PPI SyEN

SYSTEMS ENGINEERING NEWSJOURNAL
EDITION 106 | NOV 2021

Solutions for Rapid Change

AGILE METHODOLOGY PART 3
System architecture models

SE FOR SCIENTISTS
Viewing projects holistically

THE EVOLUTION OF SEBoK
A new technical precedent

A PROJECT PERFORMANCE INTERNATIONAL PUBLICATION | PPI-INT.COM

PPI SyEN

EMAIL: PPISyEN@PPI-Int.com

PUBLISHER

PROJECT PERFORMANCE INTERNATIONAL

Project Performance International
2 Parkgate Drive
Ringwood, Vic 3134 Australia
Tel: +61 3 9876 7345

Tel Brazil: +55 12 9 9780 3490
Tel UK: +44 20 3608 6754
Tel USA: +1 888 772 5174
Tel China: +86 188 5117 2867

www.ppi-int.com
contact@ppi-int.com

PPI SyEN (PPI Systems Engineering Newsjournal) is published monthly.

Archived editions and subscriptions to future editions are available for free at: https://www.ppi-int.com/syen-newsjournal/

WELCOME

Welcome back to another edition of PPI SyEN! This November edition is packed with some exciting topics pertaining to the role of systems engineering in our dynamic world.

The world is at an interesting precipe in time: on the one hand our technology advancements have surpassed what even some Sci-Fi movies predicted a few decades ago. On the other hand, while there is increased awareness about the urgency for us to change the way we extract and use resources on this planet – the rate of change in behavior is not fast enough to bring peace to our children's future and their children's future and so on. Solutions that focus on more than just the technological aspects and that consider interactions with external elements over the entire life cycle are essential to our sustained existence on this planet.

Systems engineering is not a prescription. It is a tool box of sorts that can be applied, with adequate skills and level of understanding about the system, to produce very effective results in the engineering of our systems. The needs of our world are changing rapidly and we have to adapt, we have to face the music by managing complexity skillfully and ethically for the sake of our existence.

This edition provides in depth insight into some of the most relevant elements that comprise the holistic solutions we need in order to respond appropriately to the rapid changes of our time In this edition, discover opportunities to expand your knowledge on system dynamics, get access to powerful resources related to the theory and practice of systems engineering and read about thought provoking topics such as the importance of planning for verification, integration and validation from the outset of development.

In this edition we'll answer questions such as – how do we produce models that are secure, readable and archivable for decades to come? How do we ensure that the content contained in the models serves their purpose? These are not considerations peripheral to SE – they're key considerations in the effectiveness of SE. We'll look at all of this in this month's edition.

If you're interested in the role of SE in our response to climate change, if you're passionate about recruiting our youth into the way of thinking and acting that is SE and if you're curious about what the future of SE may look like then this edition is for you!

I hope you enjoy PPI SyEN 106!

Regards

René

Managing Editor, PPI SyEN

PPI Systems Engineering Newsjournal (PPI SyEN) seeks:	**PPI defines systems engineering as:**
➢ To advance the practice and perceived value of systems engineering across a broad range of activities, responsibilities, and job-descriptions ➢ To influence the field of systems engineering from an independent perspective ➢ To provide information, tools, techniques, and other value to a wide spectrum of practitioners, from the experienced, to the newcomer, to the curious ➢ To emphasize that systems engineering exists within the context of (and should be contributory toward) larger social/enterprise systems, not just an end within itself ➢ To give back to the Systems Engineering community	*an approach to the engineering of systems, based on systems thinking, that aims to transform a need for a solution into an actual solution that meets imperatives and maximizes effectiveness on a whole-of-life basis, in accordance with the values of the stakeholders whom the solution is to serve. Systems engineering embraces both technical and management dimensions of problem definition and problem solving.*

SYSTEMS ENGINEERING NEWS

Recent events and updates in the field of systems engineering

System Dynamics Review - Call for Papers

The System Dynamics Review has issued a call for papers associated with its upcoming issue on the "Qualitative Aspects of System Dynamics Modeling"

Noting that almost all forms of system dynamics modeling use qualitative data and methods to:

- Conceptualize and structure dynamics models
- Interpret and communicate findings and insights
- Represent a system purely qualitatively to encourage stakeholder engagement or to develop consensus around a problem.

The editors are looking for practical examples of the application of qualitative methods to the modeling process, i.e. work that may inspire the thousands of systems thinkers and system dynamicists around the world who read the System Dynamics Review.

Potential topics include, but are not limited to:

- Qualitative procedures in problem elicitation
- Model conceptualization and representation, such as causal loop diagrams
- Qualitative data sources and research methods
- Integration of qualitative and quantitative data
- Validation of qualitative aspects
- Learning from social science theory and methods

Initial abstracts are due by 30 November 30, 2021. Abstracts and inquiries should be directed to the editors for the special issue: Krys Stave (krystyna.stave@unlv.edu), Nici Zimmermann (n.zimmermann@ucl.ac.uk) and Hyunjung Kim (hkim18@csuchico.edu).

Final versions of invited papers will be due no later than 31 August 31, 2022.

Society members can access all articles by logging in on the Society website and clicking the "Member Only Access" button. Join now.

Learn more.

Society of System Dynamics offers Fundamentals of System Dynamics Modelling Course

The System Dynamics Society announces the availability of a new online course, offered by DESTA, to introduce participants to the fundamentals of System Dynamics and simulation modelling with the opportunity to apply the tools of computer simulation.

DESTA is a firm located in India dedicated to providing research and consulting services for sustainable development using System Dynamics and systems thinking.

Students will:

- Practice System Dynamics modeling with Stella Software
- Deepen their knowledge about real-world complexity through System Dynamics
- Improve their understanding of outcomes of your actions
- Develop their decision-making skills with the power of systems thinking
- Learn how to generate multiple future scenarios under different 'what-if' conditions

This immersive online three week course begins on 25 November.

Learn more.

INCOSE UK Contributes to Guidance on Systems Integration by the Infrastructure and Projects Authority (IPA)

The Infrastructure and Projects Authority (IPA) is the United Kingdom's government center of expertise for infrastructure and major projects. IPA supports the successful delivery of all types of infrastructure and major projects; ranging from railways, schools, hospitals and housing, to defense, IT and major transformation programs.

Project Routemap is the IPA's support tool for novel or complex major projects. Developed by the UK government in collaboration with industry and academia, the Routemap helps sponsors and clients understand the capabilities needed to successfully deliver projects, incorporating lessons learned from other major projects and programs.

Project Routemap is comprised of eight modules:

INCOSE UK has contributed to the IPA's new Guidance on Systems Integration within the refreshed suite of Routemap modules. Topics addressed in the Systems Integration module include:

- Systems integration, and why it's important
- Typical findings relating to system integration
- Pillars of effective systems integration with questions to consider on how well a project meets these guidelines
- Good practice examples
- Suggested further reading
- Glossary

Learn more

Access the refreshed and new Project Routemap modules here.

Download the new Systems Integration Module.

SEBoK Version 2.5 Update Released

The Version 2.5 update to the Systems Engineering Body of Knowledge (SEBoK) was released on 15 October 2021.

The SEBoK provides a guide to the key knowledge sources and references of systems engineering.

Version 2.5 includes a wide range of improvements:

- Streamlined SEBoK landing page
- New Editor's Corner focused on current and emerging trends in systems engineering
- New sponsors and sponsorship packages
- Improved site navigation
- User community feedback incorporated into SEBoK content
- Improved IT infrastructure and performance

Access SEBoK here. Learn more about SEBoK in Nicole Hutchinson's feature article later in this edition.

Siemens Polarion ALM 21 R2 Available

Siemens has released Version 21 R2 of its Polarion (Application Lifecycle Management) ALM software.

- Version 21 R2 highlights new features and enhancements in response to customer requests:
- Xcelerator Share Integration – collaboration capability
- Table-type Custom Field – configurable tables
- LiveDoc Collaboration enhancements
- Improved authentication, e.g. electronic signatures and user group synchronization
- Connector enhancements for OSLC and ReqIF

Learn more

CONFERENCES, MEETINGS & WEBINARS

Upcoming events of relevance to systems engineering

Digital Engineering Symposium - Call for Presentations

The Integrate 22 Digital Engineering Symposium, sponsored by Vitech, is now accepting abstracts for 45-minute technical presentations. Presentations should highlight technology, techniques, or methodologies that advance the state of systems engineering, Model-Based Systems Engineering (MBSE), or Digital Engineering as a whole. Case studies, how-to information, and usage tips are favored, and individual or team presentations are welcome.

Presentations are encouraged from a broad range of industries such as, but not limited to, automotive, aerospace, space systems, defense, energy, industrial automation, manufacturing, construction, and medical.

Selected presentations will emphasize novel methods and approaches to solving real-world problems and will not be limited to any specific tooling.

Potential topics of interest include:

- Digital Engineering - Innovative approaches to process and data continuity, digital thread, and connected engineering.
- Systems Engineering - Including architecture best practices and MBSE methods as applied to industry solutions.
- Enterprise Architecture - The latest advances in digitalization of processes, manufacturing, and more.

The Digital Engineering Symposium shall be held in San Antonio, Texas from 6-9 June, 2022 and will share the conference site with Zuken Innovation World Americas, Zuken USA's annual user and technology conference.

Important deadlines:

- December 31, 2021: Abstract submissions due
- January 21, 2022: Acceptance notification
- February 4, 2022: Signed speaker agreement, company description, company logo, author bio, and headshot due
- April 8, 2022: Draft presentations due
- April 22, 2022: Speaker registration due
- May 6, 2022: Final presentation due

Submit abstract here.

Webinar: The Five Immutable Truths About Great Product Managers

The St. Louis chapter of the Product Data Management Association (PDMA) is hosting a free webinar on 14 December to highlight the outstanding characteristics of great product managers, regardless of industry, type of product, educational background, development methodology, or product management framework.

Learning Objectives:

- Learn the five foundational assets that all great product managers have
- Learn how to build these skillsets using tools and best practices
- Learn how they all work together to help make you a better product manager

Register here.

Registration Open for 2021 Virtual PDMA Innovators Conference and JPIM Research Forum

The 2021 PDMA Innovators Conference and JPIM Research Forum has been rescheduled as a virtual conference, now occurring on 13-15 January, 2022.

Keynote speakers include:

- Gloria Barczak: Professor Emeritus of Marketing and Innovation, D'Amore-McKim School of Business, Northeastern University
- Abbie Griffin: Associate Dean for Business Innovation, School of Medicine, University of Utah
- Anil K. Gupta, Professor at University of Maryland, Michael D. Dingman Chair in Strategy and Entrepreneurship
- Steve Rader, Program Manager, NASA Tournament Lab
- Anna-Maria Rivas McGowen, Senior Technical Fellow at NASA Langley Research Center

Full speaker bios here.

Schedule at a glance (all times U.S. Eastern)

<table>
<tr><th>Thursday, January 13
9:00 AM – 11:00 AM</th><th colspan="2">Friday, January 14
9:00 AM – 3:30 PM</th><th colspan="2">Saturday, January 15
9:00 AM – 3:30 PM</th></tr>
<tr><td rowspan="3">PDMA INNOVATORS CONFERENCE + JPIM RESEARCH FORUM
Keynote Speaker and Bridge Session</td><td colspan="2">PDMA INNOVATORS CONFERENCE + JPIM RESEARCH FORUM:
Keynote Speaker and Student Competition</td><td colspan="2">PDMA INNOVATORS CONFERENCE + JPIM RESEARCH FORUM:
Keynote Speaker</td></tr>
<tr><td>PDMA INNOVATORS CONFERENCE:
Breakouts</td><td>JPIM RESEARCH FORUM:
Breakouts</td><td>PDMA INNOVATORS CONFERENCE:
Breakouts</td><td>JPIM RESEARCH FORUM:
Breakouts</td></tr>
<tr><td colspan="2">PDMA INNOVATORS CONFERENCE + JPIM RESEARCH FORUM:
Closing Remarks and Networking</td><td colspan="2">PDMA INNOVATORS CONFERENCE + JPIM RESEARCH FORUM:
Panel, Keynote Speaker, and Networking</td></tr>
</table>

Registration is open here.

FEATURED ARTICLES

Architecture Models as Enablers of Agility

by Juan Navas, Thales Corporate Engineering

Email: juan.navas@thalesgroup.com

Based on the paper **Models as enablers of agility in complex systems engineering** presented at the INCOSE International Symposium 2020 by Juan Navas, Stephane Bonnet, Guillaume Journaux and Jean-Luc Voirin.

Abstract

This series of articles follows the engineering teams of the PythaDrone project during their endeavor of developing a drone-based product that addresses multiple market segments. The focus is on the use of system architecture models as the basis for several technical, management and organizational activities, in a context in which a company implements agility in its engineering processes. Although the PythaDrone project and the Pythagoras company are fictive, the practices described here are those put in place in some our projects and business units.

Episode 3 – Run faster and longer!

Previously on Episodes 1 and 2

In Episode 1 of this series of articles, we introduced the fictive PythaDrone team in the also fictive Pythagoras company, who is in charge of developing a lightweight drone-based product that will address different markets: agriculture, aircraft exterior inspection, and public security enforcement. The team is implementing both agility and MBSE practices in order to react faster to changes in the customers' expectations and ensure the consistency of the design.

