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IN THIS EDITION

1. QUOTATIONS TO OPEN ON

"I would willingly do requirements analysis for free for 1% of the savings."

Robert John Halligan

◇

"When you stop learning, you stop living."

Mark Evans

◇

"This is a story about four people: Everybody, Somebody, Anybody, and Nobody. There was an important job to be done, and Everybody was asked to do it. Everybody was sure Somebody would do it. Anybody could have done it, but Nobody did it. Somebody got angry about that, because it was Everybody's job. Everybody thought Anybody could do it, but Nobody realized that Everybody wouldn't do it. It ended up that Everybody blamed Somebody when actually Nobody asked Anybody."

Charles Osgood

2. FEATURE ARTICLES

2.1 Enabling the Digital Thread

by

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Abstract

In 2018, at the AIAA SCITECH Forum entitled "Seizing the Next Digital Transformation," Ms. Philomena Zimmerman gave a presentation on the Digital Thread[1] during a panel session entitled "The Dawn of Digital Engineering." It defined the Digital Thread as a continuous lifecycle where digital models were used to not only inform the specific project, but also could be used to influence future, similar projects. The concept was that if we could create an "authoritative source of truth," we could have greater confidence earlier in the design process to make critical decisions, thus saving time and money while improving performance. Using digital tools to create digital products has been going on since digital computers were invented. In the early days, this meant creating specific models by direct programming. Over time, the special purpose computer tools were generalized to create many different, although usually similar, models. With the advent of personal computers, we saw an explosion of commercial-off-the-shelf (COTS) tools for engineering. In the systems engineering space, tools like Vitech CORE and No Magic's MagicDraw were developed in the 1990s. In the design engineering space, many physics-based modeling tools were developed, including tools for mechanical, fluid dynamics, and electrical analysis. But these tools were designed originally to only work independently. As we tried to apply these kinds of tools to larger projects we ran into difficulty in collaboration and scalability. Also, interoperability between tools was very difficult, often leading only to simple comma-separated file exchanges. The vision of the Digital Thread was a seamless flow of data between these tools, thus forming a federated set of databases that becomes the "authoritative source of truth." This paper discusses an approach to enabling the digital thread through direct analysis and integration between a systems engineering tool, Innoslate®, and various design engineering tools. The combination of these tools appears to meet the goals of the Digital Engineering Strategy.

Introduction

In 2018, the Department of Defense published its "Digital Engineering Strategy."[2] This paper defined five goals that made up the strategy: 1) Formalize the development, integration, and use of models to inform enterprise and program decision making; 2) Provide an enduring, authoritative source of truth; 3) Incorporate technological innovation to improve the engineering practice; 4) Establish a supporting infrastructure and

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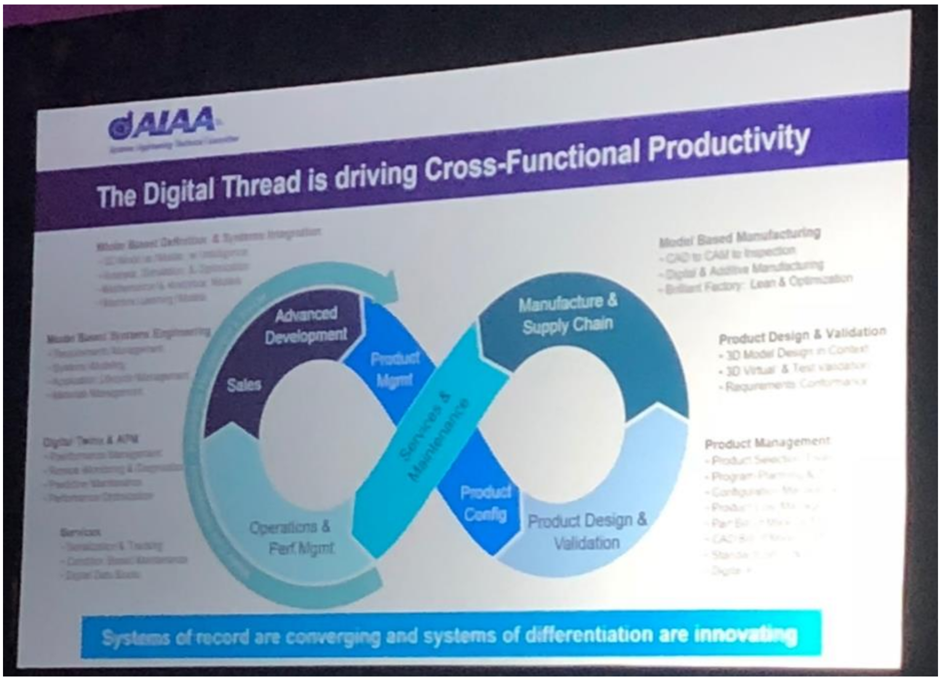
[1] "The Dawn of Digital Engineering," Philomena Zimmerman, AIAA SCITECH Forum, January 8, 2018.
[2] Digital Engineering Strategy, US Department of Defense, June 2018.

environments to perform activities, collaborate, and communicate across stakeholders; and 5) Transform the culture and workforce to adopt and support digital engineering across the lifecycle. Earlier that year at the AIAA SCITECH Forum entitled “Seizing the Next Digital Transformation,” Ms. Philomena Zimmerman gave a presentation on the Digital Thread during a panel session entitled “The Dawn of Digital Engineering.” A picture of one of her viewgraphs was captured on the next page.

The digital thread depicted represents the complete set of models used in every phase of the lifecycle. Although it is unclear how these models will become “authoritative” (which implies some Authorization Body making this determination), they would form this authoritative source of truth. The difficulty comes in the integration of data between these tools. These tools have all been developed by different tool vendors and there are no universally accepted standards for data. In fact, the basic questions remains: what data needs to be passed between the tools and what data resides “authoritatively” in which tool database?



The International Council on Systems Engineering (INCOSE) has had a “Tools Interoperability Working Group” for many years. They explored a number of potential standards and as of today, aside from ReqIF[3] for requirements, there seems to be no common interoperability standard for systems engineering tools, let alone the wide variety of tools indicated in the picture above. Part of the problem is no one has really answered the question above. The rest of this paper begins to explore potential answers to this question.

Horizontal Integration – Systems/Program Level

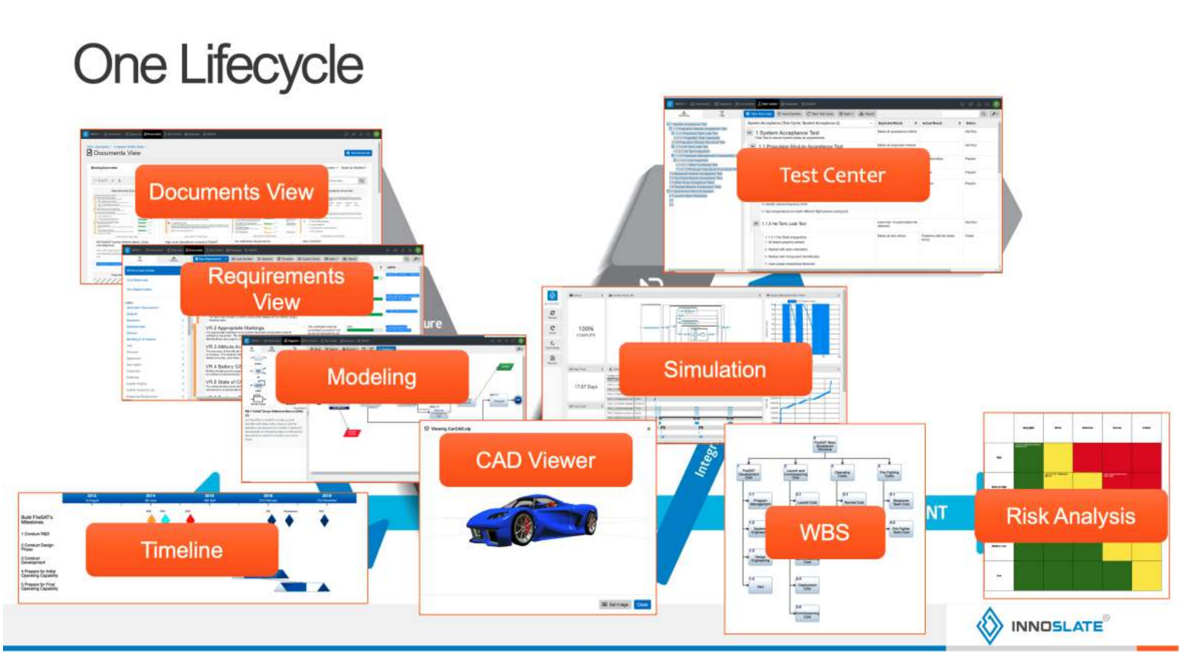
Several tool vendors have approached horizontal integration, the integration of systems engineering tools, from requirements, to modeling and simulation, to verification and validation, by linking tools in each of these areas through direct integration or through other mechanisms, such as OSLC.[4] Since in most cases the

[3] For access to the ReqIF standard, see https://www.omg.org/reqif/.
[4] For more information see https://open-services.net/.

tools were not designed to work together, the user must create and manage the links between the tool data elements.

SPEC Innovations took a different approach. Since we were designing a new systems engineering tool from scratch, we had the luxury of integrating the functionality needed for systems engineering across the lifecycle. We participated in the Lifecycle Modeling Language (LML) Steering Committee, which developed a new open standard for program management and systems engineering. LML is a hybrid, object and structured language. It provides a complete ontology, along with set small set of mandatory diagrams. LML was designed to be extended and a later release of the standard showed how it could map to SysML.

As a result, the figure below summarizes the various views and capabilities of Innoslate version 4.4.



Each phase of the systems engineering lifecycle has various modeling and simulation capabilities. Perhaps the most unique part of this approach is the concept of a *Document Model*. Each element of the Document Model represents a thought, sentence or paragraph that can be reused and traced to other elements of the overall model. It enables the user to create any type of document, create their own templates, and conduct basic word processing.

This integration also includes the means to develop, capture and evaluate cost, schedule, and performance, while mitigating risk in each of these areas for both the system and program.

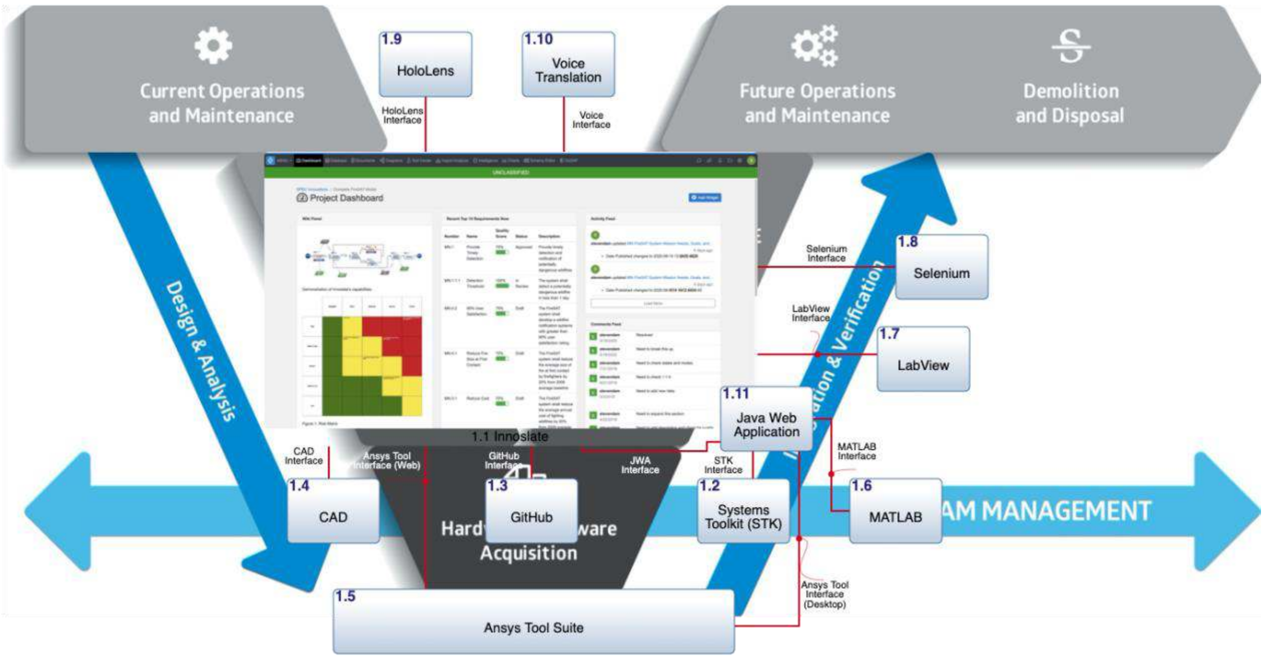
The tool can also be extended through the Schema Editor and REST & Java APIs.

Now that we have covered the program and systems level of the lifecycle, we need to determine how to integrate this level with the design engineering level.

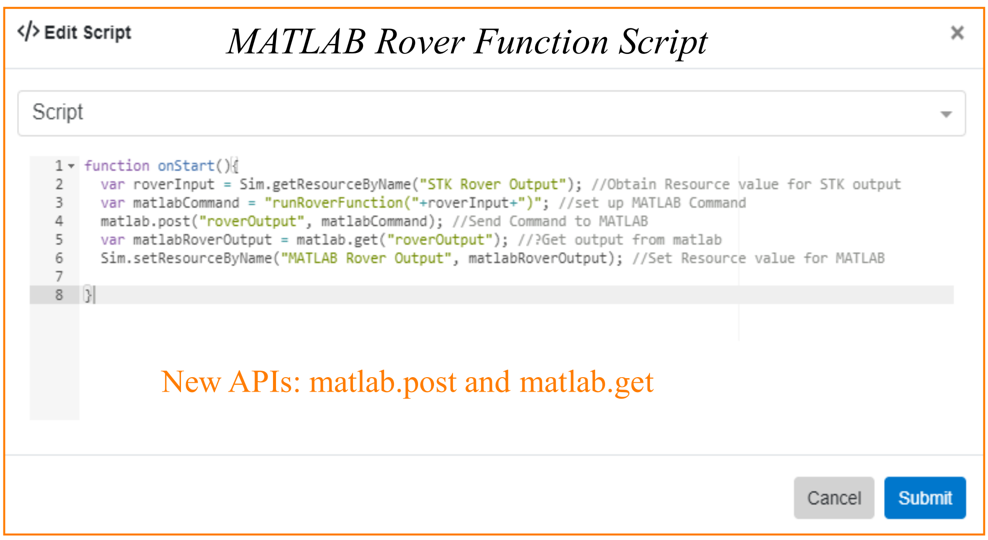
Vertical Integration – Systems to Design Level

Vertical integration is the process of moving information from the program/systems level to the design engineering (mechanical, electrical, software, etc.) level and *abstracting* the results from the design engineering work back to the program/systems level so that decisions can be made. The process of abstraction is critical in that the decision makers usually do not have the time and/or skill set to understand the design details. They count on the systems engineers to help translate the detailed design information into a more understandable form. And of course, maintain the traceability throughout the process to ensure that the mission and design requirements have been met through the V&V process.

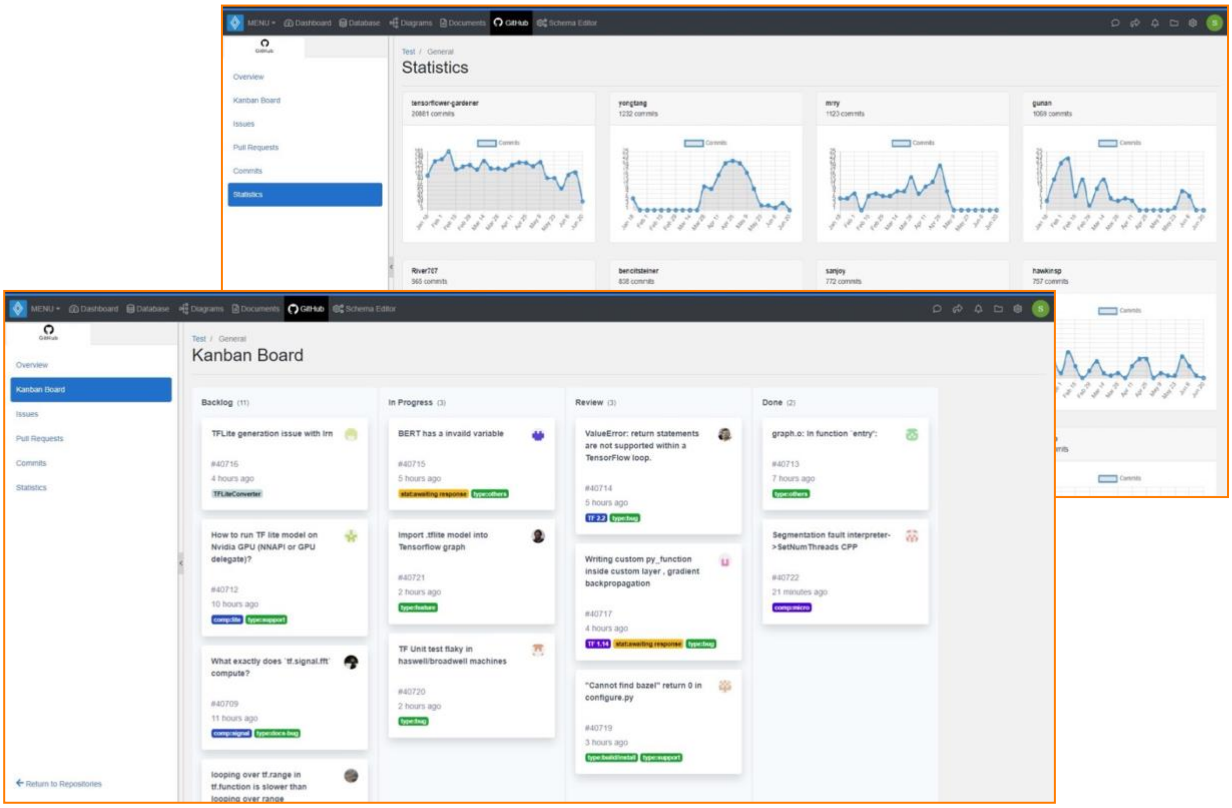
Our approach to vertical integration, given the lack of any kind of real interoperability standard, has been to identify leading COTS products and integrate directly through their APIs. The figure below shows the tools we are currently researching for integration.



