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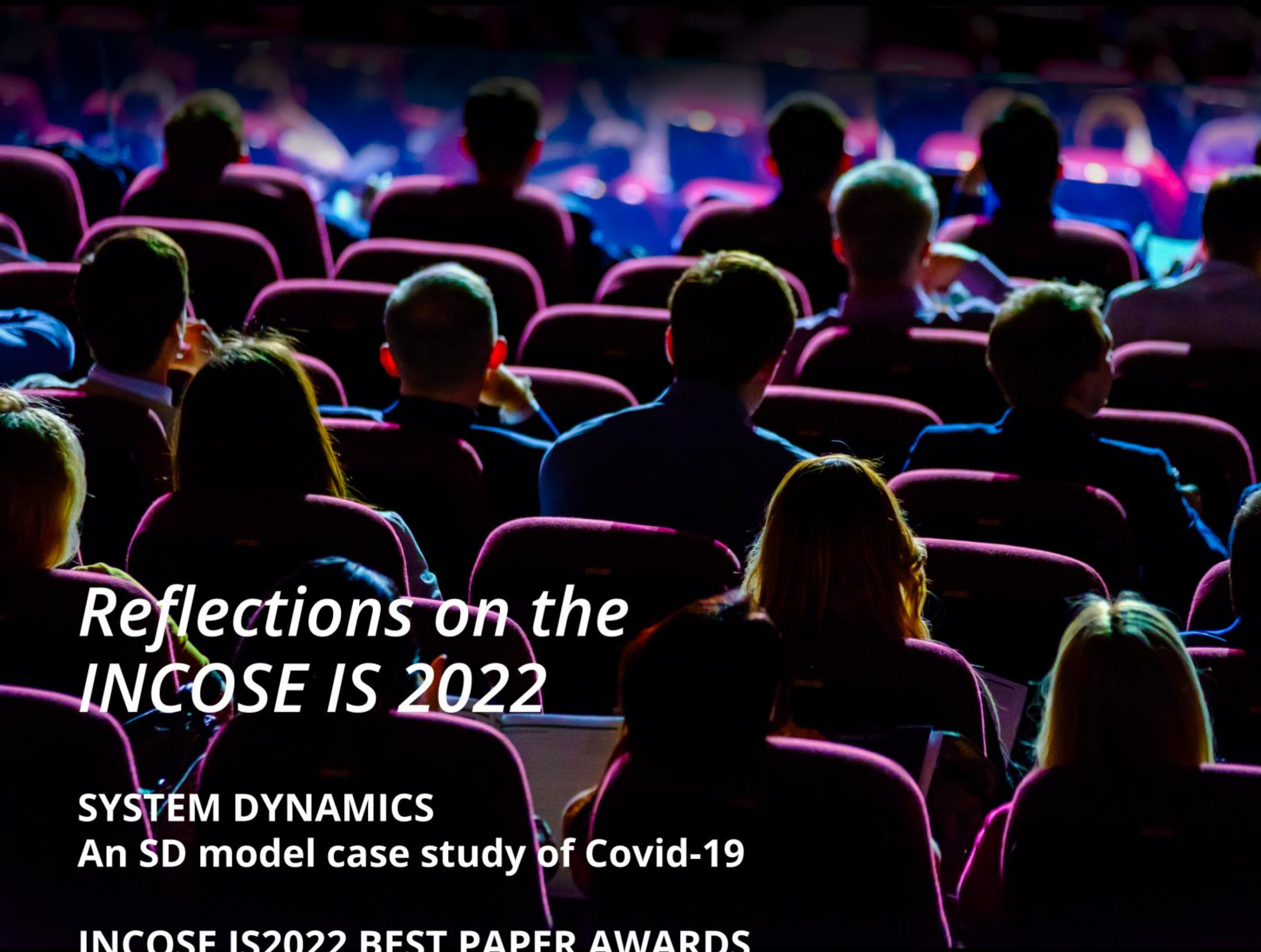

Reflections on the INCOSE IS 2022

SYSTEM DYNAMICS
An SD model case study of Covid-19

INCOSE IS2022 BEST PAPER AWARDS
Highlights from the winning presentations

SPOTLIGHT: IS2022 THOUGHTS ON EMERGENCE
Philosophical controversies from the IS2022

PPI SyEN

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WELCOME

Dearest Readers,

Welcome to this July edition of PPI SyEN! This is one of my favorite editions of our Newsjournal so far this year as it is absolutely packed with exciting updates from the SE world and excellent feature article content.

Our focus in this edition is to shine a light on the recent hybrid INCOSE International Symposium that took place from 25-30 June 2022. I had the privilege of attending virtually and I must say, what a fabulous event! It was executed exceptionally well from a technical point of view and the content of the papers and presentations was something to behold. Read more about the Best Papers as awarded by INCOSE and their summaries in the second Feature Article.

We also have a riveting piece by Paul Davies who provides a System Dynamics Model of COVID-19. System dynamics (SD) is a systems thinking tool modeling tool that allows the total effect of various complex relationships (i.e. system dynamics can quantify and explain the emergence of interrelated factors). COVID-19 is an excellent case study to which SD may be applied and Paul does so in a very systematic and engaging way.

Continuing with the theme of emergence, John Fitch and I explore how the concept of emergence came into play in the INCOSE IS 2022 as a hybrid in-person and virtual event. We gathered some thoughts from PPI presenters and consultants on 4 key questions related to emergence. These questions were proposed and addressed by Jakob Axelsson of Mälardalen University, Sweden, in his IS 2022 best paper winner titled "*What Systems Engineers Should Know About Emergence*".

In other sections of this newsjournal, read about the recently published OMG 'anything-as-a-service' glossary. You may also read about Barry Boehm's career and retirement plus discover some leading-edge conferences that are upcoming. You can also find out how to gain access to CTI's webinar on 'How to Learn Systems Engineering' as presented by Michael Gainford and René King.

I learned a few new things when reading through this edition, not least of all about the concept of Digital Humanism – find out more about what this is in SE news. There are some really high value resources to check out in the resource section and a special challenge for our astute readers in the Final Thoughts by Syenna section. If you're up for sharpening your Capability Decision skills, we'd love to receive your inputs plus you we have a very LARGE prize on offer. Enjoy this fabulous edition of the PPI Newsjournal!

René

Managing Editor, PPI SyEN

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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

INCOSE Awards Announced at IS2022

The plenary sessions at IS2022 provided an opportunity for recognition of the contributions of a variety of individuals and teams to the mission of INCOSE. Awards given included:

INCOSE Pioneer Award – for outstanding pioneer applications of systems engineering.

- Awarded to Professor *Michael C. Jackson* for the development of the foundations of systems engineering as author, educator and intellectual leader in systems thinking.

INCOSE Founder Award – for outstanding individual contributions to INCOSE, be they a single event or a lifetime of significant efforts.

- Awarded to *David Walden*, ESEP, for almost 20 years of sustained service as North Star chapter leader, as member of the leadership team in regional and international symposia, as member and chair of the Corporate Advisory Board, as co-editor and lead editor of the SE Handbook, and as INCOSE liaison to the ISO SC7 working groups.

INCOSE Fellows – individuals with significant verifiable contributions to the art and practice of systems engineering in industry, government, or academia.

- Awarded to *Dr. Claude Baron* for advancing systems engineering in Europe through innovative research and education.
- Awarded to *Dr. Jon Holt* for leading the implementation and for sustained effort in support of Model-Based Systems Engineering
- Awarded to *Dr. David Rousseau* for contributions to the field of systems science including serving as a core team member of the INCOSE FuSE project, co-founding member of the SE Principles Action Team, past President of the International Society for the Systems Sciences, and Director of the Centre for Systems Philosophy.
- Awarded to *Dr. Ariela Sofer* for significant contributions to systems engineering education and advancing the recognition of systems engineering in academia.
- Awarded to *Dr. Ricardo Valerdi* for advancing the theory and practice of cost estimation and measurement in systems engineering.

Systems Engineering Influencer Award

- Awarded to *Kevin Weinstein*, CSEP, for his leadership in promoting the business value of systems engineering throughout Booz Allen by promoting INCOSE certifications for staff and inserting digital engineering practices in large billion-dollar programs.
- Outstanding Service Awards – for contributing significant volunteer efforts on behalf of INCOSE.
- Awarded to the ABET Team (*Phillip Brown, Dennis Buede, Wolt Fabrycky, Dick Fairley, John Farr, John McCarthy, Young Moon, Dave Olwell, Art Pyster, Ariela Sofer, Steve Sutton, Robert Swarz,*

Clifford Whitcomb) for their 20-year effort to gain ABET acceptance of INCOSE's systems engineering criteria as the basis for accreditation of academic programs.

- Awarded to *Vincent Chapurlat* for successful management of the AFIS Academic-Industry Forum and the RobAFIS competition in 2020 and 2021 in a full virtual mode as well as the AFIS Engineering School in March 2022.
- Awarded to *Heather Feli* for unrelenting dedication and transformative leadership in supporting and empowering women leaders to author and publish their important works in a compilation of chapters addressing emerging trends in systems engineering leadership.
- Awarded to *Paul Kostek* for the promotion of systems engineering knowledge, leadership and events in the Seattle Metro Chapter and exceptional leadership roles in the Western States Regional Conference (WSRC), including Sponsorships and Exhibits Chairman from 2018 through 2022.
- Awarded to the SE Vision Team (*Christopher Davey, Sanford Friedenthal, Sky Matthews, David Nichols, Paul Nielsen, Christopher Oster, Garry Roedler, Paul Schreinemakers, Emma Sparks, Heinz Stower, Taylor Riehle*) for directing, managing, developing, and publishing the SE Vision 2035, which broadens, aligns, and promotes systems engineering as envisaged in the future.
- Awarded to the founding coaches of the INCOSE Institute for Technical Leadership (*Don Gelosh, Patrick Godfrey, Michael Pennotti*) for creating the Institute, enabling INCOSE members to improve their leadership skills in a collaborative learning environment.
- Awarded to *Marcel van de Ven* for outreach to the non-systems engineering community; maintaining leadership roles in several working groups and leading his company in the growth of systems engineering practices that allow the firm to reduce risks in complex and complicated projects in the Netherlands.
- Awarded to *Nicole Hutchison* in recognition of dedicated service as Associate Director, Events 2017-2022 and International Symposium 2022.

Congratulations to all those honored for their contributions.

OMG Publishes Anything-as-a-Service Glossary

In recent years the suffix "as a service" (aaS) has been appended to many things as a popular shorthand to describe solutions offered on a pay-as-you-go basis. To dispel confusion that results from inconsistent and overlapping use of these terms, the Cloud Computing Group of the Object Management Group (OMG) has published its Anything as a Service (XaaS) Glossary. The glossary includes forty-eight terms with definitions and sources.

Although the Glossary does not have the authority of an official standard, it may help readers make sense of the actual concepts covered by the various abbreviations, analyze how much is truly novel in each of them, and understand whether there is a type of service they should investigate.

Download the Anything-as-a-Service Glossary.

Barry Boehm Retires

The Systems Engineering Research Center (SERC) has announced the retirement of Dr. Barry Boehm, SERC Chief Scientist Emeritus and a distinguished contributor to software and systems engineering for over six decades. Dr. Boehm's career included leadership posts in industry (General Dynamics, RAND Corporation, TRW), government (DARPA) and academia (University of Southern California).

Dr. Boehm was the source of over 900 published works including nearly 200 journal articles, hundreds of conference papers and six textbooks. His 1981 book, *Software Engineering Economics*, documented the Constructive Cost Model (COCOMO), a software cost estimation model that has had critical impact as a leading indicator of software changes. Dr. Boehm's spiral development model has had wide impact on system and software development projects across the globe and laid an important foundation for modern agile development practices.

Dr. Boehm played a key role in the founding of the SERC in 2008, serving as Chief Scientist and Chair of the Research Council. He was instrumental as an architect and author of the Systems Engineering Body of Knowledge (SeBOK).

