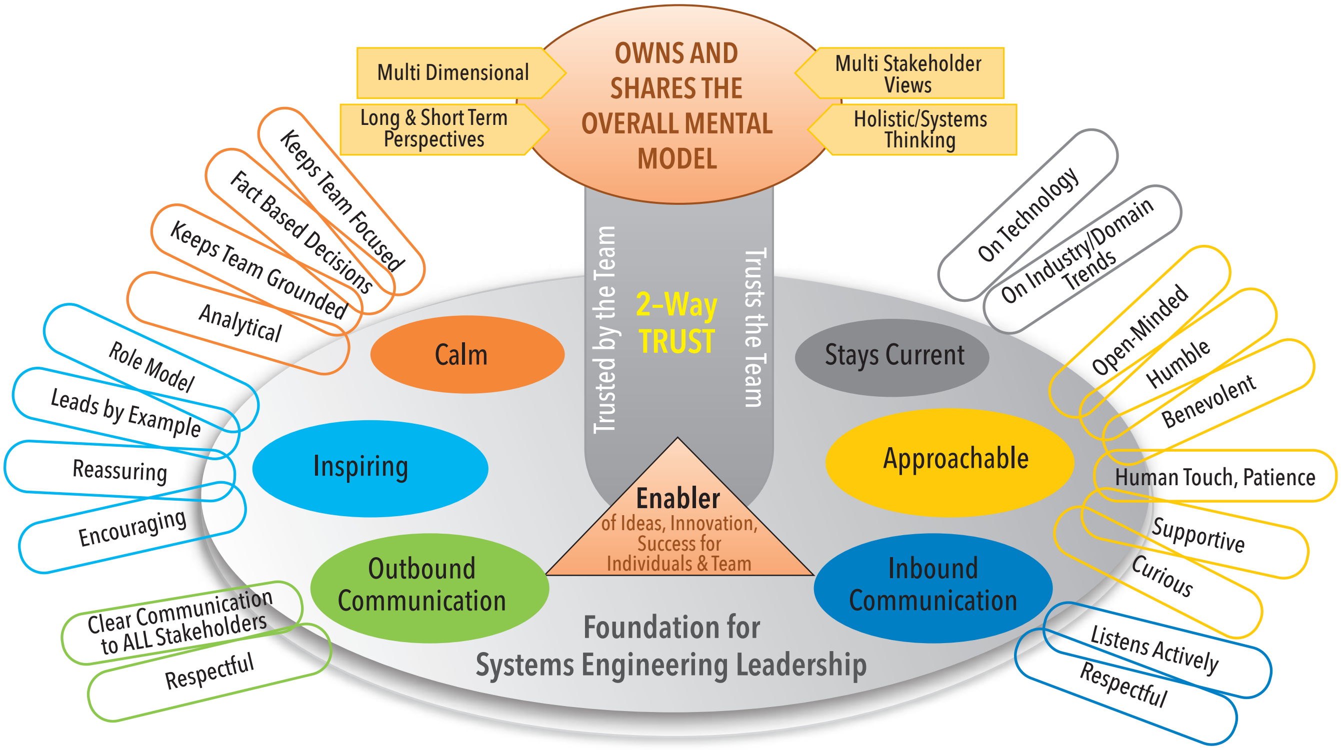
INSIGHT

This Issue's Feature:

Systems Engineering Technical Leadership



Stakeholder views of technical leadership (ARZSAD v2)

Illustration credit: from the article
Building a Technical Leadership Model
by Patrick Godfrey (page 8)

JUNE 2024
VOLUME 27 / ISSUE 3

A PUBLICATION OF THE INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING

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INSIGHT

A PUBLICATION OF THE INTERNATIONAL COUNCIL
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JUNE 2024 VOLUME 27 / ISSUE 3

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About This Publication

INFORMATION ABOUT INCOSE

INCOSE's membership extends to over 23,000 members and CAB associates and more than 200 corporations, government entities, and academic institutions. Its mission is to share, promote, and advance the best of systems engineering from across the globe for the benefit of humanity and the planet. INCOSE charters chapters worldwide, includes a corporate advisory board, and is led by elected officers and directors.

For more information, click here:
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OVERVIEW

INSIGHT is the magazine of the International Council on Systems Engineering. It is published six times per year and features informative articles dedicated to advancing the state of practice in systems engineering and to close the gap with the state of the art. ***INSIGHT*** delivers practical information on current hot topics, implementations, and best practices, written in applications-driven style. There is an emphasis on practical applications, tutorials, guides, and case studies that result in successful outcomes. Explicitly identified opinion pieces, book reviews, and technology roadmapping complement articles to stimulate advancing the state of practice. ***INSIGHT*** is dedicated to advancing the INCOSE objectives of impactful products and accelerating the transformation of systems engineering to a model-based discipline.
Topics to be covered include resilient systems, model-based systems engineering, commercial-driven transformational systems engineering, natural systems, agile security, systems of systems, and cyber-physical systems across disciplines and domains of interest to the constituent groups in the systems engineering community: industry, government, and academia. Advances in practice often come from lateral connections of information dissemination across disciplines and domains. ***INSIGHT*** will track advances in the state of the art with follow-up, practically written articles to more rapidly disseminate knowledge to stimulate practice throughout the community.

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For further information on submissions and issue themes, visit the INCOSE website: www.incose.org

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FROM THE EDITOR-IN-CHIEF

William Miller, insight@incose.net

We are pleased to announce the June 2024 *INSIGHT* issue published cooperatively with John Wiley & Sons as the systems engineering practitioners' magazine. The *INSIGHT* mission is to provide informative articles on advancing the practice of systems engineering and to close the gap between practice and the state of the art as advanced by *Systems Engineering*, the Journal of INCOSE also published by Wiley.