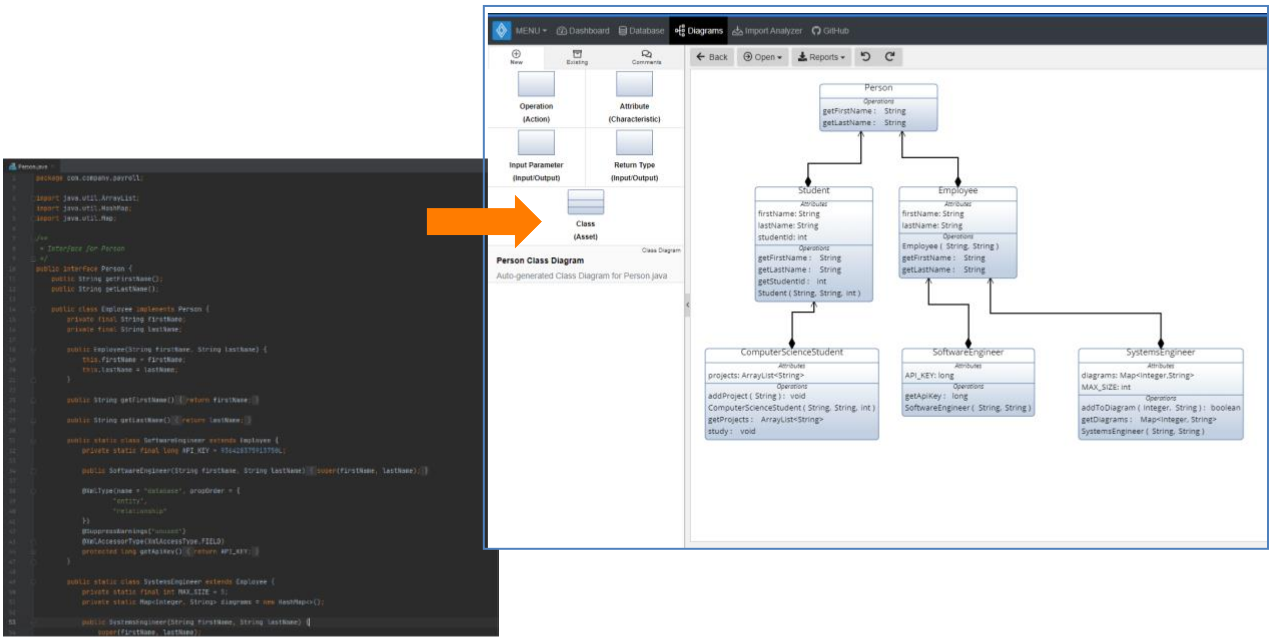
Since a number of these tools are still desktop tools, we created a Java Web Application (JWA) to interface between the desktop tool and Innoslate. In version 4.4 of Innoslate we have rolled out the initial set of tool integrations using the JWA. This latest release (1/25/2021) includes the capability to co-simulate with Systems Toolkit (STK) from AGI and MATLAB from MathWorks. To enable co-simulation, we created new APIs for Innoslate's simulator. An example in the simulator script (JavaScript) is shown below. In this example, we have a "matlab.get" API that receives the output from MATLAB for use in Innoslate's simulation and a "matlab.post" API that passes data from Innoslate to MATLAB.



The GitHub integration provides a very good example of abstraction. The user selects the GitHub repository of interest and then opens up views of the status of the software development activities. An example of two of the views (Kanban Board and Statistics) is shown below.



These views provide a window into the software development process, but do not interfere with it. In addition, we are exploring how to take code and generate an abstracted Class Diagram. A prototype capability is shown below.



Note that all of the code elements are not reflected in the Class Diagram, only the essential ones that could be related back to requirements. This capability will enable a true “round-trip” were the requirements could be passed to the code developers, in the form of a Class Diagram and generated code and then, when the software is developed, the resulting Class Diagram can be automatically compared to the original to ensure that the requirements were met. It could also show any gaps, which might show problems with the requirements, thus improving the requirements development process in the future.

Summary

Updates in the evolution of systems engineering have provided a mechanism to propel systems engineering into the future of digital engineering. LML provides a strong ontology and diagramming framework to model complex systems, including those that use AI technologies. As a cloud-native tool, Innoslate implements LML and goes beyond the current standards to provide a seamless, integrated, collaborative environment for program management, systems engineers, and other stakeholders to work together and provide the necessary legal products required by any lifecycle process.

About the Author

Dr. Steven H. Dam is the President and Founder of Systems and Proposal Engineering Company (SPEC Innovations). Dr. Dam has a BS degree in Physics from George Mason University and a PhD. in Physics from the University of South Carolina. He has been involved with structure analysis, software development, and systems engineering for over 40 years. He participated in the development of C4ISR Architecture Framework and DoD Architecture Framework (DoDAF), the Defense Airborne Reconnaissance Office (DARO) Vision Architecture, the Business Enterprise Architecture (BEA), and Net-Centric Enterprise Services (NCES) architecture. He has also been a long term member of INCOSE and was a Past-President of the San Diego Chapter before relocating to the Washington Metropolitan Area. Dr. Dam has presented numerous papers and seminars to the WMA Chapter. He is a Past Director for the Americas for INCOSE, Past-President, and Programs Chair of the WMA Chapter of INCOSE.

2.2 An Overview of Systems Engineering in the Australian Transport Sector

by

Ruben Welschen, Eduardo Bellon, Colin Brown, Richard Fullalove, Grace Kennedy, Kim Irvine, Neal Mumford, Malaeka Nadeem, John Nasr, Emma-Rose Tildesley, Hitesh Patel, Donovan Roodt

Systems Engineering Society of Australia

February 25, 2021

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Abstract

The application of Systems Engineering (SE) principles, processes, and practices has been steadily increasing within the Australian transport sector. The Systems Engineering Society of Australia (SESA) has recently made efforts to bring together individuals working within the Transportation domain to further improve the visibility of SE, to share experiences and good practice, and to support the career development of SE practitioners. This article assesses the status of SE in the transport sector. The outcomes from a recent industry workshop concerning the Maturity of SE in Transport are summarized, confirming the interest in SE and highlighting shared challenges for the domain. Sets of observations written by sector practitioners from different Australian states are provided to give a cross-sectional view of the SE practices being employed in the Australian Transport sector. Conclusions are drawn and recommendations made for both the sector and SESA.

Introduction

This provides an overview of Systems Engineering (SE) in the Australian Transportation sector, with the objective to allow the sector (which has developed differently across different states) to learn from each other and at the same time to provide the Transportation Working Group (TWG) of the Systems Engineering Society of Australia (SESA) an understanding of where it can best focus its efforts to achieve its objectives.

This article provides a high-level overview of the implementation of Systems Engineering in the transportation sector for most of the states in Australia. It does this by focusing on 3 key success factors identified in an evaluation of the application of SE in the Infrastructure sector in the Netherlands.

1. Transport related SE Standards and Procedures, their implementation in contracts
2. Senior Level Support for the implementation of SE
3. SE Skills & Training both for Practitioners and Management on both delivery and client side.

Based on our analysis there are not many formal evaluation studies of the application of SE in the Australian Transport sector. Therefore, this article uses assessments by systems engineering practitioners in the different states to provide an evaluation based on their professional experience. In order to also provide some international benchmarking and learning, the article includes a high-level assessment of the implementation of SE in the United Kingdom and the Netherlands, where the implementation of Systems Engineering in the Transportation sector is relatively advanced.

The article is not comprehensive in its review of the transportation sector, nor in its coverage of all overseas practices – we anticipate future coverage. The objective is to initiate a conversation, to exchange knowledge, and to create synergies at a national level.

SESA

1 July 2020 saw the inauguration of the new executive committee of SESA. This new executive committee, led by SESA President John Nasr, also has a new structure with distinctly new type of roles including a Chief Value Officer (Helen Williams) and national domain leads, including a Domain Lead for Transport & Cities (Ruben Welschen). The new national domain-led structure (Figure 1) is a departure from the previous organizational division of state branches; with the objective of using the domain knowledge and domain networks to provide even more value to the members in that domain.

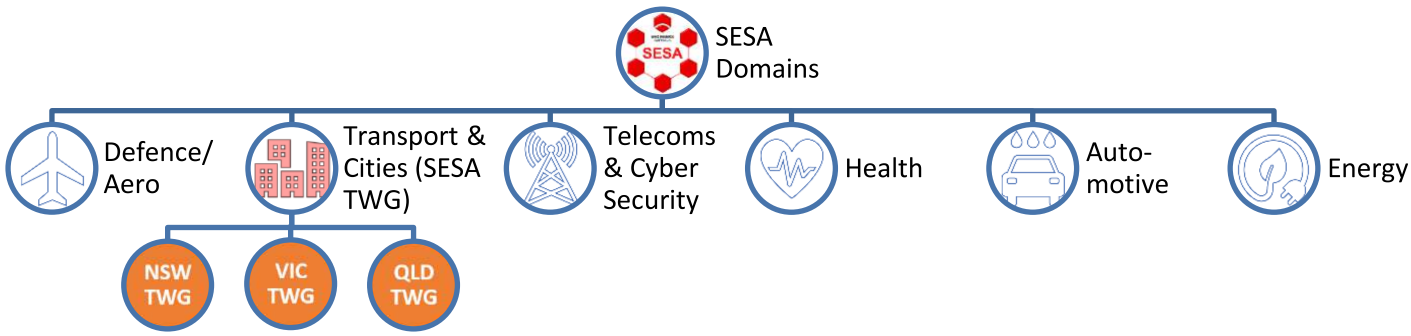

Figure 1: New SESA Domain-led Structure

SESA Transportation Working Group

The SESA Transportation Working Group (TWG) aligns closely with the INCOSE TWG (SESA being the Australian chapter of INCOSE), however the scope of the SESA TWG is broader than the charter of the INCOSE TWG. The current SESA TWG objectives are:

1. To provide a focal point for dissemination of systems engineering knowledge within the broader transportation sector in Australia.
2. To contribute to collaboration in systems engineering practice, education and research in the transportation sector.

3. To improve the professional status of all persons engaged in the practice of systems engineering within the transportation sector.
4. To encourage governmental and industrial support for research and educational programs that will improve the systems engineering process and its practice in the transportation sector.

Within the SESA TWG, there are currently three state based working groups focused on bringing together individuals within each state for specific events and sharing of state-nuanced knowledge and experiences; New South Wales (NSW), Victoria (VIC), and Queensland (QLD). The objectives of the state TWG's are now being aligned and, partially due to the COVID-19 situation there have been more nationally broadcasted events.

Panel Session on the Maturity of Systems Engineering in the Australian Transport Sector

On the 27th of October 2020, SESA organized the Australian Systems Engineering Workshop (ASEW) including a Panel session about the maturity of Systems Engineering in the Australian Transport sector. The session had 95 attendees, facilitated by the author of this article and four key speakers presented their views:

- Anne O'Neil, Systems Engineering Catalyst & Strategist from the United States of America.
- Andre Hefer, A/Associate Executive Director, Systems Engineering & Assurance, Sydney Metro.
- John Nasr, President, Systems Engineering Society of Australia.
- Owen Traynor, Systems Integration Director, Cross River Rail Delivery Authority.

The following general observations were made:

- There is a noticeable increase in the uptake of Systems Engineering in the Transport sector, partially due to the Authorized Engineering Organization (AEO) framework in NSW
- Transport requires added Systems Engineering, due to the complexity of transport networks and integrated transport solutions, and many stakeholders and users' requirements

In relation to maturity the following observations were made:

- Better application of SE is required for needs assessment and procurement.
- There is a focus on assurance and process, rather than solving the problem.
- There is a need to upskill and integrate Systems Engineering with existing roles.
- There is a need to activate informed executive sponsors.
- The safety regular can play a role in clarifying expectations for early phases and for laggards.

This article is a natural progression to further document the level of implementation of Systems Engineering in the Australian Transport sector.

General Observations

Interest in the application of SE in the Australian transport sector has gradually increased as a solution to the challenge of managing complex and multidisciplinary infrastructure projects. Although the SESA Transport & Cities Domain Lead was only appointed in July 2020, TWG interest groups in some states were already existent for several years. In 2012, the NSW TWG was setup and in 2013 Systems Engineering got a significant boost when the Asset Standards Authority (ASA) commenced operations on 1 July 2013 and mandated a system engineering approach for Authorized Engineering Organizations. Victoria followed with the establishment of a VIC TWG early 2017. Late 2020 SESA set up a TWG in Queensland. At the time of writing the TWGs combined have more than 30 active volunteers.

In comparison with the Defense Industry which has a nationally consistent procurement process, SE in transport has thus far developed per state. The Office of the National Rail Safety Regulator emphasizes the importance of SE in its Safety Message and its Major Projects Guidelines. And the Rail Industry Safety and Standards Board has published some SE related guidance such as the Guidelines Systems Safety Assurance, Human Factors Integration and AS 7473 Complex system integration in railways.

Within the Transport Sector, Systems Engineering is primarily applied in the Rail Sector, but also more and more in the Road sector. Intelligent Transport System (ITS) projects in the road sector typically apply an SE approach. Austroads, a collective of Australian and New Zealand transport agencies, representing all levels of government, identified the adoption of a systems engineering approach as a key success factor in the successful incorporation of operations in the design process. In 2014 Austroads developed a report on the Procurement of ITS which used a system engineering approach to define the relationships between the phases of the system lifecycle. Austroads is currently developing a National ITS (Intelligent Transport Systems) Architecture which is listed as a priority action in the Policy Framework for ITS in Australia 2012. This work has included an assessment of international ITS architectures, development of a context and vision, and an initial business architecture. Next steps include establishment of formal governance mechanisms and extension of the Australia's context. With increasing road congestion, constrained infrastructure and the escalation of autonomous vehicles and technology on the roadways, private and public road operators in Australia are recognizing the need to adopt a systems approach.

In terms of research, there is a small, but expanding body within academia that are focused on applying systems approaches and SE to the transport sector. For example, the SMART Infrastructure Facility of UOW (University of Wollongong) utilizes systems modeling & simulation for transportation applications. The Human Factors and Sociotechnical Systems group (University of the Sunshine Coast) applies systems thinking methods to safety in transport and infrastructure and Deakin University has used systems mapping expertise to develop the Smart Rail Route Map. SE research projects in transport have tended to be industry focused and funded. Funding avenues include contract funding directly through individual businesses as well as through collaboration with industry-wide bodies such as the Australasian Centre for Rail Innovation (ACRI), RISSB, Australian Railway Association and the Office of the National Rail Safety Regulator (ONRSR). Although individual SE projects have in the past been funded as part of larger government funded research centers, there is no national agenda for SE research, and the current economic climate sees more dependence on industry funding (regardless of sector).

Training in Systems Engineering has become more prevalent in the Australian Transportation sector. SESA members deliver a short course in “Systems Engineering Tools for Delivering Transport Projects” through Engineers Australia's professional development (PD) provider Engineering Education Australia (EEA). Many businesses who have committed to SE have also developed in-house training or bring in external PD through training consultancies and academia (see individual state sections below for more specifics). Within academia there are a limited number of universities providing SE education offerings. SESA recently published a list of SE training available on their website. For example, UOW teaches SE within their Masters of Engineering Asset Management from a rail context (since the lecturers are performing research in rail). UOW have also been brought in to provide short courses to rail operators in introductory SE, and more recently Model Based Systems Engineering introductory courses for Sydney Trains and QLD Rail.

New South Wales Observations

In NSW, the creation of the ASA in 2012 has had the biggest impact by placing systems engineering at the center of how projects should be delivered for Transport for NSW. It resulted in 15 SE standards and guidelines which provide detailed guidance for the application of Systems Engineering. The ASA developed and delivered Systems Engineering 101 training to staff and industry creating awareness of the discipline of SE and the inherent benefits of the approach.

Over the years we have seen an improvement in the specification of SE requirements in NSW public transport contracts, and it is now TfNSW established practice to prepare and submit a Business Requirements Specification (BRS), Concept of Operations, and System Requirements Specification (SRS) at key TfNSW network asset assurance and configuration gateways. The application of SE is scaled and tailored according to the level of novelty, complexity and risks. There is ongoing effort to achieve consistency of application via the SE Steering Committee and Community of Practice, as the application of SE principles & practice remains variable. Requirements analysis, functional analysis and agreement of verification & validation during the system definition review are common for Rolling Stock projects but not for infrastructure projects. This significantly affects the quality of infrastructure specifications, the clarity of verification criteria; and causes issues late in the project lifecycle affecting either the time, cost or benefit of the project.

Model-Based Systems Engineering is being increasingly applied to develop the Operational Concept, Maintenance Concept, as well as functional, physical and behavioral models and architectures for complex system delivery programs, including the Digital Systems Program and Sydney Metro.

Work is progressing to align Systems Engineering and Digital Engineering (DE) practice, by appending DE model metadata to requirements schema as a delivery project progresses, to ensure traceability from the system solution back to the SRS, and ultimately to the BRS. This will also facilitate improved whole-of-life asset management decision-making many years after system acceptance.

In the wake of the recent bushfires and floods, TfNSW is strengthening its asset resilience approach, and the Asset Resilience Strategy has adopted the INCOSE Systems Engineering Book of Knowledge Resilience Engineering concepts and guidance as an element of this approach. The strategy also adopts a System of Systems approach that considers the relationship between natural systems (i.e. the climate and weather system, as well as the ecosystem) and human-engineering systems (i.e. the transport system and its logistic supply chain).

Application of SE in complex roads programs is on the rise, with the Western Harbor Tunnel project adopting a strong SE-based approach and the establishment of a Development Partner that is the Systems Integrator or "guiding mind".

The government has recognized the benefit of the SE approach in the planning, specification, delivery and maintenance of systems, and this is apparent in the asset management and asset attestation requirements and outcomes expected by Treasury and Infrastructure NSW. The recent restructure of the TfNSW organization has seen a growth and repositioning in SE roles, including the creation of a team of systems engineers who are deployed across transport projects and provide advisory services.

There is still a lot to do to achieve a better level of maturity, particularly in the phases prior to procurement. These changes are the beginning of improving the application of SE across transport projects.

Victoria Observations

The Victorian transport network is currently undergoing significant changes, not just from a development/management point of view but also triggered by an unprecedented influx of investments in major infrastructure projects.

