with an Outstanding Service Award for work with advancing security and resilience within systems engineering.

Position Paper

Mark is co-author of NIST SP 800-160 Volume 1 Revision 1 Engineering Trustworthy Secure Systems, a publication intended to advance systems engineering in developing trustworthy systems for contested operational environments.

By IS 2024, Mark's book, Security: A Systems Engineering Approach is expected to be nearing publication by Wylie.

In the past, he has developed and delivered technical tutorials and other training for several employers and for customers, in recent years in security, cybersecurity and SSE. For INCOSE, he has delivered or co-delivered 7 INCOSE IS tutorials on the topic, as well as tutorials for chapters and regional conferences.

Tutorial#499

Systems Engineering for a Sustainable Future: Leveraging Emerging Technologies and Systems Modernization

Randall Anway (New Tapestry, LLC) - anwayr@gmail.com

Keywords. Semantic Computing;Bio-Inspired;Eco-mimicry;Sustainable;Trade-offs;Modernization

Topics. 1.3. Natural Systems; 10. Environmental Systems & Sustainability; 11. Information Technology/Telecommunication; 17. Sustainment (legacy systems, re-engineering, etc.); 3.9. Risk and Opportunity Management; 5.11 Artificial Intelligence, Machine Learning;

Abstract. In the current era of swift technological advancements and compounding global concerns, it is critical to forge a synergy between emerging technologies and global environmental sustainment and attend to the growing call for development of technologies that are simultaneously economically innovative and environmentally responsible. Innovative approaches that only leverage new technological insights without ensuring that these developments are applied and used responsibly compound existential risks rather than alleviate them. While technological innovation is a given, emerging technologies have shown immense potential in contributing to systems modernization. Semantic computing has surfaced as an enabler for organizing and utilizing information in ways that are meaningful to humans, showing great promise in developing solutions for global challenges. Further, bio-inspired systems offer promising avenues for innovation, drawing from principles observed in natural systems towards robust, adaptable, and efficient technological solutions respectful of planetary boundaries. There is a profound necessity to shine a light on the intersection of bio-inspired systems and semantic computing with regard to their dynamic interaction for effective systems modernization. Bio-inspired design, semantic computing, and value-sensitive practices provide a promising framework for creating innovative solutions that are both effective and ethically sound. This tutorial represents a critical step towards integrating ethical considerations throughout the development of technological solutions, with special attention paid to fostering systemic resilience in the face of unprecedented global challenges.

Biography

Randall Anway (New Tapestry, LLC) - anwayr@gmail.com

Randall Anway

An active member of the American Institute of Architects, and the International Council on Systems Engineering, Randall serves in a variety of capacities supporting professional development and continuing education e"orts in the fields of architecture and engineering. He holds a Master of Architecture from the University of Illinois, Urbana-Champaign and Bachelor of Fine Arts from the University of Connecticut. A registered Architect licensed in New York and Connecticut, Randall's work draws on 30 years diverse experience wrestling with academic, corporate, non- profit, and small business design and design management challenges. Since 2011 he has been specializing in design research for managing architectural adaptation and change, synthesizing theoretical and concrete perspectives on natural and human- evolved patterns and systems, and evaluating emerging technologies.

Randall has been involved with the Natural Systems Working Group since 2014 and the Social Systems Working Group since 2019. Identifying organizational partners and key contributors jointly with the NSWG is an area of current and ongoing activity.

Position Paper

utorial Development and Delivery Team (TBD)

Semantic Computing Specialist: experience in large-scale data interpretations for deploying semantic technologies in environmental monitoring and systems modernization.

Systems scientist: experience implementing modernized technology in sustainable practices.

Visionary engineer or designer: experience applying state-of-the-art technical applications toward social impact.

Expert in Bio-Inspired Engineering: noted for their work in using biological systems as templates for technological innovation.