The focus of this June issue of *INSIGHT* is systems engineering technical leadership, the criticality of which is stressed in both the *Systems Engineering Vision 2025* published in 2014 and the *Systems Engineering Vision 2035* published in 2021. Both vision documents stress the imperative for systems engineering leadership competencies being critical for the successful engineering of systems that must be included in education and training https://www.incose.org/publications/se-vision-2035. Several of the articles in the June *INSIGHT* were authored before the release of the Vision 2035, yet remain relevant.

The awardees of the INCOSE pioneer awards are exemplars of systems engineering leadership https://www.incose.org/about-incose/honors-awards/pioneer-award. "The pioneer award recognizes outstanding pioneer-applications of systems engineering in the development of successful products or services of benefit to society. Examples include applying systems engineering principles to unique, highly complex problems; the successful application of systems engineering to brand new market segments and outstanding examples of advancing the state of the art and /or practice of systems engineering beyond its current bounds." Leadership competencies underly the achievements of the pioneers.

In 2015 INCOSE established the Institute for Technical Leadership (abbreviated TLI rather than ITL) and in 2022 renamed the Technical Leadership Institute (TLI) as a "a global learning network of active INCOSE members committed to improving technical leadership skills to better address today's product, enterprise, and societal complexity. Throughout the experience, coaching and mentoring help participants maximize the benefits derived from their experiences. Upon completion of the initial two-year experience as a member of a cohort, participants are inducted as full members of the TLI, after which they continue their journey of learning together, making their own contributions as members of a vibrant, diverse and growing network for the benefit of their organizations, INCOSE, and the world at large." To date, the TLI has inducted 123 INCOSE members in the first eight cohorts. Cohort 9 is in progress with 23 members and cohort 10 is beginning their initial 2-year experience with 24 members. INCOSE members interested in learning more about the TLI and the nomination process to participate are encouraged to visit the website at https://www.incose.org/learn/tli.

We thank David Long, INCOSE Technical Leadership Institute (TLI) coach and INCOSE director for strategic integration, for his enthusiastic support and encouragement for highlighting the criticality of leadership in the engineering of systems. David worked with your editor to cull papers resulting from TLI projects for the June *INSIGHT*. The papers cite the TLI using either name depending on when they were written.

We lead off with the foundational paper "Building a Technical Leadership Model" by TLI founding coach Patrick Godfrey developed in concert with the initial TLI cohort. Patrick quotes the Vision 2025. *Education and training of systems engineers and the infusion of systems thinking across a broad range of the engineering and management workforce will meet the demands for a growing number of systems engineers with the necessary technical and leadership competencies. The roles and competencies of the systems engineer will broaden to address the increasing complexity and diversity of future systems. The technical leadership role of the systems engineer on a project will be well established as critical to the success of a project*.

The second paper authored by TLI participants, "Experiments in Leading through Influence: Reflections from a Group of Emerging Technical Leaders," reflects on a shared learning journey about technical leadership from the perspective of a group of 16 emerging technical leaders. These reflections provide insights around building awareness, navigating power and influence, benchmarking personal performance, developing capacity for change, and establishing critical friends. The final section provides lessons for working as a global team in technical leadership. This paper is of relevance to any technical leader looking to develop this capacity across technical sectors.

The third paper by 7 TLI participants, "Technical Leadership of Virtual and Remotely Distributed Teams," examines the nature of changes when leading in a virtual and remotely distributed (VaRD) environment through the lens of engineers leading teams in global and complex technical challenges. Those perspectives are analyzed to determine the factors that go into a VaRD environment. In addition, the paper analyzes how interactions between teams compare to an in-person environment, how leadership practices are applied in this environment, and how technical leadership is tailored for these

new environments. The authors' findings remain relevant as our ecosystem continues to use virtual capabilities in this post COVID-19 pandemic period. For example, INCOSE now conducts hybrid events with both in-person and virtual participation.

The fourth paper by 12 TLI participants, "Collaborative Systems Thinking Culture: A Path to Success for Complex Projects," is premised on the world being filled with hard and complex problems, oftentimes requiring involved solutions. In large organizations attempting to solve these types of problems, a mindset shift and key candidate methodologies centered on collaborative systems thinking culture (CSTC) can assist significantly. The paper explores the state of the practice, change involved with implementing systems thinking, impacts of a collaborative approach within an organization, as well as the seven phases that a reader can introduce into their organization to realize some of the benefits. The CSTC approach prepares technical teams for tackling challenging problems in an inclusive way with the intent to finish projects on time while also cultivating healthy systems engineering habits and practices. The objective is to lessen the reliance on corporate engineering procedures to drive collaborative behavior by fiat.

The fifth paper by 5 TLI participants, "Future Trends Influencing Technical Leaders and Technical Leadership," summarizes the authors' reflections on global trends and key factors influencing systems engineering in the post-COVID era. The authors focus on three key factors affecting technical leaders and their technical leadership role: 1) the heightened societal awareness of environmental concerns along with the associated demand for more environmentally friendly products, 2) the increasingly interconnected, multicultural, multigenerational work environment, and 3) the increasing capability of advanced digital tools, techniques, and processes. The authors' analysis acknowledges the need for technical leaders to think green, build an inclusive work environment, welcome differing viewpoints, avoid stereotyping, and expand their virtual tradecraft. Ultimately technology changes how technical leaders do their jobs, but not the job itself. Leaders must still set the vision and direction of the organization, communicate that vision to their stakeholders, and provide the resources and support that the team needs to achieve the vision. Emerging technologies offer leaders new and innovative means to do this in a more inviting and inclusive manner.