2019 saw a major governmental restructure aimed at integrating various agencies into a unified Department of Transport. This mammoth merger brought several challenges; one of them being to re-engineer ways of working across the newly formed Department. As such (at the time of writing this article) most of the new processes and policies that relate to Systems Engineering are currently under development.

Processes that were established prior to the formation of DoT are still being followed by delivery agencies to deliver on their existing commitments.

The application of SE in the transport industry in Victoria is not only happening for project delivery, but also in the establishment of strategies and long/mid-term transport plans through the use of enterprise SE, notably with the establishment of an integrated framework with a whole-of-departmental lifecycle at its center that stems from an innovative blend of Asset Management and SE.

Major infrastructure projects in Victoria are embracing the idea of setting project objectives through requirements early in the lifecycle and developing architectures to help manage the integration effort. However, the project teams are still structured mostly around disciplines and work packages which sometimes makes it difficult for systems theory to offer significant value.

SE is being well supported by executives across the Victorian transport system and its value understood, especially amongst supply chain and project delivery agencies. Having said that there is now an increased realization that clients and contracts must take a more holistic and integrated view throughout the lifecycle and not just in development.

A training "Introduction to Systems Engineering for Public Transport" has been provided in Victoria in 2019 by Engineering Education Australia. The Victorian DoT has an SE Capability Specialist, in charge of uplifting

DoT staff on SE competencies, has recently released an SE Wiki portal (Figure 2) in the DoT intranet and provided generic SE training to more than 150 individuals across all divisions.

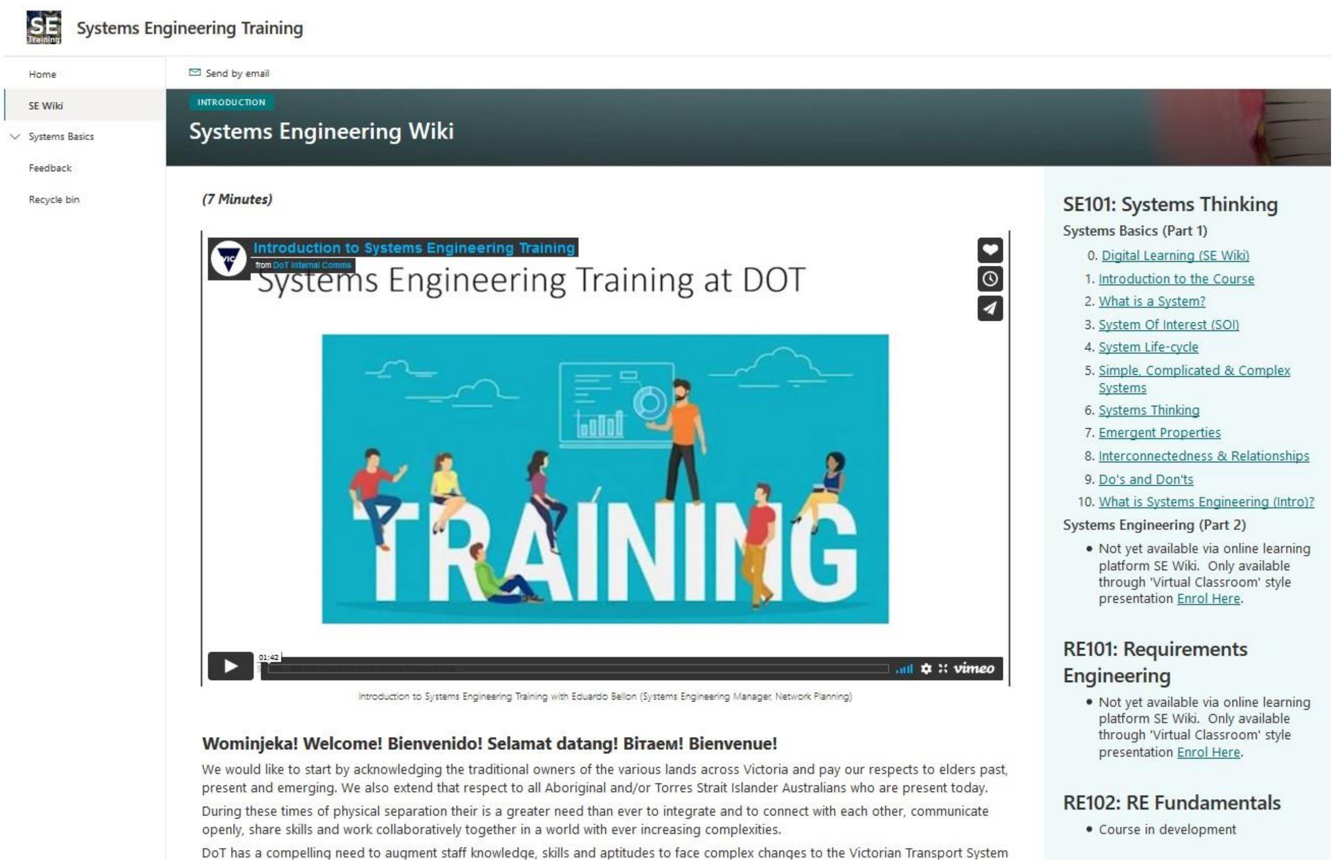

Figure 2: SE Wiki Portal for DoT

Queensland Observations

From an industry perspective there has been a definite increase in SE activity within the Queensland transport sector. Major rail projects have shown an interest in demonstrating adherence to an ISO 15288 approach. However, projects are often applying SE at the assurance phase rather than using it to understand the problem space. However, there are pockets of work being done in Brisbane to understand how the procurement side integrates with other aspects of SE.

There appears to be a recognition that things have to change and that the industry can't just keep doing things the way they've always done". Railways are evolving and systems which were once 30 plus years in the ground are now upgrading at a far faster rate. Bespoke solutions and late changes in the design equal cost and or time overruns. And the advent of cyber threat with more digital systems means a consistent approach to developing processes and interfaces requires a more holistic (System of Systems) approach to be taken.

ONRSR is taking a more proactive role in driving the application of SE in QLD rail projects. And senior management levels are supporting SE as a means of providing a better view into delivering these complex transport systems. DTMR however, is the most influential stakeholder in the introduction of SE for all QLD Transport Modes.

A training “Systems Engineering Tools for Delivering Transport Projects” has been provided in QLD in 2019 by Engineering Education Australia. In QLD there are two university courses for Systems Engineering:

- Bond University – Systems Thinking & Management Modelling for Projects
- James Cook University – Introduction to Systems Engineering and Project Management

Western Australia Observations

The Public Transport Authority of Western Australia (PTA) is currently developing the application of Systems Engineering to support the delivery of rail projects across the metropolitan area. There is pressure on Perth's rail industry to deliver a complex METRONET program. Challenges in applying a systems approach to meet assurance requirements to support projects to deliver successful integrated solutions are evident and a framework to provide further guidance is under development.

Systems Engineering is still in its infancy at the PTA, but its development is supported at all levels of the organization which appreciates the positive impact applying an integrated SE approach on projects can have in achieving successful outcomes. A Systems Engineering Steering Group has been established to identify and agree the strategy in the development of PTAs systems engineering approach to drive the enhancement of PTA’s current procedures whilst ensuring consistent delivery of projects and asset management in alignment with requirements and PTA’s Safety Management System.

Training and focused workshops have been introduced to further develop the competency of key engineering roles appointed to deliver projects and to date over 150 individuals from PTA and supply chain have attended Engineering Education Australia's 'Systems Engineering for Public Transport to drive a consistent approach to Systems Engineering across the PTA and the wider Rail industry.'

South Australia Observations

The adoption of a Systems Engineering methodology appears to be in its early stages at the SA Department for Infrastructure and Transport (DIT). DIT has recently published their first version of a Systems Engineering standard in April 2020 which “describes the implementation of the Systems Engineering (SE) framework which forms part of the Rail Commissioner’s Safety Management Systems and Processes against which Rail Accreditation has been awarded by the Office of the National Rail Safety Regulator (ONRSR)”.

Current DIT projects however do not show significant uptake of Systems Engineering. By way of example, the DIT Master Specification does not specifically include a Systems Engineering Management Plan, although does require Contractors, in their Design Management specification, to comply with “AS15288, ISO/IEC 29148 and ISO/IEC 26702”. Furthermore, DIT tenders and panels do not explicitly request Systems Engineering as a core service.

The Netherlands Observations

The Netherlands has implemented SE nationally in the civil infrastructure sector for well over 15 years now and has been held up as an example of good practice of SE in infrastructure. The Netherlands has followed a different path for its Civil Infrastructure sector than that used in Australia. In the Netherlands a single set of National Systems Engineering Guidelines and procurement practices have been adopted by ProRail, The

Dutch Rail Infrastructure Manager, The Directorate General for Public Works and Water Management and a variety of industry associations. The accompanying Dutch version of the contain a wealth of guidance in Dutch as well as information about Systems Engineering education.

ProRail and the Directorate for Public Works and Water Management have integrated SE requirements in their contracts and administered them accordingly. Research of the implementation of SE in the construction sector in the Netherlands notes that “SE is closely interwoven with all other management aspects and should be treated as such, by implicitly adopting SE in the work processes.

In the Netherlands national infrastructure projects commonly risk-assess the compliance demonstration of individual requirements during the tender phase and requirements which are considered high risk by either the client or the delivery side are discussed as part of consultative processes during the tender.

United Kingdom

Across transportation sector in the UK, Systems Engineering processes are defined, mapped to formal standards such as ISO15288 and used on projects and programs to aid in the clarity of definition of requirements, specification of solution and delivery of assurance. In December 2020, The UK Institution of Civil Engineers (ICE) published a report titled: “A Systems Approach to Infrastructure Delivery”, to address mega-project cost overruns as well as increasing use of complex technology in infrastructure as well as to reap the benefits from the use of Building Information Modelling (BIM) and digital twins.

The UK has examples of cutting-edge strategies of system thinking which are being applied to the Long-Term Strategy of Network Rail. Network Rail through Target 190 is developing efficient interaction with industry to help reduce the cost of signaling from 415K GBP to 190K GBP per Signaling Equivalence Unit. This is the UK’s instantiation of the Reference CCS Architecture (RCA) being developed in Europe. The work being produced via Target 190 relies heavily on the development of an Enterprise Architecture and System Engineering. This work is being shared with industry to help deliver new improved and streamlined processes.

Alongside Network Rail there is the UK Rail Safety and Standards Board - Whole System Interface Committee (WSIC). It is focused on understanding whole of industry issues and systems to better inform industry wide decisions and programs. The WSIC think in systems terms and believe in the necessity of translation to enable the wider business and industry to engage in the Enterprise Architecture without the modelling overhead.

There is definitely a growing level of Senior and Industry support and this is being driven by the costs of signaling being unsupportable at current levels. We see with the High Speed 2 project that BIM and the upskilling is forming a fundamental move forward. And we see this in the ICE report: “A Systems Approach to Infrastructure Delivery”. Training and updating of skills is essential and we can see that clients are now moving toward prescribing Systems Engineers in their contracts.

Conclusions & Recommendations

Based on the initial assessment there appears to be insufficient formal evaluation of the application of SE on Australian Transport Projects to provide an in-depth analysis of the application of SE in the states and territories of Australia.

➔ *The sector would significantly benefit from further research and an SE evaluation framework covering the full lifecycle (pre- and post- delivery contract) such as that used in Dutch Evaluation Studies to get a nationally comparable evaluation of the application of SE on transport projects. SESA intends to work with national and state government bodies and research institutions to facilitate this happening.*

NSW has developed detailed guidance for the application of SE. Other states are still in the process of developing application-level guidance for the transport sector. However, large transport infrastructure projects historically have not performed requirements analysis, concept phase verification/validation and functional analysis as is common during the system definition review of large rolling stock projects. There are efforts to apply SE processes prior to the delivery phase, but there is a tendency to focus on the SE during the delivery phase.

➔ *Infrastructure projects should apply good practice Systems Engineering including requirements analysis and client-side validation. A national framework for evaluation of SE on transport projects will further highlight these issues. The infrastructure sector could learn from SE processes in the Australian Defense or Rolling Stock sector or from the Dutch Civil Infrastructure sector.*

The transport sector lacks national direction in the application of SE compared to the defense sector or national guidance provided in other countries. The ONRSR mandates SE but detailed guidance and/or direction on the procurement side is not prevalent or mature.

➔ *SESA will advocate with national and state government bodies to establish further national direction, expectations and guidance.*

Given the increased interest and identified need for implementation of SE in the Australian transport sector, there is a significant SE skills shortage in the sector. In some countries and Australian states, government led initiatives in skills and training development facilitates the change to SE based working, whilst in other states it is primarily left to the industry.

➔ *To enable the transition to a more systems engineering based way of working and development of SE skills and capability in the industry, short term government initiative in skills development is required.*

Further Work Required

As with all good research, this article also identified the need for further analysis:

- Formal evaluation of the implementation of SE on Transport projects in NSW and other states
- Further analysis of the application of SE in Transport in other states such as Canberra, South Australia and Western Australia.
- Evaluation of the application of SE outside the rail sector requires further assessment.

- Comparison of good practices of SE in Transport in other countries could be expanded
- Detailed comparisons of the application of SE in other domains could developed.

List of Acronyms Used in this Paper

Acronym	Explanation
AEO	Authorized Engineering Organization
ACRI	Australasian Centre for Rail Innovation
ASA	Asset Standards Authority
ASEW	Australian Systems Engineering Workshop
BIM	Building Information Modelling
BRS	Business Requirements Specification
DE	Digital Engineering
DIT	Department for Infrastructure and Transport
DoT	Department of Transport
INCOSE	International Council on Systems Engineering
ICE	UK Institution of Civil Engineers
ITS	Intelligent Transport Systems
NSW	New South Wales
ONRSR	Office of the National Rail Safety Regulator
PTA	Public Transport Authority of Western Australia
QLD	Queensland
RCA	Reference CCS Architecture
RISSB	Rail Industry Safety & Standards Board
SE	Systems Engineering
SESA	Systems Engineering Society of Australia
SRS	System Requirements Specification
TfNSW	Transport for NSW
TWG	Transportation Working Group
UOW	University of Wollongong
VIC	Victoria
WSIC	Whole System Interface Committee

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References

1. R. S. (Robin) de Graaf, R. M. (Rick) Vromen & J. (Hans) Boes, Applying systems engineering in the civil engineering industry: an analysis of systems engineering projects of a Dutch water board, 2017
2. SESA, SESA Executive Committee Responsibilities - Appendix 5.0, in SESA AGM 2020 Papers. 2020.
3. https://www.sesa.org.au/sesa-working-groups/transport-working-group/
4. https://www.sesa.org.au/event/asew/
5. Hocking, B., Berry, J. & Waite, M., The case for systems engineering investment in early stages of Australian rail projects, 2018.
6. https://www.transport.nsw.gov.au/industry/asset-standards-authority
7. https://www.onrsr.com.au/documents/resource-centre/publication/safety-data-bulletin/aus-onrsr/safety-bulletins/importance-of-a-system-engineering-approach
8. https://www.onrsr.com.au/__data/assets/pdf_file/0016/10465/Guideline-Major-Projects-inc-EC-and-M-guideline.pdf
9. RISSB, Integration of Human Factors in engineering design v1.0 20 March 2018
10. RISSB, Systems Safety Assurance 1.0 September 18, 2018
11. RISSB, AS 7473 Complex system integration in railways, 2020
12. Austroads, AGRD02-19, Guide to Road Design Part 2: Design Considerations, 2019
13. https://eea.org.au/courses/systems-engineering-tools-delivering-transport-projects
14. https://www.sesa.org.au/news/new-graduate-certificate-in-systems-engineering-from-australias-national-university/
15. https://www.transport.nsw.gov.au/industry/asset-standards-authority/find-a-standard?f%5B0%5D=document_owner%3A830&f%5B1%5D=document_status%3A136&f%5B2%5D=standards_discipline%3A1002
16. Victorian Transport Asset Lifecycle (ViTAL) Guide, Department of Transport, DoT-GDE-002
17. https://bond.edu.au/subject/ssud71-407-systems-thinking-and-management-modelling-projects
18. https://secure.jcu.edu.au/app/studyfinder/?subject=EG3000
19. https://dpti.sa.gov.au/rail_network_access/general_information/engineering_standards
20. https://www.dpti.sa.gov.au/contractor_documents/masterspecifications/Project_Controls
21. https://www.leidraadse.nl/assets/files/downloads/LeidraadSE/V3_EN/boek_Leidraad_SE_ENG_3_72dpi-def.pdfText
22. https://www.leidraadse.nl/downloads
23. Houdt, van den S.T.A. and Vracken, J.L.M, Rolling out Systems Engineering in the Dutch Civil Construction Industry. Identifying and Managing the Factors leading to Successful Implementation, 2013.
24. UK Institution of Civil Engineers, A Systems Approach to Infrastructure Delivery, December 2020, https://www.ice.org.uk/getattachment/knowledge-and-resources/briefing-sheet/a-systems-approach-to-infrastructure-delivery/ICE_Systems_Report_final.pdf.aspx
25. https://eulynx.eu/index.php/docman-hidden/presentations-given/255-t190plus-webinar
26. https://ertms.be/workgroups/ccs_architecture
27. https://www.rssb.co.uk/what-we-do/Groups-and-Committees/Technical-Strategy/SIC-Chairs/WSIC

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The article co-authors are members of the State Transportation Working Groups, plus other experienced Systems Engineering professionals from states across Australia.

2.3 The Key to Successfully Engineering a Complex System – Modelling & Simulation

by

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Abstract

Modelling and simulation tools and techniques are used across an extraordinarily wide range of domains and have just as wide a variety of applications in these domains. This article will discuss some of these uses and assert that modelling and simulation is fundamental in allowing us to engineer solutions to the problems facing us in an ever more complex world, and why modelling and simulation should and in fact must be recognised as a discipline in its own right.

Introduction

According to some scientists, there is a 50-50 chance we are in fact computer generated virtual entities living in a simulation. (Ananthaswamy, 2020). We won't be going to go down that particular rabbit hole in this article, but I will use this opportunity to highlight the fundamental role that modelling and simulation is playing in our everyday lives, and how it will become more and more critical over time.

From a systems point of view, the capability that modelling and simulation provides for managing complexity and investigating system behaviours has made it central to the development of new systems as well as the management and maintenance of existing systems. Modelling and simulation also enable experiential learning to be carried out in a safe[5], repeatable and controlled environment - when developed and operated by simulations specialists.