In Episode 2 we situated ourselves in the third iteration of the project and we followed the Architecture team into designing a capability of the PythaDrone product using Arcadia and Capella MBSE practices. In this last episode we will focus on how software and IVV teams use the design that is created by architects; and on the "Evaluation" activity at the end of iterations.

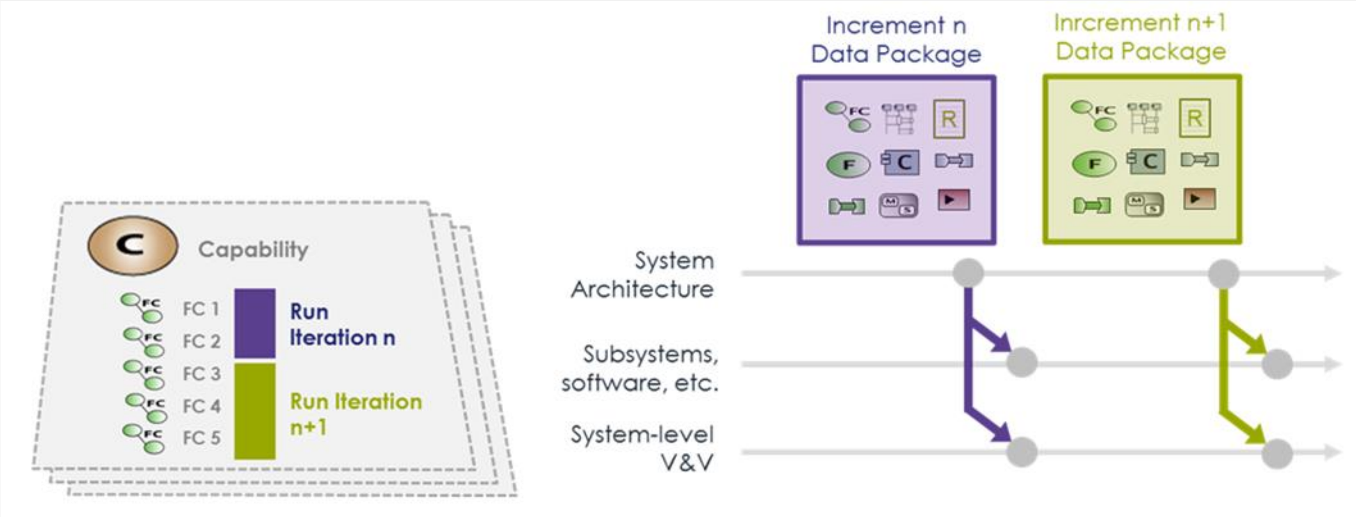
Transferring the design

During the "Run" activity of the Architecture team, verification tasks were performed to ensure the proper quality of the design increments. At the end of Iteration 3, the design is ready to be exploited by other engineering teams.

Design Data Packages

An increment design data package is made of sets of engineering data that will be transferred to either lower engineering levels teams (subsystems, software, hardware) or to other engineering teams (e.g. Verification & Validation, specialty engineering), becoming inputs for subsequent iterations.

It contains engineering artifacts associated to both Needs & Contexts and Solution perspectives. For instance, it will contain a product Capability, a set of Functional Chains describing it at the System Needs Analysis perspective, and the Functional Chains, Functions and other model elements realizing them at the Physical Architecture perspective. Moreover, it will also contain all textual requirements, constraints, justifications and simulation-based analysis that are associated to these engineering artifacts. This is illustrated in the figure below.

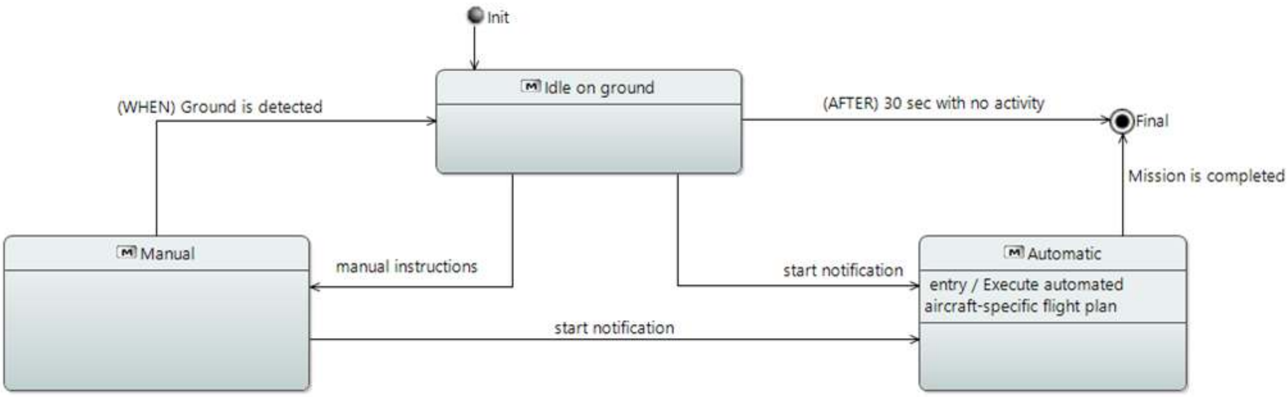


The design that is delivered to Software and IVV teams is based on the product capabilities and associated functional chains describing them (cf. Episode 2 for more information on these). Some of them are new; others are updated versions of existing ones. The table below summarizes the functional chains in the data package:

Capability	Physical Architecture Functional Chains	Status
Manually pilot the drone	Manual drone motion and orientation control	New
	Manual drone motion and orientation control with obstacles avoidance	New
	Manual drone control with tablet	New
	Manual drone control with joystick	New
Automatically follow a flight plan	Automated drone motion and orientation control	Updated
	Automated drone motion and orientation control with obstacles avoidance	Updated
Visualize data after mission execution	Visualize HD video stream	Updated
	Visualize drone attitude	Updated

As a result of the design tasks done in this iteration, the product now has two operating modes: automated or manual control. The Architecture team also worked on the supervision task that will control these operating modes, and represented it using a modes machine shown in the figure below, which shows:

- The operating modes (in gray) Manual, Automatic and Idle on ground, along with the function that shall be activated once the Automatic mode is entered
- The conditions that triggers the passage from one mode to another (arrows). Note that the design does not consider the possibility to switch from automated to manual mode.



Iteration 4 – Focus on the control software team

During the "warm-up" of this iteration, the control software team defines one EPIC for each one of the functional chains that were assigned to them. They refine these EPICs in user stories that will develop in successive 2-weeks length sprints. The content of the user stories is defined so that value (working software) is delivered after each sprint (cf. Episode 1 to know more about this "warm-up" activity).

"Run" activity runs the 6 sprints planned for this iteration, and it occurs as follows:

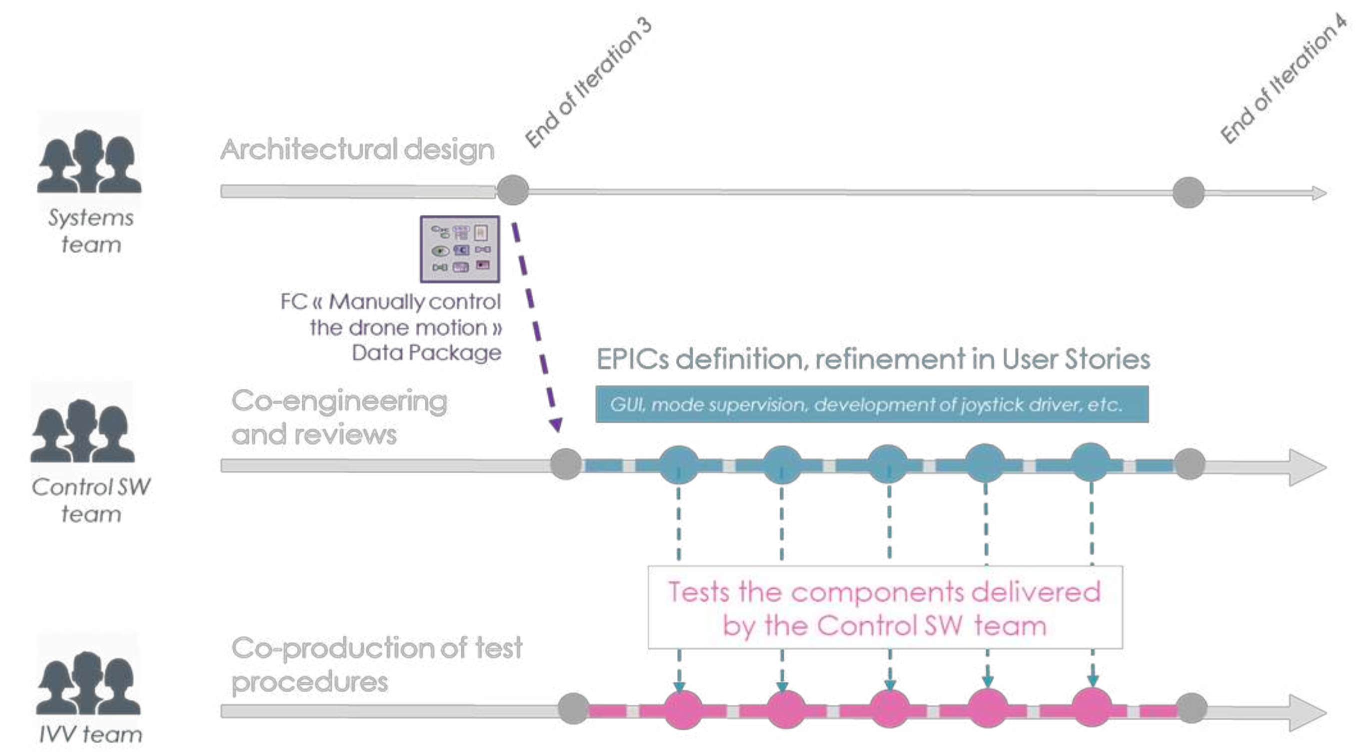
- Sprint 1 is devoted to initializing the graphical user interface and giving the possibility to switch between manual and automated modes, following the specifications provided by the Architecture team
- Sprint 2 addresses the modifications of the graphical user interface due to the redesign of the HD video stream and drone attitude visualization
- Sprints 3 and 4 are focused on translating the instructions provided by the joystick firmware in motion instructions compatible with the solution in which was previously developed for automated piloting. Graphical user interface for manual piloting from the tablet is developed too, even though it is not integrated yet. At the end of sprint 3 the drone can be piloted with the joystick
- Sprint 5 is about integrating the actual drone motion to the piloting graphical interface on the tablet
- Sprint 6 focuses on switchover corner cases and graphical user interface finalization. In parallel, some team members anticipate the "Evaluation" activity and analyze what went well and wrong in this iteration.

The main input for the software team was the design in the Physical Architecture perspective along with its associated textual requirements. However, having the System Needs Analysis Capabilities and Functional Chains in the data package as well help them to better understand how the implementation of a piece of interface or of a small feature fits in the product-wide picture, and also help them split EPICs into more meaningful user stories.

Iteration 4 – Focus on the Integration, Verification and Validation (IVV) team

During iteration 3, IVV team was already involved in the design of these functional chains, and were able to define test procedures for each functional chain (cf. Episode 2). Now in iteration 4 the team will refine the procedures and perform other tasks such as preparing the test data and specifying or developing the test means, to be able to run these validation campaigns during this iteration.

The pace of the IVV team is aligned with the one of the software development team. The IVV team integrates the components delivered by the software team every second week, and runs the test procedures written during the previous iteration. The figure below illustrates the alignment between SW and IVV teams.



The added-value of the model-based approach becomes even greater here. When a problem is encountered on a test step, finding the corresponding Function or Functional Exchange in the model is straightforward. Using automated impact analysis, the investigation on the related data is also immediate. It is straightforward to locate the possible cause of a problem. This analysis of the model can have different outputs. If the model (need and corresponding solution) is correct, a defect is created on the faulty component. If the model is actually faulty, then a defect is created on the model itself, and a change request is created for the involved component and/or functional chain.

Iteration 6 – The end of the adventure?

We take a leap in time and situate ourselves at the end of the project, 18 months after it started. All the product capabilities have been delivered on time, and customers are already placing orders for the different configurations of the product.

The implementation of agility has allowed engineering teams to react quickly to new requests from marketing. The implementation of MBSE practices has allowed engineers to deliver high-quality product increments at the end of each iteration.

Capability	% designed	% developed	% validated
Manually pilot the drone	100%	100%	100%
Automatically follow a flight plan	100%	100%	100%
Manually acquire data	100%	100%	100%
Automatically acquire data	100%	100%	100%
Visualize data during mission execution	100%	100%	100%
Visualize data after mission execution	100%	100%	100%
Analyze data during mission execution	100%	100%	100%
Analyze data after mission execution	100%	100%	100%

Now it is time for the engineering team to evaluate their performance and document the lessons learned for future projects.

Evaluation

"Evaluation" is the third kind of activities that you perform in an iteration, along with "Warm-up" and "Run" which were presented in the previous episodes. Using the sports analogy, in an iteration you need to prepare yourself (warm-up) before performing a continuous and strong effort (run), and if you want to improve you need to measure and analyze your performance (evaluate).

Warm-up Run Evaluate

This activity aims at both evaluating the product increment (i.e. what was produced during the iteration) and the engineering effort that has been performed (i.e. how it was produced).