Global Environmental Sustainability Expert: noted for contributions to the field of environmental conservation, focusing on the application of innovative tech

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Tutorial#83

Use a Framework for SE in Early-Stage R&D to Build Your Bridge that Spans the Chasm Between Research and Engineering

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Michael DiMario (CEO, Astrum Systems; Lucent Bell Labs, retired; Lockheed Martin, retired; SE in Early-Stage R&D Working Group Co-Chair) - mjdimario@outlook.com
Arno Granados (Strategic Technology Consulting; SE in Early-Stage R&D Working Group core member; Enchantment Chapter Past President) - Arno.granados@gmail.com

Keywords. SE in early-stage R&D;tailored approach;valley of death;research to engineering transition

Topics. 19. Very Small Enterprises; 3.5. Technical Leadership; 3.9. Risk and Opportunity Management; 5.5. Processes; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Researchers and funding organizations often do not understand the value of systems engineering in early-stage projects, defined as technology readiness levels TRL 1-5, during which systems engineering may be viewed as an unnecessary cost, and as a process-heavy effort applicable only for mature technologies. This may result in a relative lack of engineering rigor and of understanding of innovation context which often contributes to failures leading to the “valley of death” between fundamental research and applied development. There is more than one pathway for crossing the valley of death, and relevant application of systems engineering implemented at an appropriate level of rigor provides a foundation for transition and use of technical innovation. This tutorial provides an overview of the valley of death associated with technical and product incubation, the principles and foundational elements necessary for transitioning research projects to engineering development that bridges this valley of death, and presents a framework for systems engineering applicable in early-stage research and development (ESR&D), including tailoring considerations associated with TRL, stakeholder roles, and relevance to the use of MBSE and Digital Engineering. Associated framework metrics are presented to enable evaluation and practical implementation of the framework for systems engineering innovation management at this phase of technology development.

Biography

Ann Hodges (Sandia National Labs (ret); SE in Early-Stage R&D Working Group Co-Chair; Enchantment

Chapter Secretary, Past President) - annlhod@gmail.com

Ann Hodges retired after 48 years of service at Sandia National Laboratories (SNL) and was a distinguished member of technical staff. She was the Mission Services Division's systems engineering lead for the systems engineering part of the project and product delivery system (PPDS) at SNL and was a project manager and systems engineer for a complex exploratory-phase project. She is a primary author of the risk-informed graded approach to the application of project management, systems engineering, and quality management which is one of the key aspects of the PPDS. She collaborated with the Laboratory Directed R&D program office to tailor the application of PPDS to SNL's research portfolio.

Position Paper

Co-presented a tutorial on "Integrating SE, Project Management and Quality Management" to the INCOSE Enchantment Chapter in 9/2017 and INCOSE IS2018. Was project manager and SE for a complex exploratory-phase project and collaborated with the SNL Laboratory Directed R&D program office to tailor the application of PPDS to SNL's research portfolio. Co-developed PPDS instructional materials, and taught PPDS concepts to over 200 management and staff members. She co-chairs the SE in Early-Stage R&D Working Group and was co-editor and co-author of several papers in INSIGHT volume 26 issue 3, "SE in Early-Stage R&D: Bridging the Gap."

Michael DiMario (CEO, Astrum Systems; Lucent Bell Labs, retired; Lockheed Martin, retired; SE in Early-Stage R&D Working Group Co-Chair) - mjdimario@outlook.com

Dr. Michael DiMario is the founder and CEO of Astrum Systems, a global consulting venture focused on research and early development prototyping using a comprehensive systems approach. His corporate career began at General Electric Medical, progressed to Lucent Bell Laboratories, and Lockheed Martin. With a background in systems engineering, quality management, and software engineering, DiMario's career has spanned the leadership and management of numerous critical R&D projects and organizations. Dr. DiMario has 6 patents, numerous corporate trade secrets, a published book on systems engineering, a book chapter on systems engineering, and 49 peer reviewed papers in regard to systems engineering, innovation, quantum magnetometry, and quality management.

Position Paper

Has 6 patents, numerous corporate trade secrets, a published book on systems engineering, a book chapter on systems engineering, and 49 peer reviewed papers in regard to systems engineering, innovation, quantum magnetometry, and quality management. Was a Lockheed Martin R&D Sr. Program Manager of early-stage R&D, Lockheed and Bell Labs Director. Co-chairs SE in Early-Stage R&D Working Group and was co-editor and co-author of a paper in INSIGHT volume 26 issue 3, "SE in Early-Stage R&D: Bridging the Gap." Co-author paper in INSIGHT vol 23 issue 3 "Perceived Conflicts of Systems Engineering in Early-Stage Research and Development."

Arno Granados (Strategic Technology Consulting; SE in Early-Stage R&D Working Group core member; Enchantment Chapter Past President) - Arno.granados@gmail.com

Arno Granados is currently a Senior Principal Systems Engineer at Strategic Technologies Corporation, where he applies more than 30 years of professional experience in systems and software engineering challenges to model-based systems engineering and digital transformation. His experience with R&D includes academic research, commercial product development, and defense systems and system of systems. His experience includes ground, airborne, and space-based systems, commercial product development, medical devices, and digital ecosystem architecture. He stood up an MBSE organization at SNL, and has been active in INCOSE as past president of a local chapter, and presenter at IW and IS.