The breadth of applications and manner in which simulation is applied can be readily seen from a review of the proceedings of conferences run by organisations such as Simulation Australasia. Papers published from the 2019 Australasian Simulation Congress address topics such as the importance of understanding the role of a facilitator in a simulation event, results from a study into the use of simulation for improving Situation Awareness skills, use of simulated virtual worlds for developing nursing skills, an investigation into how the use of simulated environments used in Massive Multiplayer On-Line Role Playing Games can be used to cope with real life stressors, and the use of modelling and simulation for design techniques for search and rescue. (Naweed, Bowditch, & Sprick, 2019).

Despite the wide variety of uses of modelling and simulation, there are fundamental characteristics that are widely shared, and these characteristics represent the core of a discipline-based approach.

It should be noted that this paper is largely focussed on computer-based modelling and simulation. It is acknowledged that there are indeed many kinds of modelling and simulation that are not implemented with a computer, including, for example, role playing activities for education.

What is Modelling & Simulation?

An on-line etymology dictionary states that the word "simulation" originated in the mid-14th century, from an old French word meaning "pretence", and from the Latin "*simulationem* - an imitating, feigning, false show, hypocrisy" (Sciolist, 2021). In this sense, the use of the simulation in football (or soccer where I come from) to refer to an event where a player attempts to deceive a referee by feigning an injury or pretending to have been fouled is perhaps the ultimate embodiment of the original meaning.

A plot of the usage of the word in Google n-gram viewer shows a relatively significant usage of the word in the 1500s (the earliest date supported by Ngram), and then usage pretty much flatlines until the 1950s, when it increases exponentially. The use of the word model follows a somewhat similar pattern, albeit with a higher background level of usage. An analysis of search results for simulation in Google Scholar between 1881 and

[5] It is important to consider psychological safety as well as physical safety. Flight simulators offer the possibility of training without the hazards associated with training in the real aircraft, but could still cause psychological "damage" if training sessions are not managed appropriately. This need for psychological safety extends to simulation facilitators and instructors. For a discussion on the concept of psychological safety in simulations, see (Carrera, et al., 2016) and (Naweed, Dennis, Krynski, Crea, & Knott, 2020)

2020 leads to a similar view. It would seem that the advent of digital computers stimulated a great deal of activity in the field of modelling and simulation.

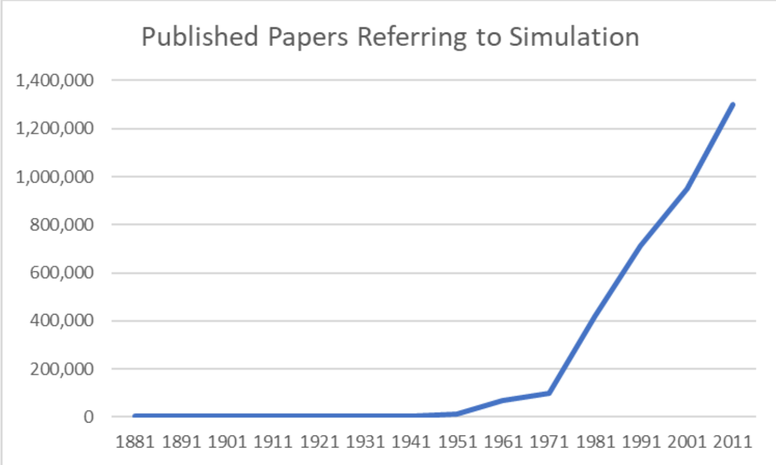

Figure 3- Google Scholar results for articles containing the word “Simulation”

In view of the alternative uses of words, definitions are appropriate to orient readers. It is usual to define simulation incrementally, as in:

- Model: an abstract representation of an object, process, or system. A model can be a physical representation (as in a model car), or conceptual, as in a mathematical model of a system.
- Simulation: the process of iterating a model over time.[6]

The noted systems thinker Donella Meadows said “everything we think we know about the world is a model, including the mental models in our heads”. However, while these models have a strong congruence with the real word, they also fall short of representing the world fully (Meadows, 2008). Or to put it another way, in a saying attributed to statistician George Box - "All models are wrong, but some are useful" (Box, 1979). To take this one step further, it has been argued by neuroscientists that our brains are prediction machines that are “constantly attempting to match incoming sensory inputs with top down expectations or predictions” (Clark, 2013). If this is the case, then in some sense one could assert that the brain is simulating the world as an important element of its strategy to enable us to cope with the enormous complexity with the finite resources available to each individual.

The relationship between a model and a simulation is usually neither one way nor static. Take for example the manner in which simulations and models are used in physics. In cosmology, scientists have created a model of the universe, and used simulation to iterate that model over time (billions of years!) to make predictions as to what we should observe today. The comparison of observation with prediction allows the model to be tuned and the process starts again. An example of this level of model-based simulation is the IllustrisTNG project, the latest iteration of which required a year to complete, running on between 16,000 and 20,000 cores. (Singleton, 2019). The possibility that our brains use this approach was discussed earlier in this article.

[6] Although generated by the author, these definitions are based on common use – see for example (US Department of Defense, 2018) and (US Department of Defense, 2020)

A more prosaic and perhaps more practical example is the use of models and simulations in weather forecasting. A forecast is essentially the output of a executing a computer model over a period of simulated time, starting with huge datasets that represent the observed current state. Weather prediction models are run multiple times, and the resulting statistics can be used to indicate the likelihood of rain on a given day in the future, for example (Australian Government Bureau of Meteorology, 2019).

There are many examples of the use of modelling and simulation in informing policy settings for public health responses to the pandemic, for example, in predicting the impact of various interventions on the rate of spread of the virus (Rogers & Molteni, 2020). One of the reports on this work noted that:

> *"Simulation models of the kind our team used allowed policymakers to think through the future and provide a basis for better-informed real-world decision making. All of us — including world-leading scientists — have learned something important this year. We have learned the value of simulation models as an additional contribution to science, and to public health." (Thompson & McClure, Melbourne's coronavirus second wave seemed impossible to defeat. Our modelling showed exactly how to do it, 2020)*[7]

Use of models and simulation in healthcare has a long history. Hundreds of years ago and, in one instance, thousands of years ago, intricate physical models were used to help teach anatomy and physiology and in training in obstetrics and many surgical disciplines. Simulators were used to learn skills before performing them on patients and in high-stakes assessment. In the 18th century, obstetric simulators that could leak amniotic fluid, and blood were used to train midwives and obstetricians to recognize and manage complications of childbirth (Owen, 2012).

In the case of aviation, simulators have been used for training almost from the very beginning, as it was soon recognized that special skills were required. As early as 1910, an article in Flight magazine extolled the virtues of a device called the Sanders Teacher, which consisted of a modified aircraft mounted to a universal joint that was fixed to the ground: (Havard, December 1910) quoted in (Rolfe & Staples, 1997).

> *The invention, therefore, of a device which will enable the novice to obtain a clear conception of the workings of the controls of an aeroplane, and of the conditions existent in the air, without any risk personally or otherwise, is to be welcomed, without a doubt.*

The aviation industry represents an important example of all of the benefits that can be gained from the use of modelling and simulation. In the design phase, simulation is used to speed up the product design cycle, including the ability to mathematically model all properties of the designed product with their interactions and to determine the behaviour under realistic operating conditions. With suitable high-fidelity multidisciplinary simulation methods at hand, the flight characteristics of an aircraft can be determined through numerical computation and the flight envelope can be flown virtually before the real first flight is performed (Kroll, Abu-Zurayk, & al, 2016). Simulation is used to develop new cockpit user interface concepts, and to evaluate

[7] For a more detailed scientific discussion of this work, see (Thompson J. , et al., 2020).

human performance factors (Kirwan, 2019). Simulators are widely used to train pilots, and to assist with accident investigation (Tydeman, 2004).

A military exercise, in which people hone their skills on real terrain with real weapons, perhaps with simulated weapon effects, is itself a simulation. The former U.S. Army Simulation, Training, and Instrumentation Command (STRICOM) (its current name is PEO STRI) has as its catchphrase "*All But War Is Simulation*".

Modelling and Simulation is explicitly stated as being a key enabler of US DoD activities. (US Department of Defense, 2018). To quote from the Department of Defense (DoD) Modeling and Simulation Enterprise (MSE) website (US Department of Defense, 2020):

> *"Modeling and simulation (M&S) is a key enabler of Department of Defense (DoD) capabilities, supports the full range and scope of DoD missions and operations, underpins innovative solutions meeting national security challenges, and saves resources. Over the past 20-plus years, M&S has become pervasive, almost ubiquitous, throughout the Department."*

It would possible to continue on in this vein for several pages, citing examples from education, economics, emergency management, mining, agriculture, town planning and … actually the list of application domains in itself would go on for many pages.

Simulation for Training – the example of Aviation

As noted above, the aviation industry is an exemplar case of the use of modelling and simulation. The progress of pilot training simulators from the simple systems used at the dawn of aviation to the wide range of highly complex and high-fidelity devices in use today has largely been driven by one overarching goal – safety.[8]

The use of simulators for civil aviation is highly regulated and standardized, with regulations defining:

- the technical specifications which simulators must meet,
- the methods by which conformance to those specifications is to be demonstrated,
- the approach to be taken to validation of a flight simulator, and
- the data upon which the simulator is to be designed and validated.

The technical specifications address not only the requirements associated with simulating the target platform, but also address requirements for the environment within which it operates, such as the visual, meteorological and radio- frequency aspects.

Regulations also cover the requirements for the processes and procedures with which an organization operating a flight simulator must comply, as a well as the way in which a flight simulator is used within a pilot training program. A simulator is subject to an initial qualification; this confirms compliance of the device with the technical specification and the organizational requirements. Flight simulators are then subject to a yearly

8 There are a number of excellent overviews of the history of the use of simulation in aviation training, see for example (Page, 2004), (Rolfe & Staples, 1997).

recheck, to confirm continued compliance with the regulations. Configuration control of the device is an essential element of the management system which a flight simulator operator is required to have in place.

These regulations have been developed over many years, by international consensus, by working groups consisting of representatives from airlines, simulator manufactures, aircraft manufacturers, and the regulators themselves. The regulations have continued to evolve over time, to consider changes in technology used for simulators, changes in the technology of aircraft themselves, to address lessons learned from accident investigations, and changes in an understanding of how humans learn and perform in stressful situations.

The technical specifications are based on an analysis of the competencies that a pilot must be trained to achieve safe and efficient operations. The latest iteration of the ICAO Manual Criteria for the Qualification of Flight Simulators (International Civil Aviation Organisation, 2015) provides significant detail covering:

- the tasks considered throughout a broad range of pilot licensing, qualification, rating and training requirements;
- a summary of seven standard FSTD examples; and
- a reference to the training task matrix which compares each task, differentiated on the basis of licence or qualification requirements, against the suite of simulation features.

Even though the technology used in flight simulators has advanced enormously, a flight simulator cannot be a perfect representation of the aircraft it simulates, or of the environment in which the aircraft operates. One of the goals of the regulatory framework is to ensure that any divergences are managed in a way that does not degrade the ability of a pilot to safely operate the corresponding aircraft. This includes ensuring that a training program using a flight simulator is based on an assessment of the specific simulator to be used, and inclusion of defined approaches to mitigate the possibility of this “negative training”. It is largely for this reason that each high-fidelity flight simulator example is assessed by the authorities – there is no equivalent of a type certificate for a full flight simulator.

An example of recent changes in training methodologies can be seen in the Evidence Based Training concept. To quote from the European Union Aviation Safety Explanatory Note (European Union Aviation Safety Agency, 2015) describing the reasoning behind the regulatory changes that introduced this new approach:

“The EBT project is a global safety initiative, whose objective was to determine the relevance of existing pilot training and to identify the most critical areas of pilot training according to aircraft generation.

Data analyses conducted for the EBT project corroborate independent evidence from multiple sources, which include flight data analyses, reporting programmes and a statistical treatment of factors reported from an extensive database of aircraft accident reports. Both processes and results were peer-reviewed by pilot training experts from airline operators, pilot associations, civil aviation authorities and original equipment manufacturers in order to ensure transparency and to bring a qualitative and practical perspective. During the study, critical core competencies were examined both in technical and non-technical areas, thus offering *the opportunity to train and assess flight crews according to a defined, useful and comprehensive set of measurement criteria.*

EBT is intended to enhance the confidence and capability of flight crews to operate the aircraft in all flight regimes and to be able to recognise and manage unexpected situations."

Not all users of simulation have the same level and depth of regulation and standardization, but all uses of simulations for training should have the same basic characteristics:

- A definition of the training competencies that the simulator is to achieve,
- An analysis of these competencies to enable the definition of a specification of the simulation, that describes the required level of fidelity against the target real world system,
- A set of data that defines the performance of the real-world system, against which the performance of a simulator can be assessed,
- A definition of supporting features that facilitate the use of the simulator as a training device (for example an instructor station), and
- A process by which the capability of the simulator to deliver the required training can be assessed, and incorporation of the outcomes into a documented training program that accounts for any limitations of the simulation.

Modelling and Simulation in Systems Engineering

The term Model Based Systems Engineering (MBSE) is growing in use over recent years, although the concept can be traced back to the early 1990s, with the term originated by Wayne Wymore in his book of the same name. The book was written as a textbook for students of systems engineering, one of the objectives being "*to explicate mathematical system theory as the basis for the development of models and designs of large-scale complex systems…*" (Wymore, *Model Based Systems Engineering*, 1993).

The International Council on Systems Engineering (INCOSE) defines MBSE as *"formalized application of modelling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases."* (INCOSE, 2007). The application of MBSE is intended to consist of *"formalized application of modelling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases*" (Walden, Roedler, Forsberg, & Shortell, 2015).

In MBSE, models augment or take the place of what would have previously been documents capturing requirements, design, interface definition, trade studies, analysis reports, verification and validation plans and reports, among others. These models, shared across the engineering team and across the system life cycle are "intended to result in significant improvements in systems requirements, architecture and design quality; lower the risk and cost of system development by surfacing issues early in the system definition; enhance productivity through reuse of system artifacts; and improve communications among the system development team" (Walden, Roedler, Forsberg, & Shortell, 2015).

Among the uses of MBSE addressed by INCOSE, it is noted that "an executable system model that represents the interaction of the system elements may be used to validate that the system requirements can satisfy the system behavioural requirements." The execution of a model could in fact be called a simulation.

INCOSE notes that models and simulations have been used for some time, with two main benefits (Walden, Roedler, Forsberg, & Shortell, 2015):

- Models and simulations confirm the needs for the systems, and the anticipated system behaviors before proceeding with the development of an actual system, and
- Models and simulations present a clear, coherent design to those who will develop, test, deploy and evolve the system, thereby maximizing productivity and minimizing error.

In fact, the original book on MBSE by Wymore includes a chapter that addresses the related concepts of isomorphism[9] and simulation, stating that "*these concepts are essential to understanding and applying system design methodology, for they are the keys to consistent elaboration and consistent simplification of systems models, to the determination of when two models are essentially the same, and to the essence of implementation*" (Wymore, Model Based Systems Engineering, 1993).

Explicitly including the word "simulation" in the approach, that is Modelling & Simulation Based Systems Engineering (M&SBSE), would recognize the distinction between pure modelling and modelling and simulation; semantically, using a model to facilitate system design and development does not automatically imply use of simulation as well. Yet to be most effective, models are used as the basis for simulations that explore system behaviours, and not just as static representations, important as those are. This is recognised by Gianna. D'Ambrogio, and Tolk in the preface to the Modeling and simulated based systems engineering handbook, where they ask the rhetorical question: "*is it possible to add more value [to MBSE] when using M&S methods and computational capabilities to numerically evaluate the properties of complex systems?*" They go on to answer their own question by stating "*It is well known that the earlier mistakes are uncovered in system designs, the cheaper it is to correct them. Introducing M&S-based systems engineering, as an extension of MBSE practices to also include simulation methods, offers the opportunity for a more comprehensive coverage of the design space by enabling systems engineers to identify a wider set of early mistakes*" (Gianni, D'Ambrogio, & Tolk, 2015).

The concept of a Digital Twin has gained significant attention in recent years. A digital twin can be defined as a "high-fidelity model of the system which can be used to emulate the actual system". More generally, digital twins are recognised as an important contributor to a Model Based Systems Engineering (MBSE) approach to system development and sustainment. MBSE and digital twin concepts are at the heart of the model-based approach to the US Department of Defense's Digital Engineering initiative (Guide to the INCOSE Systems Engineering Book of Knowledge, 2021).

To be effective across the full capability lifecycle, the scope of a digital twin must include a model of the environment in which a system operates, including interfacing systems. These interfacing systems could also

[9] Two systems have identical input/output behavior if and only if their minimizations are isomorphic images. (Wymore, When can we safely reuse systems, upgrade systems, or use COTS components?, 2000)

be enabling systems, that is, those systems needed to support the development, management or sustainment of the system.

The use of a model in a digital twin without enabling simulations limits the ability of the digital twin to fully represent the evolution of the system for which the digital twin has been generated.

In the context of Artificial Intelligence enabled Robotic Autonomous Systems, the use of digital twin concepts and digital engineering more broadly will be critical to all phases of the capability life cycle. It will not be possible to fully specify, design, develop, test, train, and support such systems without the use of modelling and simulation based digital twins.

The importance of MBSE, supported by simulation (M&SBSE!), is well recognised by the Australian Defence Force (ADF). For example, the foreword of the recently released Sovereign Industrial Capability Priority Implementation Plan for Test, Evaluation, Certification, and Systems Assurance notes that "*the rapid change in technology associated with these capabilities results in a need for more agile testing methodologies, including using models and simulations within live, virtual and constructive environments*". Model Based Systems Engineering is identified as a key enabling capability for the ADF over the next decade. Increased use of modelling and simulation is seen as an important approach in enabling the ADF and industry to address future trends and technological evolutions. This includes:

- Using broader industry and commercial sector developments in using Live, Virtual, and Constructive modelling and simulation to support and improve testing and certification outcomes.
- Expanding the use of synthetic representations that allow for virtual product and production design through to real-world automated production, operating models and reduced risks of achieving performance.
- Leveraging the Defense virtual training environment to include modern Defense and industry test and evaluation facilities, training areas and ranges that are integrated, networked, and incorporate routine use of Live, Virtual, and Constructive modelling and simulation (Australian Department of Defence, 2020).