Regarding the first objective, note that the major part of the integration, verification and validation effort is performed incrementally during the run iterations, and the evaluation focuses on ensuring that the whole can be released. The nature of the tasks performed here strongly varies following the life cycle of the system:

- During early stages, it may include multi-viewpoints analysis (safety, security, performance, reliability, testability etc.), the preparation of a review of experts or the execution of simulations
- Later it may include the approval by the customer or the packaging of software and hardware releases.

Regarding the second objective, the engineering team members review the engineering practices, identify what went well and wrong, elucidate ways to improve the way they perform their engineering effort, including the dependencies with stakeholders, both outside and inside their organization.

Now that the product has transitioned to an operations phase, is it the end of the adventure? Absolutely not! Customers are already asking for enhancements and new features, and the customer experience in aircraft inspection market has grown interest on the product in a new market: the inspection of electric infrastructure, for which the product will need to provide a longer autonomy.

It seems that a new "warm-up" activity will need to be launched very soon, in order to prepare the engineering teams for a new endeavor!

List of Acronyms Used in this Paper

Acronym	Explanation
MBSE	Model Based Systems Engineering
PLE	Product Line Engineering

References

Dove, Schnidel 2018. Agile Systems Engineering Life Cycle Model for Mixed Discipline Engineering. 28th Annual INCOSE International Symposium 2018.

INCOSE, 2014, 'A World in Motion – Systems Engineering Vision 2015'.

ISO/IEC/IEEE 15288, 2015, 'Systems and software engineering – System life cycle processes'.

IEEE 1220, 2005, IEEE Standard for Application and Management of the SE Process.

Voirin J-L, 2017, 'Model-based System and Architecture Engineering with the Arcadia Method', ISTE Press, London & Elsevier, Oxford, 2017.

Capella, 2019, Capella Polarsys Website: https://www.polarsys.org/capella/.

Bonnet S, Voirin J-L, Normand V , Exertier D, 2015, 'Implementing the MBSE Cultural Change: Organization, Coaching and Lessons Learned', 25th INCOSE International Symposium.

Navas, J, 2019, 'How MBSE practices support the effective implementation of a Product Line Engineering approach', 29th Annual INCOSE International Symposium, 2019.

Bonnet S, Voirin J-L, Navas J., 2019, 'Augmenting requirements with models to improve the articulation between system engineering levels and optimize V&V practices', 29th Annual INCOSE International Symposium, 2019.

ISO/IEC TR 24748-1, 2010, 'Systems and software engineering — Life cycle management — Part 1: Guide for life cycle management'.

About the Author

Juan Navas is a Systems Architect with 15 years' experience on performing Systems Engineering activities and implementing innovative engineering practices in multiple organizations. He currently leads the Modelling & Simulation team at Thales Corporate Engineering and dedicates most of his time to expertise and consulting for Thales business units and other organizations worldwide, accompanying managers and architects when implementing MBSE practices. He holds a PhD on embedded software engineering, a MSc Degree on control and computer science, and Electronics and Electrical Engineering Degree.

Systems Engineering for Scientists – Combining Synthesis with Analysis

by

Clark Stacey *(Email: clark.stacey@npl.co.uk)*

Joshua M. R. Shaylor *(Email: joshua.shaylor@npl.co.uk)*

National Physical Laboratory, Hampton Road, Teddington, TW11 0LW, United Kingdom

Abstract

The United Kingdom's National Physical Laboratory has developed a new approach to systems engineering that is specifically aimed at scientists engaged in designing and developing scientific measurement instruments. The default approach naturally employed by most scientists when starting the specification of an instrument is to break it down into its constituent parts and to focus on the scientific and technological aspects of the design. This paper describes a simple three-stage framework that emphasizes top-level requirements and synthesizing an understanding of the whole system-of-systems within which the instrument will operate. The framework includes a systematic approach to identifying and understanding the functional interactions that the instrument will have with other external systems. Initial trials of this framework within instrument development projects at NPL are discussed. The authors offer their views on its effectiveness at encouraging scientists to start the design process by taking a step back and understanding the whole design space, before focusing on the technology and scientific challenges.

Keywords: Systems Engineering; Scientists; Psychology; Requirements; Specification; Synthesis; Analysis.

Introduction

The National Physical Laboratory (NPL 2020) has developed a new approach to systems engineering that is specifically tailored for the development of scientific measurement instrumentation by small teams of research scientists. It aims to address some of the organizational, cultural and psychological issues that can limit productivity and delivery when scientists are responsible for the whole product development lifecycle with only limited support in terms of engineering or marketing.

In addition to utilizing knowledge from systems thinking and system engineering sources, such as the INCOSE Systems Engineering Handbook (Walden et al. 2015) and the international standard ISO/IEC/IEEE 15288:2015 on systems and software engineering (ISO/IEC/IEEE 2015), this new approach also draws on insights from the disciplines of psychology, marketing and project management. The primary goal is to influence the scientist's thinking and behavior in such a way that they take a more holistic and whole-lifecycle perspective during the early phases of a development project. This is intended to counter their intrinsic tendency to focus almost exclusively on the scientific and technological aspects of the development until much later in the project lifecycle. At that point it can be extremely expensive to rectify inappropriate design decisions that have been made due to a lack of consideration of the fundamental requirements and market demand for the product.

Background

During November 2016 NPL launched a new business stream called 'NPL Instruments' and began to recruit a team of engineers to help meet the growing demand from industry, academia and other national metrology institutes for scientific measurement instruments and facilities based on NPL's world leading metrology research. Prior to that point there was no formal role of 'Engineer' within NPL and the scientists undertook the engineering design and build of instruments with only limited support from two mechanical design engineers and some technicians within an engineering workshop. The aim of establishing a new team of instrumentation engineers was to enable a more focused and efficient approach to the engineering aspects of development projects, to improve delivery to customers and to reduce the need for scientists to be pulled away from their research in order to engage in product development.

Despite introducing this new team of engineers, it was clear that in a research organization such as NPL, the majority of the early stages of development and engineering design would still fall to scientists. Although the instrumentation projects delivered by NPL's scientists prior to 2016 had generally been delivered successfully and to a high level of technical quality, there was still significant room for improvement in terms of meeting budgets and schedules. Through review and analysis of these previous projects it was identified that poor requirement definition and the subsequent scope creep were the main causes of overruns. Therefore, if NPL were to successfully grow this high-value low-volume instrumentation business stream, a new approach would be required for early stage development. This new approach would need to be more holistic, with a greater focus on defining requirements and consideration of the whole development lifecycle.

Psychology of Scientists

The amount of autonomy granted to scientists has been identified as one of the primary factors in influencing their level of performance, productivity and creativity (Chen et al. 1999). Two studies (Lam 2010, 2011) investigating pressures on academic scientists to be more entrepreneurial and commercial found that most of them viewed having to apply their science to industry as a restriction and an attack on their autonomy. While NPL has a culture that is far more predicated on the practical application of research than that of many academic institutions, there is still likely to be a tendency for most of its scientists to be drawn more towards the technical challenges of a development project, than to considerations relating to the original requirements of the application or market.

Theories in social psychology considering intrinsic motivation (Porter and Lawler 1968) or inherently autonomous motivation (Gagné and Deci 2005) have been the foundation for many studies (Chen et al. 1999, Dewett 2007, Sauermann and Cohen 2008, Lam 2011) that have looked specifically at the motivation of scientists undertaking research activities. These studies agree that the motivation of scientists is strongly dominated by intrinsic (inherently autonomous) motivation, as opposed to the controlled motivation that is based upon extrinsic contingent rewards. That most scientist's primary motivation for undertaking their research is that they find it inherently interesting in and of itself, as opposed to rewards relating to commercial or social outcomes, may also make it more difficult to encourage their earlier consideration of requirements from external stakeholders.

Cognitive psychologists have identified that on average, scientists tend to have a higher systemizing quotient (a measure of ability to understand and work with complicated systems) than non-scientists. But it has also been identified (Baron-Cohen 2012) that as a group, scientists tend to have a lower average level of cognitive empathy (the ability to understand from the perspectives of others). This psychology research suggests that many scientists may have a greater than average tendency toward having a narrower range of interests (Baron-Cohen 2008) and often a focus on mechanistic or mathematical systems that are more deterministic, predictable and stable in their nature. These tendencies may provide additional barriers when it comes to encouraging scientists to engage with multiple stakeholders in order to systemize top-level market-driven requirements that initially may be more contradictory, emotive or intangible in nature.

An additional challenge to creating a cultural shift at NPL was that in the decades prior to the launch of NPL Instruments, its scientists had mainly been involved in designing and building instrumentation for their own use within NPL. They would use these instruments for providing commercial measurement services or as national standard measurement facilities. In these cases, the conceiver/designer of the instrument would often be responsible for its ongoing operation, maintenance and continuous improvement. These high levels of autonomy and personal sense of ownership of the instrument arguably add even more weight to the aforementioned psychological characteristics of the scientists.

Systems Thinking versus Scientific Thinking

Analytical reductionism is the paradigm at the heart of the scientific method and could be considered as the foundation of most modern western civilizations. Specifying a complicated system by breaking it down into smaller, simpler and more manageable constituent parts is a proven and successful approach that has enabled the development of a sophisticated scientific understanding of the world. Often colloquially referred to as 'scientific thinking', analysis is the natural default approach for scientists when starting to specify new instrumentation during a research and development project.

However, employing analysis as the sole approach to specification comes at the price of deemphasizing both internal interactions between component parts and also external interactions with other systems outside of the system-of-interest. Analysis therefore becomes less predictive as systems become more complex, more connected and more interdependent. The alternative to specifying a system-of-interest by analytically reducing it down to its constituent parts, would be to focus on its functional interactions with other external systems through a process of synthesis. In this context, synthesis is the combining of a system-of-interest with all the other systems with which it interacts, in order to form an understanding of the whole system-of-systems within which it operates. Through this process of synthesis, it is then possible to develop an alternative specification for the system-of-interest in terms of the role it plays within that system-of-systems. This approach is sometimes considered part of the paradigm referred to as 'systems thinking'. A synthesis approach to specification has the potential to provide a perspective on the design space that is more holistic and may be more focused on the application or market.

An analogy often used to explain this approach to NPL scientists was to ask how they would specify a man. Answers would generally involve: starting with limbs, torso, head, etc.; then sub-systems like central nervous system; respiratory system, digestive system, etc.; then component systems such as brain, heart, lungs, veins, etc.; then down to a cellular level, molecular level, etc. It would then be pointed out that this specification would not provide any information on what a particular man was likely to do to earn a living. An alternative specification was then suggested to them based on things like family relationships, social status, nationality, education, cultural tastes and finances, all of which are dependent on the man's interactions with systems that are external to himself. In doing so a model of the human society system-of-systems is synthesized in order to be able to specify the man by the role he plays within it.

When this synthesis approach is applied to the design of scientific instrumentation, it involves thinking of an instrument as a 'black box' (ignoring its internal functionality) and then identifying the external systems with which it will need to interact. These systems might include: users; the laboratory environment; supplies and services; test specimens or calibration artefacts; data processing and storage technology; business processes and quality management systems. The next step would be to identify functional interactions and the inputs and outputs with those external systems. For example, an instrument's performance might be sensitive to the temperature in the laboratory in which it is used, and this would need to be considered in its design. Equally, the instruments may generate a significant amount of heat, which may affect the performance of air conditioning within the laboratory. Another example might be consideration of what information a user of the instrument will need to enter as part of its operation, and what information they will expect out (and in what form).

This synthesis approach to specification encourages scientists to give more consideration to external factors influencing the design and to potential issues that might otherwise be left until much later or until they actually occur as issues. When combined with their more intuitive analytical reduction of the system, this approach has the potential to give scientists a much broader understanding of the overall design space.

A New Framework

The foundation of the new approach to systems engineering that has been employed at NPL is a framework consisting of three consecutive stages for specifying the scientific measurement instrument that is being developed. The three stages are: 'Requirement Specification'; 'Functional Specification'; and 'Technical Specification'. It is important to note that while the names given to these three stages may be similar to terminology from the INCOSE Systems Engineering Handbook (Walden et al. 2015), international standard ISO/IEC/IEEE 15288:2015 (ISO/IEC/IEEE 2015) and other system engineering references, within this framework developed at NPL they represent specific ideas that are subtly different to their use in traditional systems engineering.

The third stage, Technical Specification, contains details of what the instrument will consist of in terms of architecture, internal interfaces and functions, components, materials, dimensions and tolerances. Prior to adopting this new framework, the typical approach intuitively employed by scientists would be to start their design thinking at this stage. Sometimes they would start by focusing on architecture, but more often they would start by focusing on components and potentially useful technologies directly related to the primary scientific challenge.

The main goal when introducing this new framework at NPL was to encourage scientists to start the design process having a deep understanding of the whole scope of the job that the instrument is required to perform and to develop a more holistic understanding of the whole design space. The first stage in this process is to develop a detailed Requirement Specification. This Requirement Specification consists of a list of top-level requirements written following normal system engineering guidelines (ESA-ESTEC 2009) such as: being expressed in a complete sentence; quantified; unambiguous; unique; self-contained; and including a justification. The source, priority and conflicts with other requirements are also recorded for each requirement, along with details of the validation criteria for demonstrating that the requirement has been achieved.