The sixth paper by 6 TLI participants is "A Systems View of Career Development for Systems Engineering Leadership." The pathways that individuals take are not only broad and varied, but also equally affected by personal life decisions and external factors. This paper describes a two-fold study that aims to: a) provide insight into commonalities in the career journeys of systems engineering leaders, and b) ascertain how key areas affect career development. Five key areas are explored: education, technical experience, soft skills experience, job satisfaction, and work-life balance. A mixed and multi-method approach is taken, gathering data from sixty-one participants through interviews, surveys, and facilitated workshop. The study found that although there is no 'blueprint' that yields successful systems engineering leadership, there are themes/trends that are common. An influence model highlights these trends in the form of the key areas, factors affecting them, and the interrelationships between them.

The final paper by 7 TLI participants is "A Tinkerer's Mindset: Lessons from the Technical Leadership Institute's Cohort 8 on Safe-to-Fail Probing as a Tool for Informing Judgement." Tinkering—or making small changes to experiment toward an improvement in performance—is seemingly a natural characteristic of many systems engineers. As such, systems engineers are uniquely qualified to develop complex solutions necessary to overcome lack of clarity, achieve order, and avoid failure. Further, there is a much broader conversation surrounding the possibility of "failure" being beneficial in systems engineering projects. In response to the needing to inform judgment in situations shrouded in uncertainty, the authors examine the role that safe-to-fail probes play in informing judgement for systems engineers. Two data collection mechanisms are established to empirically investigate the role(s) of safe-to-fail probing in systems engineering. Overall, the data sets offer conclusions describing the potential role(s) of safe-to-fail probes for systems engineers working in uncertain environments. Resulting from this (limited) empirical exploration are additional insights and implications for how systems engineers may invoke safe-to-fail probes to improve decision-making in uncertain and challenging situations. Such a tinkerer's mindset can help systems engineers transition from the constraints of "intolerable failure" to the opportunities related to probing-sensing-responding to "responsible failures."

We hope you find *INSIGHT*, the practitioners' magazine for systems engineers, informative and relevant. Feedback from readers is critical to *INSIGHT*'s quality. We encourage letters to the editor at insight@incose.net. Please include "letter to the editor" in the subject line. *INSIGHT* also continues to solicit special features, standalone articles, book reviews, and op-eds. For information about *INSIGHT*, including upcoming issues, see https://www.incose.org/products-and-publications/periodicals#INSIGHT. For information about sponsoring *INSIGHT*, please contact the INCOSE marketing and communications director at marcom@incose.net. ■

INSIGHT Special Feature

Building a Technical Leadership Model

Patrick Godfrey, Patrick.Godfrey@Bristol.ac.uk

[Editor: This foundation paper for systems engineering technical leadership cites the *Systems Engineering Vision 2025* (Copyright 2014 by the International Council on Systems Engineering) and remains relevant with the publication of the *Systems Engineering Vision 2035* (Copyright 2021 by the International Council on Systems Engineering) https://www.incose.org/publications/se-vision-2035.]

Authorship Clarification: For the purposes of paper publication it is necessary to identify a lead author, never the less this paper has been produced by the joint efforts of the whole of the 2015/17 cohort who are: Hari Devarapalli; Kimberly Gill; DeAnthony Heart; Ben Hudson; Edwin Ordoukhanian; Amaury Soubeyran*; Earnest Ansu-Gyeabour*; Olivier Dessoude*; Serge Landry*; Rudolph Louw*; Jason Sohlke; Courtney Wright*; Isaac Burk*; Bernardo Delicado; Quoc Do*; Diana Mann*; Dave Mason; Michael Do*; Bill Good; Suja Joseph-Malherbe*; Juan Llorens; Jonathan Rigaud*; Ahmed Abdelkhalek; Stephanie Chiesi*; Ramesh Ramakrishnan*; Zane Scott*; Andrew Wheeler* and the 5 Coaches who are: Mike Pennotti, Donald Gelosh*, Patrick Godfrey*, John Thomas, and Ruth Deakin Crick*. They all contributed to the model and discussions. We should also recognize names marked with an asterisk who contributed sections of text or presentations. Finally, we should recognize that the methods used are from social science. We are indebted to Professor Ruth Deakin Crick who as the only social scientist on the team has provided invaluable input and guidance in this area.

ABSTRACT

INCOSE's Vision 2025 identifies the development of systems thinking and technical leadership as one of seven key areas of systems engineering 'competency' required for delivery. Vision 2025 states: "Education and training of systems engineers and the infusion of systems thinking across a broad range of the engineering and management workforce will meet the demands for a growing number of systems engineers with the necessary technical and leadership competencies." "The roles and competencies of the systems engineer will broaden to address the increasing complexity and diversity of future systems." "The technical leadership role of the systems engineer on a project will be well established as critical to the success of a project." These requirements imply the need to rapidly expand the art and science of systems technical leadership. In response to this need, INCOSE established an institute for technical leadership. This paper describes the Institute and the work that the first cohort ("Cohort of 2017") has accomplished on developing a technical leadership model for systems engineers. It is envisaged that this first technical leadership model for systems engineers will be further developed and matured by the following cohorts of the INCOSE's Technical Leadership Institute.

INTRODUCTION

Driven by the need to make a step-change in the well-being of people worldwide, INCOSE's Vision 2025 (INCOSE 2014) has set out a vision for:

- *Expanding the APPLICATION of systems engineering across industry domains*
- *Embracing and learning from the diversity of systems engineering APPROACHES.*
- *Applying systems engineering to help shape policy related to SOCIAL AND NATURAL SYSTEMS.*
- *Expanding the THEORETICAL foundation for systems engineering.*
- *Advancing the TOOLS and METHODS to address complexity.*
- *Enhancing EDUCATION and TRAINING to grow a SYSTEMS ENGINEERING WORKFORCE that meets the increasing demand.*

Accordingly, INCOSE has established an institute for technical leadership (INCOSE 2015) and appointed five coaches. Its purpose is defined as follows:

> *As INCOSE continues to grow in an ever more complex and interdependent world, we seek to accelerate the development of systems engineering leaders who will exemplify the best of our organization and our profession.*

The benefits are seen as:

- Individual members will become more capable leaders within their organizations
- INCOSE will have a growing pool of capable leaders from which to draw on, filling leadership positions
- INCOSE's international reputation will be enhanced by helping to develop systems engineering leaders of the highest calibre.