Modelling and Simulation as a Discipline – Some Common Themes

There are some important considerations that INCOSE believes are important for successful use of MBSE. These can be summarized as (Walden, Roedler, Forsberg, & Shortell, 2015):

- Model Scope: "The model must be scoped to address its intended purpose."
- Indicators of Model Quality: "the adherence of the model to modelling guidelines and the degree to which the model addresses its intended purpose".
- Standards: "standards for system modelling languages can enable cross discipline, cross project and cross organisation communication. The use of modelling standards for modelling languages, model transformations and data exchange is an important enabler of integration across modelling domains."
- Model and Simulation Integration: "models and simulations must establish semantic interoperability to ensure that a construct in one model has the same meaning as the corresponding construct in another model."

- Configuration management: "The management of models and simulations throughout the system lifecycle includes configuration management concerns related to versioning and change control".
- Ongoing validation: "as changes are introduced to the models and simulations, the team needs to ensure they remain a sufficient representation of the system for their intended purpose".

Interestingly, while there is discussion of management of data generated by models (and simulations) there does not appear to be any mention of the need to ensure data used as an input to a model is valid, and used appropriately. There is also no explicit mention of the need to model the external environment in which a system will operate. As noted earlier, there is a strong focus on data and environment simulation in the regulations applying to flight simulator.

Apart from the data and environmental points, it can be seen that there is a strong correlation between the considerations above, and those discussed in the section covering the use of simulation for training in the aviation industry.

There is also convergence between some of these concepts and the use of simulation for scientific purposes. For example, the model scope and indicators of model quality defined by INCOSE are broadly equivalent to the concept of correspondence discussed in a paper by Grim et al. Correspondence is the degree to which a simulation corresponds to the reality it is intended to represent:

"We believe that, from the perspective of simulation design, correspondence is not a single relation but many—that what is really at issue is a wealth of relevant relations between representations and what is represented, and between simulations and what is simulated.

Different conceptions of correspondence will be relevant to the different kinds of simulations that simulators make, and the different purposes to which their simulations are put. Different aspects of a single simulation may correspond to aspects of reality in different ways. … It is the designer's or user's intentions that determine what a simulation is a simulation of and what features are to be taken as corresponding with reality" (Grim, Rosenberger, Rosenfeld, Anderson, & Eason, 2011).

The Need for a Dedicated Modelling and Simulation Workforce

A paper by Blackmore and Allitt, presented at the 2019 Australasian Simulation Congress discusses some of the workforce challenges associated with simulation faced by the Australian Defence Force. The paper notes that the use of simulation for training has experienced significant growth and that this growth has been driven by increased computing power, as well as advances in availability of training system content development platforms as well as the game development industry. In terms of workforce availability, "*securing, training, and retaining personnel with requisite technical skills to deliver distributed simulation environments, paired with detailed understanding of Defence systems and processes, is a growing problem*.

By means of a case study, the paper illustrates the significant challenge the simulation industry faces, stating in the conclusion that: "*The bridge between the professional and technical skills required to perform in a simulation role, and the domain knowledge necessary to succeed in these roles, is difficult to traverse. Career progression emerges as a key source of workforce attrition. The lack of external, relevant training and* *educational pathways for employees places the burden for training with the employer*" (Blackmore & Allitt, 2019).

While the paper is focussed on simulation for training in the ADF, and indeed a specific kind of simulation enabled training, the key points of the study generalize to the modelling and simulation industry as a whole - effective use of modelling and simulation requires people with specific skills and experience.

Summary and Conclusions

While this article has only scratched the surface, it is clear that modelling and simulation tools and techniques have already made significant contributions to our society, and that the contribution will only continue grow in significance over time. While the uses of modelling and simulation vary enormously, there are fundamental aspects of their application that are consistent across all of these uses. The recognition of modelling and simulation as a discipline in its own right is an essential element in ensuring that the specialists and experts needed to take full advantage of the benefits that modeling and simulation can provide. To make the contribution of simulation to engineering explicit, we should start referring to Modeling & Simulation Based Systems Engineering.

There is a high degree of overlap between the skills and knowledge required across a wide range of modelling and simulation applications, which would enable the development of training for simulation specialists that would provide readily transportable qualifications across the differing domains making use of simulation and modelling.

List of Acronyms Used in this Paper

Acronym	**Explanation**
ADF	Australian Defence Force
DoD	Department of Defense (US)
EASA	European Union Aviation Safety Agency
M&S	Modeling and Simulation
ICAO	International Civil Aviation Organisation
INCOSE	International Council on Systems Engineering
MBSE	Model Based Systems Engineering
M&SBSE	Modelling and Simulation Based Systems Engineering
SimAust	Simulation Australasia
US	United States

References

Ananthaswamy, A. (2020, October 13). *Do We Live in a Simulation?* Retrieved from Scientific American: https://www.scientificamerican.com/article/do-we-live-in-a-simulation-chances-are-about-50-50/

Australian Department of Defence. (2020). *Sovereign Industrial Capability Priority Industry Plan, Test, evaluation, certification and systems assurance.* Australian Government.

Australian Government Bureau of Meteorology. (2019, March 29). *Explainer: computer weather models*. Retrieved from Australian Government Bureau of Meteorology: http://media.bom.gov.au/social/blog/2102/explainer-computer-weather-models/

Blackmore, K. L., & Allitt, E. W. (2019). Balancing Defence Service Experience and Technical Skills to Deliver Simulation Workforce Capability: A Case Study. *Intersections in Simulation and Gaming* (pp. 115 - 128). Gold Coast: Springer.

Box, G. (1979, February 8). Robustness in the strategy of scientific model buidling. *Robustness in Statistics*, 201 - 236.

Carrera, A. M., Naweed, A., Leigh, L., Crea, T. C., Krynski, B., Helveldt, K., . . . Khetia, S. (2016). Construcitng SafeContainers for Learning: Vignettes of Breakdown in Psychological Safety During Simulated Scenarios. *Intersections in Gaming & Simulation -Australasian Simulation Conrgress.* Melbourne: Springer.

Clark, A. (2013). Whatever Next? Predictive Brains,Situated Agents and the Future of Cognitive Science. *Behavioural and Brain Sciences*.

European Union Aviation Safety Agency. (2015). *Explanatory Note to Decision 2015/027/R.*

Gianni, D., D'Ambrogio, A., & Tolk, A. (2015). *Modelling and Simulation-Based Systems Engineering Handbook.* CRC Press.

Grim, P., Rosenberger, R., Rosenfeld, A., Anderson, B., & Eason, R. E. (2011). How simulations fail. *Synthese*.

Guide to the INCOSE Systems Engineering Book of Knowledge. (2021). Retrieved from https://www.sebokwiki.org/wiki/Digital_Engineering

Havard, D. (December 1910). The Sanders Teacher. *Flight*.

INCOSE. (2007). *Systems Engineering Vision 2020.* INCOSE.

International Civil Aviation Organisation. (2015). *Doc 9625 Manual of Criteria for the Qualification of Flight Simulation Training Devices (4th Ed).* ICAO.

Kirwan, B. &.-M. (2019). Charting the Edges of Human Performance. *MATEC Web of Conferences*.

Kroll, N., Abu-Zurayk, M., & al, e. (2016). DLR project Digital-X: towards virtual aircraft design and flight. *CEAS Aeronautical Journal*.

Meadows, D. (2008). *Thinking in Systems.* White River Junction, Vermont: Chelsea Green Publishing.

Naweed, A. P., Dennis, D. P., Krynski, B. B., Crea, T. P., & Knott, C. M. (2020). Delivering Simulation Activities Safely: What if We Hurt Ourselves? *Simulation in Healthcare: The Journal of the Society for Simulation in Healthcare*, 60-66.

Naweed, A., Bowditch, L., & Sprick, C. (2019). Intersections in Simulation and Gaming. *Third Annual Australasian Simulation Congress.* Gold Coast: Springer.

Owen, H. (2012). Early use of simulation in medical education. *Simulation in healthcare : journal of the Society for Simulation in Healthcare,*, 102 - 116.

Page, R. (2004). *Brief History of Flight Simulation.* Simulation Australasia.

Rogers, A., & Molteni, M. (2020, March 30). The Mathematics of Predicting the Course of the Coronavirus. *Wired Magazine*.

Rolfe, K., & Staples, K. (1997). *Flight Simulation.* Cambridge: Cambridge Universtiy Press.

Sciolist. (2021, February 01). Retrieved from Online Etymology Dictionary: https://www.etymonline.com/word/simulation

Singleton, J. (2019, December 11). *The Most Detailed Simulation of Our Universe Ever* . Retrieved from The IllustrisTNG Project: https://www.tng-project.org/data/forum/topic/245/the-most-detailed-simulation-of-our-universe-ever/

Thompson, J., & McClure, R. (2020, October 29). *Melbourne's coronavirus second wave seemed impossible to defeat. Our modelling showed exactly how to do it*. Retrieved from ABC News: https://www.abc.net.au/news/2020-10-29/coronavirus-melbourne-how-we-hit-our-target/12826692

Thompson, J., McClure, R., Blakely, T., Wilson, N., Baker, M., Wijnands, J. S., . . . Stevenson, M. (2020, July 16). *Modelling SARS-CoV-2 disease progression in Australia and New Zealand under public health settings: an agent-based SEIR approach to support public health decision making.* Retrieved from SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3588074

Tydeman, R. (2004). The Use of Full Flight Simulators in Accident Investigation. *ISASI Proceedings* (p. 164). Gold Coast: International Society of Air Safety Investigators.

US Department of Defense. (2018, October 15). Modeling and Simulation (M&S) Management. *DoD Directive 5000.59*.

US Department of Defense. (2020, October 26). Retrieved from Department of Defense (DoD) Modeling and Simulation Enterprise (MSE): https://www.msco.mil/

US Department of Defense. (2020, September 15). *M&S Glossary*. Retrieved from Department of Defense Modeling and Simulation Enterprise: https://www.msco.mil/MSReferences/Glossary/MSGlossary.aspx

Walden, D. D., Roedler, G. J., Forsberg, K. J., & Shortell, T. M. (2015). *INCOSE Systems Engineering Handbook: A Guide for Life ycle Processes and Activities.* John Wiley & Sons.

Wymore, W. (1993). *Model Based Systems Engineering.* CRC Press.

Wymore, W. (2000). When can we safely reuse systems, upgrade systems, or use COTS components? *Systems Engineering, The Journal of the International Council on Systems Engineering*, 82 - 95.

About the Author

Philip Swadling is Chair of the Board of Simulation Australasia. He is also Technical Director for Avionics with Thales Australia, and Deputy Technical Director for the global Thales Training & Simulation Business Line. Philip has nearly 30 years' experience in the simulation industry, working on a range of training simulators as well as the use of simulation and modelling in solution development. He holds a B.E in Electrical Engineering and a B.Sc. in Computer Science from the University of NSW.

3. ADDITIONAL ARTICLE

3.1 INCOSE Wasatch Chapter: How May We Serve You?

by

Paul White

International Council on Systems Engineering (INCOSE) Wasatch Chapter

February 13, 2021

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Abstract

Who are systems engineers? What do they do? How will Systems Engineering drive improvements and innovations, making our future world a better place? For answers to these questions, we encourage you to check out our International Council on Systems Engineering (INCOSE) Wasatch chapter. In this article, we cover who we are, what we do, and how we can serve you.

What is Systems Engineering?

Systems engineering is an interdisciplinary field of engineering that focuses on how to design and manage complex systems over their life cycles. Systems engineers, who practice systems engineering, are at the heart of creating successful new systems. They are responsible for the system concept, architecture, and design. They analyze and manage complexity and risk. They decide how to measure whether the deployed system actually works as intended. They are responsible for a myriad of other facets of system creation. They develop systems by using state-of-the-art tools, techniques, methods, knowledge, standards, principles, and concepts. Systems engineers launch successful systems by applying innovative and creative approaches.

The first systems engineers started in the 1940s with Bell Telephone Laboratories and initially were employed by the United States Department of Defense. Since then, systems engineers have played a vital role in developing successful aerospace systems, and they have broadened the applications of systems engineering into many other domains. Today, systems engineers work in many different industries: academia, aerospace, commercial, defense, health care, and manufacturing. Many companies, large and small, employ systems engineers and value their contributions in developing state-of-the-art technologies or in sustaining and modernizing older, legacy systems. Indeed, as systems increase in complexity, systems engineers will play an even more integral role in developing and deploying systems in even more domains, such as combating climate change, developing new treatments for disease, planning more effective transportation networks, and delivering cleaner food and water to our growing world population.

What is INCOSE?

INCOSE is a not-for-profit membership organization founded to promote systems engineering. INCOSE promotes systems engineering by:

- Hosting regular events to disseminate and increase systems engineering knowledge and proficiency.
- Providing a focal point for networking among systems engineers and companies.
- Offering certification programs that enable systems engineers to formally demonstrate their professional competency in systems engineering.

INCOSE was chartered as an organization in 1990. INCOSE has experienced steady growth since its founding. INCOSE now has more than 18,000 members—among 74 active chapters—across the United States of America and in many parts of the world.

For more information, you may go to the INCOSE website at www.incose.org.

What is the Wasatch Chapter?

We chartered the INCOSE Wasatch Chapter in January 1997 to serve the Utah systems engineering community. Our membership resides throughout Utah: Salt Lake City, Layton, Logan, Ogden, Provo, Saint George, and points in between. We named the chapter "Wasatch" (pronounced Wah-sach)—for the Wasatch Mountain Range—to identify with our region but not to convey boundaries on membership. We invite all members and non-members to chapter activities.

We provide value to our members by providing relevant systems engineering presentations, networking events, and opportunities to develop leadership through local, national, or international INCOSE roles. We foster a world-class systems engineering environment for our current and future membership. As a testament to our value, we have enjoyed steady growth, especially in recent years. Our members work at many local companies, including:

- The Aerospace Corporation
- BAE Systems
- Boeing
- General Dynamics
- General Electric
- Hill Air Force Base
- Kihomac
- L-3 Harris
- Lockheed Martin
- Northrop Grumman
- Siemens
- The University of Utah
- Utah State University
- Weber State University

We believe that systems engineering principles and practices offer the best solution for Utah companies and organizations competing in today's global marketplace, and that the proper application of systems engineering can contribute to the overall betterment of the social, economic, and environmental condition of the area. When the aim is to improve cost, quality, and schedule performance--whether in industry, government, or education--we believe that systems engineering provides the most viable structured approach for doing so.

For more information, you may visit our website at www.incose.org/wasatch.

When do we meet?

We hold our monthly meetings on the second Thursday of every month. Our meetings start at 6:00 p.m. with dinner and networking, following by chapter announcements at 6:30 and a featured presentation from 6:45 – 8:00. We feature timely and relevant systems engineering topics, delivered by an expert in the field.

We have been delivering our meetings in a hybrid format, with people meeting in person at a host location or attending virtually via a meeting platform such as Zoom or Webex. This hybrid format enables our meetings to reach a much wider audience and to feature a more diverse slate of presenters and topics.

Notably, our hybrid meeting format proved incredibly adaptable during the COVID-19 pandemic. After March 2020, we quickly transitioned to totally virtual meetings to ensure that our chapter members and friends were kept safe and healthy. We received overwhelming positive feedback from our meeting attendees. In fact, our meeting attendance increased throughout 2020; and we are still going strong in 2021. For the foreseeable future, we will continue to meet virtually. We look forward to transitioning to the “new normal” as soon as feasible.

What events do we sponsor?

We sponsor many major events throughout the year. For example, we sponsor the Utah Engineers Council (UEC) Banquet, AIAA/INCOSE August is for Aerospace, Western States Regional Conference (WSRC), and Holiday Social.

The UEC Banquet, held on the Saturday of Engineers Week in February, celebrates engineering, recognizes local engineering talent, and awards scholarships to college engineering students. We participate by sending representatives to the event. We sponsor one $1,500 scholarship per year to a deserving college engineering student. We recognize our members’ achievements by submitting nominees for the UEC awards, namely the Fresh Face of Engineering, Engineering Educator of the Year, and Engineer of the Year. We are proud to support the UEC as a member society and look forward to continued wonderful associations with them.

Paul White, INCOSE President and UEC Vice Chair, (L) with Jacob Browning, UEC Chair, at UEC Banquet in 2020.

Along with the UEC Banquet, we collaborate with the American Institute of Aeronautics and Astronautics (AIAA) Utah Section for the annual August is for Aerospace event. The event takes place at a local restaurant, typically in Layton. Local civic, academic, industry, and government leaders participate in the event. The event focuses on recruiting and retaining a skilled workforce, particularly for ICBM programs. Participants network and discuss relevant topics, including how universities can better prepare engineering graduates, how to attract talented engineers from out of state, and which specialties are most demand in the local area. Students and young professionals are encouraged to mingle with senior leadership. The event is always a great success, and many in attendance have independently expressed a desire to continue these events going forward.

Attendees at the 'August is for Aerospace' event in 2019

In addition to hosting the 'August is for Aerospace' event, the annual WSRC is a regional conference that features a three-day program with:

- Education Presentations – Technical presentations, panel discussions, tutorials, and workshops concerning state-of-the-art systems engineering topics.
- Keynote Speakers – Seasoned professionals who will impart their experiences and expertise.
- Leadership Meetings – Open, collaborative sessions among INCOSE working groups and chapter leaders.
- Networking Events – Social, more informal, events attended by key individuals at companies and organizations.

The WSRC draws systems engineering professionals from the local area and across the United States. The Inaugural WSRC took place in Ogden, Utah, in 2018 and has continued in Los Angeles (2019) and Seattle (2020). Future locations include San Diego (confirmed for 2021), Colorado, New Mexico, and Oregon.

Attendees enjoying a moment of socializing at WSRC

Finally, we hold our holiday social in December of every year. We celebrate our accomplishments for the year and recognize exemplary contributions from our members. We talk about the upcoming year, particularly focusing on how we can enhance our service to our members, companies, and local communities.

Chapter Officers from 2019 and 2020 (L to R): John McCrea, Angie Harbert, Vince Johnston, and Paul White. (Not Pictured: Rachel Geerlings, Ernest Kyed, Paul Nelson, & John Richards)

Chapter members and friends enjoy a light moment of networking at the holiday social

AIAA/INCOSE Virtual Mini-conference

For this year, we have partnered with the AIAA to host an inaugural “Wasatch Aerospace and Systems Mini Conference” virtually on April 15-16. The theme of the conference is “Celebrating the Creativity of Engineers”. The program will feature dynamic keynote speakers and presentations from experts in the local industry. We are excited to offer this event with AIAA.