Position Paper

Mr. Granados is a core member of the SE in Early-Stage R&D Working Group and co-author of two papers in INSIGHT volume 26 issue 3, "SE in Early-Stage R&D: Bridging the Gap". "Digital Engineering Enablers for Systems Engineering in Early-Stage Research and Development" and "A Bridge Blueprint to Span the Chasm Between Research and Engineering—A Framework for Systems Engineering in Early-Stage Research and Development" on which this tutorial is based. He was Director of Engineering at Cloud Cap Technologies successfully bringing two new products from early-stage development to the commercial market.

INCOSE Contents

INCOSE Content#1004

Architecture starts when you carefully split a system into two subsystems. There it begins...

Maarten Bonnema (University of Twente) - g.m.bonnema@utwente.nl

Topics. Architecture

Abstract. When systems become too large to be developed by a small team, the system needs to be split into smaller pieces. While this splitting can be done organically, it is much wiser to consciously create a system architecture. Such an architecture should promote coherence between the parts of the system. Also, the architecture should enable consistency in the development effort while allowing for concurrent development. In this talk we will explore the reasons for creating an architecture, the essential ingredients of an architecture, ways of describing an architecture, and discuss approaches for creating one.

Biography

Maarten Bonnema (University of Twente) - g.m.bonnema@utwente.nl

G. Maarten Bonnema is professor of Systems Engineering and Multidisciplinary Design (SEMD) at the Faculty of Engineering Technology at the University of Twente. He has worked as a Systems Engineer at ASML. His research aims at supporting system design, conceptual design and mechatronic design by improving multidisciplinary communication and systems thinking. Two main application areas are high-tech systems and electric mobility. He has a broad teaching expertise spanning design in general, industrial design engineering, and systems engineering.

INCOSE Content#1001

Deciding what to build and why…

Dinesh Verma (Stevens Institute of Technology and Systems Engineering Research Center (SERC)) - dverma@stevens.edu

Topics. The Why, What, and Value of SE – begin with WHY and set the big picture; consider including how to position SE to various audiences and stakeholders

Abstract. Likely the best articulation of systems engineering was by Dr. Mike Griffin in his March 2007 Boeing Lecture "Systems Engineering and the "Two Cultures" of Engineering." An excellent systems engineer in his own right, Dr. Griffin has the ability to communicate and engage at the highest levels of leadership in government and industry. This talk for me is personal. From my time as the Founding Dean of a new School of Systems and Enterprises at Stevens Institute of Technology to leading the Systems Engineering Research Center (the largest research center focused on Systems Engineering in the world), I try to embody the message as I speak to diverse audiences ranging from potential students to practitioners, corporate executives, and Congressional leaders. The discipline of systems engineering is relatively young from an academic perspective. Yet modern societies depend more on robust execution of systems engineering than most in society realize. How do we better frame the why, what, and how of systems engineering from the viewpoint of an audience that is non-technical – program and project managers, policy wonks, legislative staffers and leaders, and business leaders – to effectively communicate and enlist their support as we seek "a better world through a systems approach."

Biography

Dinesh Verma (Stevens Institute of Technology and Systems Engineering Research Center (SERC)) - dverma@stevens.edu

Dinesh Verma served as the Founding Dean of the School of Systems and Enterprises at Stevens Institute of Technology from 2007 through 2016. He currently serves as the Executive Director of the Systems Engineering Research Center (SERC), a US Department of Defense sponsored University Affiliated Research Center (UARC) along with the Acquisition Innovation Research Center (AIRC). During his twenty years at Stevens he has successfully proposed research and academic programs exceeding $200m in value. Prior to this role, he served as Technical Director at Lockheed Martin Undersea Systems in the area of adapted systems and supportability engineering. Dinesh received his PhD and M.S. in Industrial and Systems Engineering from Virginia Tech.