Barry Boehm's accomplishments have been recognized by numerous awards by professional societies that demonstrate the breadth of his impact on the field of engineering across disciplines:

- Fellow, International Council on Systems Engineering (INCOSE)
- Fellow, American Institute of Aeronautics and Astronautics (AIAA)
- Fellow, Association of Computing Machinery (ACM)
- Fellow, Institute for Electrical and Electronic Engineers (IEEE)
- Member, National Academy of Engineering
- Founders Award, SERC
- Pioneer Aware, INCOSE

Robert Halligan, PPI's founder, reflects on Barry Boehm's contributions, saying:

> "From his professional origins in software engineering, Barry Boehm recognized the applicability of systems engineering principles and methods to software engineering. He substantially influenced the confluence that occurred of systems engineering and software engineering into the meta-disciplinary set of principles and methods that make no distinction in their application to software systems and to physical systems. A manifestation of this confluence is CMMI.
>
> The Spiral Model, defined by Barry Boehm in a software development context, became generalized as a stage based, stage-gate, risk and opportunity-driven development methodology, a sibling to waterfall, incremental and evolutionary strategies. The Spiral Model is thus another part of the huge systems engineering legacy of Barry Boehm."

Other PPI team members remember their first encounters with Barry Boehm with words such as "gentleman" "humility" and "vision".

The entire PPI team congratulates Barry Boehm on his amazing career, thanks him for his diligence and perseverance in bettering our world and wishes him all the best in his well-earned retirement.

Read the SERC announcement here.

CONFERENCES, MEETINGS & WEBINARS

Call for Proposals: Capella Days 2022

The annual free online gathering of the Capella (MBSE tool) and Arcadia (MBSE method) community, Capella Days 2022, is scheduled for 15-17 November 2022. Capella Days bring together the creators of Capella/Arcadia, providers of Capella add-on and services, and MBSE experts and industrial users.

A Call for Proposals has been issued, seeking feedback from industrial users concerning their application of Capella. Topics of interest for these online presentations include:

- MBSE challenges
- Arcadia methodology adoption
- Capella deployment
- Lessons learned

The early submission deadline is 1 Sept; final submission is due on 15 September. The final program will be announced on 1 October.

Learn more. Submit your talk here.

Digital Humanism Summer School 2022

Digital Humanism looks at the interplay of technology and mankind, it analyzes, and tries to influence the complex interplay of technology and humankind, for a better society and life. Digital Humanism recognizes the need for an interdisciplinary approach, integrating humanities, social, technical, and engineering sciences; crossing different disciplines to break down disciplinary silos.

The Technical University of Vienna, Austria will host the Digital Humanism Summer School 2022 on 19-23 September. The five-day program is open to students at the PhD and advanced master level as well as interested persons from industry, institutions, and civil society.

Lecture topics include (but are not limited to):

- Societal Responsibilities of the Digital Scientist and Professional: Techno-sociality, Critical Science, Reflective Action
- Automated Decision Systems: Why Human Autonomy is at Stake
- AI and Global Ethical Issues
- The Road Less Taken: Pathways to Ethical and Responsible Technologies
- How to Model Fair Ecosystems
- Using AI and Cryptoeconomics to Facilitate Citizen Deliberations at Scale
- CONFERENCES, MEETINGS & WEBINARS
- Online Platforms: Key Debates and Contending Perspectives

- Lessons from Texas, COVID-19 and the 737 Max: Efficiency vs Resilience
- Work in the Digital Economy
- Sovereignty in the Digital Age

Multiple project sessions will engage participants in an exploration of how the values of digital humanism can inform and guide the conception of socio-technical systems.

Learn more here. Register here.

Embedded Systems Innovation (ESI) Symposium 2022

TNO, the Netherlands Organisation for applied scientific research, hosts an annual conference through its Embedded Systems Innovation (ESI) arm. The ESI Symposium 2022 will be a hybrid event on 27 September 2022, with its physical location in Veldhoven, Netherlands. The theme of this 20th anniversary conference is *Integrating Systems*.

Keynote speakers are:

- Gail Murphy, Professor of Computer Science at the University of British Columbia (Canada)
- Bernhard Quendt, Chief Technical Officer Thales Group

Six presentation tracks will explore the Integrating Systems theme:

- Business-driven integration
- Confidence in diversity
- Integrating classical and autonomous systems
- Platform-based integration
- Optimization in context
- Continuous integration and deployment

Presentation topics include (but are not limited to):

- Maritime Unmanned Systems of Systems
- Using AI to improve Scenario-Based Testing
- Introduction to platform-based integration
- Fixing reference architecture...
- Adaptive system behavior for highly dynamic situations
- Learning in Digital Twins to automate the calibration of high-tech systems
- A 4-Box Development Model for Complex Systems Engineering
- Continuous Integration/Continuous Deployment (CI/CD) in Large Enterprise Environments

Learn more and register here.

CONFERENCES, MEETINGS & WEBINARS

Wind Energy Systems Engineering Workshop

The Wind Energy Systems Engineering (WESE) Workshop is a biennial event that invites speakers from academia, industry, and international research laboratories to discuss topics relevant to systems engineering and the wind industry. WESE 2022 will take place in Boulder, Colorado, USA on 30 August – 1 September at the University of Colorado RASEI Center.

The workshop will include:

- Keynotes from local Colorado wind and aerospace innovators.
- Systems engineering sessions focused on the evolving grid and economic landscape, wind farm design, high-fidelity models, industry perspectives and broadening the "system" to include hybrid plants, supply chain needs, grid resiliency and environmental impacts.
- Systems engineering design tool advances.
- Tour of TBD wind energy research, design, or manufacturing facilities in the area.

Learn more here. Register here.

SERC Annual Sponsor Research Review 2022

The Systems Engineering Research Center (SERC) is hosting its annual Sponsor Research Review set to take place from 15-17 November 2022. The hybrid (physical-virtual) conference will be held at the National Press Club in Washington DC. This three-day event will begin with the AIRC (Acquisition Innovation Research Center) Sponsor Research Review on 15 November. The SERC Sponsor Research Review (SSRR) will be held on 16 November and the SERC Doctoral Student Forum (SDSF) will be held *virtually* on 17 November.

This three-day event brings together sectors of the systems engineering and acquisition research communities – government, industry, and academia – and provides an opportunity to share progress on research addressing the most challenging issues facing the U.S. Department of Defense (DOD) and other federal departments and agencies.

See details here.

The deadline for nominating (via a 500-word abstract/biography) a doctoral student to present at the virtual 10th Annual SERC Doctoral Students Forum is 16 September.

CTI's Michael Gainford and René King Present 'How to Learn Systems Engineering (or Anything!)' for INCOSE and GfSE

On the 6th of July, Certification Training International (CTI) presented to approximately 230 people for the monthly INCOSE/GfSE Webinar series. GfSE is the German Chapter of INCOSE. CTI is a subsidiary company of PPI.

CTI's Managing Director, René King, and long-time presenter, Michael Gainford, presented on the topic *How to Learn Systems Engineering (or Anything!)*. The webinar, was structured around the four sections of the learning life cycle, shown in Figure 1.

1. Principles: What are the ten learning principles to be adhered to in any learning event
2. Progression: How to track learning progress according to established objectives in a learning event
3. Growth: How to grow knowledge and skills beyond the learning event
4. Propagation: How to share knowledge and skills gained with colleagues for the benefit of our projects and organizations

Figure 1. Outline of the learning life cycle as described in the CTI 'How to Learn Systems Engineering'

At the start of the webinar, a set of definitions was stated to describe a learning event and the various characteristics and responsibilities associated with a learning event. These definitions, characteristics and responsibilities were the foundation for the principles that apply to any learning context. The major takeaway was that learning occurs in a multi-directional format between facilitators and delegates. Each participant in the learning scenario contributes their theoretical and experiential knowledge to the learning value overall. Another takeaway is that all learners - and each of us as engineers and indeed humans are learners - are to take responsibility for our learning. This includes identifying our learning style, participating actively, and carving a path to our professional development. The principles presented covered areas such as the importance of providing an environment where mistakes are allowed, the importance of practical exercises in the form of group work, and the value of developing meaningful questions to demonstrate knowledge in a subject area, among others.

The Q&A session comprised Michael and René responding to more than ten thought-provoking questions from the attendees. Questions covered topics such as how to keep webinars interesting, whether it's necessary to unlearn previous 'malignant' knowledge before learning systems engineering, and the relationship between Bloom's Taxonomy and the learning life cycle proposed by Michael. The conversation in the Zoom chat was equally thought-provoking.

The webinar is free to watch for any INCOSE members at INCOSE Connect. In addition, CTI is willing to make the video available to our readers upon request. If this is of interest, don't hesitate to get in touch with René at rking@certificationtraining-int.com to obtain access to the video.

FEATURED ARTICLES

A System Dynamics Model of Covid-19 … and what this can tell us

by Paul Davies (PPI Presenter and Principal Consultant)

Email: pdavies@ppi-int.com

Introduction

System Dynamics (SD) is a modeling technique conceived as far back as the 1950s to understand the nonlinear behavior of complex systems over time, using stocks and flows, feedback loops and numerical integration. It was developed by Jay Forrester and others at the MIT Sloan School of Management, originally to study the effects of policy and market conditions on corporate outcomes. Nowadays it is used to study a wide variety of cause-and-effect behaviors, including industrial dynamics, cyber-physical systems in complex environments, political influence, innovation adoption, climate change, pharmaceutical effects, and information dissemination. What can it teach us about the effects of introduction of new or upgraded systems?

This paper aims to demonstrate that Model Based Systems Engineering (MBSE) is not just about SysML, and that additional value can be obtained from simple simulations of the interaction between an envisaged solution and the problem context. This is illustrated here with an SD model case study, starting with a basic model of the infection dynamics of the Covid-19 (SARS CoV-2) virus, including feedback loops for population mixing and cross-infection. The model is gradually expanded to include the various intervention strategies encountered in real life, including isolation, travel restrictions, social distancing and enhanced hygiene. By varying coefficients in flows and feedback loops, the sensitivity of outcomes to values of infection rates, adherence to each intervention strategy and delay times can be shown.

The original model is sourced from Tom Fiddaman, a respected figure in the SD community, but adapted from modeling behavior in a rural community in Montana, USA, to the denser population dynamics in the UK. We conclude with a reflection on what we can abstract from this exercise, with reference to James Martin's "Seven Samurai" model, to think about modeling the effects of introduction of any system into a changed environment.

Introduction

Jay Forrester's original System Dynamics work [Forrester 1961] was in modeling variations in employment over time in industrial settings, dependent on policy and structure of the companies involved. From there, the field evolved to include models of urban policies and their effects in the late 1960s [Forrester 1969], world population dynamics (early 1970s), productivity as a function of management and project structures (1980s and 1990s), leading to much wider applications and quantification of systems thinking in the early 2000s via the work of Donella Meadows [Meadows 2008] and John Sterman [Sterman 2000].

See [Radzicki and Taylor 2008] for an interesting history of the subject. But in principle, SD can be applied to modeling almost anything that has complex, time-varying behavior subject to certain problem types discussed below. It is a useful tool in the hands of a systems engineer faced with an unstructured problem space requiring careful consideration of the impact of introducing a new or modified system into that context. Perhaps if soft systems analysis [Checkland 1999], [Senge 1990] is the qualitative method, then SD is its quantitative partner.

The Aims

The aims of this paper are:

- To illustrate the principles of SD with a basic model and references for further reading.
- To show how a model of a complex system evolves, illustrated by a model of the dynamics of the Covid-19 pandemic, with the objective of improved understanding and decision-making.
- To extract some lessons learned for systems engineers in the analysis of intervention strategies in postulating new or modified systems to solve perceived problems.

Approach

System Dynamics (SD) is essentially a suite of tools and methods for simulating the evolution of complex systems over time. The basics of the approach are outlined below, with a couple of simple examples. This is followed by the step-by-step build of the more complex model of the dynamics of Covid-19 infection and the efforts to combat it, with the objective of optimizing its containment.