It is recognised that leadership capability develops from awareness of both hard and soft skills required to build and strengthen relationships and teams along with the experience of practising those skills in work environments. This process can be enhanced by coaching, peer-to-peer learning, and phenomenological research. This paper reports on a process of phenomenological, grounded research which takes as its starting point the structures of experience and consciousness (Kant 1770) of the 27 members of the cohort and the 5 coaches.

What is Leadership and Why is it Important?

Companies today are like modern tribes (Sinek 2104) and like any tribe they have traditions, symbols, language, and leaders. Sinek (ibid) argues that everything about human-beings is purpose-built to help increase opportunities for survival and success, and the need for leaders is no exception.

The purpose of a leader is to ensure that there is leadership, which is an on-going process of a series of inter-related choices and actions which define and realize a purpose (Scouller 2011).

Leadership is a verb and is about taking action (Maxwell 2103) and although it is readily assumed that being in a position makes one a leader, this is not necessarily the case as has been shown numerous times in recorded history (Maxwell ibid).

Whilst there are many well established references to leadership development that range from Machiavelli's book *The Prince* (first published 1532) to Northouse's Book (2007) *Leadership: Theory and Practice*, none focus on the need for systems technical leadership, or the specific requirements of leadership in conditions of socio-technical complexity. Following Covey and others, a distinction is drawn between the attributes of leaders and managers, although one person can have both of the requisite skills sets for both roles (leader, manager). Furthermore, there can be no single prescription for leadership competency. The requirements are context dependent as is embodied by the concept of situational leadership compared to positional leadership. For example, Churchill was said to be an inspiring wartime leader but was voted out of power by the 1945 general election. His leadership had served a specific purpose at a given point in time, under specific conditions.

For the purposes of this project, we have avoided defining what technical leadership is at this stage because, in keeping with our phenomenological approach, we first wanted to discover what it meant to the cohort, all of whom were selected for their leadership potential in systems engineering. What emerges from this process, and recorded in this paper, is the emergence of a shared definition of the purpose and processes of systems engineering leadership.

Inaugural Cohort of 2017

The first cohort consisted of 27 delegates. They were nominated by INCOSE chapters world-wide as systems engineers who had demonstrated leadership potential. They were sponsored by their employers to attend workshops aligned to International Symposium (IS) 2015, International Workshop (IW) 2016, IS2016, and IW2017. The delegates also met virtually as teams and the whole cohort met in webinars. Mentorship was an important aspect of the programme and as such the first cohort were peer mentors to one another for the period of the programme. The delegates of the first cohort committed to being mentors for the next set of delegates.

The first workshop was held the day after IS2015. One of the first topics the cohort explored was the "attributes of a successful systems engineering leader." Rather than being presented with existing models of leadership the cohort teams were asked to identify what they thought were the attributes of a successful leader in systems engineering. This topic enabled the cohort to investigate how to enhance the process of 'becoming a more self-aware leader.' The attributes were assembled into a model of core attributes and the delegates were then asked to identify WHY each key attribute was important. For example, if 'visionary' had been identified then the WHY statement might be: 'an aligned view of the whole is needed to integrate the parts.'

A second face-to-face workshop was held at the beginning of IW2016. The workshop included:

- A discussion of the consolidated leadership model integrating the input from the whole cohort
- Interpreting the leadership practices inventory (LPI) 360° feedback which was done during the months of November and December 2015. The session included understanding the data, that is, comparing the self-assessment with the ratings from others, choosing one or two areas for further focus, finding opportunities to learn or enhance specific skills and applying what was learned in group – as well as individual context.
- Understanding cognitive biases. A bias that was emphasized was the assumption that when we (as individuals) talk, the speaker and the audience are always on the same page. The reality is that we are not – the audience does not know what you know….
- During IW2016 itself members of the cohort met for breakfast each day to discuss the model and during the day contributed observations about the model which have been edited to form the narrative for the consolidated model and conclusions.

This paper reports on the outcome of this grounded enquiry. Put simply, the cohort "created a shared view of the attributes of what they believed were great systems engineering leaders and why these attributes are important". It was recognised that this was a complex problem and that there was considerable uncertainty as to what would be the outcome. The cohort was learning together and on a 'learning journey' which began with a clear purpose, but the outcome was not known in advance (Deakin Crick 2014 http://bit.ly/1WMvTt0 and Godfrey 2014).

The INCOSE Technical Leadership Project

The purpose of the project was to develop a shared model of technical leadership for systems engineers. The outcome was intended to firstly provide a cohort definition of what systems technical leadership is in an engineering environment which is grounded in the experience of 27 international systems engineers and 5 coaches. Secondly, to validate this model by analysing existing literature and current professional experience on leadership and developing an explanation about why this model is relevant to the technical tasks of systems engineering leadership.

Research Design and Methodology

This process was framed as a grounded, collaborative enquiry which captured, analysed, and then synthesised the experience and perceptions of the 27 international delegates in successive iterations. The journey began with the identification of the shared purpose followed by the collaborative processes which would enable the new knowledge to be generated and integrated across the teams.

The delegates organised themselves into teams of five or six each with a coach. Each team first identified the attributes of someone they believe to be a great system engineering leader, and next collected a set of 'leadership narratives' where team members recounted the story of a leadership challenge they had experienced in the last six months that required a 'systems' approach. The narratives were analysed by the teams in order to identify key factors which are important for success.