INCOSE Content#1007

Embrace Yourself! Our Responsibilities and Competencies as Complex Problem Solvers

Nicole Hutchison (Systems Engineering Research Center (SERC)) - emtnicole@gmail.com

Topics. Competencies, Career Paths, and Opportunities - giving early careers the bigger picture

Abstract. Over the last decade, the field of systems engineering has matured rapidly. As part of this, a number of systems engineering competency frameworks have been created with substantial overlap between the frameworks. As we gel as a discipline, we should also focus on the power that many systems skills bring. In particular, systems engineers should be good complex problem solvers (and according to the World Economic Forum, complex problem solving is – and has been - one of the top skills needed globally). This talk will talk about the skills required for complex problem-solving and highlight how you, as a systems engineer, are uniquely positioned to help our colleagues and organizations develop these skills.

Biography

Nicole Hutchison (Systems Engineering Research Center (SERC)) - emtnicole@gmail.com

Dr. Nicole Hutchison is a senior research scientist at the Systems Engineering Research Center. Her expertise lies in the areas of workforce development, specifically competencies and career paths. She has led and supported the creation of competency frameworks for systems engineering, mission engineering, digital engineering, and AI. Prior to joining the SERC, she worked for a defense contractor, supporting the US Departments of Defense, Homeland Security, Health and Human Services, and Justice.

INCOSE Content#1006

Engineering in the Digital Age – Revolutionize Digital Engineering with MBSE

Prof. Dr.-Ing. Lydia Kaiser (Technische Universität Berlin) - lydia.kaiser@tu-berlin.de

Topics. MBSE and Digital Engineering

Abstract. We live in the digital age, where interconnected, autonomous, and multimedia systems are the new reality. To meet the demands of the digital future, we need to revolutionize the way we engineer. Digital Engineering is poised to be a game-changer and promises to transform our industries, but it cannot succeed without MBSE. In these 30 minutes, we will take a look at the history of engineering and glimpse into its digital future. This presentation will introduce you to the fundamentals of MBSE, guiding you through its landscape and providing a roadmap for entry. It will address the most pressing questions: What exactly is a model? Why does everyone seem obsessed with SysML? Do I need to be fluent in SysML? What do I need to know to be able to talk about it and how do I start my own journey into MBSE? As well-educated engineers, stepping into your career or a new organization, you'll encounter new challenges: complexity, interdisciplinary collaboration, and an increasing number of cutting-edge technologies with immense potential and (unknown) risks. Discover how to deal with these challenges through Digital Engineering and why it demands MBSE. Shape the revolution in your organization and become a pioneer in this transformative field.

Biography

Prof. Dr.-Ing. Lydia Kaiser (Technische Universität Berlin) - lydia.kaiser@tu-berlin.de

Lydia Kaiser is the Head of the Digital Engineering 4.0 department at Technische Universität Berlin and the Einstein Center Digital Future. She teaches and conducts research in the field of digital engineering, focusing on Model-Based Systems Engineering.

She earned her degree in Physics from Paderborn University and completed her Ph.D. in 2013 in the area of Model-Based Systems Engineering. As a researcher, Lydia Kaiser worked with different industrial partners on research projects and developed new approaches to enable engineers to deal with complexity and interdisciplinarity. She trains engineers in various career steps in systems engineering and awakens enthusiasm for Model-Based Systems Engineering.

INCOSE Content#1005

Interfaces and the Somebody Else's Problem Field

Paul Davies (Thesystemsengineer.uk) - paul@thesystemsengineer.uk

Topics. Interfaces

Abstract. Nobody working on a project wants to be tasked with resolving interfaces. It generally happens too late and is seen to be a root cause of project failures. These are sweeping generalisations, yet there is a grain of truth. It becomes a vicious circle of blame waiting for the next project to do the same. In effect, interfaces are often subject to the 'Somebody Else's Problem' field, described in 'Hitchikers' Guide to the Galaxy'. Every Interface is an opportunity to lose information, time, control and money through contention between stakeholders at either end. Interface management is perceived as a critical skill in the engineering of successful systems, but finding useful material proves elusive. It is not that there is a gap in the collective Body of Knowledge (BoK) – but there is definitely a gap in the documented BoK. This presentation explores characteristics of this gap, and strings together key concepts in best practice. Differences between best practice for interfaces and best perceived practice for architecting systems are noted with recommendations for changes in approach. The talk is based partly on the INCOSE Systems Engineering Handbook and partly on the INCOSE UK 'Don't Panic!' guide to managing interfaces, written by the.