Unlike many traditional approaches to systems engineering, this Requirement Specification has only one hierarchical level of requirements that are solely aimed at defining the job that the instrument needs to carry out, without any reference to a particular design or technological approach. Ideally the Requirement Specification should not include details of the constituent elements of the instrument or how it will function, unless these are specific requirements of a specific customer. The definition that has been used at NPL is "The Requirement Specification contains details of parameters, restrictions, boundaries and constraints that must be achieved during the development and/or operation of the product in order to deliver the required solution."

The aim of this approach to requirements is first of all to actually have a set of requirements at the start of the development project. The second aim is to avoid a set of requirements being developed that are just focused on the technology and primary scientific challenge. To further encourage broader thinking, a set of types of requirement is suggested to encourage consideration beyond just measurement performance: performance; usability; maintainability; safety; legal; security; marketing; and management.

Once a detailed Requirement Specification has been established, the second stage of the framework is to develop a Functional Specification. Within this framework the term 'Functional Specification' is referring to functional interactions with systems that are external to the system-of-interest and is based on synthesis rather than analysis. The instrument to be developed is thought of as a 'black box' and internal functional interactions are not considered. Again, the aim is to encourage scientists to gain a deep understanding of the whole design space before considering the technical details of a particular solution.

The first step in the synthesis of a Functional Specification is to identify the external systems with which the instrument will interact or have some form of dependency. These external systems may include: users; the laboratory environment; supplies and services (e.g. electrical power, gases, cooling water); test specimens or calibration artefacts; other instruments or devices; data processing and storage technology; business processes and quality management systems. The next step would be to understand the nature of the functional interactions and interfaces with these external systems. Then the final step would be to understand and specify the required inputs to and outputs from these external systems. This Functional Specification does not include details of how the functionality will be implemented, such as internal system architecture, components or materials. Additionally, this stage can be a good time to carry out an initial assessment of failure modes associated with each of the functions that are identified.

In order to help explain to scientists this three-stage process for specifying an instrument to be developed, NPL created a graphical representation that can be seen in Figure 1.

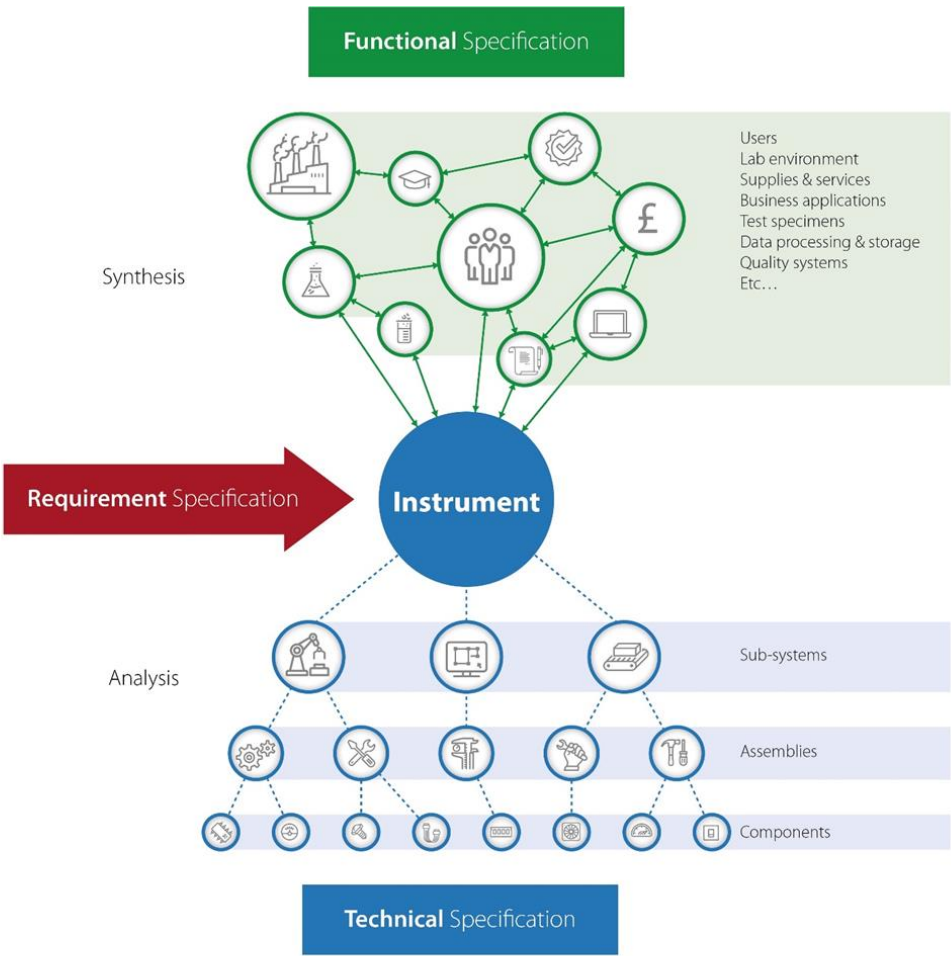


Figure 1. Graphic used to represent and explain the new framework.

A simple example of how the three types of specifications work together is a requirement to store ancillary equipment associated with the use of a measurement facility that NPL supplies built into a semi-trailer to enable on-site measurement of pollution emitted from power stations. The Requirement Specification includes details of the type, dimensions, and other properties of the ancillary equipment and why it is required to be stored in a container incorporated within the measurement facility. The Functional Specification includes details of when and how the operators will interact with container, how it will interface with the trailer and details of environmental effects such as weather or rough roads during transit. Some examples might include: whether the equipment needs be accessed from within the trailer or from outside; whether the container needs to be lockable to limit access; the location of the container within the trailer to comply with manual handling regulations; whether the equipment needs to be isolated from vibration or extreme temperatures; where and how the container will be fixed into the trailer. The Technical Specification would then include details of the container's dimensions, tolerances, materials and components.

Organizational Change

The new three-stage approach to specifying scientific measurement instruments and an associated spreadsheet tool began development during April 2017 and, following trials, was formally introduced for use within NPL's Instrument Team during April 2018. In June 2018 this new approach to specification was included within an NPL corporate procedure entitled "Design and Development of Scientific Instrumentation". During this period, in order to disseminate understanding of the new approach beyond the Instruments Team, some 'early adopters' (Rogers 2003) were identified among NPL's scientists. These early adopters already had an interest in or knowledge of engineering and were encouraged to try out the three-stage framework on projects that did not have direct involvement of engineers from the Instruments Team.

At this point, most NPL scientists were still not familiar with the term 'systems engineering' or the ideas and values that it represents. In order to aid collaboration with NPL Instruments engineers and the implementation of this new approach, NPL commissioned the Centre for Systems Engineering at University College London (UCLse 2020) to provide a series of two-day introductory courses on systems engineering. The course was presented to groups of twenty NPL staff by Professor Alan Smith (retired Director of both UCLse and the Mullard Space Science Laboratory) and was first held during June 2018. It was subsequently held five more times with a total of one-hundred-and-fifteen scientists, engineers and project managers being provided with a base level of understanding of requirements management and development lifecycles.

The final step was during July 2018 to introduce a full-time role of systems engineer within the NPL Instruments Team. The main focus of this role is to lead the specification of new instrumentation under development at NPL and to help guide projects through their development lifecycle.

Processes and Tools

As part of this initiative, NPL rewrote a corporate procedure and introduced a local procedure for NPL Instruments, both of which are built around the traditional system engineering 'V-model' (Walden et al. 2015). Twenty-eight document templates were also developed in order to drive these processes. These templates include documents for managing: design reviews; configuration; verification; validation; change control. The most important and impactful of the templates is a sophisticated spreadsheet-based tool for recording and managing the three types of specification within the new framework.

NPL only has a limited marketing function and product managers within its organization, so much of the marketing considerations and their implications for engineering design need to be kept within the focus of the scientists and engineers. One of the document templates introduced as part of this new approach is for capturing the original business case for carrying out the development of a new instrument. This is one of the many ideas from the Association for Project Management (APM 2015) being introduced across NPL. This new type of business case document acts as a reference to the underlying need for the instrument and the associated drivers and constraints. Again, it aims to overcome scientists' natural tendencies and continually drawing attention back a more holistic view of the design space. Where appropriate this document includes marketing information such as: competition and market segmentation; value proposition; target marketing position and price point; and potential distribution channels.

Initial Outcomes

The initial attempts at implementing this new approach were only partially successful. Although many scientists were enthusiastic and had an intellectual understanding of the approach, there was still a strong tendency for them to focus on the technology of the solution when it came to applying these ideas in practice. This was the point at which NPL established a role of Senior Systems Engineer within its Instruments Team to act as a consultant on instrument development projects, guiding the scientists through the development of their Requirement Specifications and Functional Specifications. This approach was reasonably successful and so NPL subsequently recruited an experienced systems engineer from outside the organization.

The systems engineers also found that many scientists were resistant to defining a very detailed and comprehensive set of specifications as they felt that they were no longer able to be cognizant of the whole design space all at the same time. This may be a product of the scientists primarily working within a reductionist regime, where problems are broken down into manageable chunks in order to enable rigorous analysis and intellectual reflection. Some scientists were not comfortable relying on documentation tools and processes, and would have preferred to limit the amount of detail to the point where it could all be available in their minds for immediate recall. These concerns were eventually at least partially overcome through demonstrating the value in practice of having all three types of specification, representing three separate perspectives on the design space, available in a structured form for easy reference during the design process and to act as a checklist during design reviews.

Another significant challenge was that some scientists and project managers felt that defining requirements and external interactions prior to the main design activity represented additional work that slowed down their project, rather than allowing them to more immediately demonstrate having made practical progress. This was partially overcome by the persuasiveness of the systems engineers and pointing to the significant cost impacts of scope creep and delayed delivery in previous projects. However, this desire for immediate practical progress remains a barrier and will do so until the new approach becomes further integrated in corporate process and culture.

The first successful development of a detailed and comprehensive Requirements Specification using the new spreadsheet-based tool was as part of the development of a new national standard instrument currently being developed within the area of Dimensional Metrology. The requirements capture process was led by a scientist on secondment into the Instruments Team and included: analyzing specifications of five existing systems that would be replaced by the new instrument; interviews and witnessed measurements with users of the existing instruments; extracting specific requirements from international measurement standards and quality/safety regulations; reviewing state-of-the-art in other national metrology institutes; discussing the requirements with commercial instrument manufacturers that may be interested in developing a commercial version of the new instrument. Having this Requirement Specification then allowed for: evaluation of priorities and conflicts; confirming the details of requirements with stakeholders through a traceable record; having a detailed checklist to assess potential designs against a large number of specific criteria; and developing formally agreed validation plans for each requirement.

This first fully completed Requirement Specification provided the Systems Engineers with an example that could be used to help further establish the approach and convince scientists of its value. The new approach has subsequently been used for a number of projects, including turning a laboratory prototype radiometer into a commercial product, one of which was sold to a foreign national metrology institute and successfully used by them in an international intercomparison for measurements of high temperatures. The new approach was key in developing the mechanical engineering and ergonomic designs for a new technique for scanning for breast cancer without the use of ionizing radiation. And the best example of a completed Requirement Specification, Functional Specification and Technical Specification that NPL have produced so far was part of a project that developed a novel technique for in-situ measurement of the gap between the grid-plates of ion thrusters used as propulsion for satellites in space.

There is still a lot of learning ahead on how to make the best use of this framework and gradually make it part of NPL's default approach. However, the experience so far indicates that this formulation of some of the key ideas of systems engineering has proved simple and coherent enough to be embraced by most scientists without them feeling that it is too onerous. From the initial applications, this new approach appears to be effective at encouraging scientists to gain a deeper understanding of requirements and external interactions, before they then focus on the technology and scientific challenges of possible solutions.

Next Steps

NPL is currently planning to further integrate systems engineering into its corporate processes as part of a larger scale transformation project that will build on the initial successes of introducing the Instruments Team and utilizing the new framework for specification. These next steps may include establishing a design authority and a clearer demarcation between scientific research and engineering. However, NPL is primarily an applied research organization and these changes will need to be made with great care, so as not to undermine its position as a world leading national metrology institute. Whilst employing more of a system engineering approach has added value to NPL's development of instrumentation and given many scientists a greater appreciation of the engineering aspects of their work, if applied too comprehensively across the whole organization it could have the potential to adversely affect NPL's research productivity. Curiosity and following serendipitous results can be an essential part of discovery and innovation. Scientific research, especially when aimed at generating high-value intellectual property, can be suppressed by overly structured or efficient management. NPL will primarily need to ensure that its scientists remain as world-class metrologists, but while simultaneously continuing to build its engineering infrastructure and developing a culture that integrates systems engineering into its development of instrumentation.

Acknowledgements

The work described within this paper was funded by NPL Management Ltd and the UK Government's Department for Business, Energy and Industrial Strategy (BEIS) through the UK's National Measurement System programs.

About the Authors

Clark Stacey is a Chartered Engineer and Chartered Physicist with over twenty years of experience in designing scientific instrumentation. He has a Master's degree in Management Studies, which included research into the relationship between the motivational psychology of scientists and the challenges of getting scientific innovations to market. He also has professional qualifications in project management and business coaching. His current role is as a Senior Research Engineer at the National Physical Laboratory in the United Kingdom.

Joshua M. R. Shaylor has been employed at the National Physical Laboratory since 2016 and currently holds the position of Higher Research Scientist working within the Mass Metrology group. He received a Master's degree in Integrated Mechanical and Electrical Engineering (MEng Hons) from the University of Bath, United Kingdom (2010–2015). His primary area of focus is in the modernization and development of deadweight force standard machines and their associated control systems, with a secondary focus in commercial dynamic testing machines. He is a member of the Institution of Engineering and Technology.