Each team then designed a graphic model of leadership attributes (see example Figure 1), with an explanation of WHAT

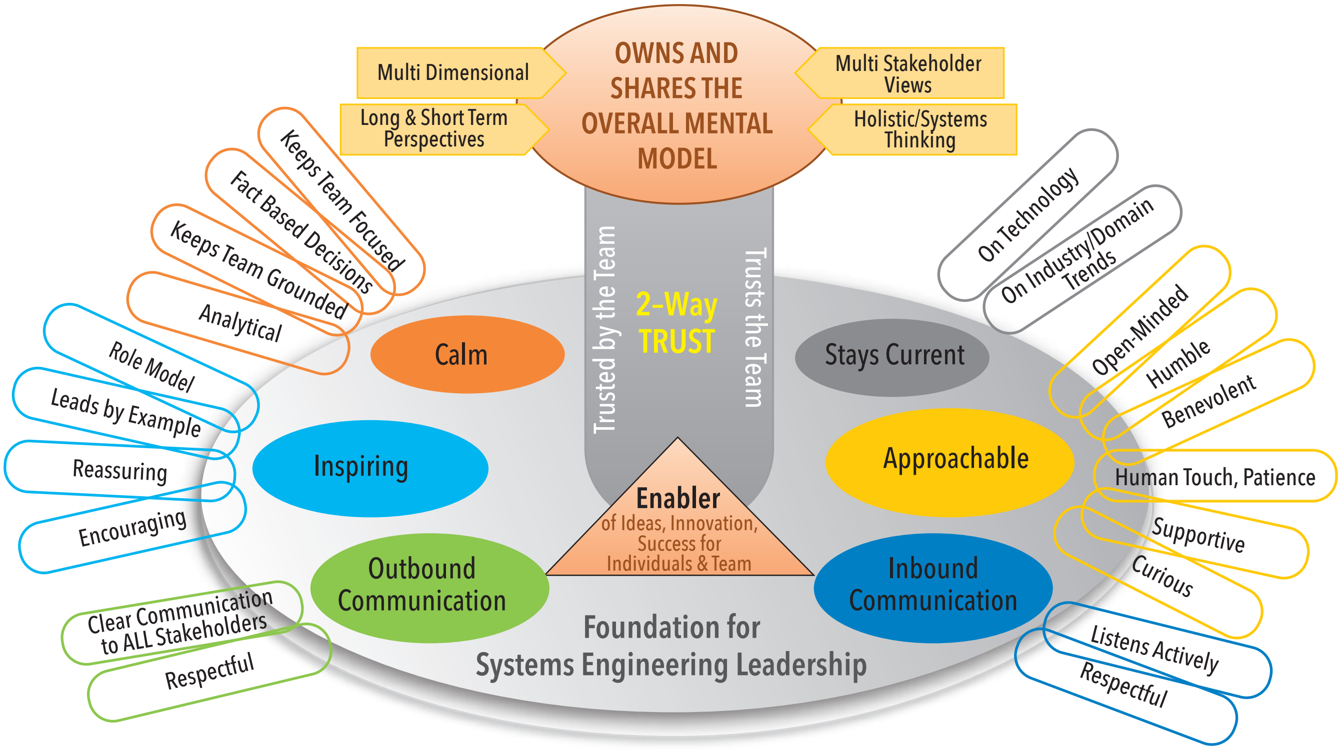

Figure 1. Stakeholder views of technical leadership (ARZSAD v2)

the attribute is, WHY it is important for systems engineering leadership and also the identification of how it might operate in a real-world environment as a COMPETENCE.

At a follow-up webinar, each team presented its model. Some preferred to present them graphically while others spoke to their spreadsheets. The coaches concurred that the models were authentic expressions of the teams' experience as technical leaders. There was good alignment between the models demonstrated by a common set of constructs that emerged from the five teams, even though the language in use varied, which contributed richly since systems technical leadership is promoted as a universally required skill and practise. See later section on the consolidated model.

TECHNICAL LEADERSHIP MODEL

Each team had a coherent view of their model identifying how the components are related. Most presented the attributes of leadership from the point of view of an observer of a systems technical leader (outside looking in). An example of one of the models is shown as Figure 1 and described below. Very interestingly, one team chose to view the attributes from a leader's and team's point of view (inside looking out) under the headings: "I am _____"; "I bring to the team _____"; "We are seen (by the world) as _____" as shown in Figure 2 and described below.

The ARZSAD Model postulates that the attributes of a systems engineering leader are interrelated. While themes and groupings can be made, the linkages between related elements are also important and need to be shown. Twenty-five (25) key qualities which can be broadly grouped under *calm, stays current, approachable, inbound communication, out-bound communication*, and *inspiring*, form the foundation for a systems engineering leader.

Inbound communications across multiple stakeholders and systems thinking along with a multi-dimensional approach are connected through a bridge of practical thinking, to build a mental model of the system of interest. This is connected to the outward communication so that the leader can ensure that the team has the same mental model as stakeholders (paradigm). This is the basis for understanding short term and long-term perspectives of the system.

Enabling attributes are the ones that help progress the system/organization forward on a consistent and sustainable basis. The approachable, inspiring and calm attributes of the systems technical leader promotes the creation of an environment for collaboration and innovation. Another enabler the team discovered after its initial working session, is the leader's mindset and approach to staying current and abreast of the latest technologies and methodologies. A leader is able to determine how the latest technologies and approaches affect the industry he/she is involved in and how to implement the relevant and practical ones within his/her work for greater efficiency and improved performance. Finally, a leader is able to find ways to introduce new ideas to the team in a way that is accepted, embraced, and applied.

These attributes together lead to the emergence of mutual trust between the leader and the team. Mutual trust is at the center of all the attributes linking them together and driving the leadership model.

This sets the foundation for the organization/system to materialize the initial goals and then iterates to continue the growth process in a sustainable manner. As an enabler, the systems engineering leader drives new ideas, throughout the organization ensuring individuals' success and growth as well.

The Inspirations Team — The Inside Looking Out Model

To be a leader requires one to internalize what it means in terms of one's own behavior, the performance of the team, as well as how the team is perceived by the world.