The Basics

The SD approach focuses on the model elements in the table below:

<table>
<tr><td colspan="2"><u>Problem structuring</u> – what is the behavior that we are trying to explain or predict? What are the entities, possibly abstract, that we are trying to quantify? What influences and interactions affect the growth or decay of those quantities? What characterizes those interactions?</td></tr>
<tr><td colspan="2"><u>Causal Loop Diagrams</u> (CLDs) – these are graphical representations of the problem structure, showing the entities, the influences, and the feedback loops involved.</td></tr>
<tr><td><u>Stocks</u> – these are representations of the value of an entity (a variable) that we have identified, at any given point in time.</td><td><u>Flows</u> – these are variations of inputs to and outputs from the Stocks, over time.</td></tr>
<tr><td><u>Feedback Loops</u> – these occur when outputs of a Stock and Flow sequence are routed back, usually via intermediate Stocks, Flows or functions, as inputs. This forms a chain of cause-and-effect, and the net effect of the loop may be positive (“reinforcing”) or negative (“balancing”).</td><td><u>Delays</u> – these are representations of the time taken for an applied function or Flow to take effect. Variable delays (for example, incubation periods, or time to adopt a strategy) are an important construct leading to apparently anomalous behaviors of complex systems.</td></tr>
<tr><td colspan="2"><u>Boundary Conditions</u> – SD models typically need initial conditions for variables influencing the Stocks. Good modeling tools allow sensitivity analysis by supporting “what-if?” variations in these boundary conditions.</td></tr>
</table>

Non-linear dynamics – Flows and feedback loops, and consequently Stocks, generate behaviors in different parts of the model with different time constants. Apart from exponential growth and decay, we observe oscillations, resonance, and sometimes overshoots in response to attempted control via balancing loops. Especially in the case of models with multiple feedback loops, these behaviors can interact with each other unpredictably, and with extreme sensitivity to initial conditions as per Chaos Theory [Gleick 2008].

A simple illustration

We start with a model well-known throughout the SD world, and captured in John Sterman's seminal work [Sterman 2000]. In the upper illustration of Figure 1, we see a reinforcing loop, labeled with an "R". More eggs lead to more chickens, and more chickens lead to more eggs. If we plot the resultant system behavior over time, the numbers of both chickens and eggs grow exponentially if left unchecked.

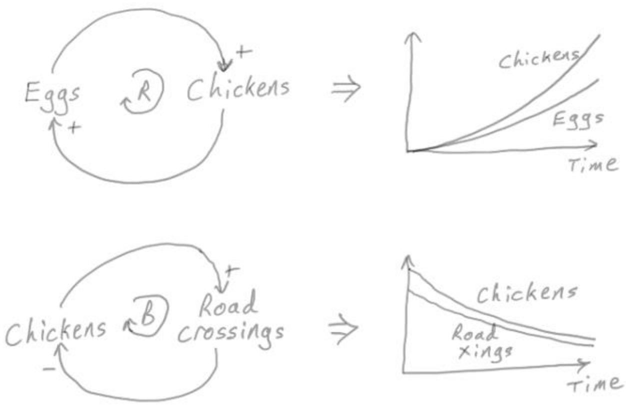


Figure 1 – Which came first, the chicken or the egg?

How fast? Well, we would need to model the flow rates and delays from chickens to eggs, and vice versa. One way of doing this is to observe such a closed environment, and varying model coefficients and delay times until the modelled behavior matches the observations.

In the lower illustration, we see a balancing loop, labeled with a "B". The more the chickens cross the road, the fewer surviving chickens we see. The Stock of chickens decays exponentially.

In Figure 2, we examine what happens if we combine the two feedback loops. There are many possibilities. In A, there is a delay before the chickens start to cross the road, but subsequently the rate of crossings exceeds the birth rate from eggs. In B, there is an approximate balance between the rates, which can lead to interesting oscillatory population behavior rather than a steady state.

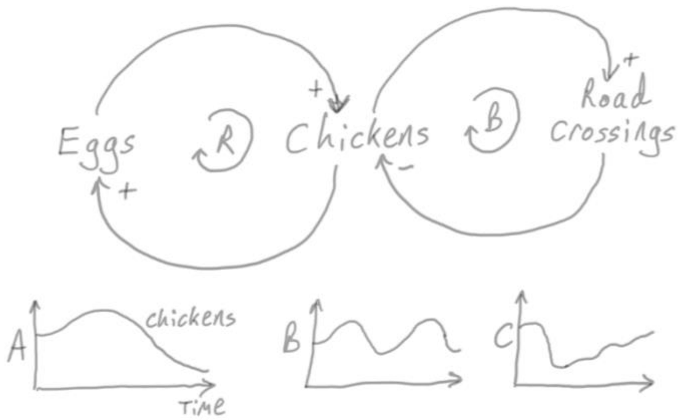


Figure 2 – Combined Loops

In C, we see a case where chickens gradually learn not to cross the road, but not all of them. This leads to the truism [Sterman 2000] that such modeling is essentially an iterative process – models have to be postulated, matched with observed data, and their flow rates, functions and delays successively refined until we can explain the observed behavior with the aid of the model.

A slightly more complex illustration

Instead of representing the model as a CLD, Figure 3 (also well-known, and captured in [Sterman 2000]) is part-way to a full System Dynamics diagram. Stocks are represented as rectangles, Flows as valve symbols, and boundary conditions and functions as labeled entities with their influence on Flows and branch conditions shown as arrows with solid arrowheads.

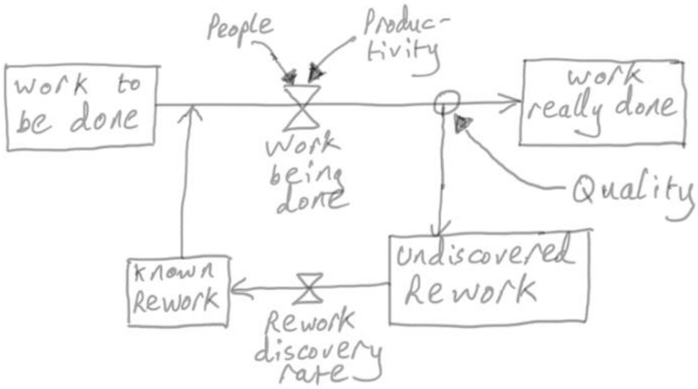


Figure 3 - Project completion model

Note that this model is continuous, in common with almost all scenarios amenable to SD treatment. Breaking the work into discrete phases, with enumerated rework cycles, is an arbitrarily imposed project management constraint, and hardly ever corresponds with real life on projects. However, if your only tool is a Gantt chart, that's what you have to do. With typical right-first-time fractions of no better than 68% on commercial projects, and less than 50% on defense projects [Sterman 2000], there would be a lot of rework phases; it is not recommended to suggest to your project manager that it will take an infinite time to achieve 100% quality.

A step-by-step model of Covid-19 infections

We now progress to building an SD model representing the dynamics of the Covid-19 effect on the population. This particular model is based on one kindly put into the public domain by Tom Fiddaman of Ventana Systems [Fiddaman 2020], the publishers of the Vensim SD tool. Many other SD modeling tools are available; Vensim is used here for the sake of convenience and cost.

The starting point is a known infection pattern called SEIR, which stands for Susceptible-Exposed-Infected-Recovered, the four Stocks (called Levels in Vensim) representing the states in which the population may exist. To which, sadly, a fifth stock labeled Died has to be added. The double-lined arrows through the center of Figure 4 below show the fundamental Flows (rates) between them.

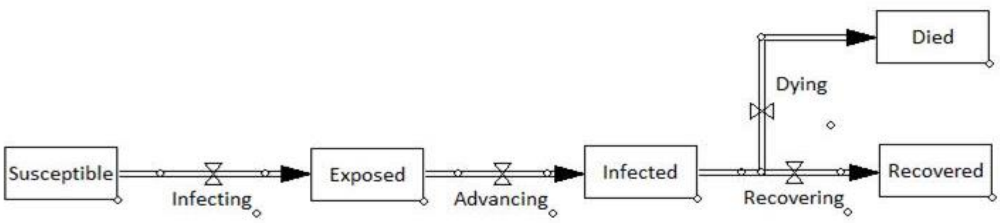


Figure 4 - Basic SEIRD model

The 'Active Infected' variable in Figure 5 then shows the basic reinforcing feedback loop of infection; they infect any susceptible people they come into close contact with. Infected people don't become Active Infected if they isolate themselves, but we'll look at that later.

The initial rate at which the Susceptible population become infected is dependent on R0, the basic reproduction number of the virus, and on the infection duration, as shown top left in Figure 4. Note that strictly speaking, R0 is a derived parameter dependent on several other variables, and it has to be deduced from the observed number of infections rather than from epidemiological principles. The rate at which people exposed to the virus become fully infected is dependent on the incubation time, which is not necessarily the same as the infection duration. Lastly, the Dying and Recovering flow rates depend on the fatality rate of the virus, which in practice is not initially known, and cannot be deduced until a statistically significant number of cases have run their course. Plus, we need a reliable test, in terms of specificity and sensitivity, to estimate the numbers of infections that do, and do not, lead to severe outcomes. In practice this took weeks to months to develop and refine.

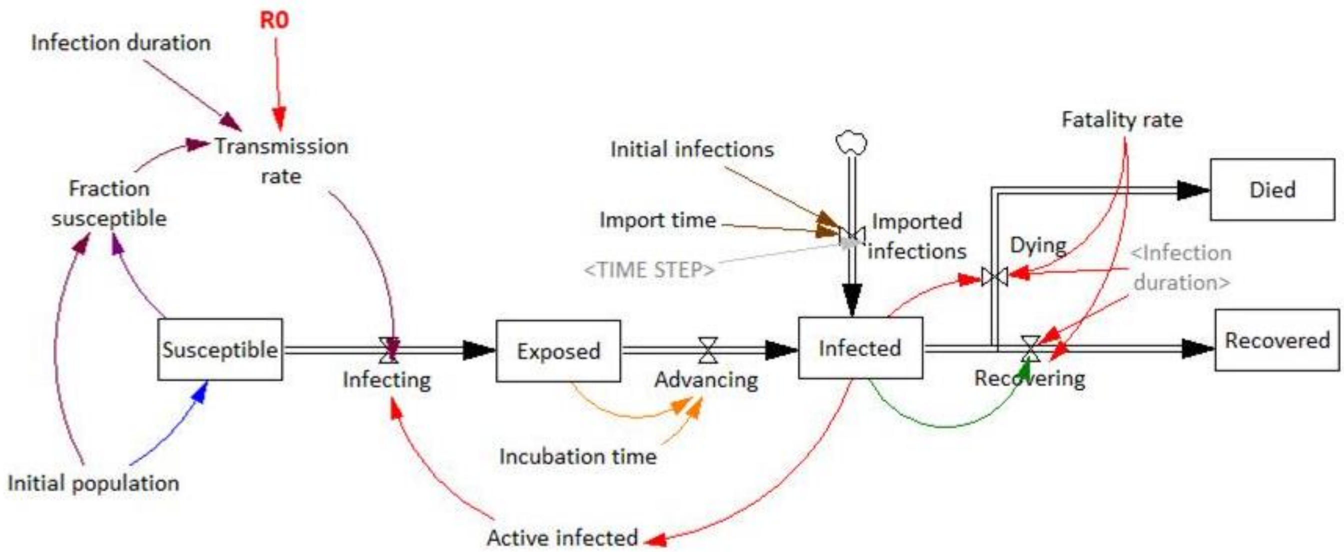
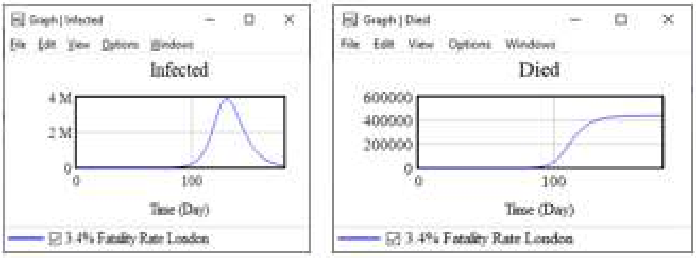


Figure 5 - The SEIRD model of infection, with feedback loops [Fiddaman 2020] with minor adaptations

However, the model will show a steady state of zero infections unless initial some infections are imported into the population. Figure 4 represents this as a fixed number being introduced at a specific time after the start of the simulation, as the downward double-lined arrow.

Of course the model needs underlying equations to make it work, which are not complicated but space here (and the difficulty of representing integral equations) does not allow an exposition – please contact the author, or Tom Fiddaman's paper, for details.

Figure 6 shows the results of a simulation with an R0 of 5.7 [Healthline 2020, BMJ 2020], the initial estimates of the incubation period of 7 days, an infection duration of 10 days and a fatality rate of 3.4% [WHO 2020]. It simulates 2 imported infections 19 days after the start, with the simulation starting on 1st January 2020 – the diagnosis at the time. These figures are the best fit for the first wave of virus infections; later variants exhibited different values of R0, and possibly incubation and infection durations. The model works best assuming homogeneous distribution of the transmission rate, dependent on R0 and the contact density, so I have chosen to model an initial population of 13 million, the approximate population of Greater London and its commuter belt.