For more information, you may go to the event website at https://www.eventbrite.com/e/wasatch-aerospace-and-systems-engineering-mini-conference-tickets-135569577255.

or email utah.aiaa@gmail.com.

Summary and Conclusions

Systems engineering is an interdisciplinary field that spans multiple industries. Systems engineers work in academia, aerospace, commercial, defense, health care, and manufacturing; and they are employed by many local companies.

INCOSE is the industry organization for systems engineers. We chartered the Wasatch chapter to provide INCOSE services to our local area. We welcome INCOSE members and non-members alike to our chapter activities.

We host monthly meetings and many other events throughout the year. These events offer great value to our members, companies, and local communities. We look forward to continued growth and service for the foreseeable future.

For more information about INCOSE, you may go to www.incose.org.
For more information about the Wasatch chapter, you may go to www.incose.org/wasatch.
or contact Paul White, chapter president, at paulwhite849@gmail.com.

List of Acronyms Used in this Paper

Acronym	Explanation
AIAA	American Institute of Astronautics and Aeronautics
INCOSE	International Council on Systems Engineering
UEC	Utah Engineers Council

References

https://en.wikipedia.org/wiki/Systems_engineering
https://www.incose.org/systems-engineering
https://www.incose.org/wasatch
https://www.incose.org/incose-member-resources/chapters-groups/ChapterSites/wasatch/chapter-news/2017/09/12/incose-wasatch-chapter-aiaa-utah-section-host-august-is-for-aerospace-event
https://www.eventbrite.com/e/wasatch-aerospace-and-systems-engineering-mini-conference-tickets-135569577255

About the Author

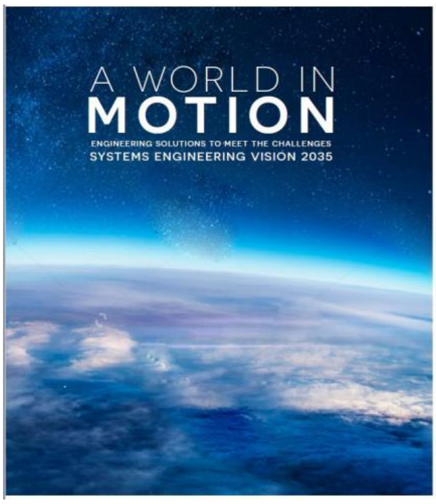
Paul White works as the Digital Engineering Branch Lead for BAE Systems at Hill Air Force Base, Utah. He has worked previously for Kihomac in Layton, Utah; Astronautics Corporation of America in Milwaukee, Wisconsin; and L-3 Harris in Dallas-Fort Worth, Texas. He possesses 20 years of experience in aerospace among ICBM, A-10, Airbus A400M, Boeing, Big Safari, IBS, and AWACS.

He serves as president of the INCOSE Wasatch chapter. He is the current Chair of the UEC. He serves as the INCOSE Assistant Director of Technical Events.

He obtained a graduate certificate in Systems Engineering and Architecting from the Stevens Institute of Technology. He holds a Master of Science and Bachelor of Science in Computer Science from Texas A&M University—Commerce and Texas A&M University, respectively. He is a Certified Systems Engineering Professional (CSEP) through INCOSE and holds an OCSMP Model Builder—Intermediate certification from the Object Management Group (OMG).

4. SYSTEMS ENGINEERING NEWS

4.1 A Preview of INCOSE's Systems Engineering Vision 2035



A preview of INCOSE's Systems Engineering (SE) Vision 2035 was provided during the Virtual INCOSE International Workshop (IW) held in January 2021. Sandy Friedenthal indicated that the current version is a preliminary draft. The preliminary review began on February 1, 2021. A final review is planned for August 2021, and the rollout is planned for the INCOSE IW in January 2022. The theme from the SE Vision 2025 continues: "A World in Motion", along with a new sub-theme: "Engineering Solutions to Meet the Challenges".

The SE Vision 2035 Core Team includes Chris Davey (Ford Motor Company), Sanford Friedenthal (*Lead*) (SAF Consulting), Sky Matthews (IBM), David Nichols (NASA/Jet Propulsion Laboratory California Institute of Technology), Paul Nielsen (Carnegie Mellon University Software Engineering Institute), Christopher Oster (Lutron Electronics), Troy Peterson (System Strategy, Inc.), Garry Roedler (INCOSE), Paul Schreinemakers (*Review Team Lead*) (How2SE), and Heinz Stoewer (*CTO*) (Space Associates and TU Delft).

The 2035 SE Vision and Objectives are as follows:

Purpose

Inspire and guide the direction of systems engineering across diverse stakeholder communities, which include:

- Engineering & Executive Leadership
- Engineering Practitioners
- Policy Makers
- Professional Organizations
- Researchers, Academics, & Students
- Standard Bodies
- Tool Vendors

Objectives

- Align Systems Engineering Initiatives
- Address Future Systems Engineering Challenges
- Broaden the Base of Systems Engineering Practitioners
- Promote Systems Engineering Research

Evolution

This vision will continue to evolve based on on-going collaborations with the stakeholder community. The briefing that was presented by the Core Team provides extensive details and is available here.

Table of Contents

4. Realizing the Vision

a. The Path Forward
b. Collaboration
c. Organizational Change
d. SE Grand Challenges
e. Specific Recommendations

The briefing that was presented by the Core Team provides extensive details and is available here.

4.2 Krystal Porter, Winner of the BEYA Award

Krystal Porter, a leading engineer with INCOSE Corporate Advisory Board (CAB) Company *Leidos*, and also a Washington Metro Area Chapter member, received the Black Engineer of the Year (BEYA) Dr. Wanda M. Austin Legacy award.

You can read more about Krystal and the award here.

You can also watch Krystal and other engineers receive their awards at the HBCU Engineering Dean's Recognition Event here.

4.3 Object Management Group (OMG) Q4 Recap

Contributed by

John Fitch
PPI Principal Consultant and Course Presenter

The Object Management Group has issued a video recap of their December 2020 Technical Committee meeting. This 49-minute webinar provides an overview of recently approved specifications, identifies opportunities to participate on work in progress by various OMG task forces and explores the agenda for the March 2021 meeting.

Access the webinar via BrightTALK here.
PDF slides are also available.

4.4 Message from the INCOSE President: Looking Forward to 2021

Contributed by

John Fitch
PPI Principal Consultant and Course Presenter

INCOSE President Kerry Lunney has recapped the challenges of 2020 and how meeting those challenges has positioned INCOSE for advancement in 2021 and beyond. Highlights included:

- Adoption of Zoom as a video conferencing platform and Microsoft Teams as a collaboration tool.
- Move to virtual events for the International Symposium IS2020 and the International Workshop IW2021.
- Increased virtual offerings including exchange cafes, webinars, workshops and mini-events.
- Flexibility in membership and certification policies in the face of COVID-19 hardships and constraints.
- Travel restrictions and associated virtual collaboration workarounds.
- Impact on the INCOSE Outreach program.

Thanks for the dedication of INCOSE volunteers and members during 2020.

Read the full message here.

4.5 PDMA Best Practices 2020 Research Survey

Contributed by

John Fitch
PPI Principal Consultant and Course Presenter

The Product Development Management Association (PDMA) is conducting a research study that continues their on-going investigation of new product development (NPD) practices at the business unit level. The survey asks questions about a business unit's new product development practices, processes, and outcomes, including information about portfolio management processes, innovation strategy, technology tools and how the COVID-19 pandemic has impacted new product development and plans.

The survey applies to products targeted at businesses and/or consumers, comprised of physical goods and/or services, consisting of software and/or hardware whether such products are incremental, significant, or radical innovations.

Access the survey here.

4.6 MIT Faculty of Engineering Launches a 5-week Online Course Called Application of System Thinking

Contributed by

Emmanuel Abuede (MSc)

PPI Intern & Researcher

The MIT Faculty of Engineering is organizing a 5-week online course commencing on the 5th of April 2021 dedicated to the *Application of System Thinking to Improve the Performance of Your Projects*.

From the course website:

"We are surrounded by systems. The products, processes, and projects that we work on are increasingly complex and interrelated systems. Organizations are calling on you, their technical professionals, to drive and optimize complex projects under high-pressure conditions.

Through this online course, MIT faculty will teach you how to think of things as systems -- the process of understanding how entities influence one another within a whole. You'll be able to then communicate that gaining insight and apply new methods, techniques, and vocabulary to your projects and processes. System thinking (or "systems thinking") helps organizations examine complexity and simplify it; recognize patterns, and create effective solutions to challenges. Understanding and approaching problems from a systems perspective in technical environments is an essential skill for your career."

Find out more about the course here.

4.7 World Engineering Day for Sustainable Development

Contributed by

Emmanuel Abuede (MSc)

PPI Intern & Researcher

To celebrate World Engineering Day which took place on 4th of March, Springer Nature has made articles and journals on the platform free until March 31, 2021.

https://www.springernature.com/gp/researchers/sdg-programme

4.8 Progress on the Fifth Edition of the INCOSE Systems Engineering Handbook

Contributed by

John Fitch

PPI Principal Consultant and Course Presenter

The INCOSE 2021 International Workshop was held (virtually) on January 25 – February 5, 2021. The Workshop included meetings held by nearly 30 INCOSE working groups; many of these groups held multiple virtual working sessions during the week.

The team of 125+ authors and editors working on the Fifth Edition of the System Engineering Handbook met 7 times during the week. Their first session focused on updates to the Systems Engineering Foundations section of the Handbook. Later sessions addressed improvements to subsequent sections, including:

- Part II – Life Cycles and Systems Engineering Dimensions
- Part III – System Life Cycle Processes
- Part IV – Cross-cutting Systems Engineering Concepts
- Part V – Practicing Systems Engineering
- Part VI – Application of Systems Engineering

The editorial team shared their vision for the updated handbook at a Town Hall session with the rest of the IW2021 participants.

The key tenets guiding Handbook development are the desire to contain best practices for the engineering of systems, while keeping its content both domain-neutral and country-neutral. Not surprisingly as SE practitioners, the Handbook team formally defined requirements and completed an architectural design trade study to come up with the revised structure of the Fifth Edition Handbook.

INCOSE is intentionally coordinating the update and release of the Fifth Edition with the revision of ISO/IEC/IEEE 15288 standard, currently planned for 2023. Multiple INCOSE Handbook authors and editors are contributing to the 15288 standard to improve alignment between these two documents.

Dave Walden, Lead Editor for the SE Handbook Fifth Edition, stressed the importance of broad participation in this initiative:

"If you want to contribute to enhancements to the SE Handbook, there are two ways to participate. First, engage with INCOSE working group that is leading each section. These working groups are the experts to which we look for high quality content. Second, you can participate in the Fifth Edition review process that will begin in April 2021."

4.9 Progress on ASME-INCOSE Plant System Design (PSD) Standard

Contributed by

John Fitch

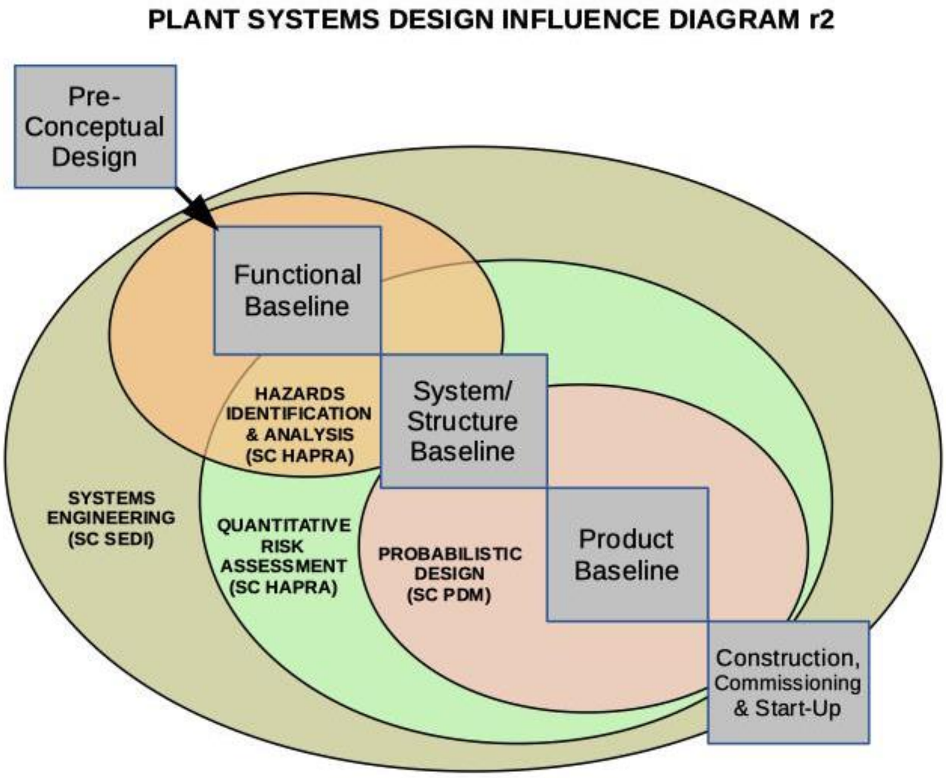
PPI Principal Consultant and Course Presenter

The INCOSE 2021 International Workshop included a productive working session by the team that is developing a Plant System Design standard; a collaborative effort by the American Society of Mechanical Engineers (ASME) and INCOSE.

The standard, which will be published by ASME, focuses on the design and development of energy, nuclear, oil and gas and petrochemical facilities. This standard will change how these facilities are designed by infusing systems engineering principles into the associated development processes. Because of the unique hazards posed by system failures at such facilities, the standard will integrate the best practices associated with hazard analysis into a Systems Engineering view of the plant lifecycle.

The standard is written to support the design of new first-of-a-kind plants that incorporate new technologies. Application begins with initial design contract, continues through completion of the design development, and ends after resolution of issues and reconciliation of any changes during fabrication, construction, plant startup and commissioning.

The figure below depicts the relationship of the 3 key technical areas that the standard addresses, as well as how they relate to design evolution.

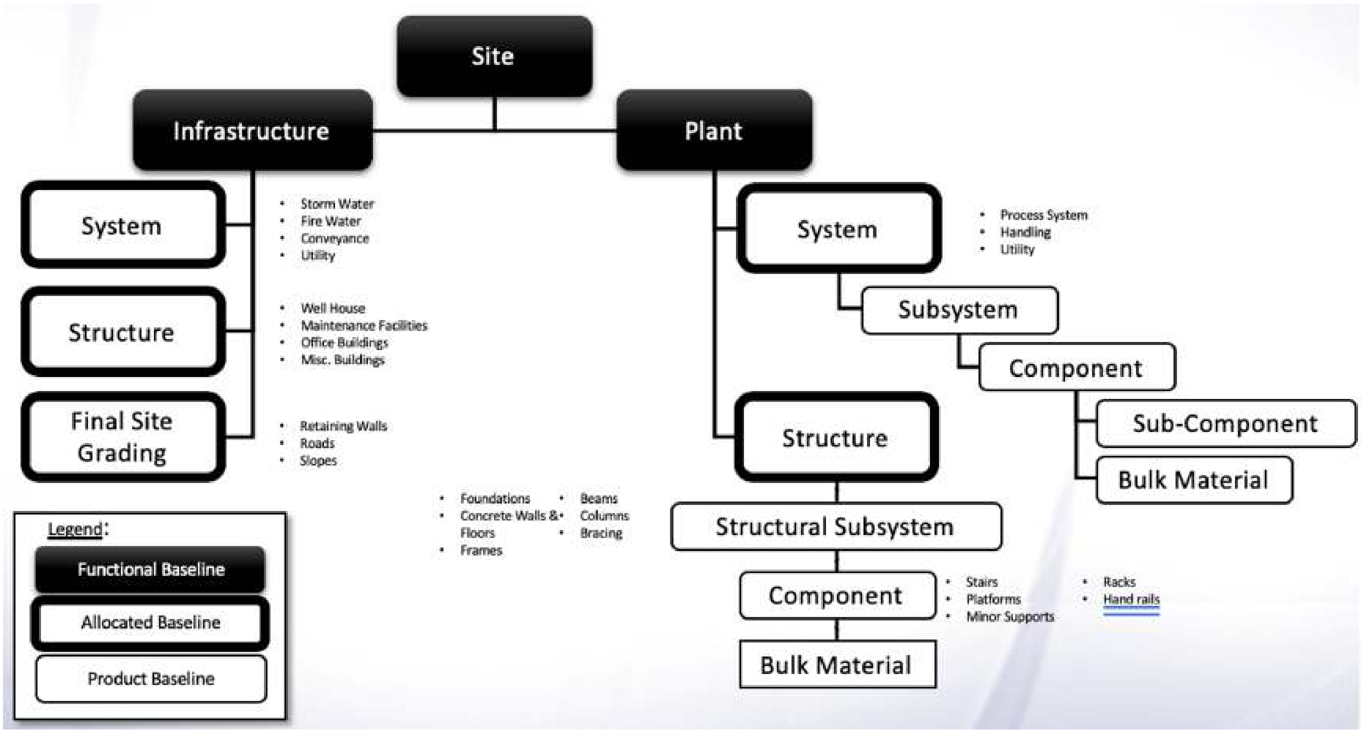


Highlights of this initiative include:

- This is the first ASME standard developed primarily through virtual meetings.
- The standard advocates use of systems engineering tools and the volunteers are using an MBSE tool (Innoslate) to develop and align the contents of the standard.
- A key technical focus of the standard is to integrate systems engineering design processes, practices and tools with traditional plant design processes, practices and tools.
- The PSD-1 standard will place a strong emphasis on System Requirements Analysis to address the tendency to jump to technology-driven solutions early in the plant design process.
- The PSD-1 standard will introduce the concept of baselines into the Plant design community.
- ASME will collaboratively develop PSD-1 training and certification resources with INCOSE.
- The PSD-1 standard is scheduled to be approved and ready for publication in 2023.

One of the challenges that the PSD team has addressed is the diverse use of the term “system” among the plant design community. They have developed a Plant Systems Design Standard Taxonomy that establishes the naming conventions and relationships that are used in the standard. For example, the taxonomy distinguishes two classes of systems on a typical site:

- Infrastructure systems and structures such as storm water, conveyance and site-level utilities
- Plant systems and structures that deliver in-plant processes, material handling or process-related utilities.