"I am" circle: I am an essentialist and am not afraid to engage with uncertainty. There are certain attributes we believe an individual needs to possess in preparation to becoming a leader.

These are included in the "I am" circle: humility, discipline, able to learn fast, being persistent, has a wide spectrum of interests, and unafraid of the unknown. The concept of essentialism may be based on McKeown's view: "It is about how to get the

Figure 2. Inside looking out model of technical leadership (Inspirations Team)

right things done. It is about making the wisest possible investment of your time and energy in order to operate at your highest point of contribution by only doing what is essential" (Mckeown 2014).

"I bring to the team" circle: The team is cohesive. The engagements are passionate, able to convince and inspire a team. A wide range of skills is required to achieve something useful because nobody knows it all. The individual is or becomes a leader when he/she starts engaging people. The following was thought to be important: to be clear – that is when communicating with the team, the person is not ambiguous; to have a sense of humour and energy and therefore able to energize the team; inspire the team; empower individuals to execute; be a team player.

"We bring to the world" circle: We (the team) are able to change the world for the better; create solutions that are cheaper, safer, and relevant. We arrived at the solution in a participatory manner truly understanding the trade-offs and the solution meets the needs of the customer. The team is viewed by the community (world) as: visionary; trustworthy; able to integrate people, and ideas. The team is inspired to work towards the same purpose.

Developing a Consolidated Model

These points-of-view indicate the possible emergence of an architecture for systems technical leadership. For example, it could be useful to model different stakeholder views of the attributes of systems technical leadership and thus account for the complexity of the task. It is also apparent that some attributes could present in a sense, apparently conflicting attributes, for example. being calm and passionate. The leader has to decide what is appropriate in the context at the given moment of time. This is a shared model for the team, so the language is what they have chosen to use. However, the reasons WHY attributes were selected have been recorded by each team and have been used to create a narrative that introduces the components of the consolidated model.

The consolidated model has been prepared by a volunteer subgroup from the whole cohort. It was noted that the attributes in the inside looking out model, Figure 2 are included by the other teams, so they were not repeated in the consolidated model. A mind map, focused on being a systems engineering leader was produced using all the attributes that emerged. These naturally organised itself into six behaviours defined as:

- *Holds the vision;*
- *Thinks strategically;*
- *Fosters collaboration;*
- *Communicates effectively;*
- *Enables others to be successful;*
- *Demonstrates emotional intelligence.*

For clarity of presentation each is described separately below – consistent with "systems thinking" layering. In practice each branch is interdependent with the others, so a complete mind map is provided as Appendix A. The narrative provided below was developed by members of the cohort developing responses to the question: "Why is each branch of the model an important component of the role of being a systems technical leader."

Holds the Vision. The vision for an engineering endeavor generally arises from the needs of stakeholders, which can be conflicting. In this specific context, the vision within technical domains is driven by the impelling purpose that motivates people to come together to define and integrate the components to achieve successful outcomes. It is unavoidable committed to the need for creativity in engineering.

The technical leader motivates the efforts of the people through many intermediate steps and is generally held responsible for communicating the mental models and frameworks which integrate the combined efforts of those involved. Vision can, at times, become overwhelming due to inevitable uncertainties in the creative process; in which case it becomes important that the vision is held, and the challenges met. Feedback mechanisms need to be created that monitor performance, progress, and quality. Risks need to be identified, understood and where necessary mitigated. In complex or innovative projects, the recognition of the emergence of unintended outcomes ("emergent properties") are particularly important.

(➤ See Figure 3)

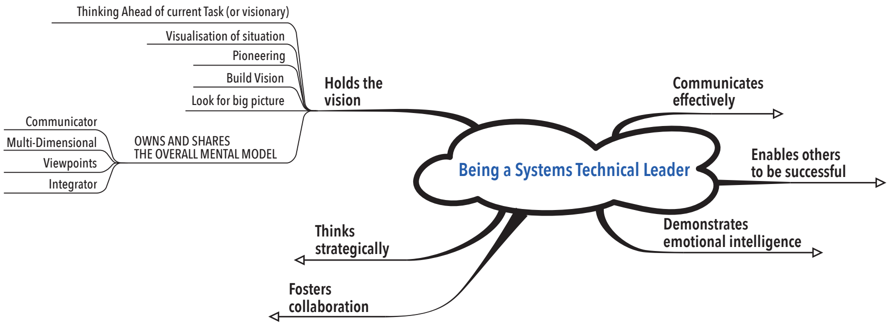

Figure 3. Consolidated model – holds the vision

This role of holding the vision, can be likened to that of a film director who controls a film's artistic and dramatic influence on the audience, and visualizes the script while guiding the technical crew and actors in the fulfilment of that vision (adapted from Wikipedia ref). In terms of guiding a technical team in fulfilment of a system-level vision, the technical leader would need to understand the nature of the system under consideration (system of interest) as well as the containing system, how it would be used operationally, and devise ways to help the technical team to internalise it.

Thinks Strategically. Whilst the vision provides a top-level view of **why** the engineering endeavour is needed the strategy provides the top-level plan for **how** it is created. The strategic thinker:

- enables stakeholder alignment to purpose and stimulates buy-in
- is able to create 'roadmaps' that facilitate the timely integration of technical delivery and business plans
- views a problem in a holistic manner, thereby enabling better understanding, better decision making and a better solution
- provides the basis for efficient and effective use of resources
- helps to shape, influence and mitigate uncertainty of the organization
- enables the organization to set incremental, achievable goals
- gives a clear sense of direction to the team thereby increasing team motivation.