ONS	Week no.	Deaths not involving COVID	All deaths - Five-year average	COVID-19
28/02/2020	Week 9	10,816	11,183	0
06/03/2020	Week 10	10,895	11,498	0
13/03/2020	Week 11	11,014	11,205	5
20/03/2020	Week 12	10,542	10,573	103
27/03/2020	Week 13	10,602	10,130	539
03/04/2020	Week 14	12,912	10,305	3,475
10/04/2020	Week 15	12,303	10,520	6,213
17/04/2020	Week 16	13,593	10,497	8,758

Table | Infected

Time (Time)	78	79	80	81	82	83	84	85	86
Infected : 3.4% Fatality Rate London	7447.1	8672.3	10098.8	11759.5	13692.7	15943	18562.1	21610.1	25156.7
Died : 3.4% Fatality Rate London	153.782	179.102	208.588	242.924	282.906	329.461	383.667	446.779	520.253

Figure 6 - Model predictions and ONS statistics

Epidemiologists had already started working with mathematical modelers and were using SD or SD-like models by March 2020. Comparing to the Office for National Statistics reports [ONS 2021] of contemporaneous death rates mentioning Covid-19 (top right of Figure 6), we see good correlation. Good modeling technique requires that we conduct sensitivity analysis around the assumptions for the key model variables. Figures 7-10 show these, with a short commentary to each one.

Sensitivity to R0

Active Infections

Time (Days)	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
Infected : R0=2	18	19	20	21	22	23	24	25	26	28	29	30	32	34	35
Infected : R0=3	137	149	162	176	191	208	226	245	267	290	315	342	372	404	439
Infected : London Base Case	7447	8672	10099	11760	13693	15943	18562	21610	25157	29283	34082	39664	46153	53695	62459
Infected : R0=7	33483	39994	47763	57029	68076	81240	96914	115564	137734	164060	195280	232245	275932	327448	388037

Deaths

Time (Days)	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
Died : R0=2	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2
Died : R0=3	5	6	6	7	7	8	9	10	10	11	12	13	15	16	17
Died : London Base Case	154	179	209	243	283	329	384	447	520	606	705	821	956	1113	1296
Died : R0=7	584	698	833	996	1190	1421	1697	2027	2420	2888	3446	4110	4900	5838	6951

Comments

- *Day 0 in the simulation is 1st January 2019*
- *PM warned the UK population not to travel and to stop non-essential contact 16th March 2020; first lockdown became legally enforceable 25th March 2020, = day 85 in the simulation*

Figure 7 - Model sensitivity to R0

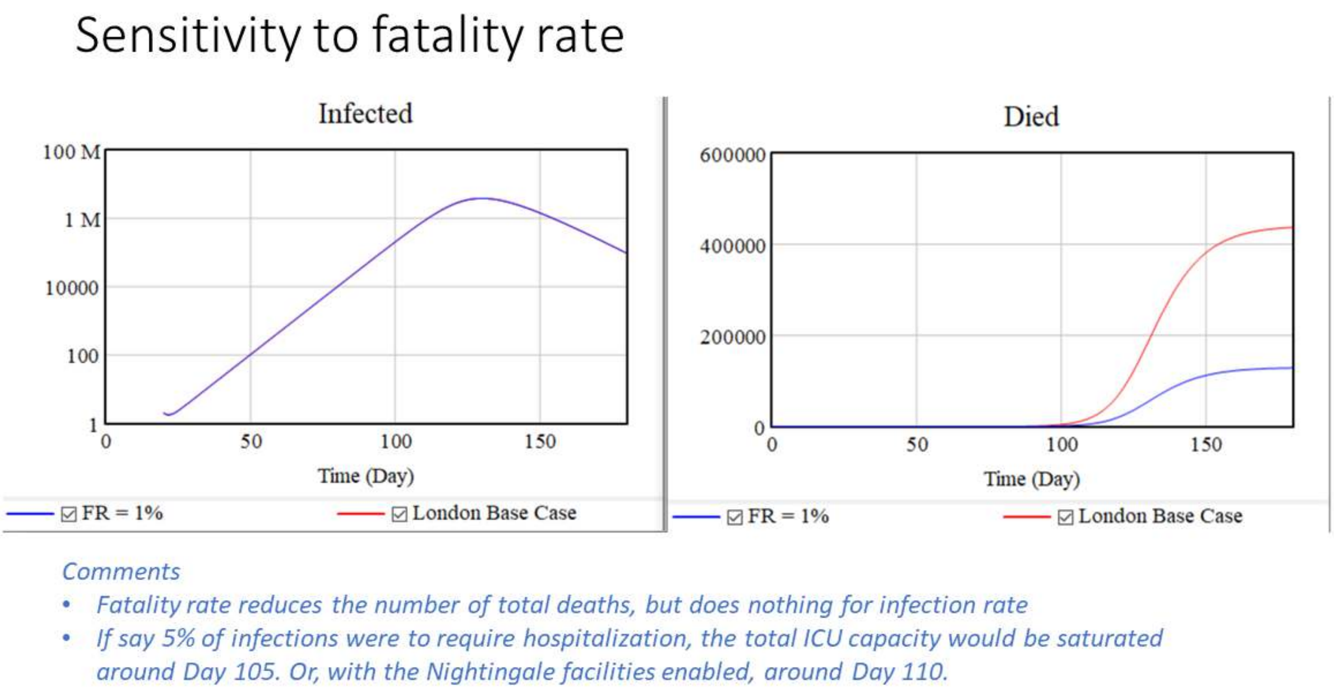


Figure 8 - Model sensitivity to fatality rate

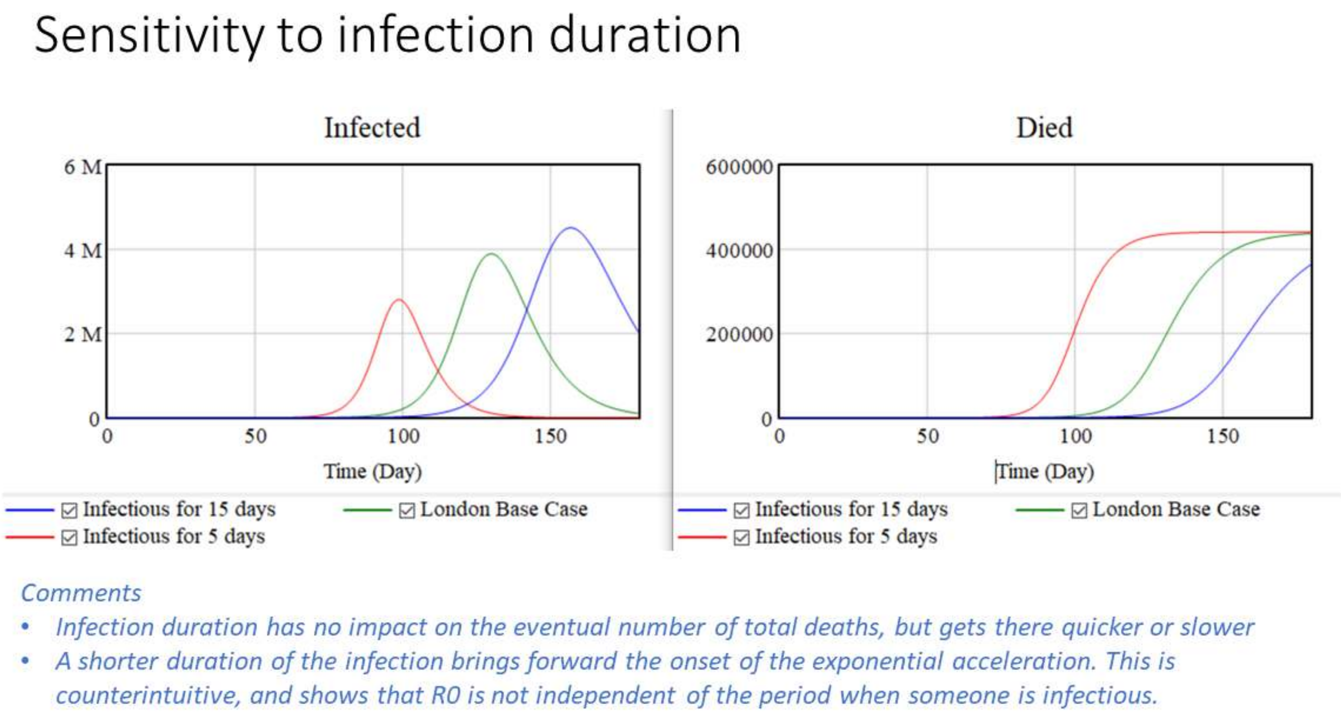


Figure 9 - Model sensitivity to infection rate

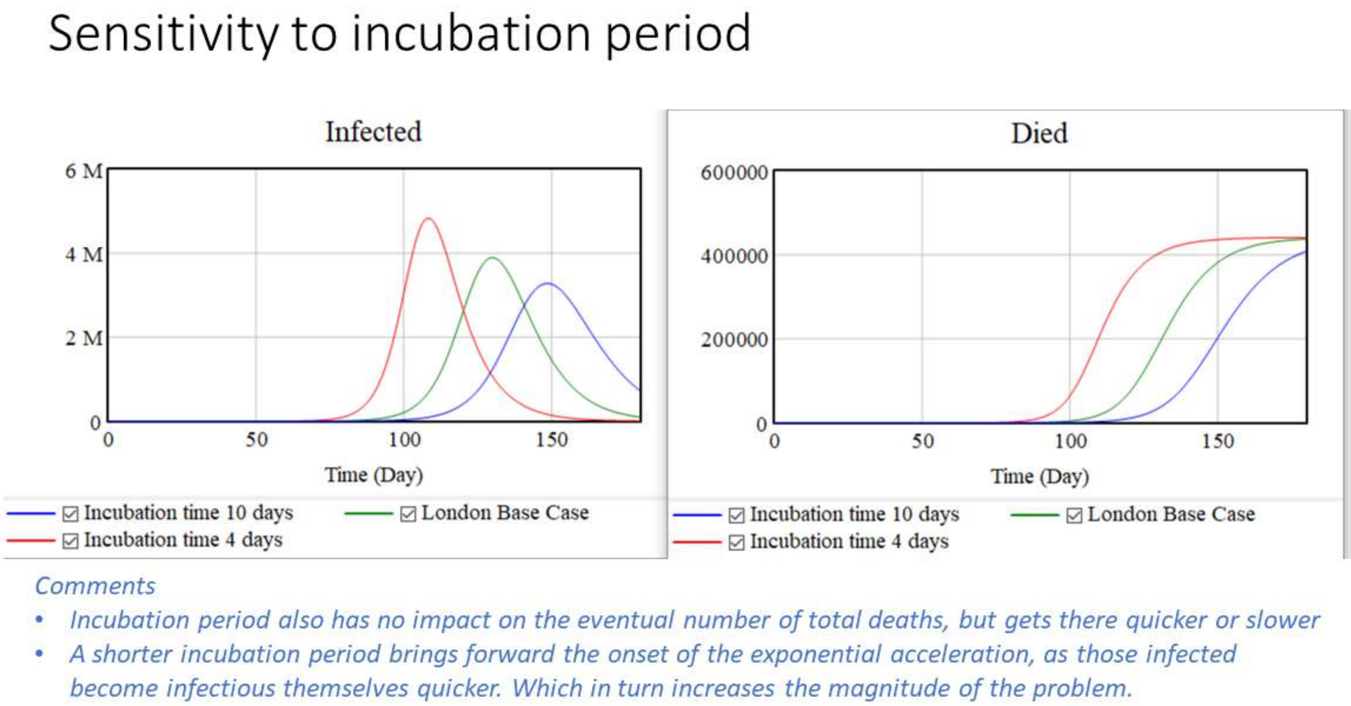


Figure 10 - Model sensitivity to incubation period

After conducting the sensitivity analyses with the model, several deductions can be made:

- Significant under-reporting was occurring right up until lockdown decisions had to be made
- At that point, the real doubling period of infections and deaths could have been anything between 2 and 6 days, with a possible final death toll of over 400,000 in the London area alone
- The testing, diagnosis and analysis capability was insufficient to make accurate predictions; to some extent, the scientists were reliant on data from China and Italy, of unknown quality
- At the point the first UK lockdown decision was made (23rd March 2020), the best guess at the remaining time until the NHS intensive care capability would be overwhelmed by Covid-19 cases would have been less than 3 weeks. Given a 10-day lag time for any response (the duration of the infection), this is a very small margin for error. However, the scientists could not have given the politicians confident assurances that it wouldn't be an over-reaction. The uncertainty in all the major variables was (at the time) at least a factor of two either way.