References

APM. 2015. The APM Project Management Qualification Study Guide. Buckinghamshire, GB: Association for Project Management.

Baron-Cohen, S. 2008. "Theories of the Autistic Mind," The Psychologist 21: 112–116.

Baron-Cohen, S. 2012. "Autism and the Technical Mind: Children of Scientists and Engineers may Inherit Genes that not only Confer Intellectual Talents but also Predispose them to Autism." Scientific American 307(5): 72–75.

Chen, C. C., C. M. Ford, and G. F. Farris. 1999. "Do Rewards Benefit the Organisation? The Effect of Reward Types and the Perception of Diverse R&D Professionals." IEEE Transactions on Engineering Management 46(1): 47–55.

Dewett, T. 2007. "Linking Intrinsic Motivation, Risk Taking, and Employee Creativity in an R&D Environment," R&D Management 37(3): 197–208.

ESA-ESTEC. 2009. "Technical Requirements Specification (ECSS-E-ST-10-06C)". Noordwijk, NL: ESA Requirements and Standards Division.

Gagné, M., and E. L. Deci. 2005. "Self-Determination Theory and Work Motivation." Journal of Organizational Behavior 26: 331–362.

ISO/IEC/IEEE. 2015. ISO/IEC/IEEE 15288:2015. Systems and Software Engineering - System Life Cycle Processes. Geneva, CH: ISO.

Lam, A. 2010. "From 'Ivory Tower Traditionalists' to 'Entrepreneurial Scientists'?" Social Studies of Science 40(2): 307–340.

Lam, A. 2011. "What Motivates Academic Scientists to Engage in Research Commercialization: 'Gold', 'Ribbon' or 'Puzzle'?" Research Policy 40: 1354–1368.

NPL. 2020. "About Us." https://www.npl.co.uk/about-us.

Porter, L. W., and E. E. I. Lawler. 1968. Managerial Attitudes and Performance. Homewood, US-IL: Irwin-Dorsey.

Rogers, E. M. 2003. Diffusion of Innovation. New York, US-NY: Free Press.

Sauermann, H., and W.M. Cohen. 2008. "What Makes Them Tick? Employee Motives and Firm Innovation - Working Paper 14443." National Bureau of Economic Research. Cambridge, US-MA.

UCLse. 2020. "About UCLse." https://www.ucl.ac.uk/systems-engineering/about-uclse.

Walden, D. D., G. J. Roedler, K. J. Forsberg, R. D. Hamelin, and T. M. Shortell. eds. 2015. Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities. Hoboken, US-NJ: John Wiley & Sons.

Update on the Systems Engineering Body of Knowledge (SEBoK)

by Nicole Hutchinson, PhD. Stevens Institute of Technology

Email: nicole.hutchison@stevens.edu

Abstract

In 2012, the Guide to the Systems Engineering Body of Knowledge (SEBoK) set a new precedent – delivering a curated, authoritative professional body of knowledge in a wiki format. Until that time professional bodies of knowledge had been created as documents, or in some cases, those documents had been converted to static websites. The SEBoK team created a mechanism for maintaining quality while allowing for more rapid update and turnover. Since 2012, the SEBoK model has been used by several bodies of knowledge. This article provides perspective on the evolution of the SEBoK, answers some common questions around the SEBoK, and discusses future evolution.

Introduction and Background

Starting in 2009, the Body of Knowledge and Curriculum to Advance Systems Engineering (BKCASE™) project was launched by the US Department of Defense to create a body of knowledge for systems engineering and a reference curriculum for systems engineering graduate education. The creation of the Guide to the Systems Engineering Body of Knowledge (SEBoK) and the Graduate Reference Curriculum for Systems Engineering (GRCSE™) has been detailed in many publications (e.g. Adcock 2016; Miller et al. 2013; Hutchison et al. 2012). A summary is that a global team of over 80 individuals across government, industry, and academia, supported by hundreds of reviewers around the world, created the SEBoK and GRCSE over three years, with the initial offerings (called version 1.0 for both) released in 2012.

The SEBoK set a new technical precedent – delivering a curated, authoritative professional body of knowledge in a wiki format. To that point, professional bodies of knowledge had been created as documents, or in some cases, those documents had been converted to static websites. The SEBoK team created a mechanism for maintaining quality while allowing for more rapid update and turn over. The SEBoK is now on version 2.5, the seventeenth major release since 2012, while becoming the most-used reference for systems engineering in the world. The SEBoK has seen over 2 million unique users and continues to see growth over time. This rapid evolution has been coupled with a focus on quality, with every update to the SEBoK meeting several key criteria:

- **Philosophy** – the SEBoK is a guide to the body of knowledge, not a compendium. This means that authors and editors strive to add new references and summarize as appropriate, not to re-create existing materials.
- **State of Practice and the Art** – the SEBoK reflects the discipline of systems engineering as it stands, including both current practices and approaches as well as advanced techniques that are still maturing.
- **Descriptive** – As part of accurately representing the practice, the SEBoK seeks to summarize and describe the literature available around the world, not just a single point of view. This means that if the systems community disagrees about a topic, both perspectives are reflected in the SEBoK, with discussion around situations where one perspective or another might more readily apply.

- **Available** – The SEBoK only includes resources that users can reasonably access. This does not mean "free" – users might have to purchase textbooks and journals, for example – but it does mean that the materials are accessible. For example, proprietary materials that are behind an organization's firewall or anything that would be considered sensitive or classified in a government context is not included.

SEBoK Use

The SEBoK is the number one resource for systems engineering information in the world and basic statics about the SEBoK are found in Figure 1. The SEBoK sees an average of 30,000 users per month and is consistently referenced in government, academia, and industry.

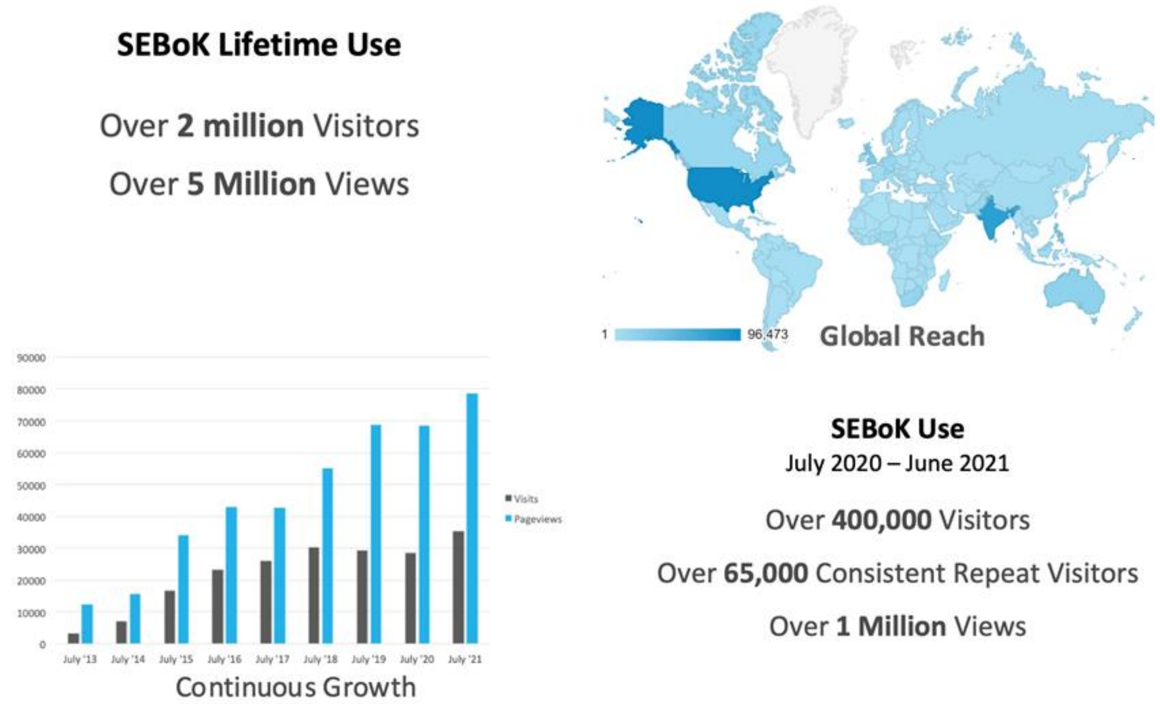


Figure 1. Overview of SEBoK Use (lifetime and academic calendar year 2021)

As figure 1 illustrates, the heaviest use of the SEBoK comes from the United States. This has been the case since its launch in 2012. However, the patterns of geographical use over time have also shown where systems engineering as a discipline may be surging and growing. For example, India, the country with the second heaviest SEBoK use so far in 2021, was not in the top 10 when the SEBoK launched in 2012. The UK and Australia were the second- and third-heaviest users of the SEBoK, respectively, early on and though their use has increased over time, it has not grown as rapidly as use in India.

Additional analysis of SEBoK use shows a consistent growth in use over time (shown in pageviews in Figure 2). It also gives indications of academic use of the SEBoK, as the Dec-Jan and June-July time frames tend to see dips in use. Anecdotally, the SEBoK editors have received indications from faculty across a variety of universities stating that they use the SEBoK in their courses, some to supplement their texts and some in place of traditional textbooks. But Figure 2 also illustrates that academic use of the SEBoK is only part of the user community. Estimations based on the data from SEBoK use indicate the SEBoK gets 20-30,000 pageviews a month from academic sources, meaning that currently an average of 50,000 pageviews come from government and industry each month.

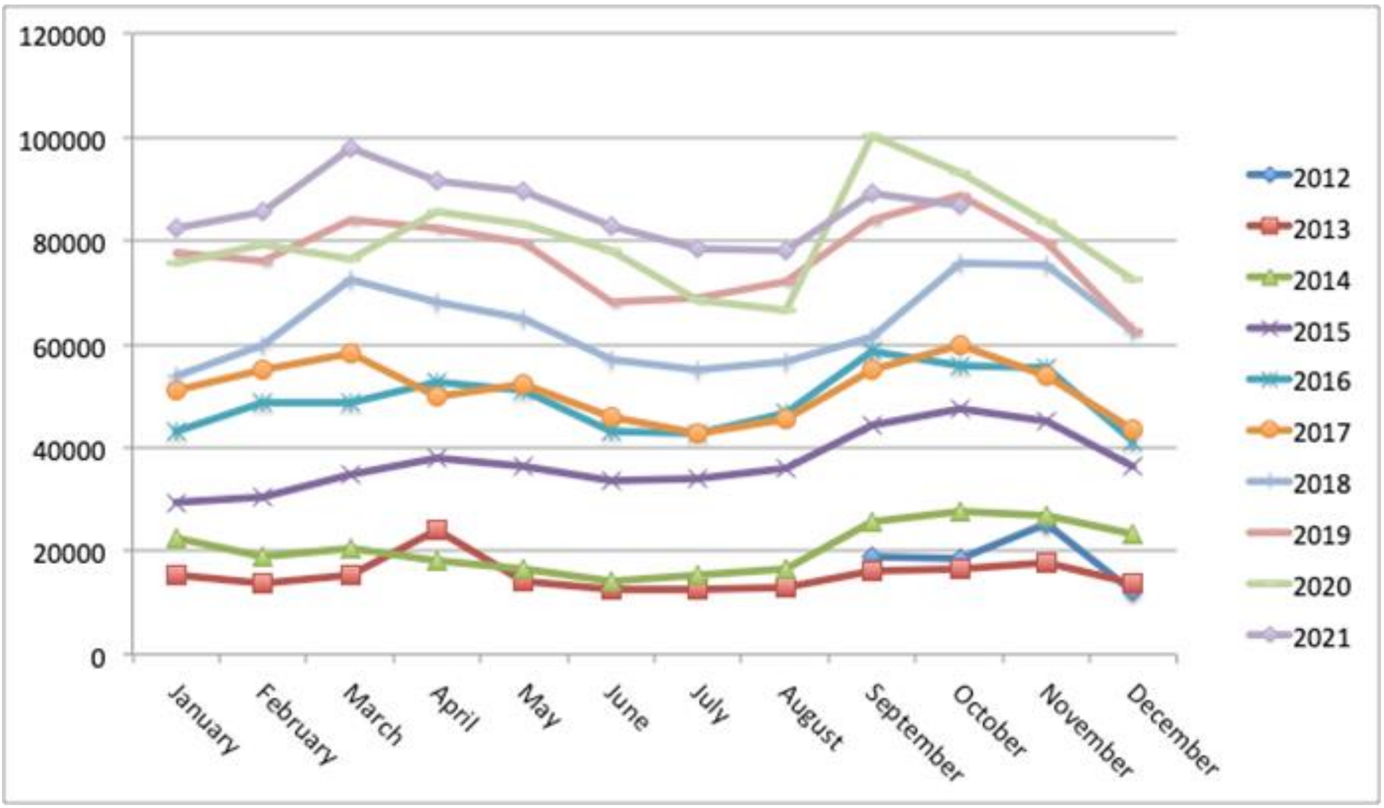


Figure 2. Overview of SEBoK use (in pageviews) by month since 2012.