(➤ See Figure 4)

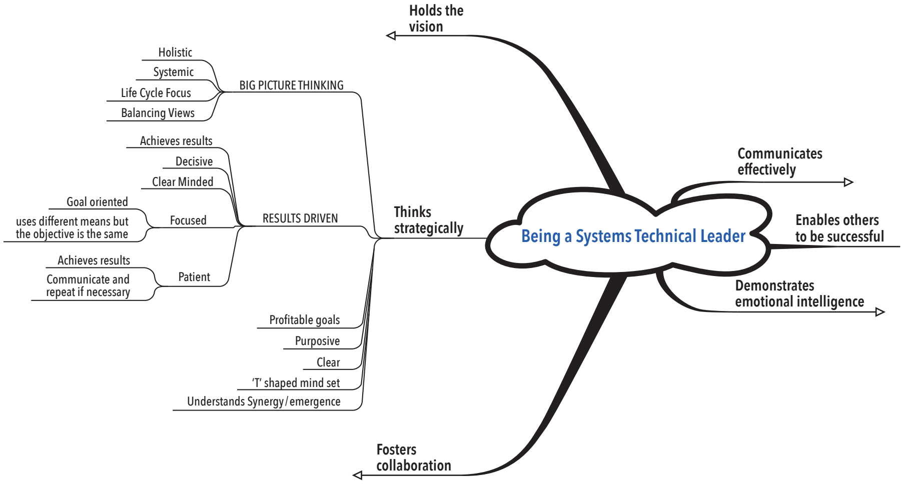

Figure 4. Consolidated model – thinks strategically

Whilst holding the vision, the technical leader applies strategic systems thinking skills to the decomposition of the problem into actionable pieces and convinces the team members of the importance of carrying out each of these actions to achieve the desired overall impact.

Fosters Collaboration. Any complex/complicated engineering endeavour can only be achieved through the integrated effort of many people of different world views. To engineer integration requires an understanding of the social and technical attributes that enable it, that is, the ability to **collaborate.** To achieve this, technical leaders need to be aware of the different viewpoints and skills that are necessary for collective success. Therefore, they encourage contributions from various stakeholders, they maintain a favourable environment that stimulates people to provide varied contributions but keep the actors focused on a common vision, harnessing their fruitful contributions. Since this will inevitably require difficult issues to be resolved, there needs to be a foundation of two-way trust and respect. Without this, collaboration is impossible, and the resulting relationships are merely transactional.

(➤ See Figure 5)

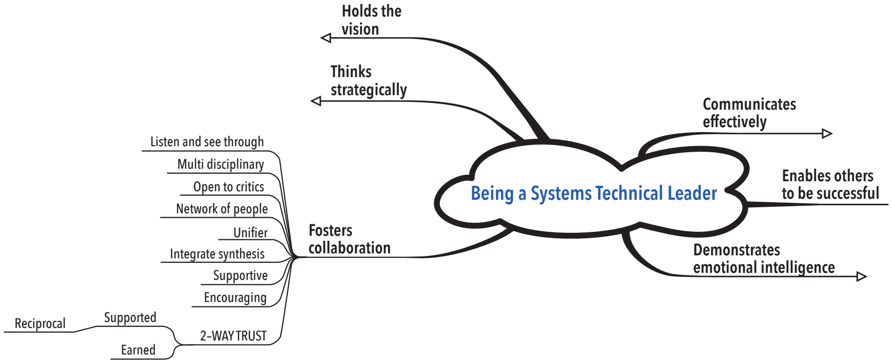

Figure 5. Consolidated model - fosters collaboration

Communicates Effectively. The ability to communicate effectively is the basis of meaningful relationships. Socio-technical relationships have a strong influence on the success of any engineering product or service. Focusing on the receiver and observation of what enhances or diminishes understanding