We now look at intervention strategies to prevent the spread of the virus. Figure 11 shows the policy levers at the government's disposal highlighted. These are Movement Restrictions, Behavioral Risk Education (including social distancing and personal hygiene), Treatment Effectiveness, Hospital Capacity and Isolation Policy (including implied testing capability). It is worth noting that this counts as an extremely simplified model by SD standards [Homer 2020], and more complex models were certainly in use by the Department of Health, its advisors, and supporting Universities [NHS 2020]. The effects of vaccination are excluded from this version of the model, as this occurred much later.

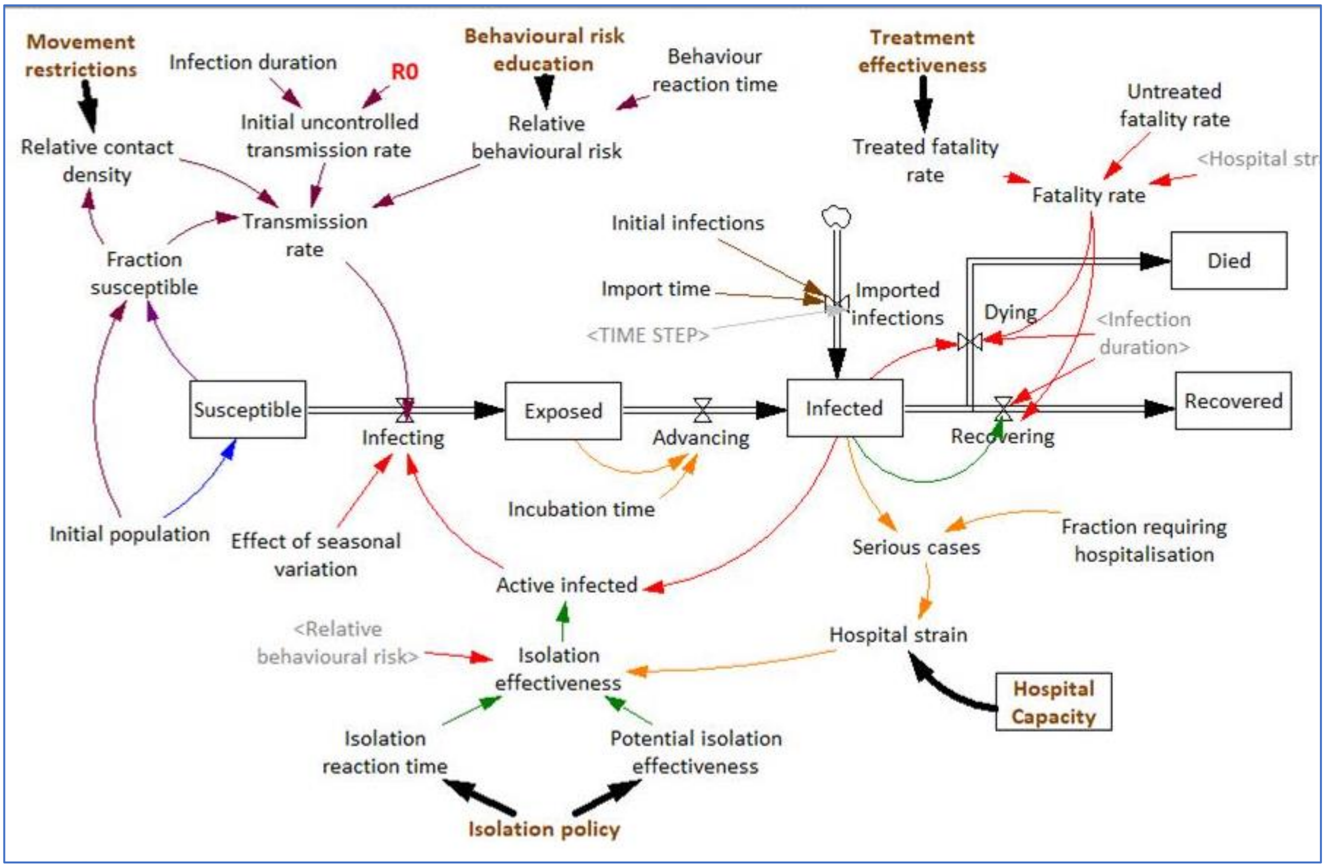


Figure 11 - Full model with policy levers [Fiddaman 2020] adapted by the author

Figure 12 shows the output of the model with the policy levers implemented in line with estimates of their real-life rollout and (perhaps optimistic) effectiveness.

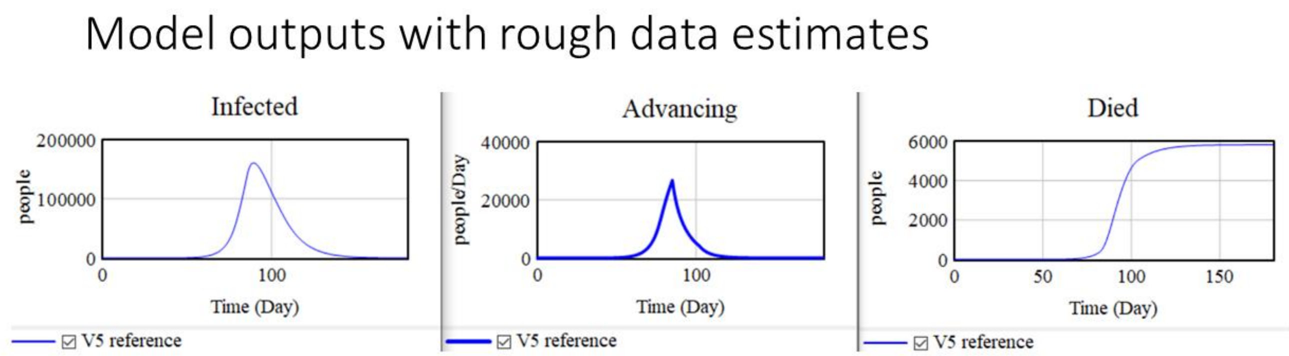


Figure 12 - SD Model output with policy levers implemented

Using intuitive mathematical models for the effects of the policy levers on the main model variables, one can obtain a range of model outcomes for numbers infected, fatalities, and hospital strain. Even with the imperfect data available at the time, some important qualitative conclusions can be drawn:

1. Improving treatment effectiveness (alone) cuts down the number of fatalities but does nothing to alleviate the strain on the hospitals, or the rise in infection rates.
2. Therefore hospital capacity had to be augmented, extremely quickly.
3. Because it acts earlier in any feedback loop, and with a much shorter delay time, movement restrictions have a far greater effect on infection rate reduction than improved behavioral risk or isolation of the infected.
4. With imperfect reporting and testing capability, especially early in the pandemic, it is very difficult to curve-fit the values for incubation time, duration, and R0 with any confidence.

5. Moving outwards beyond the model presented here, several economic factors influence behavioral risk and therefore transmission rate and isolation effectiveness. Increasing the effectiveness of the policy levers (e.g. through the furlough scheme) bears a significant short-term cost, but pays medium- to long-term dividends as shown below.

This last conclusion was a real point of policy contention between politicians (& economists) and scientists, worldwide. The former tried to argue that reduced controls would lead to economic advantage, i.e., continuing to work during the crisis while other economies stagnated. In fact, the converse is true – any initial advantage is completely swamped by the massively increased sickness numbers due to relaxed controls, as shown in Figure 13, reproduced from [Wren-Lewis 2021], in turn reproduced from The Lancet. The 'Elimination' OECD countries concerned were Australia, New Zealand, Iceland, South Korea and Japan.

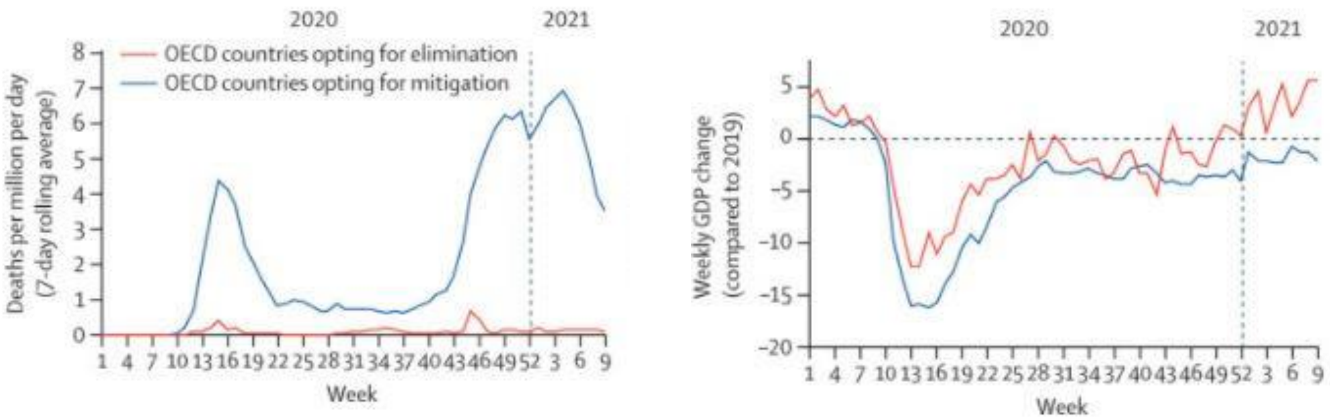


Figure 13 - Effects of elimination versus mitigation

Abstraction for generalized Systems Engineering applications

Consider the James Martin '7 Samurai' model of Systems Engineering [Martin 2004], reproduced at Figure 14, generally applicable to the introduction of any new or improved system.

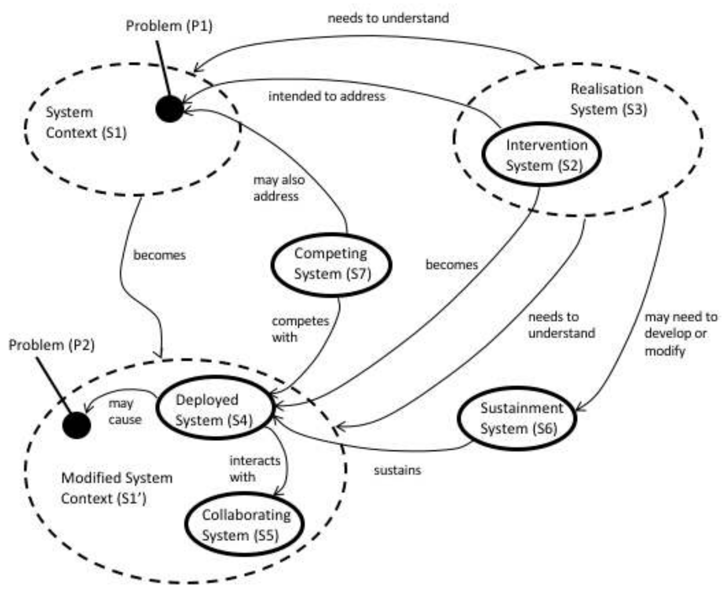


Figure 14 - Seven Samurai model

There needs to be a timeline between the initial perception of the problem space P1 and the context S1, our envisaged system S2, its eventual deployment S4, and interactions with the (changed) context S1' and new problems P2, together with collaborating, sustaining, and competing systems S5-7. All systems engineers should visualize and draw such a rich picture before even considering what form S2 should take. Think about all the influences, causal loops, and delay times, and model the interactions with any conceptual candidates for S2 within the scope of your realization system S3. Will it really have the effect the stakeholders require? Using System Dynamics to run "What-If?" scenarios for different combinations of assumptions, before fixing requirements and functional models could help to prevent disastrous or costly policy mistakes.

Problems in Systems Engineering to which SD might be applied to good effect

Here is a list of example contexts in which the SD method would be useful at an earlier stage than other MBSE approaches:

- "To what extent will the procurement of my new super-duper security widget outwit the terrorist cell armed with an untraceable mobile phone and a credit card?"
- "At what point in its life cycle should I cancel a failing project?"
- "When will this project converge to 99% adherence to specified requirements?"
- "Which is more cost-effective: a new hospital, or spend on health promotion?"
- "What are the right policy levers to apply, to implement carbon emission reduction? Is the answer the same at international level as at national level?"
- "Projecting forward in time, with potential evolutions of the problem context, will this solution system provide the cost-effectiveness our stakeholders require?"
- "For high-value public procurement of complex systems with high degrees of interoperability and unclear requirements, what is the best mix of contracting models?"