The team is coordinating with a variety of INCOSE working groups (e.g. Infrastructure, Requirements, Critical Infrastructure Protection and Recovery) to ensure consistency with INCOSE best practices. INCOSE members can contribute to the PSD-1 Standard by joining these working groups through INCOSE Connect.

ASME members can support the PSD-1 Standard development by becoming a contributing member of the ASME Standards Committee or one of its subcommittees. The Systems Engineering Design Integration (SEDI) subcommittee will have the most direct interface with INCOSE.

For further information, please contact:

- Ralph Hill, Chair of the ASME Standards Committee for Plant Systems Design: hillr@asme.org
- Mike deLamare, Systems Engineering Leader at Bechtel and Acting Chair of the PSD Systems Engineering and Design Integration (SEDI) subcommittee: madelama@bechtel.com

5. FEATURED ORGANIZATIONS

5.1 The International Organization for Standardization (ISO)

The **International Organization for Standardization** (ISO) is the world's largest developer and publisher of international standards. ISO is a network of the national standards institutes of 162 countries, one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system. ISO is a nongovernmental organization that forms a bridge between the public and private sectors. ISO enables a consensus to be reached on solutions that meet both the requirements of business and the broader needs of society. View the ISO Standards list. The following standards are some of the most common standards used in the practice of systems engineering:

- ISO/IEC/IEEE 15288:2015 Systems and software engineering -- System life cycle processes
- ISO 9001:2015 Quality management systems — Requirements
- ISO/IEC/IEEE 24765:2010 - Systems and software engineering – Vocabulary
- IISO/IEC TR 24766 - Information technology — Systems and software engineering — Guide for requirements engineering tool capabilities
- ISO/IEC 26702 IEEE Std 1220-2005 - Systems engineering — Application and management of the systems engineering process

Access the link above to read about these standards and many more.

5.2 Simulation Interoperability Standards Organization

The **Simulation Interoperability Standards Organization (SISO)** is an international organization dedicated to the promotion of modeling and simulation interoperability and reuse for the benefit of a broad range of M&S communities including developers, procurers, and users world-wide.

SISO Standards Products are formally approved items that reflect consensus agreements on products, practices, or operations, as required, by simulation industry applications. SISO Standards Products are to be stable, well understood, technically competent, and have multiple independent interoperable implementations. In addition, SISO Standards Products should enjoy significant public support and be useful in some or all parts of the simulation community.

SISO is involved with IEEE, ISO, and SISO standards. SISO provides an environment for the development of products that support the interoperability and reuse of distributed simulations. Learn more about the Standards Activity Committee - the committee that oversees the development and support of SISO Products. Visit these webpages to download SISO Products:

- SISO Standards Products
- SISO Guidance Products
- SISO Reference Products
- SISO Administrative Products

As part of its support, SISO provides quick-turnaround responses to requests for interpretation or guidance in the use of these SISO Products.

In 2003 the IEEE Computer Society Standards Activities Board approved SISO SAC as the Computer/Simulation Interoperability (C/SI) Standards Committee. In 2015 the IEEE Standards Association Standards Board re-authorized C/SI for standards development. The SISO SAC Chair or Vice-Chair serve as SISO's primary contact for all IEEE Standards activities.

More Information

Visit SISO's Digital Library

6. NEWS ON SOFTWARE TOOLS SUPPORTING SYSTEMS ENGINEERING

6.1 INCOSE Model-Based Capabilities Matrix – Evolution

Contributed by

John Fitch
PPI Principal Consultant and Course Presenter

The INCOSE International Workshop (IW2021) included a report on the evolution and initial use of the Model-Based Capability Matrix (MBCM). The MBCM assessment tool and User Guide were written by Al Hoheb, Senior Systems Engineer at the Aerospace Corporation, and Joe Hale, Manager NASA/MSFC, and was first published in January 2020. It is available as a free download at the INCOSE Store (Products page) with an INCOSE membership or for non-members who set up an INCOSE Store account.

The workshop was run by Al Hoheb of the Aerospace Corporation and Michael Russell of the MITRE Corporation, who have been applying the matrix assessment during its development back to 2018. Al provided feedback from the community's MBCM use. Al and Michael then discussed recommended best practices, lessons learned and "pro" tips. The workshop audience was then polled to gather additional feedback.

Some interesting findings are that the matrix is being widely used in government and commercial applications across many industries. While many users find the matrix helpful as-is, others have chosen to create their own versions based on the INCOSE publications. Most notably, the United States Air Force used the MBCM as the basis of their Air Force Digital Maturity Metrics that are likely to be a mandatory self-assessment across Air Force Programs. Representatives from NASA Johnson Space Center and the United States Navy are also considering tailored versions for their application. However, other government agencies including the Department of Homeland Security and members of the intelligence community prefer to use the matrix as-is. Commercial users, large and small, have adopted the MBCM to springboard their use of modeling. Some contractors have created additional assessment tools and checklists to use in conjunction with the published materials to assist organizations create roadmaps to meet their business objectives.

Russell summarizes the intent of the MBCM:

"The MBCM provides organizations with a snapshot of their readiness to adopt Digital Engineering (DE), and highlights the need to take a hard look at the organizations culture and processes as a precursor to a focus on software and infrastructure."

The MBCM assessment may be readily adapted to a variety of goal-oriented viewpoints; two goal viewpoints are "built-in":

- Digital Engineering (DE) framework from the U.S. Office of Secretary of Defense (OSD)
- Enterprise, role-based capability model

The DE view is helpful for government organizations to show traceability-to and compliance-with top level direction and as a reporting tool. The enterprise and role-based view is most useful to organizations that are applying the matrix to develop their organizations. The two viewpoints are aligned with them sharing the same capabilities, descriptions, and stage definitions.

The MBCM enables the assessment of an organization's modeling prowess against 42 capability areas. A five-stage assessment model is applied to each capability:

- Stage 0: No MBSE capability or MBSE applied ad hoc to gain experience
- Stage 1: Modeling efforts are used to address specific objectives and questions
- Stage 2: Modeling standards are applied; ontology, languages, tools
- Stage 3: Program/project wide capabilities; model integrated with other functional disciplines; digital threads defined and digital twin
- Stage 4: Enterprise-wide capabilities; contributing to the enterprise, programs/projects use enterprise defined ontologies, libraries, standards

The MBCM team encourages members of Systems Engineering community to use the MBCM to "*see what works and what could be improved*." Generally, self-assessment workshops take about 4 hours to garner useful results. Feedback of assessment results is helpful to the MBCM Challenge Team so they can continuously improve the assessment's applicability to new use cases and its effectiveness at promoting Digital Engineering maturity.

Interested parties may also contribute their expertise through active participation in the INCOSE MBCM Challenge Team. Contact Al Hoheb at albert.c.hoheb@aero.org.

6.2 QVscribe

Contributed by

Alwyn Smit
PPI Principal Consultant and Course Presenter

QVscribe uses Natural Language Processing to proactively check for best practices identified by associations such as INCOSE and leading industry experts. By automating quality and consistency, QVscribe encourages engineers to be innovative and build complex systems with reduced risk of introducing errors in the later stages of development. Teams can standardize the way requirements are written, so the conversation can be elevated, focusing on what matters: the content.

What QVscribe checks for:

1. **Quality Analysis:** QVscribe's Quality Analysis checks for compliance with standards such as the INCOSE Guide for Writing Requirements. The analysis includes proper use of imperatives, clear language, and other industry best practices. QVscribe allows authors to get a comprehensive view of their document without leaving their requirements management tool. The dashboard view allows authors to understand their progress and see any underlying warnings throughout the document.

2. **Unit & Term Consistency:** Detection, enumeration, and classification of all measurement units and noun phrases to help verify their correct use and location in the requirements, ensuring consistency across your document, regardless of how many authors have worked on it.

3. **Similarity:** QVscribe automatically identifies that the pictured requirements are quite similar. In fact, these requirements are also missing important information, as each requirement should stand on its own, without the need to reference headings for context. QVscribe makes it easy to spot missing information, duplicate requirements, and contradictions by showing you the most likely suspects and highlighting the differences.

QVscribe can jumpstart the authoring of your requirements with fill-in-the-blank templates that are pre-configured to follow the Easy Approach to Requirements Syntax (EARS). EARS conformance ensures natural language requirements are simple and complete.

QVscribe integrates with the following platforms:

1. Jama
2. IBM Rational
3. Microsoft Word
4. Microsoft Excel
5. Polarion
6. Visure

6.3 Ranking Released by 360Quadrants

Contributed by

Alwyn Smit
PPI Principal Consultant and Course Presenter

360Quadrants synthesizes inputs from four key stakeholders i.e., experts, buyers, vendors and analysts to identify product capabilities in detail, which help businesses make informed partnering decisions.

In their latest analysis 360Quadrants has assessed 23 software vendors that offer PLM software and placed on a quadrant under the categories: Visionary Leaders, Innovators, Dynamic Differentiators, and Emerging Leaders.

These software providers were assessed based on more than 90 accurately selected data pointers, which were finalized based on the product and business strategy of the software provider, and the data collected from buyers as well as industry experts.

Read the full article on the Wall Street Call.

6.4 System Composer

Contributed by

Emmanuel Abuede (MSc)
PPI Intern & Researcher

System Composer enables the definition, analysis, and specification of architectures and compositions for model-based systems engineering and software design. With System Composer, it is possible to allocate requirements while refining an architecture model that can be designed and simulated in Simulink.

Fine out more about the tool here:
https://www.mathworks.com/products/system-composer.html

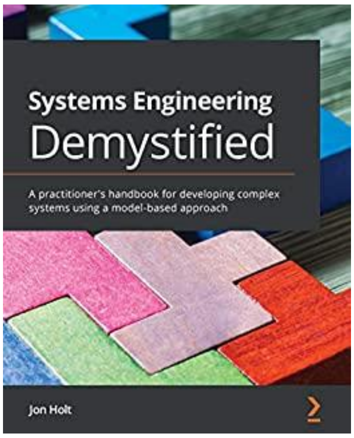
7. SYSTEMS ENGINEERING PUBLICATIONS

7.1 Systems Engineering Demystified: A practitioner's handbook for developing complex systems using a model-based approach

by

Jon Holt

Technical Director of INCOSE UK



From the Amazon.com Webpage:

Get to grips with systems engineering life cycles, processes, and best practices and discover techniques to successfully develop complex systems.

Key Features

- Discover how to manage increased complexity and understand systems better via effective communication
- Adopt a proven model-based approach for systems engineering in your organization
- Apply proven techniques for requirements, design, validation and verification, and systems engineering management

Systems engineering helps us to understand, specify, and develop complex systems, and is applied across a wide set of disciplines. As systems and their associated problems become increasingly complex in this evermore connected world, the need for more rigorous, demonstrable, and repeatable techniques also increases.

Written by Professor Jon Holt – an internationally recognized systems engineering expert – this book provides a blend of technical and business aspects you need to understand in order to develop successful systems. You'll start with systems engineering basics and understand the complexity, communication, and different stakeholders' views of the system. The book then covers essential aspects of model-based systems engineering, systems, life cycles, and processes, along with techniques to develop systems. Moving on, you'll explore system models and visualization techniques, focusing on the SysML, and discover how solutions can be defined by developing effective system design, verification, and validation techniques. The book concludes by taking you through key management processes and systems engineering best practices and guidelines.

By the end of this systems engineering book, you'll be able to confidently apply modern model-based systems engineering techniques to your own systems and projects.

- Understand the three evils of systems engineering - complexity, ambiguous communication, and lack of understanding
- Realize successful systems using model-based systems engineering
- Understand the concept of life cycles and how they control the evolution of a system
- Explore processes and related concepts such as activities, stakeholders, and resources
- Discover how needs fit into the systems life cycle and which processes are relevant and how to comply with them
- Find out how design, verification, and validation fit into the life cycle and processes

Who this book is for:

This book is for aspiring systems engineers, engineering managers, or anyone looking to apply systems engineering practices to their systems and projects. While a well-structured, model-based approach to systems engineering is an essential skill for engineers of all disciplines, many companies are finding that new graduates have little understanding of systems engineering. This book helps you acquire this skill with the help of a simple and practical approach to developing successful systems. No prior knowledge of systems engineering or modeling is required to get started with this book.

Table of Contents

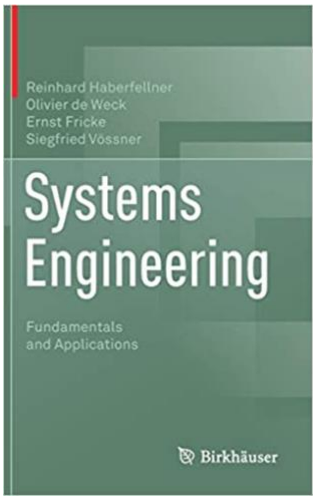
Publisher: Packt Publishing (January 29, 2021)
Kindle, Paperback
ISBN-13: 978-1838985806
ISBN-10: 1838985808

More Information

7.2 Systems Engineering: Fundamentals and Applications

by

Reinhard Haberfellner, Olivier de Weck, Ernst Fricke, and Siegfried Vössner



From the Amazon.com Website:

This translation brings a landmark systems engineering (SE) book to English-speaking audiences for the first time since its original publication in 1972. For decades the SE concept championed by this book has helped engineers solve a wide variety of issues by emphasizing a top-down approach. Moving from the general to the specific, this SE concept has situated itself as uniquely appealing to both highly trained experts and anyone managing a complex project. Until now, this SE concept has only been available to German speakers. By shedding the overtly technical approach adopted by many other SE methods, this book can be used as a problem-solving guide in a great variety of disciplines, engineering and otherwise.

By segmenting the book into separate parts that build upon each other, the SE concept's accessibility is reinforced. The basic principles of SE, problem solving, and systems design are introduced in the first three parts. Then, specific case studies are covered in the fourth part to display potential applications. Part five offers further suggestions on how to effectively practice SE principles; for example, it points out frequent stumbling blocks and also the specific points at which they may appear. In the final part, many different methods and tools, such as optimization techniques, are given to help maximize the potential use of this SE concept.

Engineers and engineering students from all disciplines will find this book extremely helpful in solving complex problems. Because of its practicable lessons in problem-solving, any professional facing a complex project will also find much to learn from this volume.

7.3 Utilizing the MBSE Digital Thread to Accelerate Product Development

SIEMENS

SIEMENS has published an eBook that addresses how to orchestrate a technical program with model-based systems engineering. "The challenges stem from meeting trends in the aerospace and defense industry. This eBook highlights the current industry megatrends and describes how to utilize the MBSE digital thread to accelerate product development."

Access the eBook

7.4 Analytics Insight Magazine

Analytics Insight Magazine is a Print and Digital Publication focused on Artificial Intelligence, Big Data, and Analytics. The Analytics Insight Magazine features opinions and views from top leaders and executives in the industry who share their journey, experiences, success stories, and knowledge to grow profitable businesses.

Analytics Insight's market focus remains on disruptive technologies. The market analysis of these technologies supports decision-makers across organizations and enterprises predict emerging trends, build comprehensive strategy, improve existing products and solutions, plan market expansion and reach out to customers.

The Analytics Insight platform uses extensive market research, historical data, and algorithms to pinpoint emerging trends and future growth opportunities and help organizations determine where to compete. It helps decision-makers innovate technology processes, predict sales with the ability to sense, react and adapt to changing market conditions.

More Information

7.5 AIAA's Journal of Aerospace Information Systems Concerning Systems Engineering's Top Space Challenges

Systems engineering has permeated the engineering ethos in the same way information systems previously redefined the very approach to aerospace science. As systems engineering has grown, numerous core challenges have become paramount in the space domain. This special issue in the *Journal of Aerospace Information Systems* tackles pressing, space-related systems engineering challenges that demand cross-disciplinary solutions.

Anticipated Publication Date: 1 December 2021

7.6 Ethnic Culture and the Systems Engineering Process

by

Tim Ferris

Contributed by

Emmanuel Abuede (MSc)
PPI Intern & Researcher

Before the formations of Systems engineering, managers use their choice of process and experience to execute and manage engineering projects. But then, the advent of Systems engineering process has helped to layout standards that has been helpful to managers and contractors to deliver projects on time, on budgets and with desired performance. Here on this website, there is an expansive coverage of Systems Engineering processes and Ethnic culture

https://onlinelibrary.wiley.com/doi/abs/10.1002/inst.200811128

7.7 Re-evaluating Systems Engineering as a Framework for Tackling Systems Issues

by

Stephen Cook and Tim Ferris

Contributed by

Emmanuel Abuede (MSc)
PPI Intern & Researcher

The paper makes clear that Systems engineering was developed to address challenges concerned with design, implementation, and operation of large, complex technical systems however there are still existing aspects in its approach that reflect the worldview of traditional engineering.

Over this period, the framework that underpins systems engineering has also progressed from engineering science to a transdisciplinary position that incorporates many of the established systems approaches to management. This paper examines the nature of contemporary systems engineering and gives a conclusion of a whole new perspective of Systems Engineering and its attendant applications.

Access the paper here:
https://onlinelibrary.wiley.com/doi/epdf/10.1002/sres.822

7.8 An Aerospace Requirements Setting Model to Improve System Design

by

Tomas Centrich, E. Shehab, P. Sydor, T. Mackley, P. John and A. Harrison

Contributed by

Emmanuel Abuede (MSc)
PPI Intern & Researcher

Overview by Emmanuel Abuede:

This paper describes how decisions at an early conceptual stage of the product lifecycle, are made with relatively low confidence, but such decisions greatly influence the overall product and service development. It is, therefore, critical to define the risks involved in order to help designers to make informed decisions. This research project investigates the risk and uncertainties in delivering products to meet top-level business requirements. The aim is to improve the existing process of setting business requirements and the current design approaches to achieve an optimized system design. This project also examines different approaches in assessing the risk of product and service delivery. To achieve that, a dedicated software tool, based on Weibull distribution function reliability model, has been created.