SEBoK Structure

The SEBoK began with seven "Parts" or major themes. The current version of the SEBoK includes eight distinct parts, as illustrated in Figure 3. The parts represent the logical architecture of the SEBoK, or the authors' and editors' mental models of how systems engineering information is organized and related. These parts have remained largely stable since release in 2012, though within the parts the knowledge areas have changed to reflect updates in the discipline. Part 8 was added in 2020 to reflect the most cutting-edge knowledge in systems engineering.

Part 1 is an introduction to the SEBoK and to the discipline of systems engineering itself. It sets expectations about what users can expect to find, what is considered out of scope, and thoughts on users and uses. This sets the context of the SEBoK and provides foundational insights into the discipline.

Part 2, "Systems Engineering Foundations", provides an overview of the systems principles that underlie the discipline of systems engineering. It helps define the "what" of systems engineering – what are systems, what does it mean to take a systems approach to a challenge or problem, and what is systems science. Part 2 also introduces the concepts of system models, what they are, and why they are beneficial.

Part 3, "Systems Engineering and Management" builds upon these foundations to define the fundamentals of the discipline of systems engineering itself. It includes the "typical" systems engineering lifecycle knowledge expected around process – for example the types of processes defined in ISO 15288 or the INCOSE Systems Engineering Handbook – as well as fundamentals of managing systems engineering work and processes orthogonal to the lifecycle such as configuration and risk management. It descriptively answers the question, "What is systems engineering?", providing pointers to a variety of methods, processes, and tools.

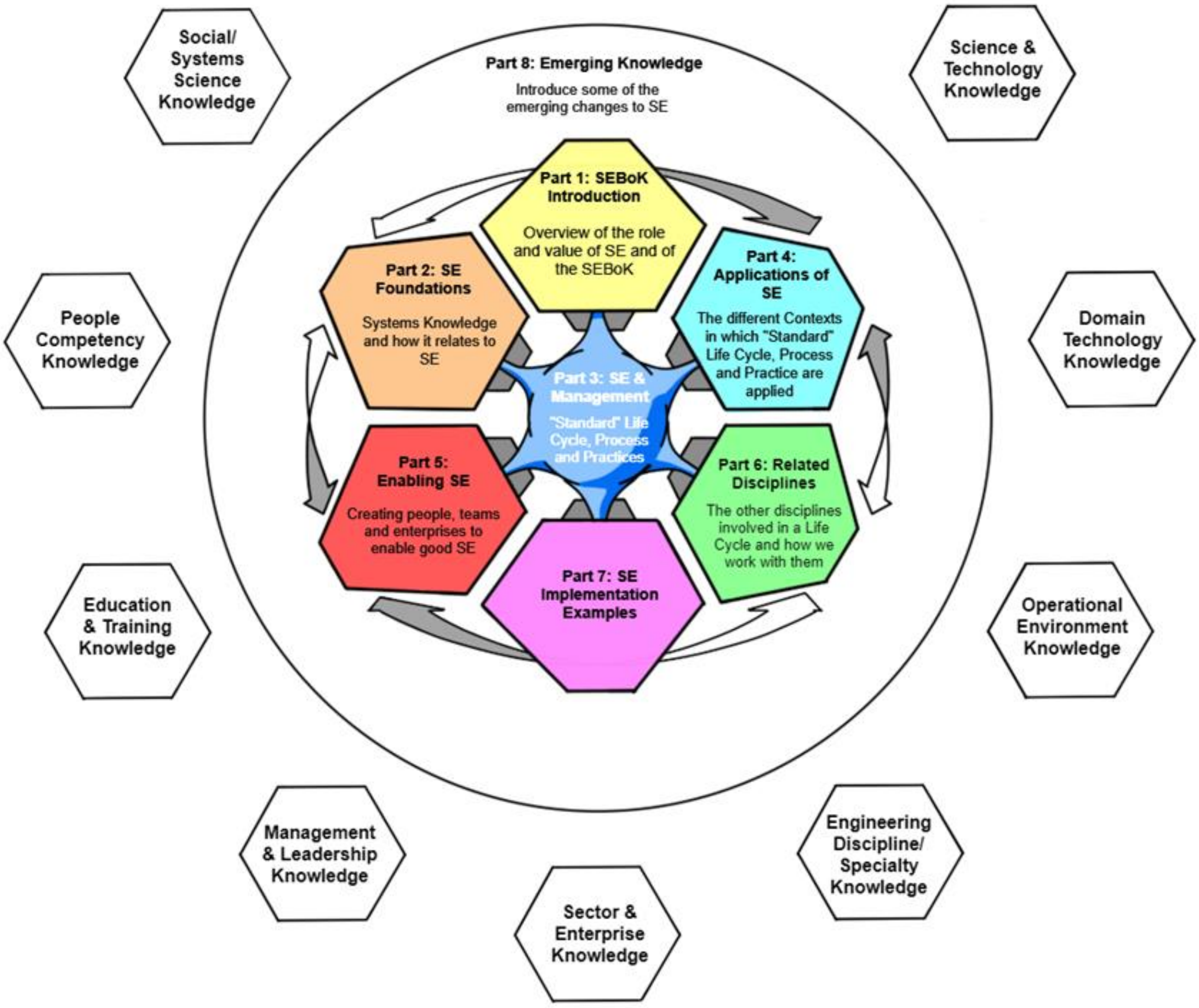


Figure 3. SEBoK Organization

Part 4, "Applications of Systems Engineering", describes what changes about systems engineering based on the context. For example, what does a practitioner need to do or think about differently if working on a product system versus an enterprise system? What are special considerations around systems of systems? And, finally, Part 4 includes an example of specific things systems engineers need to know when working in one particular domain: healthcare. This first example was added in 2015 and the goal is to add more of these domain-focused examples over time.

Part 5, "Enabling Systems Engineering" goes outside of the realm of process, methods, and tools to talk about the fundamental competencies required of systems engineers and the organizational considerations to enable systems engineering capabilities.

Part 6, "Related Disciplines" touches on a number of disciplines that are relevant to systems engineering and answers the questions, "What does a systems engineer need to know about this discipline?" It includes standard disciplines like software engineering and industrial engineering as well disciplines that focus around system attributes like safety, security, and reliability.

Part 7, "Implementation Examples", is perhaps one of the more unique among bodies of knowledge. These are, essentially, case studies of real-world systems – some successful, some not – that illustrate the benefits of and pitfalls of systems engineering in a real-world context. These examples link back to the knowledge contained elsewhere in the SEBoK, so that if an individual finds a challenge or situation similar to their own in an example, they can follow the wiki back to additional sources.

Part 8, "Emerging Knowledge" was added in 2020 and represents the desire to make it even easier to incorporate rapidly evolving knowledge into the SEBoK. It includes topics such as what is the relationship between systems engineering and artificial intelligence and how is "digital engineering" related to systems engineering and specifically model-base systems engineering. It also includes recent dissertations in systems engineering, again providing insights into advances in the practice.

As mentioned, this is all built on a wiki platform that enables cross-linkages between content, helping users readily explore and understand relationships between different topics.

SEBoK Evolution

The above outlines where the SEBoK is now. But where is the SEBoK going? The desire is for the SEBoK to continue to evolve and improve along with the discipline. The addition of "Emerging Knowledge" certainly supports that, but there is more to do. The SEBoK Editorial Board will also continue seeking authors for emerging content, but a major challenge is improving visibility of cross-cutting content. For example, it does not make sense to simply have an article on model-base systems engineering (MBSE) when model-centric approaches are increasingly becoming the norm. All the content on traditional systems engineering approaches needs to include considerations for how this is updated in a modeling context until, eventually, there is no distinction – document-driven systems engineering approaches will fade and the SEBoK will need to reflect that. The SEBoK is creating Lead Editor positions for these types of cross-cutting areas, and this will be a major beneficial shift in the SEBoK approach.

In 2019, the SEBoK began incorporating relevant videos as part of the references around topics. In the almost 10 years since the SEBoK was released, the world has fundamentally changed how it looks for information. Instead of Googling the PDF of the owner's manual on a broken appliance, people look for a "How to" on YouTube. As videos and social media take the place of more traditional (written) formats, shorter, pithier content is becoming the expected norm. The SEBoK is working to link to more video content, as this is becoming a rapidly growing part of the overarching body of systems engineering knowledge.

Finally, the SEBoK wiki was novel in 2012 and has set a precedent for what a body of knowledge can be. In 2020-2021, in the US Department of Defense body of knowledge efforts around digital engineering have been developed and both have utilized a wiki platform for development and delivery, influenced largely by the success of the SEBoK. Another effort to create a hardware assurance body of knowledge will utilize wiki technology and has resulted in addition of the Hardware Assurance article in the SEBoK. The wiki structure provides exciting opportunities not just within the SEBoK but to allow bodies of knowledge to link to one another, improving access to information.

Get Involved

In order to meet the challenges outlined above and to continue to evolve, the SEBoK is looking for support in a number of areas:

- Cross-cutting Lead Editors – for areas such as MBSE, agile, and data analytics. These individuals will help craft "anchor" articles on the topics and then review the SEBoK holistically to identify where these areas can be addressed now, identify expected future trends, and plan for the SEBoK's evolution to incorporate them.
- Videos – the SEBoK Editorial Board welcomes individuals to either recommend existing videos for inclusion or to create video content for the SEBoK. Note that video content still needs to fit the principles of the SEBoK such as balanced perspective and descriptive versus prescriptive approaches.
- Authors – the SEBoK is always looking for individuals who would like to propose revisions and updates to existing content or provide recommended new articles.
- Reviewers – anyone can provide comments on the SEBoK content directly in the wiki. These comments are regularly reviewed and help the SEBoK continue to improve.

- Sponsors – there are opportunities for organizations to sponsor the SEBoK, providing visibility for their organization. Sponsorship supports infrastructure improvements, student editors, and a variety of other opportunities for the SEBoK to grow and evolve.

For questions about the SEBoK, please contact sebok@incose.org.

Acknowledgements

I would like to acknowledge the SEBoK Stewards – the International Council on Systems Engineering (INCOSE), the IEEE Systems Council, and the Stevens Institute of Technology – for their continued support. The stewards ensure the continued life of the SEBoK and provide oversight through the Governing Board. I would also like to thank the members of the SEBoK Editorial Board. Finally, Dr. Art Pyster (SEBoK Governing Board Chair), Dr. Rob Cloutier (SEBoK Editor in Chief), and Ms. Madeline Haas (SEBoK Student Editor) are critical to the SEBoK team, and we would not be able to thrive without them.

References

Adcock, R., Town hall meeting, INCOSE International Workshop 2016, Torrance, CA US, 2016. (Available for PDF download)

INCOSE. 2015. Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities, version 4.0. Hoboken, NJ, USA: John Wiley and Sons, Inc, ISBN: 978-1-118-99940-0

Hutchison, N., Pyster, A., Enck, S., Koning, HP. 2012. "What's in a Wiki?: Using Collaborative Technology for Developing, Reviewing, and Publishing the Systems Engineering Body of Knowledge (SEBoK)", Proceedings of the 22nd Annual International Symposium, International Council on Systems Engineering (INCOSE) 2012, Rome, Italy, July 9-12, 2012. (Available through INCOSE.)

ISO/IEC/IEEE. 2015. Systems and Software Engineering -- System Life Cycle Processes. Geneva, Switzerland: International Organisation for Standardisation / International Electrotechnical Commissions / Institute of Electrical and Electronics Engineers. ISO/IEC/IEEE 15288:2015.

Miller, W., Walden, D., Adcock, R., Pyster, A., Roussel, J. "Will the SE Body of Knowledge (SEBoK) change INCOSE and Systems Engineering forever?", Proceedings of the 23rd Annual International Symposium, International Council on Systems Engineering (INCOSE) 2013. (Available through INCOSE.)

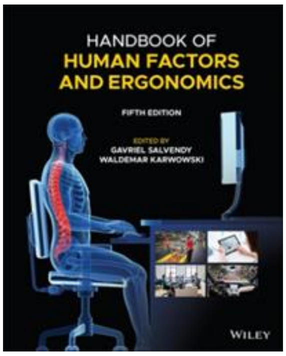
About the Author

Dr. Nicole Hutchison serves as the Managing Editor for the Systems Engineering Body of Knoweldge (SEBoK). She is a Principal Investigator and research engineer at the Systems Engineering Research Center (SERC). Her primary work through the SERC includes the Helix project, the development of the mission engineering and digital engineering competency frameworks, and work on digital engineering metrics and simulation. She was a member of the BKCASE research team from 2009-2014 and now serves as the Editor for Healthcare for the Systems Engineering Body of Knowledge. Before joining Stevens, she spent 5 years working for Analytic Services, supporting the US Departments of Defense, Homeland Security, Health and Human Services, and Justice. She has helped to plan and conduct exercises in Emergency Management, helped run the Louisiana Family Assistance Center following Hurricanes Katrina and Rita, and served 10 years in emergency medicine. She holds a PhD in systems engineering from Stevens as well as a master's degree in Biohazardous Threat Agents and Emerging Infectious Disease from Georgetown University. She is also an INCOSE CSEP.