This range of problems is characterised by: complex causal influences with different time dynamics; combinations of reinforcing and balancing feedback loops; and outcomes which are not predictable from functional and behavioral models of a closed system. Note also that many of these are political hot potatoes; at a guest lecture at MIT in 2012, John Sterman explained why these questions will never be addressed in political manifestos. In essence, any potential answer will upset a major stakeholder – either the political donors, the voting public, the relevant government department or the banks – so it is "safer" to avoid the issue. However, that does not mean that policy-makers should avoid the opportunity to be better-informed, and it is our ethical duty as responsible professionals to do our part in achieving this.

Conclusions

Lessons learned from general SD modeling:

1. Models do not seed themselves. When you start, many of the flow rates and boundary conditions will be unknown. Some of the models can be extracted from known patterns (like the SEIR model above), but real (systems) thinking needs to be applied to identify and characterize the influencing factors.
2. Modeling is iterative. Given the above, an overriding need in the first instance is to collect data from observations of your Stocks. Then, performing sensitivity analysis and modifying your boundary conditions, until the model performs similarly to the observed data, builds confidence. Tentative predictions of future values can be made, and deviations incorporated into updates of your boundary conditions.

3. "All models are wrong, but some tell you something useful" (George Box). Continuous verification and validation of the model is a must; never trust the model over the measured data - see also [Hazle & Towers 2020]. If the model predictions become accurate and tell you something on which you can base corrective action, then it is useful.
4. Functional and behavioral modeling of a potential solution system to a complex problem, without time dynamics of external factors and boundary constraints, is insufficient to reveal emergent properties of the system context space.
5. System Dynamics is a valuable tool in the systems engineer's armory, as has been demonstrated. This is MBSE, but it isn't SysML.

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About the Author

Paul Davies (Cantab, C.Eng, CSEP MINCOSE) supposedly retired in early 2014, but soon realised he needed to give something back to the systems engineering community and help mentor the next generation of practitioners. An experienced systems engineer with thirty years in the defense and aerospace industry, six years in the nuclear industry, and a couple of years in rail, he has a wealth of diverse experience to call on. With a soundtrack record in delivering successful projects in the face of challenging customers, project managers and operational environments, Paul is a recognised authority on systems engineering.

A Cambridge graduate mathematician by training, Paul fell into systems engineering quite by accident. This started by building a solid background of engineering knowledge and physical processes underpinned by mathematical modeling and algorithm development.

Later he concentrated his interest in simulation, performance analysis, verification & validation, and requirements definition. By the age of 30 Paul had been given responsibility for several multi-million-dollar engineering projects.

He has since gained enormous experience in all phases of project life cycles, specializing in early-stage requirements elicitation, interface and risk management, and in stakeholder acceptance.

In addition to applying systems engineering to high-tech projects, Paul has held functional management roles: in process improvement, in assessing individual and team competence, and in coaching and mentoring.

Before his retirement, Paul held the position of Discipline Manager for Systems Engineering at Network Rail Infrastructure Projects in the UK. He was primarily responsible for promoting improvements in process and standards, and in practitioner competence and training in all aspects of systems engineering, a relatively new concept to the rail industry.

Prior to this, he worked for Thales UK for over 25 years, predominantly in electronic warfare and command and control systems.

Subsequent to his project responsibilities, Paul managed the business unit innovations process and the supervision of University research, including the establishment of business cases and planning technology transfer. In parallel, he was a member of the corporate Systems Engineering Council, delivering continuous improvement in SE process and methods, and relevant training.

Paul has been a Visiting Professor at Loughborough University and a Visiting Fellow at Bristol University, and also a member of the conseil d'administration of the prestigious Institut Supérieur de l'Aeronautiqe et de l'Espace in Toulouse. He has acted as industrial supervisor for a number of PhD, Engineering Doctorate and Masters students at five Universities in the United Kingdom.

He is a Past President of the INCOSE UK Chapter, in which role he founded its sponsoring Advisory Board and compiled its first entry into the INCOSE Chapters Awards, immediately winning a Gold Circle Award at the first attempt, and subsequently the President's Award for Outstanding Chapter. At international level, he has undertaken leadership roles on the Requirements Working Group and the SE Management Technical Committee, and as Outreach Director. He also acted as Master of Ceremonies at three INCOSE International Symposia. Paul's efforts for INCOSE were recognised by his being given the Founders' Award in 2015.

Through an INCOSE UK initiative, he gained his Chartered Engineer title in 2012 through the IET, becoming one of the first fifty engineers to do so specifically in systems engineering. Paul has conducted training courses and workshops in requirements, interface management, verification and validation, systems engineering management, competence assessment, and SE return on investment, with very positive feedback. He has been in constant demand for the presentation of courses and tutorials at many INCOSE events, both in the UK and internationally, winning several Best Paper and Presentation Awards.

He has presented and coached in French and Spanish as well as English. With such a good alignment of aims, SE outlook, and commitment to excellence, Paul was delighted to join the Project Performance International/Certification Training International team in July 2017, as a Course Presenter.

Paul lives in Warwickshire, England, with his wife Carole. They have two adult children and two granddaughters. He counts among his interests, chess, keeping fit, pub quizzes, and of course, family.

INCOSE IS2022 Best Papers Summary & Themes

by John Fitch (PPI Presenter and Principal Consultant)

Email: jfitch@ppi-int.com

INCOSE IS2022 Best Paper Awards

The opening plenary session of the INCOSE International Symposium (IS2022) on 27 June 2022 included the announcement of multiple Best Paper awards. The PPI team at IS2022 attended these talks, drew multiple highlights from each presentation and have summarized these takeaways. The winning papers and the honored authors included:

Extending UAF for Model-Based Capability Planning and Enterprise Portfolio Management
Author: James Martin (Aerospace Corporation)

Key points/takeaways:

- The Unified Architecture Framework (UAF), an OMG standard for modeling an enterprise, is being extended to better support enterprise capability development and the management of an enterprise portfolio of systems, services, people, technologies, processes, facilities, and associated enablers.
- An enterprise architecture can provide the basis for evaluating the effectiveness of future portfolio configuration alternatives.
- The UAF team is recommending that the Domain Metamodel (DMM) be extended to include new classes of information (model element types) that they believe are unique to the enterprise, e.g., drivers, outcomes, challenges, opportunities, risks, capabilities, and effects, to better answer the questions routinely posed by the enterprise.
- The proposed metamodel extensions will support generation of a variety of new views, e.g., strategic motivations, strategic processes, strategic states, and strategic information, that will be captured as UAF view specifications. Capability roadmaps may also be generated from the extended metamodel.
- The metamodel and view extensions were illustrated by application to a Search and Rescue (SAR) capability example.
- The paper summarizes a ten-step workflow for developing an enterprise architecture using the extended UAF metamodel.
- The UAF team believes that Model-based Systems Engineering (MBSE) coupled with the new UAF extensions will prove to be useful enablers of upstream enterprise decision making processes.

This paper presents an interesting approach to the application of a standards-based architecture framework (and particularly domain metamodels and views) to the enterprise strategy and portfolio management domain. However, PPI offers the view that the ability to map strategic enterprise concerns (the SAR example) to the UAF extensions does not make a case that the UAF extensions are the most effective or efficient way to capture and communicate these types of strategic knowledge.

No data was provided concerning alternative metamodels or modeling constructs, and their estimated relative merits in enabling improved strategic enterprise decision-making and associated business or mission outcomes were not addressed.

PPI encourages the conduct of research to determine if these strategic goals could be better accomplished with fewer model elements and fewer new viewpoints, for example, by treating the enterprise as any other system would be treated and leveraging (with perhaps some aliasing or subclassing) existing classes, relationships, and viewpoints.

Two Variant Modeling Methods for MBPLE at Airbus
Authors: Marco Forlingieri (Airbus); Tim Weilkiens (oose)

Key points/takeaways:

- Both Product Line Engineering (PLE) and MBSE are fundamental contributors to the successful engineering of systems.
- There is a need for integration of these two disciplines to form a Model-based Product Line Engineering (MBPLE) capability that can deliver improved cost and schedule performance of development projects.
- The MBSE-PLE integration should be accomplished by first separating methods development concepts from tool-specific implementations.
- Two approaches for accomplishing MBPLE, i.e., formalizing the modeling of variation, were proposed and compared, using Airbus examples.
- The “Direct” approach to variation modeling focused on a simple modeling approach that creates a 150% model (superset of all model elements across all feature variants). The Direct model is less costly and well-suited to early use in projects to evaluate different architecture variants.
- The “Clean” approach focused on creating reusable abstract concepts. The Clean approach models many specializations, which should pay off in the long-term through higher architecture modularity.
- The Direct model may be migrated to the Clean approach by separation of core and variable elements.
- Airbus organizations have used both the Direct and Clean approaches on different aspects of their architectures (Operational, Functional, Logical and Technical) based on a variety of business goals and constraints. Both approaches have demonstrated value in multiple business contexts.
- Although SysML v1 isn’t designed for modeling product lines, the addition of feature modeling tools and profile extensions can be used within MBPLE. SysML 2.0 will provide built-in variant modeling constructs, but not a feature class.

This paper represents advancement in the combined practical application of MBSE and PLE. By presenting two methods-focused approaches addressing a common problem/design, sharing their differences in model construction and process execution and relative strengths and weaknesses, the authors have helped to jump-start other organizations along this journey.

The paper avoids a one-size-fits-all perspective, while recognizing the potential of a hybrid approach that may be subject of future research.

Storytime, Audience to Authors: Enhancing Stakeholder Engagement
Authors: Chamara Johnson, Devon McDonnell, Denis Simpson (WSP); Dale Brown (Hatch); Allison Ruggiero, William Gleckler (Metropolitan Transit Authority)

Key points/takeaways:

- The paper focuses on how to determine the audience for the System of Interest (SOI) and ways to engage this audience.
- Though written from the context of public agencies that are managing infrastructure and transit projects, the paper's principles are broadly applicable to other systems and products.
- A ConOps deliverable, developed through stakeholder engagement that preferably makes them the primary authors, is presented as a critical element in gaining stakeholder consensus on the purpose and goals of the system, what it will do, how it will be used and who will be using it.
- In transportation infrastructure projects, the ConOps may include operational concept information associated with the systems that comprise the infrastructure system.
- The authors recommend that the ConOps be "like a children's storybook; accessible to everyone".
- The paper defines stakeholders as those "who may have a vested interest AND may potentially impact the System-of-Interest (SOI)" and distinguishes a class of "influencers" among this broader community.
- Much of the paper addresses techniques to foster stakeholder engagement, the timing of such engagement (typically early in the project) and where in the ConOps outline typically stakeholder might be engaged. Engagement techniques include interviews, requirement workshops, surveys, diagrams/photos/graphs, benchmarking, document analysis, end-user observation, brainstorming, peer reviews and training sessions.
- The paper defines Stakeholder Engagement as the process of eliciting or receiving of information from stakeholder or other resources. Stakeholder Engagement is the main path to discovering requirements and design information. Its end goal is continuous buy-in.
- Because of the diversity of stakeholders on a typical project, the authors recommend that a Stakeholder Management Plan be created to guide stakeholder interactions.

Benefits of Systems Engineering in Large Infrastructure Projects: the much-anticipated empirical proof
Authors: Jaume Sanso, David Martin (SENER Engineering)

Key points/takeaways:

- Demand is rapidly increasing for a structured approach to systems engineering on large infrastructure projects.
- Firms that exhibit resistance to such process changes may need an empirical demonstration of the benefits of systems engineering this inertia.
- The paper outlines a methodology to perform studies on Return on Investment of Systems Engineering (SE-ROI) in large infrastructure engineering companies.
- Research was performed using historical data on seventy infrastructure projects to calculate the level of systems engineering effort compared with total project engineering cost. A cost ratio (total project cost/forecasted project cost) was also calculated as a measure of cost overruns.

- The data convincingly show that cost performance of infrastructure projects improves as systems engineering effort increases up from the industry average of 1.5 % to 6.5% of total project engineering cost.

The authors admitted, given the difficulty in extracting systems engineering effort buried in typical infrastructure project cost data, that there was a high level of uncertainty as what was the optimum level of system engineering investment based on the projects studied. However, with the infrastructure project averaging at just 1.5%, there is significant room for additional investment before reaching a point of diminishing return.