Access the paper here:
https://www.sciencedirect.com/science/article/pii/S2212827114009408?via%3Dihub

7.9 Review on Life Cycle Inventory: Methods, Examples, and Applications

by

Samantha Islama, S.G.Ponnambalama, Hon Loong Lamb

Contributed by

Emmanuel Abuede (MSc)
PPI Intern & Researcher

Overview by Emmanuel Abuede:

Life Cycle Inventory (LCI) is a crucial phase of the life cycle assessment. LCI deals with the qualification and accumulation of a systems input and output date. When applied as an analysis technique as in this study, different literatures have reported the different LCI methods and their area of applications such as process-based LCI models used in food products, energy products, pharmaceutical products, etc., IO LCI model used in global carbon footprint, water footprint, ecological footprint, etc., hybrid model is applied in energy technologies, GHG intensities, energy requirements, etc.

In summary, this study is a guideline for choosing an appropriate LCI technique.

Access the paper here:
https://www.academia.edu/29050265/Review_on_life_cycle_inventory_methods_examples_and_applications?email_work_card=thumbnail

8. EDUCATION AND ACADEMIA

8.1 Healthcare Systems Engineering Program

Northeastern University College of Engineering has a Healthcare Systems Engineering Institute (HSyE) that is working to embed evidence-based systems engineering improvement methods into local healthcare organizations. HSyE is funded by the Department of Health and Human Services through the Center for Medicare and Medicaid Innovation (CMMI) program. HSyE's mission is to impact healthcare improvement through education, research, and application in systems engineering methods. This mission is pursued through HSyE undergraduate and graduate academic programs, national experiential coop education and summer internship programs, three federally-awarded healthcare IE centers, competitive scholarships, and strategic partnerships. Systems engineers use a variety of methods to model, analyze, predict, improve, and optimize the performance of complex systems.

More Information

8.2 Department of Industrial and Manufacturing Systems Engineering

Lehigh University
Bethlehem, Pennsylvania USA

Industrial and Systems Engineers apply analytics and decision-making skills to optimize complex processes, systems, networks, investments, and organizations in nearly all sectors of activity, including energy, finance, healthcare, logistics, manufacturing, production, telecommunication, and transportation.

Lehigh's Industrial and Systems Engineering (ISE) Department explores and teaches data-driven analytics, optimization, and high-performance computing to provide students the tools to solve a number of complex industrial challenges in areas such as manufacturing, production, healthcare, and financial services.

ISE faculty and graduates perform in the design, improvement, and optimization of processes and systems. They use problem-solving and analytical skills to find ways to make processes better, easier, cheaper or safer, and devise new ways to address issues such as minimizing financial risk, supporting next generation electricity distribution, and optimizing operating room procedures.

More Information

8.3 New Graduate Certificate in Systems Engineering from Australia's National University

Australia's National University (ANU) has released a new Graduate Certificate of Systems Engineering. This Graduate Certificate can be completed as a standalone postgraduate qualification or used as a pathway to a Master of Engineering at ANU.

8.4 M.S. in Industrial and Systems Engineering

College of Engineering and Engineering Technology

Northern Illinois University USA

The Master of Science at the College of Engineering and Engineering Technology program encourages students to develop advanced concepts and techniques to improve systems while encouraging students to engage in real-world engineering projects and projects that can be developed in formal presentations. Students are aided in developing skills that can be applied to a number of fields, including manufacturing, healthcare and transportation.

An advanced degree can be specialized to focus on engineering management, which is offered online. Two tracks – engineering decision analysis or global logistics – are offered to develop further technical skill, aimed at improving your business skills and cultivating effective leaders.

More Information

8.5 Opportunity: University Professor for the Specialist Field of Enterprise and Process Engineering

The Faculty of Informatics at TU Wien would like to further strengthen its profile in Business Informatics and in particular in various subdisciplines of enterprise engineering and business process management. The position as professor for Enterprise and Process Engineering has been allocated in TU Wien's development plan to the focal area Information & Communication Technology. The Faculty of Informatics, one of the eight faculties at the TU Wien, plays an active role in national and international research and has an excellent reputation. The main areas of research include Computer Engineering, Logic and Computation, Visual Computing & Human-Centered Technology, as well as Information Systems Engineering.

The successful candidate should have an excellent research track record in one or more of the following areas (but not limited to):

- Enterprise Engineering
- Enterprise Architecture
- Enterprise Modeling
- Enterprise Governance and Transformation
- Enterprise Information Systems
- Business Process Management:

- Workflow Systems and Technologies
- Process Modeling
- Process Mining
- Agile Processes
- Process Provenance, Auditing and Transparency

More information

Detailed information is available at https://informatics.tuwien.ac.at/news/1993.
Applications should be directed to https://jobs.tuwien.ac.at/Job/145775.

9. SOME SYSTEMS ENGINEERING-RELEVANT WEBSITES

From The Cutting Edge

INCOSE develops cutting-edge materials in order to share its wealth of knowledge with the systems engineering community. These materials are developed by INCOSE experts with vast theoretical and practical knowledge with a focus on providing impactful guides for the community. The categories of these materials include Conference Products (Papers and Presentations Library, INCOSE Chapters, INCOSE Working Groups, and Webinars); INCOSE Technical Products; the INCOSE Store; INCOSE Corporate Advisory Board (CAB) and Academic Council;

The Body of Knowledge and Curriculum to Advance Systems Engineering Project (BKCASE);

Guide to the Systems Engineering Body of Knowledge (SEBoK); and the Graduate Reference Curriculum for Systems Engineering (GRCSE).

Access the Cutting Edge

Electropedia: Online Electrotechnical Vocabulary

Electropedia is produced by the IEC, the world's leading organization that prepares and publishes International Standards for electrical, electronic, and related technologies – collectively known as "electrotechnology". Electropedia (also known as the "IEV Online") contains all the terms and definitions in the International Electrotechnical Vocabulary or IEV which is published also as a set of publications in the IEC 60050 series that can be ordered separately from the IEC webstore.

Electropedia is the world's most comprehensive online terminology database on "electrotechnology", containing more than 22 000 terminological entries in English and French organized by subject area, with equivalent terms in various other languages: Arabic, Chinese, Czech, Dutch (Belgian), Finnish, German, Italian, Japanese, Korean, Mongolian, Norwegian (Bokmål and Nynorsk), Polish, Portuguese, Russian, Serbian, Slovenian, Spanish and Swedish (coverage varies by subject area).

Electropedia is produced under the responsibility of IEC Technical Committee 1 (Terminology), one of the 204 IEC Technical Committees and Subcommittees.

Access Electropedia

Open Services for Lifecycle Collaboration (OSLC)

Several tool vendors have approached horizontal integration, the integration of systems engineering tools, from requirements, to modeling and simulation, to verification and validation, by linking tools in each of these areas through direct integration or through other mechanisms, such as Open Services for Lifecycle Collaboration (OSLC).[10] This website contains information including specifications, resources and news related to OSLC.

Learn More about OSLC

Online Browsing Platform (OBP)

The Online Browsing Platform (OBP) provides search-based access to the most up to date content in ISO standards, graphical symbols, codes and terms and definitions. Content can be previewed, search within documents is provided, and it is possible to navigate between standards.

SEVOCAB: Software and Systems Engineering Vocabulary

A project of the IEEE Computer Society and ISO/IEC JTC 1/SC7, the SEVOCAB website provides definitions for software and systems engineering terms from ISO, IEEE, and PMI international standards. You can search for definitions of a term from the standards, or for all the definitions in a source standard. To provide an understanding of related concepts, SEVOCAB will return not only any definitions for the term, but also all the definitions that use the term

https://pascal.computer.org/sev_display/index.action

The Engineer

The-Engineer website is dedicated to latest engineering news in the areas of engineering business and technology, innovation, and legislation https://www.theengineer.co.uk/news/

MBSE4U

The following webpage hosts information on the most popular and common SysML/MBSE Modelling tools.

Tim Weilkiens, author of the page writes:

“There is no "best modeling tool". The best tool for project A is another than the best tool for project B. It depends on the different requirements of the projects.”

https://mbse4u.com/sysml-tools/

[10] For more information see https://open-services.net/.

Scaled Agile Framework

Version 5 of the Scaled Agile Framework (SAFe) represents the most ambitious expansion of that mission in our history: to enable the business agility that is required for enterprises to compete and thrive in the digital age. This requires every part of the organization involved in delivering technology-based solutions – development, operations, manufacturing, legal, marketing, finance, compliance, sales, and others – to embrace the principles and practices of Lean and Agile. This if the home of the SAFe, containing courseware, training, community resources, and information regarding certification programs.

Read the FAQs on how to use SAFe content and trademarks here:
https://www.scaledagile.com/about/about-us/permissions-faq/

Explore Training at:
https://www.scaledagile.com/training/calendar/

10. STANDARDS AND GUIDES

10.1 ISO/IEC/IEEE 16085 (Risk Management) Has Been Updated

ISO/IEC/IEEE 16085 —"Systems and software engineering—Life cycle processes—Risk management" provides a universally applicable standard for practitioners responsible for managing risks associated with systems and software during their life cycle. It has recently been revised to align with updates of other related standards, as well as to include new content related to risk management challenges inherent to large, complex systems-engineering programs and projects.

The new standard provides information on how to design, develop, implement, and continually improve risk management in a systems and software engineering project throughout its life cycle. It elaborates on the risk management process described in International Standards ISO/IEC/IEEE 15288—"Systems and software engineering—System life cycle processes" and ISO/IEC/IEEE 12207—"Systems and software engineering—Software life cycle processes."

By providing a comprehensive reference for integrating the wide variety of processes, practices, techniques, and tools encountered in systems and software engineering projects and other life-cycle activities, ISO/IEC/IEEE 16085 enables a unified approach to risk management.

ISO/IEC/IEEE 16085 was developed by the joint ISO and IEC (International Electrotechnical Commission) technical committee ISO/IEC JTC 1, Information technology, subcommittee SC 7, Software and systems engineering, the secretariat of which is held by BIS, ISO's member for India. The standard was prepared in cooperation with the Institute of Electrical and Electronics Engineers (IEEE).

More Information

10.2 SAE OnQue™ Digital Standards System

This webpage provides access to SAE OnQue™ Digital Standards System, a system of cloud-based, actionable standards data. SAE publishes standards on many aspects of systems engineering. The platform claims robust search functionality, or users can link directly to model-based design, digital twin, or other applications.

10.3 Requirements Interchange Format (ReqIF)

The Requirements Interchange Format™ specification provides standards-based exchange of requirements authored in different Requirements Management (RM) tools; almost all RM and SysML modeling tools today support ReqIF import and export.

For technical and organizational reasons, two companies in the manufacturing industry are rarely able to work on the same requirements repository and sometimes do not work with the same requirements authoring tools. A generic, nonproprietary format for requirements information is required to cross the chasm and to satisfy the urgent industry need for exchanging requirement information between different companies without losing the advantage of requirements management at the organizations' borders.

With the help of a dedicated interchange format for requirements specifications, it is possible to bridge the gap:

- The collaboration between partner companies is improved by the benefits of applying requirements management methods across company borders.
- The partner companies do not have to use the same requirements authoring tool and suppliers do not need to have multiple requirements authoring tools to fulfill the need of their customers with regards to compatibility.
- Within a company, requirement information can be exchanged even if various tools are used to author requirements

Requirements Interchange Format (ReqIF) defines such an open, non-proprietary exchange format. Requirement information is exchanged by transferring XML documents that comply to the ReqIF format.

Source: Object Management Group

10.4 Standard for Command-and-Control Systems - Simulation Systems Interoperation

SISO-STD-019-2020: Standard for Command-and-Control Systems - Simulation Systems Interoperation has been released, along with a Guidance Document and the Standard for the Land Operations Extension (LOX) to C2SIM. Visit this link to view and download.

11. SOME DEFINITIONS TO CLOSE ON

11.1 Digital Thread

1) The digital thread is a term for the lowest level design and specification for a digital representation of a physical item. The digital thread is a critical capability in model-based systems engineering (MBSE) and the foundation for a digital twin.

Source: Wikipedia

2) The digital thread is “a communication framework that connects traditionally siloed elements in manufacturing processes and provides an integrated view of an asset throughout the manufacturing lifecycle.” We define it more generally as an integrated view of everything about an asset or product throughout its lifecycle.

The ultimate goal of a digital thread strategy in manufacturing is to increase productivity and product quality while decreasing costs. With insight into every aspect of the product lifecycle, organizations can make more informed decisions throughout product development.

Source: Tech Target

11.2 Digital Twin

1. A digital twin is the generation or collection of digital data representing a physical object. The concept of digital twin has its roots in engineering and the creation of engineering drawings/graphics.

Source: Wikipedia

2. The digital twin is the virtual representation of a physical object or system across its life-cycle. It uses real-time data and other sources to enable learning, reasoning, and dynamically recalibrating for improved decision making.

Source: IBM

12. CONFERENCES AND MEETINGS

For more information on systems engineering related conferences and meetings, please proceed to our website.

12.1 Featured Conference

The Sixteenth International Conference on Systems (ICONS)

18 – 22 April 2021

Porto, Portugal (Onsite and Virtual Event)

ICONS 2021 conference tracks:

- Systems theory and practice
- Systems engineering
- Intelligent and vehicular transportation systems
- System Instrumentation
- Embedded systems and systems-on-the-chip
- Advanced embedded systems and applications/services
- Target-oriented systems [emulation, simulation, prediction, etc.]
- Specialized systems [sensor-based, mobile, multimedia, biometrics, etc.]
- Validation systems
- Security and protection systems
- Advanced systems [expert, tutoring, self-adapting, interactive, etc.]
- Application-oriented systems [content, eHealth, radar, financial, vehicular, etc.]
- IT Systems
- Safety in industrial systems
- Complex systems
- Computer vision and computer graphics

Special tracks:

WiSEB 2021: Widening Systems Engineering Borders
Chair: Giulio Telleschi, MBDA, Italy giulio.telleschi@mbda.it
Coordinator: Matteo Fasano, MBDA, Italy matteo.fasano@mbda.it

AI4SysSoS: Challenges for Artificial Intelligence-Machine Learning in Complex Systems and Systems of Systems Chair: Dr.Ramakrishnan Raman, Honeywell Technology Solutions, India
Ramakrishnan.Raman@honeywell.com
Coordinator: Dr. Ali K Raz, George Mason University, USA araz@gmu.edu

Register here

12.2 Other Notable Conferences

The 5th International Symposium on Aviation and Aerospace System Engineering (SAASE 2021) is coming up on the 14 – 16 May 2021 in Beijing, China. The conference is in conjunction with the 5th International Conference on Aeronautical Materials and Aerospace Engineering (AMAE 2021), SAASE is organized by Hong Kong Society of Mechanical Engineers (HKSME). More information about the conference will be found in this website https://www.saase.org/Cfp.html.

13. PPI AND CTI NEWS

13.1 Dr. Ralph Young Will Pass the Batton for PPI SyEN Editorship to Kevin Nortrup

Ralph Young *Kevin Nortrup*

As the saying goes, all good things come to an end eventually. Dr. Ralph Young is stepping down as Editor of PPI SyEN Systems Engineering Newsjournal after a marathon innings that will continue to include the celebration April 2021 100th Edition. Kevin Nortrup will take over the Editor role from Ralph commencing with the May 2021 Edition of PPI SyEN.

The whole PPI/CTI team extends to Ralph our thanks for his leadership of PPI SyEN. To put Ralph's contribution in perspective, the history of editorship will be:

PPI SyEN	1 – 34	Oct 2008 - Jul 2011	Alwyn Smit
PPI SyEN	35 – 47	Aug 2011 - Aug 2012	Dr. Ralph Young
PPI SyEN	48 – 50	Sep 2012 - Dec 2012	Suja Joseph-Malherbe
PPI SyEN	51 – 100	Jan 2013 - Apr 2021	Dr. Ralph Young

that is, Ralph will have edited 63 editions of SyEN, a monumental accomplishment, when he retires with the April edition. PPI Managing Director Robert Halligan said, in relation to Ralph's retirement, "Ralph, PPI, the readership of PPI SyEN and the engineering community in general owe you a great debt for the endless hours you have devoted each month to PPI SyEN, for the consistently high standard of PPI SyEN you have achieved, and for the value your toil has generated for the engineering community."

New editor, Kevin Nortrup CSEP, CPHIMS, LSSGB, FHIMSS, DSHS will bring to the role from May 2021 onwards a strong complement of technical, organizational and management excellence, together with creativity, vision, leadership, and passion for continuous learning and improvement. Kevin has already contributed greatly to the engineering community, fulfilling leadership roles in the International Council on Systems Engineering (INCOSE), Co-chair, Enterprise Systems Working Group, 2018-present; the Healthcare Information & Management Systems Society (HIMSS); the Society for Health Systems (SHS); the International Society for Systems and Complexity Science for Health (ISSCSH) Board of Directors, 2019-present; and the Institute of Industrial & Systems Engineers (IISE) Board of Directors, Indiana Chapter, 2019-present, all whilst operating since 2003 his successful consulting business, Sugar Creek Solutions LLC.

13.2 CTI Managing Director Completes MSc in Systems Engineering

CTI Managing Director René King graduated in December 2020 with a Master of Science (MSc) in Systems Engineering from the University of the Witwatersrand, Johannesburg, South Africa. The 50/50 MSc comprised of courseware and research. Topics as part of the degree program included Requirements Analysis, Integration, Verification and Validation and Architectural Design. Her research report was titled, 'Development of a Conceptual Framework for the Understanding and Analysis of Operational Capacity for a Freight Railway Network.'

Well done on this achievement, René!

14. PPI AND CTI EVENTS

https://www.ppi-int.com/ppi-live-online/

For a full public PPI training course schedule, please visit https://www.ppi-int.com/course-schedule/

For a full public CTI Live-Online™ INCOSE SEP Exam Preparation course schedule, please visit https://certificationtraining-int.com/incose-sep-exam-prep-course/

To enquire about CTI Live-Online™ INCOSE SEP Exam Preparation Training for your organization, please visit https://certificationtraining-int.com/on-site-training/

15. UPCOMING PPI PARTICIPATION IN PROFESSIONAL CONFERENCES

PPI will be participating physically in the following upcoming events. We support the events that we are sponsoring, and look forward to meeting old friends and making new friends at the events at which we will be exhibiting.

The INCOSE International Conference 2021

Date: 17 – 22 July 2021
Location: Virtual Event

Kind regards from the PPI SyEN team:

Robert Halligan, Editor-in-Chief, email: rhalligan@ppi-int.com

Dr. Ralph Young, Editor, email: syen@ppi-int.com

René King, Managing Editor, email: rking@ppi-int.com

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Tell us what you think of PPI SyEN. Email us at syen@ppi-int.info.