SYSTEMS ENGINEERING RESOURCES

Useful artifacts to improve your SE effectiveness

Handbook of Human Factors and Ergonomics, 5th Edition



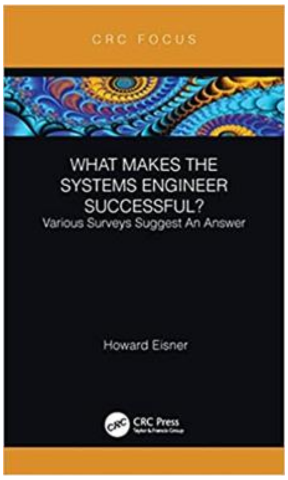
Wiley is spotlighting the release of the Fifth Edition of the ***Handbook of Human Factors and Ergonomics***. Considering the relevance of this topic, Wiley states: "As we begin the return to the office, the current state of our work environments is under the microscope. With this increased focus on the workplace, people are also paying more attention to how intelligent machines are integrated into our work spaces and how they work alongside humans."

This handbook, edited by Gavriel Salvendy and Waldemar Karwowski, features new coverage on AI, social media, information technology, cybersecurity, and data analytics. Recommended readers include experts in ergonomics, safety engineers and human-computer interaction specialists.

Discounts are available for members of various professional societies.

Learn more here. View Chapter 1.

What Makes the Systems Engineer Successful? Various Surveys Suggest An Answer



This book, Howard Eisner's tenth related to engineering, systems and management, offers a survey of successful attributes of the systems engineer. It focuses on the key positive attributes of what today's systems engineer should be and puts a model in place for achievement and behavior for future systems engineers.

Written in survey form, the book provides a description of how and why systems engineers can be, and have been, successful. It offers successful attributes, focuses on the key positive qualities, and drills down to the success features to aim for and the failure characteristics to avoid. By doing so, Eisner, an INCOSE and IEEE fellow and professor emeritus at George Washington University, draws out a path toward success in this field.

The audience for this work includes any engineer (regardless of label – e.g. systems, industrial, mechanical, or general) and those in technical management.

Contents:

1 Systems Engineering: No Room at the Top	7 Expert/ESEP
2 Selected Best Systems Engineers	8 Expert/Domain Knowledge
3 Synthesizer	9 Perseverer
4 Listener	10 Recapitulation
5 Curious/Systems Thinker	Appendix A – INCOSE Fellow Inputs
6 Manager/Leader	Appendix B – Across the Board Articles

Publisher: CRC Press, ISBN-13: 978-0367545499

Available in both hardcover and e-book (Kindle) editions from multiple sources:

- Amazon
- Routledge (Taylor Francis)
- Eason's

Book: Value Proposition Design

One of the most popular "How-to" guides among entrepreneurs is ***Value Proposition Design*** by Alex Osterwalder and Yves Pigneur.

Value Proposition Design builds on an earlier work by the same authors, ***Business Model Generation***, that introduced a simple tool, the Business Model Canvas, is its primary method of guiding, capturing and visualizing the thinking about the design of a business.

The Business Model Canvas represents the design of a business as seven sets of decisions that must be aligned to achieve a sustainable business:

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
	Key Resources		Channels	

These decisions, working together, set the Cost Structure and Revenue Streams for the business and therefore determine its sustainability. Note the central role of the Value Propositions in aligning the activities/resources (what we do and how) of the enterprise with customers (and how we reach them).

Value Proposition Design, first released in 2014, takes a detailed look at the relationship between two parts of the Business Model Canvas; Customer Segments and Value Propositions. This relationship is visualized in the form of a Value Proposition Canvas, comprised of a Value Map and Customer Profile.

Value Map		Customer Profile	
Products & Services	Gain Creators	Gains	Customer Jobs
	Pain Relievers	Pains	

The premise of Value Proposition Design is that the design of a sustainable new business must begin with the ability to identify and validate a unique value proposition for the business based on a customer discovery process. Second, a highly differentiated value proposition is insufficient to ensure business viability; that depends on finding customers who are willing to pay for this value.

Rather than starting from a novel technology, conceiving a unique product that is built around this technology and then marketing this innovation to various communities, Value Proposition Design starts with a value proposition hypothesis, then conceives low cost and quick-to-perform experiments to validate and refine the hypothesis. The goal of Value Proposition Design is to avoid building products that no one wants or if wanted, no one is willing or able to pay for. Speed is also of the essence; startups should fail ast and pivot as soon as a value proposition hypothesis is determined to be non-viable because it misses satisfying the potential customers' highest priority unmet needs (pains/gains).

Experienced engineers may read Value Proposition Design and ask, "What's new?" Understanding stakeholder needs and aligning solution concepts to maximize value delivered are techniques common to most successful engineering methods. Validating solution concepts against such needs through a variety of early models and prototypes is also common practice. Is Value Proposition Design a set of familiar practices repackaged with unique terminology, visualizations and points of emphasis?

Although the answer to these questions is certainly open to debate, what is certain is that Value Proposition Design has become a leading methodology among entrepreneurs. Adherents of Value Proposition Design are convinced of its merits; a case where a simpler and less rigorous method may yield better results by being applied early and often with an experimental mindset.

Value Proposition Design is available wherever business books are sold. The Strategyzer website provides links to multiple booksellers, including Amazon, Barnes & Noble and Porchlight. This site also includes access to a sneak peek at the book's content.

Definition: Uncertainty quantification

"Uncertainty quantification (UQ) is the science of quantitative characterization and reduction of uncertainties in both computational and real world applications. It tries to determine how likely certain outcomes are if some aspects of the system are not exactly known."

Learn more:

Product Data Management and Data Exchange Landscape

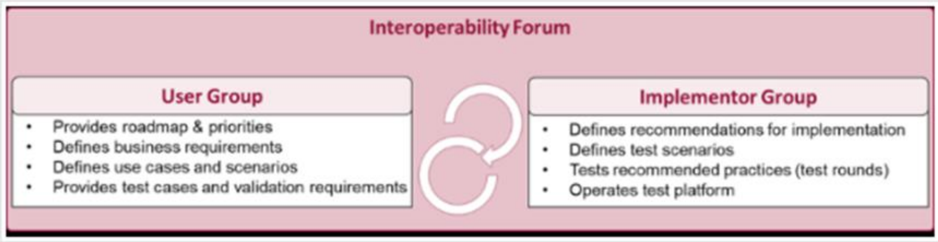
Product Data Management (PDM) is the function, often within product lifecycle management (PLM), that is responsible for the management and publication of product data, especially engineering data. Full lifecycle management of such data requires a set of consistent standards that define PDM information models and recommended practices for PDM interoperability and data exchange (DX). Common information models and exchange standards for enterprise and product data enable:

- Seamless passing of data along a chain of lifecycle tools (e.g. requirements, design, manufacturing and support) within a single organization.
- Sharing of such data with suppliers/subcontractors and customers who often use differing tools to accomplish the same engineering and lifecycle management functions.

As engineering and product lifecycle management has become increasingly digitized over the past decades, an ecosystem for development of PDM/DX standards has evolved. Industry associations, particularly in the defense, aerospace and automotive sectors, recognizing the need for supply chain integration and related efficiencies, and defect prevention, have pushed for such standards. Software tool vendors, desiring to lower the costs of integration and testing with upstream and downstream tools and being compelled to accept the reality of data sharing between competitor tool offerings, have also embraced such standards. Standards organizations have benefited from the collaborative relationship between tool users and implementers.

A business construct, the Implementor Forum (IF) aka Interoperability Forum, has emerged as a proven mechanism to pursue the complementary business objectives of industry associations (software tool users), software tool vendors (implementers of interoperability standards) and standards organizations.

Although these forums have unique elements, the roles of the User Group and Implementor Group can be generalized as shown below:



Generic Interoperability Forum organisation

Source: AFNet Overview of Requirements Verification and Validation Interoperability Forum (RV&V-IF)

Although the IF's are the focal point for the realization of PDM/DX capabilities, the broader ecosystem includes these types of organizations:

- Industry Associations and Consortia (IF Hosting Organizations)
- Implementor/Interoperability Forums
- Long-Term Archive & Retrieval (LOTAR) Consortium/Project
- INCOSE
- Global Standards Community
- Global Engineering Community

The N-Squared Diagram that follows captures the general interactions between these types of organizations:

Industry Associations & Consortia (IF Hosting Orgs) *** PDES, Inc.** *** AFNeT** *** prostep ivip** *** ASD** *** VDA**	Implementor Forum hosting, planning, oversight & infrastructure Document maintenance: Recommended Practices Member access to Implementor Forums	LOTAR facilitation	MOU-based collaboration on data exchange standards for Model-based(SE, Mfg, Sustainment)	Inputs to: ISO 10303-AP233, STEP standard for Systems Engineering Data Exchange ISO 1303 Application Protocols & OMG/OASIS LOTAR standards	
IF project reporting & work products	**Implementor Forums** *** PDM** *** MBx** *** RV&V** *** JT**	LOTAR requirements integration into software tools		International PDM, MBx, RV&V & JT interoperability recommended practices (input to standards).	Verified interoperable product lifecycle & data exchange software
LOTAR project reporting & work products		**LOTAR consortium (aerospace manufacturers)**	Participation in Tool Integration & Model Lifecycle Mgmt Working Group	Inputs to LOTAR standard * AST-STAN (EN) 9300-xxx (Europe) * AIA (NAS) 9300-xxx (USA)	
MOU-based collaboration on data exchange standards for Model-based(SE, Mfg, Sustainment)		Inputs to digital data exchange standards	**INCOSE**	Standards liaison & influence	Engineering knowledge, practices & influence
PDM/LOTAR standards releases Standards development process & resources	PDM/LOTAR standards releases Standards development process & resources	PDM/LOTAR standards releases Standards development process & resources	PDM/LOTAR standards releases Standards development process & resources	**Global Standards Community** *** ISO** *** ASD-Stan** *** AIA**	PDM/LOTAR standards releases
Participation in, funding (dues) & feedback to Data Exchange industry associations	Participation in & feedback to Data Exchange Implementor Forums	Participation in & feedback to LOTAR	Participation in & feedback to INCOSE working groups	Staffing/expertise for standards development initiatives	**Global Engineering Community**

An overview of several key organizations follows.

PDES Inc.

PDES, Inc. is an international consortium committed to accelerating the development and implementation of standards that enable enterprise integration and Product Lifecycle Management interoperability. PDES, Inc. supports the Digital Enterprise through the development and implementation of information standards to support Model-based Engineering, Model-based Manufacturing, and Model-based Sustainment from design to archival and retrieval. Founded in 1988, the organization includes members from industry, government and academia.

Benefits to an enterprise of participation in PDES Inc. include:

- Access to the world's leading experts and knowledge base in STandard for the Exchange of Product model data aka STEP (ISO 10303-AP233) deployment
- Strong relationships with leading prime contractors and OEMs
- Access to best practices for STEP implementation
- Facilitation of business opportunities with participating companies.

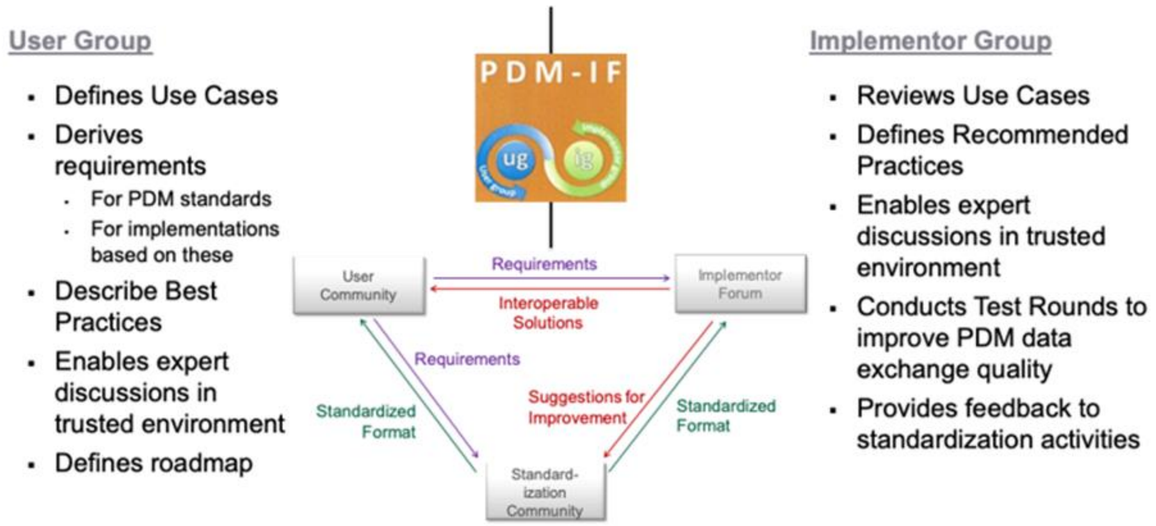
The International Council on Systems Engineering (INCOSE) and PDES Inc. have a Memorandum of Understanding (MoU) to collaborate in related professional areas of mutual interest to benefit the state of practice in systems engineering for all engineering practitioners, especially in the area of data exchange standards in support of Model-based Systems Engineering, Model-based Manufacturing and Model-based Sustainment.

Testing data exchange implementations using standards has been an integral part of the PDES Inc. and INCOSE partnership, resulting in the development of ISO 10303-AP233, the STEP standard for Systems Engineering Data Exchange. The goal of the PDES Inc/INCOSE MoU is to expand the model-based engineering data exchange standards collaboration to include additional ISO 10303 Application Protocols, and OMG and OASIS standards, with a focus on LOTAR (LOng Term Archiving and Retrieval).

For more information on PDES Inc.