PPI cautions that precise definitions of terms and extreme care are needed in discussing "% of systems engineering effort" – systems engineering is how good engineers do their work! Good engineers always decide what to do and what not to do using the same criterion: maximizing the value from their work. The levels and balance of activities vary enormously with circumstances.

Applying Model-Based Systems Engineering Methods to a Novel Shared Systems Simulation Methodology
Authors: Jeremy Ross, Chris Craft, Chris Caron, Stephen Pien, Ashishkumar Prajapati (Ford Motor Company); Michael Vinarcik: University of Detroit Mercy

Key points/takeaways:

- The need for reduced system development time in the face of increasing system complexity is driving a growing demand for better methods for integrating system architectural models with system simulation and analysis models. Phrased as a question: "How can the rigor and precision of a model-based approach be extended from the system definition space into the system simulation and analysis domain?"
- The paper presents a solution, the Shared Systems Simulation Methodology, that explicitly couples the model-based architecture parameters with system simulation variables and enables the architecture model to be the single source of truth for each architecture configuration alternative.
- The paper illustrated the Shared Systems Simulation Methodology using the example of a human lunar habitat.
- Coupling system simulation results with architecture parameters enables two-parameter trade studies to evaluate design alternatives.
- The authors present and review the effectiveness of five approaches for managing design properties across design configurations at the architecture/simulation model boundary.
- Of the five approaches, the *coupled design catalog* was found to best manage the complexity of system design variables. This approach creates Excel-based parameter design catalogs as unique simulation elements integrated between a MagicDraw architecture model and ModelCenter simulation workflow via a ModelCenter Connector plugin.

PPI notes that the paper did not address a full multi-criteria trade-off study (aka multi-attribute decision analysis) capability. In this paper, a trade study was limited to the visualization of 2-parameter simulated response surfaces for design alternatives.

The research appears to be highly specific to the MagicDraw – ModelCenter Connector – ModelCenter tool chain. It is unclear how applicable the results, e.g., the five model interface approaches and their effectiveness, would be if applied to another set of MBSE – integration – simulation tools.

The Best Student Paper award went to:
Construction System Failures: Frame Notation of Project Pathogens and their Propagation Across Time and System Hierarchy
Authors: Takaharu Igarashi, Karen Marais (Purdue University)

Key points/takeaways:

- The construction of buildings or civil engineering structures has a higher-than-acceptable level of failures; improvements are needed to improve their safety across their operational life. "*We need a framework that can better describe failures specific to construction, and capture the wide spectrum of these failures*"
- Construction systems are complex socio-technical systems that include a dynamic mix of temporary multiple organizations (TMOs); there is frequent turnover among stakeholders. Prevailing system safety concepts (accident models and failure analysis techniques) are not well adapted to manage this turnover.
- The paper introduces the concept of time-focused "frames" to system safety processes to illustrate how pathogens (latent defects) are generated and propagated by defective processes and end up embedded in the physical structure.
- To demonstrate the benefits of a frame-enabled construction safety model, the paper uses the 2007 collapse of an interstate highway bridge and its long chain of defect generation and propagation as an example of a construction system failure.
- The authors introduce a new five-layer safety information model of the construction system that captures the interactions between the TMOs, information-creating processes, physical construction processes, physical artifacts, and the physical environment.
- This information model can be the source of multiple useful visualizations of the failure generation, propagation, injection, and activation sequences (threads) that may be used for safety failure analysis.
- Future research opportunities have been identified to improve the coverage, efficiency, and usability of the construction safety model with the goal of proactive use for safety planning and design. (failure prevention).

This paper provides a good example of how innovations in engineering methods, models, and tools may remove barriers to adoption in domains where systems engineering disciplines have limited penetration. The authors' focus on the model's usability among the construction community led them to novel information constructs and views rather than force-fitting existing systems engineering standards, ontologies and artifacts to the construction failure modeling and analysis task.

Some overarching themes were shared across the IS2022 best papers:

- Systems engineering is on the march; extending the benefits of the discipline into new domains and continuously improving the capabilities to engineer systems effectively.
- Innovations in methods, information models, tools and data visualizations are needed to apply and right-size systems engineering practices to new domains. There is a creative tension between bottom-up innovation led by new domain practitioners and comprehensive standards-based systems engineering practices being created by SE experts.
- MBSE is maturing; has a clear set of value propositions, but best practices and tools are also rapidly evolving so that there is presently no universal recipe for success.

- SE can be applied at many levels, e.g., enterprise capability development and portfolio management, design of critical infrastructure or subsystems, forward engineering of products and backward-looking failure analysis leading to continuous learning and improvement.

Congratulations to all those honored for their contributions. There is much to look forward to in terms of new innovations in the practice of systems engineering in the coming year.

"

There is very little that must be done in systems engineering practice. There are things that we choose to do, or choose not to do, for exactly the same reason - producing the best result on the balance of probabilities.

Robert John Halligan

PPI SyEN SPOTLIGHT: IS2022 Thoughts on Emergence

by John Fitch (PPI Presenter and Principal Consultant) and René King (PPI Senior Engineer)

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IS2022 Thoughts on Emergence

IS2022 featured a presentation and paper by Jakob Axelsson of Mälardalen University, Sweden, titled "*What Systems Engineers Should Know About Emergence*". Axelsson provided a simple and intuitive definition of emergence as "phenomena on the system level not present in individual elements".

Key points and take-aways included:

- A deeper understanding of emergence is crucial to the field of systems engineering because systems are designed/created to achieve emergent system-level behaviors.
- Emergence, a 2500-year-old topic, has been a source of debate in philosophy, system science and complexity science, but extensive debate has not yielded a precise characterization of emergence that has general acceptance.
- The paper focused on practical implications of the open questions concerning emergence.
- The role of an explicit observer is essential for understanding and handling emergence.
- Emergence and complexity share a common trait, i.e., the amount of information required to describe a system.

Axelsson raised four questions concerning emergence about which there are still significant philosophical controversies:

- What Phenomena Should Be Called Emergent?
- Are Emergent Phenomena Predictable?
- Can System-Level Phenomena Affect Element-Level Phenomena?
- Must There Be an Observer for an Emergent Phenomenon to Exist?

These questions triggered a spirited discussion among the five PPI team members who directly participated in IS2022 (Robert Halligan, Rene King, Randall Iliff, Alwyn Smit, John Fitch). In general, there was consensus on the team's answers, but the differences uncovered another layer of questions yet to be answered.

What Phenomena Should Be Called Emergent?

The PPI team responses echoed Axelsson's definition:

- Any property the origin of which is in the parts but is beyond the arithmetic sum of the value of the property with respect to each part.
- A unique property not attainable in whole or in part without the system of interest.
- A property, not observable in the parts, but created by their combination in some configuration.

- Anytime something interacts with something else that has a boundary to produce characteristics or behavior that wouldn't be otherwise achievable independently.
- Any property or behavior that is a result of the components working together.

But a follow-on discussion ensued concerning whether arithmetic properties of a system that could be the sum of the same properties on individual system elements (sharing the same units) should be classified as emergent. Examples included system cost or mass. If all the parts share a property, is that property truly emergent at the system level?

Are Emergent Phenomena Predictable?

The PPI team believed that emergent phenomena are predictable within limits.

- Predictable in proportion to experience, yes. Before you mixed blue and yellow together you may not have known that green would have resulted. Having mixed the two colors, now you know that if you mix those two colors you'll probably get green. However, that doesn't mean you'd be able to predict that purple would come from blue and red. The premise still exists that experience is the basis of prediction.
- A portion of emergent behavior is reliably predictable to closed state expression. Another portion can be managed as a probability distribution. And a fraction is truly chaotic, particularly with systems that are dynamically unstable. The design goal is to make group one as large as possible, group three rare, and manage the probabilistic region by reducing coupling dependency.
- For new combinations of materials or technologies, emergence is likely predictable only by extrapolation from prior experience, confirmed by experimentation. The ability to predict and prediction uncertainty are independent of whether a system property is emergent or not; it depends on whether basic research has been conducted such that there is sufficient understanding of causality and/or demonstrated correlations to use as the basis of prediction. Where science hasn't trod, we are left with trial and error to discover emergent properties.
- Emergent phenomena are usually predictable, and to varying degrees. Predicting emergence is the foundation activity of system design (verb).
- Prediction is the intent of design. However, we often have unintended emergent behavior.

The consensus was that predictability of emergent properties is based on the state of our knowledge and experience, with the possibility that some chaotic phenomena are and perhaps always will be beyond our reach.

Can System-Level Phenomena Affect Element-Level Phenomena?

- For systems constructed of elements with cognition, e.g., a human team, the observation of a system-level phenomenon can cause the elements to adapt their behavior, thereby changing the system level phenomenon. Similarly with any other system employing feedback of the value of a system phenomenon to adaptively control that value by changing element-level phenomena.
- When does system-level phenomena not affect element-level-phenomena - perhaps only when the element level is itself a closed system? When do you find truly closed systems?
- System-level phenomena may be the source of adaptive feedback that controls the behavior of the parts.
- Definitely, if people are involved. For non-human elements it depends on the design.

- I've seen tons of system level characteristics propagate verbatim down a stack of system levels. Programmatic requirements like union labor, "buy American", small business set asides and so on. Any change to the external requirement ripples through the balance of the system.

The PPI team had the most diverse interpretations of this question and therefore a wider variability in our responses.

Must There Be an Observer for an Emergent Phenomenon to Exist?
The PPI team, pragmatic engineers all, was unanimous in their answer – No! Our logic was explained by analogies and metaphors:

- No observer needed, fuel and oxidizer are going to detonate on contact regardless of witnesses.
- Systems do what they do depending on their design/structure whether any of us are around to care.
- Sounds like the story of: if there is a tree falling in the forest…

That common answer didn't discount the importance of system stakeholders as observers of system behavior and therefore the determiners of which behaviors are relevant. It's likely that the team would answer "Yes!" to a question reworded as "*Must There Be a Stakeholder who cares for an Emergent Phenomenon to be considered Relevant to the System of Interest*?"

The PPI team believes it observed examples of emergent behaviors at IS2022 that may shed some light on these questions. One example concerns the organizational learning behaviors that emanate from the structure of a hybrid conference such as IS2022 when compared with a purely in-person or purely remote/virtual conference.

Our hypothesis (not fully backed up by data at this point):

- The assimilation of feedback from participants in a hybrid conference has different characteristics (emergent properties) than that same function (assimilation of feedback) has in either a 100% in-person or purely virtual conference.
- The different characteristics (emergent properties) could be described in terms of different levels of performance, i.e., feedback quality or volume or relevance that is higher or lower in hybrid combination compared with simple sum of (in-person + virtual) feedback.

Presenters and organizers at IS2022, please help us out by providing your insights. What was your observation or experience:

- Did you perceive that presenters and organizers received better/poorer, more/less or higher/lower relevance feedback when they attempted to assimilate feedback from both in-person and virtual sources?
- Did the combination of feedback sources through different media (e.g., online post-presentation surveys vs. face-to-face hallway chats with presenters or verbal complaints to organizers) yield more or less actionable improvement ideas/insights?

If so, that difference in flow and quality of actionable improvement ideas may be an emergent property of the hybrid conference system design.

Look for a future edition of SyEN to tackle another layer of questions concerning emergence and its relevance to systems engineering principles and practices. Even better, join the discussion now by sharing your insights on emergence with PPISyEN@ppi-int.com.