Biography

Paul Davies (Thesystemsengineer.uk) - paul@thesystemsengineer.uk

Paul Davies is semi-retired, and was previously the Discipline Manager for Systems Engineering at Network Rail Infrastructure Projects. In that role he was responsible for promoting improvements in process and in practitioner competence in all aspects of systems engineering. Prior to this, he worked for Thales UK, with nearly thirty years' experience in SE research, innovations management, SE functional leadership, and project engineering management. Over a succession of challenging projects with challenging customers, Paul learned many empirical lessons on interfaces, internal and external to systems, and they are distilled here.

Paul is a Chartered Engineer, a Certified Systems Engineering Professional, a Past President of the UK Chapter of INCOSE, and has been a popular presenter and tutorial lead at many INCOSE events.

INCOSE Content#1003

Requirements—Why Bother?

Dr. Mike Ryan (Capability Associates Pty Ltd.) - michael.ryan@incose.net

Topics. Requirements

Abstract. The role of requirements in systems development is perhaps one of the most contentious issues in modern systems engineering. Some believe that formal requirements, particularly text-based requirements, are no longer necessary as part of modern development methodologies. Yet, others point out that the lack of adequate requirements has been shown to be one of the principal causes of project failure. So, who is correct? Why would a project team bother to expend all that effort and angst in developing requirements if they aren't necessary? This presentation will summarise the opposing perspectives and highlight the importance of a robust set of concepts, needs, and requirements in the design and development of a system of interest, as well as in the critical activities of verification and validation.

Biography

Dr. Mike Ryan (Capability Associates Pty Ltd.) - michael.ryan@incose.net

Dr. Michael Ryan is the Director of Capability Associates Pty Ltd. He lectures and regularly consults in a range of subjects including communications systems, systems engineering, requirements engineering, capability management, and project management. He is a co-chair of the INCOSE Requirements Working Group. Dr. Ryan is a Fellow of Engineers Australia, an INCOSE Fellow, a Fellow of the Institute of Managers and Leaders, a Fellow of the Royal Society of New South Wales, and a senior member of the IEEE. He is the author or co-author of 14 books, 4 book chapters, and over 450 technical papers and reports.

INCOSE Content#1002

Systems Thinking: What Systems Engineers Need to Know

Dr. Michael C Jackson OBE (University of Hull) - m.c.jackson@hull.ac.uk

Topics. Systems Thinking

Abstract. Systems Thinking is an approach used to address complex real-world problems. According to INCOSE-UK, it is 'an essential skill for Systems Engineers … and provides a key intellectual underpinning for Systems Engineering'. Unfortunately, the literature associated with Systems Thinking can seem dense and more concerned with theoretical matters than practical application. This presentation seeks to cut through the academic noise and pinpoint the crucial features of Systems Thinking for Systems Engineers. There are four essential things that Systems Engineers need to know about Systems Thinking. First, that it developed as a complementary approach to science because the scientific method struggles in the face of complexity. Second, Systems Thinking has been successful in developing a range of systems methodologies (systems engineering, system dynamics, the viable system model, soft systems methodology, critical systems heuristics) that can engage with different aspects of complexity. Third, it is necessary to understand the strengths and weaknesses of these different methodologies and to use them in combination to bring about systemic improvement. Finally, such 'Critical Systems Thinking' requires a radical reorientation of mindset on the part of Systems Engineers.

Biography

Dr. Michael C Jackson OBE (University of Hull) - m.c.jackson@hull.ac.uk

Michael C. Jackson is Emeritus Professor at the University of Hull and MD of Systems Research Ltd. He graduated from Oxford University, gained an MA from Lancaster University and a PhD from Hull, and has worked in the civil service, in academia and as a consultant. Between 1999 and 2011, Mike was Dean of Hull University Business School, leading it to triple-crown accreditation. Mike has been President of the International Federation for Systems Research and the International Society for the Systems Sciences. He was editor-in-chief of Systems Research and Behavioral Science for 26 years. In 2011 Mike was awarded an OBE for services to higher education and business. In 2017 he received the Beale Medal of the UK Operational Research Society for 'a sustained contribution over many years to the theory, practice, and philosophy of Operational Research'. In 2022 he received the Pioneer Award of the International Council on Systems Engineering for 'the development of the foundations of systems engineering as author, educator and intellectual leader in systems thinking'. Mike is known as a key figure in the development of 'critical systems thinking' - a topic on which he has published ten books and over 150 articles. His last book Critical Systems Thinking and the Management of Complexity was published by Wiley in 2019. His new book Critical Systems Thinking: A Practitioner's Guide will be published by Wiley in 2024.