PDM Implementor Forum

The Product Data Management (PDM) Implementor Forum (PDM-IF) is a company membership-based organization including a User Group (industrials), and Implementor Group (vendors), with roles as shown below.



Source: PDM Implementor ForumPDM-IF home page:

The main goal of the PDM-IF is to develop international PDM interoperability recommended practices:

- Answering the needs of manufacturing industries for a set of consistent standards providing PDM information models and associated recommended practices for PDM interoperability
- Covering the full product life cycle, from concept phase, to support and dismantlement
- Common to the different disciplines, systems, structures, etc.
- Managed consistently through time by ensuring upward compatibility with legacy PDM standards and existing PDM data repositories
- Based on an open web based infrastructure
- Providing common guidelines for the PDM domain of the following STEP modular Application Protocols: AP 209, AP 233, AP 242, AP 210, OASIS PLCS and AP 239.

Another goal of the PDM-IF is the establishment of shared test activities in the PDM domain, based on agreed and reliable methods.

For more information on PDM-IF.

LOTAR

LOTAR is an international consortium of aerospace manufacturers, jointly facilitated by AIA, ASD-STAN, AFNeT, prostep ivip and PDES, Inc.

The prime objective of the LOTAR consortium is the creation and deployment of the EN/NAS 9300 series of standards for long-term archiving and retrieval of digital data, based on standardized approaches and solutions. The integration of LOTAR requirements into software tools is to be ensured by close cooperation with the MBx Interoperability Forum and the PDM Implementor Forum.

The LOTAR project is organized in different workgroups (WGs). Each WG is comprised of subject matter experts and develops the corresponding parts of the LOTAR standard, as well as related documents. Scope areas include 3D Mechanical CAD with PMI, PDM, Composites, Electrical Harness, Model-Based Systems Engineering (MBSE), as well as Engineering Analysis and Simulation (EAS).

The main deliverable of the LOTAR project is the LOTAR standard. The standard is based on the ISO 14721 “Open Archival Information System (OAIS)” Reference Model. The documents for the standard are published as the European Norm (EN) 9300-xxx series under ASD-STAN in Europe, and as the National Aerospace Standard (NAS) 9300-xxx in the USA under AIA.

Throughout each year, the LOTAR project meets at four workshops online or at alternating locations in Europe and the USA. In addition, a number of LOTAR-related events are conducted where the project is being presented, or which share the topic of long-term archiving and retrieval. The project also issues regular progress reports and news articles to publicize its work.

LOTAR is a participant in INCOSE's Tool Integration and Model Lifecycle Management WG, which provides a forum for discussion and information dissemination on best practices, methods and processes that promote the development, validation and deployment of standards to advance data exchange capability of digital data created during a product development lifecycle.

For more information on LOTAR International

More Information

The interactions among all of these industry players are quite complex, so to learn more, check out these sources:

Consortia:

- PDES, Inc.
- AFNET
- prostep ivip

- ASD
- VDA
- LOTAR

Implementor/Interoperability Forums:

- PDM
- MBx
- RV&V
- JT

Other resources:

- Recommended Practices For STEP AP242 Business Object Model XML Configuration Management
- MBx Forum Memorandum of Understanding Announcement

PPI RESOURCES

PPI offers a multidute of resources available to all of our clients, associates and friends! Click on any of the links below to access these resources today.

Systems Engineering FAQ: https://www.ppi-int.com/resources/systems-engineering-faq
Industry-related questions answered by PPI Founder and Managing Director Robert Halligan.

Key downloads: https://www.ppi-int.com/keydownloads/
Free downloadable presentations, short papers, specifications and other helpful downloads related to requirements and the field of Systems Engineering.

Conferences: https://www.ppi-int.com/resources/conferences-and-meetings/
Keep track of systems engineering-relevant conferences and meeting dates throughout the year.

Systems Engineering Goldmine: https://www.ppi-int.com/se-goldmine/
A free resources with over 4GB of downloadable information relevant to the Engineering of systems and a searchable database of 7,800+ defined terms. You can expect the content of the SE Goldmine to continue to increase over time.

Systems Engineering Tools Database beta (requires SEG account authorization to log in): https://www.systemsengineeringtools.com/
A resource jointly developed and operated by Project Performance International (PPI) and the International Council on Systems Engineering (INCOSE). The SETDB helps you find appropriate software tools and cloud services that support your systems engineering-related activities. As a PPI SEG account holder, you have ongoing free access to the SETDB.

PPI SyEN Newsjournal (actually a substantial monthly SE publication): https://www.ppi-int.com/systems-engineering-newsjournal/
You're already reading our monthly newsjournal! However click on the link to access the history of 100+ monthly newsjournals containing excellent articles, news and other interesting topics summarizing developments in the field of systems engineering.

SYSTEMS ENGINEERING IN SOCIETY

Expanding applications of SE across the globe

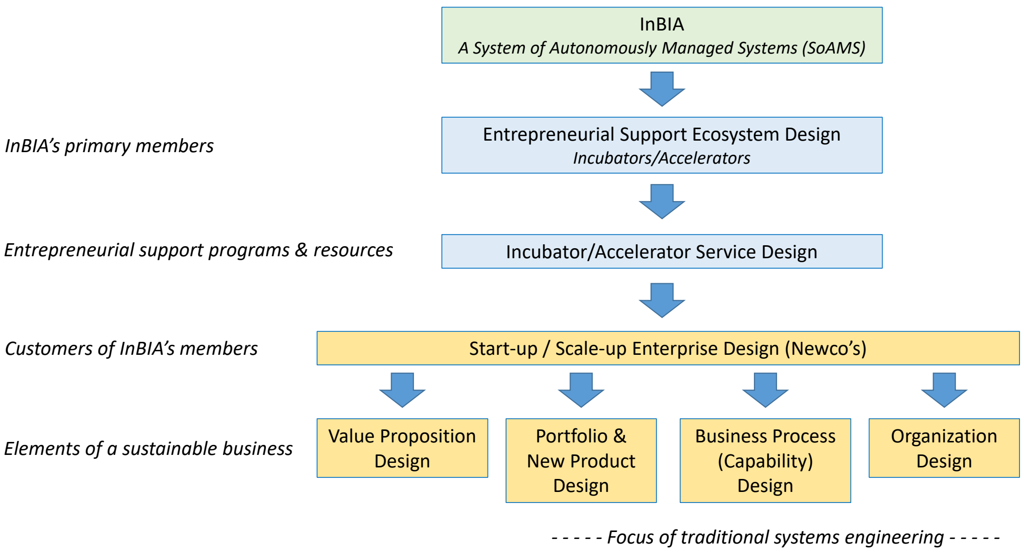
Featured Organization: International Business Innovation Association (InBIA)

The InBIA is the largest member-based entrepreneurial support network in the world, a global non-profit with over 1,200 members that leads entrepreneurship support organizations in 30 countries. For over 30 years, InBIA has provided industry best practices through education while enabling collaboration, mentorship, peer-based learning, and the sharing of innovative ideas for entrepreneurs across the globe.

InBIA is a leader in providing industry resources for building thriving entrepreneurial ecosystems through sustainable entrepreneurial programs across a wide scope of global settings, industries and disciplines.

InBIA, as a member-driven organization, focuses on collaboration among the global community of independently-managed entrepreneurial support organizations and the entrepreneurs they support. As such, InBIA is itself a System of Systems (SoS), or more precisely a System of Autonomously Managed Systems (SoAMS).

While not normally thought of as an engineering-focused organization, InBIA offers services that provide patterns, methods and tools for the design of entrepreneurial support ecosystems, e.g. business incubators or accelerators and their service offerings.



In turn, InBIA services help member organizations help their customers, the entrepreneurs, with the design of their start-up and scale-up companies (which are themselves business systems that require full lifecycle design processes). In particular, these services help entrepreneurs with the process of value proposition design that yields a sustainable business. Value proposition design guides the design of portfolios consisting of new products. A sustainable business also requires concurrent engineering of business processes (capabilities) and an organization that can support the value proposition.

Learn more about the InBIA.

SYSTEMS ENGINEERING IN SOCIETY

Systems Engineering Junior Handbook

The Los Angeles chapter of INCOSE offers a Systems Engineering Junior Handbook aimed at teaching basic systems engineering concepts and practices to pre-university students considering careers in Science, Technology, Engineering and Math (STEM).

The handbook, released in 2015, includes topics such as:

- Systems Engineering Principles, e.g. What is a System, Systems Science, What is Systems Engineering
- Systems Life Cycle
- Systems Engineering Management
- Systems Engineering Practice on a Robotics Competition

PPI shares the belief that students, particularly those with a STEM focus, should learn the thinking skills that are necessary for engineering solutions to problems and societal challenges.

Download the handbook here.

Systems Engineering MS Program at George Mason University

George Mason University (Fairfax, Virginia, USA) offers a Master of Science program in systems engineering that addresses range of issues relevant to the design, implementation, analysis and management of systems.

Concentration areas include:

- Advanced Transportation Systems;
- Architecture-Based Systems Integration;
- Command, Control, Communications, Computing, and Intelligence;
- Financial Systems Engineering;
- Systems Engineering Analysis;
- Systems Engineering of Software-Intensive Systems; and
- Systems Management.

Research activities include both fundamental and applied research. The systems engineering graduate program recognizes the importance of balancing an education in quantitative models and engineering tools with a proper understanding of the systems perspective.

The graduate program leading to the Master of Science in Systems Engineering emphasizes both analytical and practical aspects of engineering complex systems. Students are expected to demonstrate proficiency in using qualitative and quantitative tools relevant to systems engineering practice.

Program details.

Systems Engineering SubReddit

Reddit is a social news aggregator, a large group of forums in which registered users can talk about almost anything. Reddit is divided into forums called "subreddits." Users (the editors) are content creators as well as consumers and curators. The community uses a points system of upvotes and downvotes to determine which content and discussions are important and subsequently displayed at the top of the feed. Reddit contains a Systems Engineering subreddit that includes an extensive set of posts that range from questions concerning systems engineering education and career options, discussions on best practices and tools, hiring ads, webinar announcements, community news e.g. handbook releases, along with some sketchy requests for assistance (please take this exam for me!) and non-relevant promoted ads.

FINAL THOUGHTS, FROM SYENNA

Dear reader(s),

This month my hope for the COP26 Climate Conference was to see some evidence of systems thinking. Many of our political leaders proclaim that they will be “guided by the science”, but are they aware that the scientific method is essentially based on reductionist thinking, which needs to be balanced with some holistic thinking; that there is such a thing as the reductionist trap; and that to understand whole system behavior we need to focus on behavioral relationships more than on things?

Apropos of this, the following three examples come to mind (the third being partially hypothetical):

1) For thirty years, the European Union (EU), with all the best intentions, pursued a policy of reducing greenhouse gas emissions. In that period, global emissions continued to rise. Much manufacturing in the EU closed down in line with the policy, but Europeans still demanded their “stuff”. Manufacturing moved overseas, where the use of fossil fuel is intense. The stuff had to be sent back to Europe in highly polluting cargo vessels. In a nutshell, the EU leaders “shifted the burden”.

2) When fish stocks got seriously depleted, world leaders ruled that smaller fish should be returned to the ocean so that they had a chance to spawn future generations. The result: the average size within a species reduced, and health got worse. The reason: smaller fish tend to be small because they are weak or unhealthy. Our contra-Darwinian meddling was selecting poor specimens for future propagation.

3) A city banned high emissions vehicles from its central business district. Result: the worst-polluting vehicles went around the ring road instead of using the cross-city highway (more miles). The ring road became a logjam (more emissions per mile). Emissions were intensified and moved closer to the residential areas.

Could COP26 initiatives make equivalent mistakes? Surely it can’t be right to replace almost 1.5 billion fossil-powered vehicles with 1.5 billion “zero emission” vehicles? Who is thinking about the planetary resources to support that? Will future wars be about exotic materials for battery production instead of oil? What about the environmental and social implications in countries that provide those materials? How will we safely fuel our vehicles with hydrogen (for example)?

When my diesel car becomes uneconomic, I probably will replace it with an electric one, but that is a sticking plaster. I need to face up to the root cause of my problem, which is the selfish mental model that drives me to have a “private” car. There is no such thing, because the life cycle penalties of a vehicle impact everyone.

If I chose to change my behavior, I could set up a car-sharing syndicate next week with some like-minded people. Improving the utilization of our vehicles (whether fossil-powered or not) would dramatically cut the planetary resources needed to build and recycle them (the whole life cycle view that is too often ignored). We shouldn’t expand busy road junctions, widen roads, or build new ones, the activities of such create very high emissions. Instead we should change our working patterns and mental models, reducing the number of vehicles on the roads.

To be honest, I don’t know if I will swallow my own medicine, but some government incentives would help... It would be relatively cheap to incentivize car syndicates (assuming they are a good answer). Top-down could meet bottom-up.

FINAL THOUGHTS, FROM SYENNA

In summary, systems thinkers know that a focus on things, stuff, and technology won't solve the climate problem in time. Ironically, they struggle to provide scientific proof of this, because science isn't set up to do that. There must be a balancing focus on behaviors and mental models, whole system, and whole life cycle. We need our leaders to be courageous in setting out what they know to be right, without necessarily waiting for scientific proof. This is what I was looking for in the output from COP26.

I trust that some of the above is controversial, because it needs to be. Please do send in your thoughts to PPISyEN@ppi-int.com.