SYSTEMS ENGINEERING RESOURCES

Useful artifacts to improve your SE effectiveness

Construction and Infrastructure Systems at IS2022

The INCOSE International Symposium (IS2022) included numerous papers and presentations that addressed the application of systems engineering disciplines to construction and infrastructure projects. The importance of this topic and its level of interest among the systems engineering community is indicated by the fact the three of the six Best Paper awards (highlighted in the preceding Best Papers article) address this growing market for the application of SE practices:

Benefits of Systems Engineering in Large Infrastructure Projects: the much-anticipated empirical proof
Authors: Jaume Sanso, David Martin (SENER Engineering)

Storytime, Audience to Authors: Enhancing Stakeholder Engagement
Authors: Chamara Johnson, Devon McDonnell, Denis Simpson (WSP); Dale Brown (Hatch); Allison Ruggiero, William Gleckler (Metropolitan Transit Authority)

Construction System Failures: Frame Notation of Project Pathogens and their Propagation Across Time and System Hierarchy
Authors: Takaharu Igarashi, Karen Marais (Purdue University)

Additional papers/presentations on infrastructure systems and their construction included the following:

Systems Engineering applied in the construction industry to achieve a BREEAM certification.
Cecilia Haskins, Hanne Helseth: University of Southern Norway (USN)

Key points/takeaways:

- Buildings have environmental impacts over their entire life cycles (50+ years) and are responsible for 40-50% of global energy usage and anthropogenic greenhouse gas emissions.
- Very limited attention is paid to designing buildings and infrastructure for end-of-life and material recovery.
- There are over 600 building certifications aimed at developing sustainable buildings around the globe; the Building Research Establishment Environmental Assessment Method (BREEAM) is a leading certification approach in Europe.
- The master's thesis behind the paper sought to answer the research question, "*How can SE processes help achieve a BREEAM certification?*" by addressing the certification regime's importance to the construction industry, barriers to BREEAM certification, and recommended SE activities.
- A construction industry survey was used to inform the research questions.
- Barriers to certification include cost/time investment concerns and a late start on the certification process. Commitment to BREEAM must occur in the building concept phase.

- The paper mapped BREEAM criteria to U.N. Sustainable Development Goals (SDGs); new construction has the potential to contribute to nearly half of the SDGs.
- The paper provides a mapping between the systems engineering V-model and BREEAM certification process steps that highlights the need for early commitment to certification.
- A requirements hierarchy diagram was proposed as a method to visualize BREEAM requirements within the context of building requirements.
- Future research may focus on methods to digitize BREEAM to improve its adoption and efficiency.

Visual Lean planning tools in the construction industry: A case study
Authors: Caroline Saatvedt Witte, Satyanarayana Kokkula, Gerrit Muller: University of South-Eastern Norway

Key points/takeaways:

- Despite its size and economic impact, the construction industry has untapped potential in its productivity, with frequent project delays and conflicts.
- A growing number of contractors are implementing visual Lean tools to improve project success.
- The paper uses a building redesign case study and industrial lessons learned to explore the question "*How can visual Lean planning tools be used in a Norwegian construction project to increase the cohesion between planning and production?*"
- Research indicates that critical success factors include look-ahead plans, soundness checks, early phase planning, Building Information Models (BIM), and the application of visual Lean planning in both the infrastructure design and production (construction) phases.

Investigating Systems Engineering Approaches in the Construction Industry: A Multi-Case Study
Authors: Tobias Fredrik Lynghaug, Satyanarayana Kokkula, Gerrit Muller (University of South-Eastern Norway)

Key points/takeaways:

- The application of systems engineering in the construction industry is increasing.
- The Norwegian construction industry has started implementing a tailored version of the SE approach adopted from the oil and gas industry, under the name "Systematic Completion".
- The paper investigates three research questions: 1) *How does SE affect the technical contractor's project management performance in public healthcare building construction projects?* 2) *What are the prerequisites to make Systems Engineering work for the technical contractor?* 3) *What are the elements that contribute to effective Systems Engineering in construction?*
- Project case studies and interviews with contractor personnel indicate a positive perception of SE's effect on time, cost, and quality, but because the projects studied were incomplete, actual performance improvement could not be confirmed.
- Prerequisites for successful SE among contractors include the importance of well-defined interfaces, unambiguous documentation, and a shared understanding of SE and how to perform it.
- The elements that most contribute to effective SE in construction include requirements analysis, functional analysis, design synthesis, integration and test planning, and user involvement/need specification.

Case Study: Using Digital Threads in a large System of Systems (SoS) for System Certification
Author: Oliver Hoehne (WSP USA)

Key points/takeaways:

- This presentation provided a case study on how the California High-Speed Rail System (CHSRS) is preparing for system certification (safe, secure, ready to operate) throughout the systems development life cycle.
- CHSRS exhibits typical system of systems (SoS) challenges as a program delivered through multiple independently designed and constructed systems.
- The presentation summarized SoS Engineering verification, validation and certification activities that are planned to achieve system certification, along with the digital traceability thread that provides required objective evidence in the form of various submittal and reports.

Tilting at Windmills: Drivers, Risk, Opportunity, Resilience and the 2021 Texas Electricity Grid Failure
Authors: Matthew Hause (SSI), Lars-Olof Kihlström (Syntell AB)

Key points/takeaways:

- This paper provides a retrospective analysis of the winter 2021 Texas electricity grid failure, including the risks, opportunities and drivers of the grid, failure causes, and incentives needed to prevent future failures.
- The authors used the Unified Architecture Framework's metamodel to represent the Texas power grid and its drivers, challenges, states, capabilities, opportunities, risks, effects, and outcomes.
- Multiple UAF views of the Texas grid were created to support failure analysis and model the capabilities needed to prevent future failures. Simple simulations were performed using the UAF grid model to support failure analysis.
- A primary failure cause was the failure to winterize generating equipment and enabling systems, e.g., natural gas delivery, in the absence of economic incentives/rationale and legal requirements to do so.

PPI congratulates all of these authors as they press the case for right-sized systems engineering applied to this important domain. We note that these papers and presentations suggest that rightsizing can mean very different things; from the use of simple Lean or stakeholder engagement practices to the intensive use of architectural frameworks such as UAF to model and eventually simulate large infrastructure projects as systems of systems.

Readers should note that INCOSE has multiple working groups and initiatives that touch on the application of systems engineering to the infrastructure domain and associated construction projects (including, but not limited to):

- Infrastructure Working Group: Bring together designers, builders, and operators of economic and physical infrastructure systems to advance the application of systems engineering.
- Critical Infrastructure Protection and Recovery Working Group: Forum for the application, development and dissemination of systems engineering principles, practices and solutions relating to critical infrastructure protection and recovery against manmade and natural events causing physical infrastructure system disruption for periods of a month or more.

- Oil and Gas Working Group: Advance the state-of-the-art of SE into the Oil and Gas sector and to develop the appropriate work processes, tools, and competencies to mature the SE thinking and ways of working.
- Power and Energy Systems Working Group: Organize experts from within the ranks of INCOSE as well as other professionals in the Energy sector of the economy to facilitate a “systems approach” to the analysis and future development of effective energy solutions.
- Resilient Systems Working Group: Promote understanding of resilience in engineered systems and provide clear descriptions these principles in INCOSE publications.
- Telecommunication Working Group: Improve delivery of telecommunications solutions by enhancing the systems engineering body of knowledge for telecommunications applications.
- Transportation Working Group: To promote and grow the application of systems awareness, thinking and engineering within ground transportation systems and their supporting technical and business infrastructures (with emphasis on highways, bus, rail, and transit).
- Smart Cities Initiative: Support communities in developing their Smart Cities Concepts, Applications, Technology and Services (CATS) by leveraging systems engineering tools and principles.

Join INCOSE here. Learn more about joining an INCOSE working group here.

Featured Organization: Digital Twin Consortium

The Digital Twin Consortium (DTC) is a distinct program of the Object Management Group (OMG) that was founded in 2020 to drive the awareness, adoption, interoperability, and development of digital twin technology. The consortium is open to any business, organization, or entity with an interest in digital twins.

DTC goals include:

- Building and establishing an extensive multi-faceted ecosystem.
- Identifying and filling gaps in technology development.
- Driving interoperability through frameworks and open-source code.
- Developing and advocating consistent best-practice methodologies.
- Working to influence policy and standards requirements.
- Publishing and amplifying architectures, statements, and viewpoints.
- Advancing scientific and technical research to expand the market.

The DTC sponsors nearly a dozen working groups focused on domains such as Academia & Research, Aerospace & Defense, Manufacturing, etc. A variety of initiatives are producing resources to accelerate digital twin understanding, development, and adoption, including:

- Digital Twin Capabilities Periodic Table (CPT) - an architecture and technology agnostic requirements definition framework that is aimed at organizations who want to design, develop, deploy and operate digital twins based on use case capability requirements. Capability areas addressed include data services, integration, intelligence, user experience, management, and trustworthiness. Download the CPT overview here. A CPT user guide, toolkit and worksheet are also available for download.

- Digital twin definition resources – consensus definition of a digital twin and associated webinars and blogs.
- Global ecosystem expansion – through regional initiatives.
- Glossary Of digital twins.
- Member Digital Marketplace - a public platform for DTC membership to promote and showcase their product offerings, services, core competencies and innovation in digital twin enabling technology.
- Open-source repository on GitHub – member contributions including open-source software code, collaborative documents for guidance and training, open-source models, etc.
- Use Case Reference Library – member-contributed real-world use cases for digital twin solutions.

The DTC publishes additional resources in a variety of media:

- DTC blog.
- Consortium/member events.
- News items.
- Publications, e.g., whitepapers and reports.
- Press releases.
- Videos.
- Webinars.

Membership in the DTC follows a tiered structure of fees and membership rights for start-ups, universities/non-profits, government units and four levels of commercial firms based on annual revenues. Approximately 200 organizations make up the current membership.

New PDMA Podcast and Blogs

The Product Development Management Association (PDMA) hosts a Knowledge Hub (kHUB) that includes a diverse set of resources, e.g., podcasts and blogs, associated with product innovation and management. Three new resources have been added to this online repository:

- Global Innovation Institute (GInI) – Blog for an organization founded by the creator of the popular Business Model Canvas and author of Value Proposition Design, Alex Osterwalder.
- ProductQuest – Weekly podcast that details one team's journey toward better innovation and product strategy.
- Produktowcy – Official broadcast of PDMA Central Europe. Guests are experienced practitioners who share knowledge related to all aspects of product management - from product strategies through design, technology development or financing to soft aspects such as the development of culture in the company.

View the full set of 24 PDMA recommended podcasts and blogs here.

FINAL THOUGHTS FROM SYENNA

Dear Reader,

Inspired by three recent SyEN articles concerning decision patterns (SyEN Edition #107 – December 2021, Edition #111 – April 2022 and Edition #113 – June 2022), I have been seeing decisions everywhere I look. I recently attended a family gala event and while I enjoyed the festivities, food and fellowship with infrequently seen family and friends, I couldn't help but walk through a Capability Design decision pattern in my head. Pondering the various activities and experiences that made up this event, I continued to ask "If X (a current activity or observation) is the answer, what was the question?".

By the time the event ended, this mental exercise at reverse engineering had built up a fairly complete decision model of the event design that might be used to jump-start and improve the next such gathering. I've found this is a poor gal's path to continuous learning and ever-increasing creativity and thinking efficiency.

For fun, let's see if you can replicate my reverse engineering prowess by mapping a list of event design alternatives to the decisions (design questions/issues) for which they provide a potential solution.

A three level Capability Design decision pattern as applied to this mystery event is attached. Expanded definitions for each decision are available in SyEN Edition #107 (December 2021).   Please note that in some cases multiple solution alternatives are expected for a decision. An alphabetically sorted list of 25 alternatives is included; see if you can fill in the model by mapping each alternative to the appropriate decision.

Finally, see if you can infer the type of family event being designed from the lower level decisions and their alternatives.

The first SyEN reader that submits a correct solution (Decision/Alternative table + mystery event name) to SyEN will receive a *L.A.R.G.E. prize. Enjoy!

Your friend, Syenna.

*L.A.R.G.E = Limited Appreciation & Recognition for Great Effort. 😊

FINAL THOUGHTS FROM SYENNA

Capability (Event) Concept

ALTERNATIVES

1 Build on success for next event in 2 years
2 Catered and family-made food
3 End of high/secondary school
4 End of university
5 Event hosting
6 Food preparation
7 Gifts received
8 Hand-made cards with email/text follow-up
9 Informal fellowship (hang out together)
10 Invite + Prepare + Set up + Conduct + Clean-up + Thank
11 Large personal home
12 Leftovers for family & friends
13 Location staff + family & friends melee
14 Loose team of family & friends coordinated by Mom
15 Loosely-managed; greet at the door; no Master of Ceremonies or defined activity flow.
16 Number of participants
17 Participant satisfaction index (smiles & laughs)
18 Photo opportunities with friends & family
19 Post-event cards, emails & texts
20 Procure 90% of the resources; family & friends make the rest
21 Reciprocal attendance & support
22 Rented facility
23 Site staff configures room; family & friends decorate
24 Table games
25 Video log of key person's life

Usage Scenarios

Core Methods

Process Architecture

Capability Interfaces

Organization Design

Platform

Metrics

Growth Plan

Invitation Method

Preparation Method

Set-up Method

Conduct Method

Clean-up Method

Thanking Method