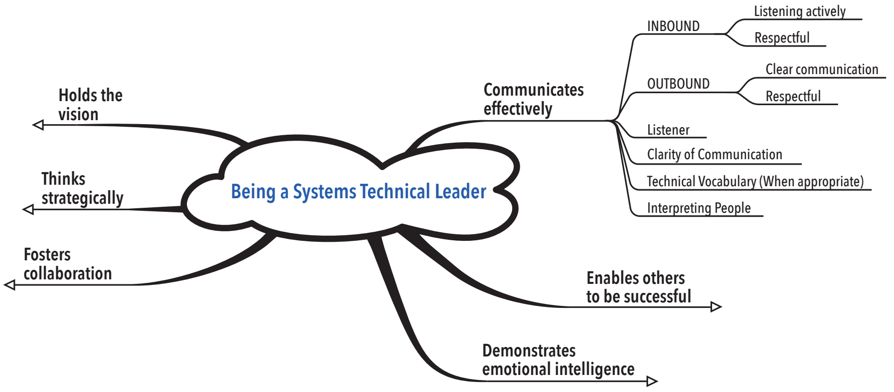

Figure 6. Consolidated model – communicates effectively

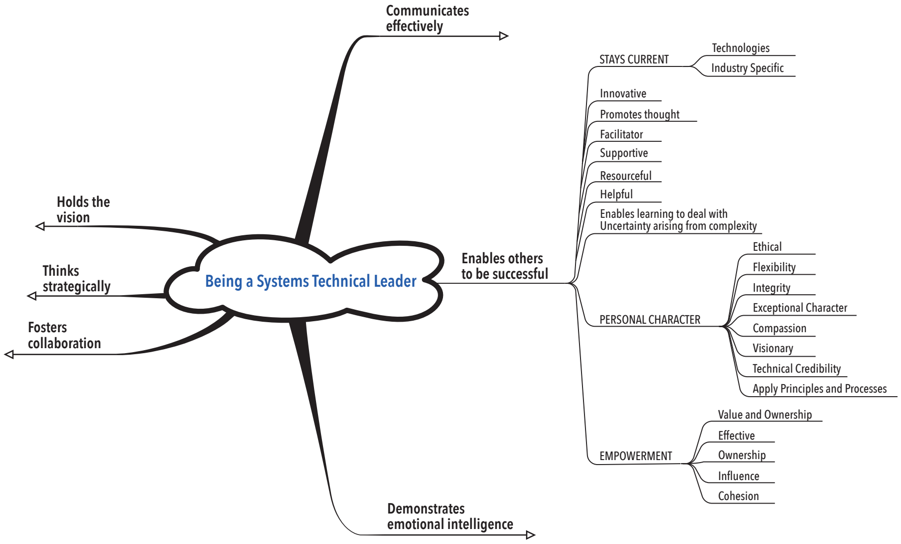

Figure 7. Consolidated model – enables others to be successful

of the message, is a critically important skill for those integrating a diverse set of disciplines, world views, and cultures. Active listening conveys respect for other's input, encouraging and further assisting in the clarification of the speaker's diverse perspective, thereby reducing risk and maximizing input. It also maximizes group energy facilitating synergistic growth. Particular care is needed with respect to when to use technical vocabulary, whilst its application reduces technical ambiguity and risk, it creates barriers for an audience unfamiliar with the technology. Paradoxically the leader has to be adaptable to understanding the communications from a diversity of technical disciplines. Different cultures/languages often use different words or phraseology to convey a similar meaning, for example the phrase "to table" an agenda item is understood in the American context as to stop further discussion and take it off the agenda whilst in many English-speaking countries the same phrase means the opposite, in fact to put it on the table for discussion.

(➤ See Figure 6)

Enables Others to be Successful. The concept that a systems technical leader is the enabler of others' success is entirely consistent with the need to generate synergy between the people and components involved. Given the need to align to a common purpose, no one succeeds until everyone succeeds, and hence we need to consciously drive for collective success, which in turn will ensure that high levels of motivation and sustainable performance are maintained across the teams. A sense of empathy detects potential difficulties in the team and assures them of understanding, commitment and contribution to helping them resolve the problem at hand.

By enabling others, the technical leader ensures quality outcomes are achieved. This is at the core of the generic idea of "leaders" as enables of others to "follow" them.

Technical people are enabled when they are empowered to make their own decisions within the framework of a specified goal with an understanding of the applicable boundaries such as legal and others. Take requirements decomposition as an example: A-level requirements define "what" at a strategic level. B-level requirements define "what" at a tactical level. C- and D-level requirements, which are usually levied on subsystems/assemblies, define "how." By decomposing requirements along these lines, the subsystems/assemblies are empowered to devise solutions that can easily be traced back to B and A-level requirements. In effect, leaders must know when to step back and trust that their people know what they are doing and will do what needs to be done.

(➤ See Figure 7)

Demonstrates Emotional Intelligence. The forgoing indicates the need for the technical leader to be perceptive of people's needs in order to inspire them to give their best as each person reacts to or processes the same inputs/prompts differently. A leader should also know how to utilize people's strengths – "push the relevant buttons to encourage/produce the desired output."

Emotional intelligence enables the technical leader to:

- Negotiate effectively towards win-win situations – examples include driving towards consensus on a design or an approach to development; the manner in which to engage with individuals when needing to speak about difficult issues.
- Get people to truly enjoy their job and giving them a reason to stay beyond just money and benefits. For example, plant the seed as a process for developing motivation.
- Motivation stems internally from the individual.

(➤ See Figure 8)

A train (steam train) requires heat to operate. Heat is produced by the fire pit, which in turn boils water and the water produces steam which drives the steam pistons, which eventually drives the train forward. The whole chain of events is started by a spark which in turn lights the kindling which lights the fire. As the spark initiates the process, so emotional intelligence initiates the impelling purpose that inspires success. It is interesting to

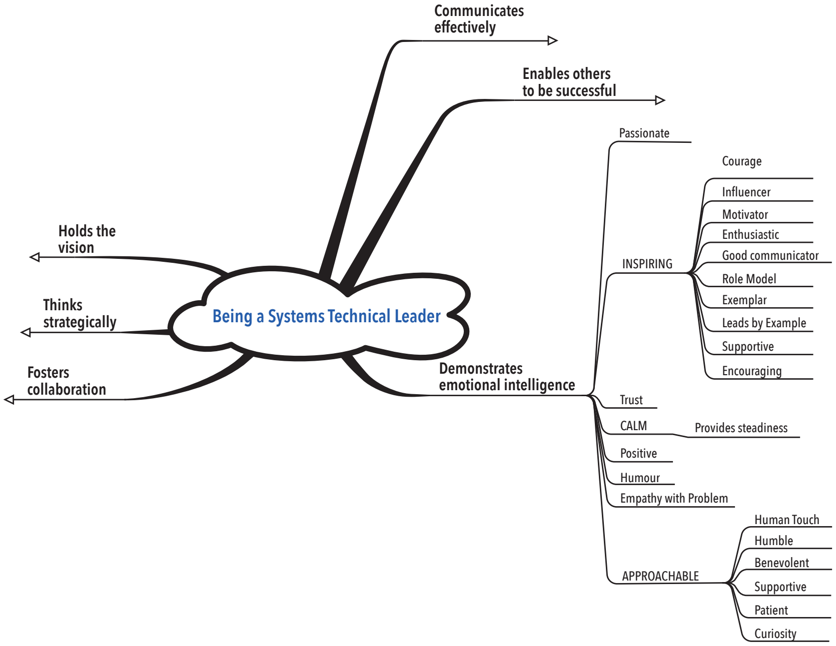

Figure 8. Consolidated model – demonstrates emotional intelligence

observe that the initiating spark is in fact a very small action with dramatically large results — from a spark to a moving train.

For a leader to demonstrate emotional intelligence, the person should have self-mastery and self-acceptance. A leader also should remember to think effectiveness with people and efficiency with things. Emotional intelligence allows leaders to essentially take their own feelings, prejudices, and fears out of the equation and focus on those of the team.

MODEL VALIDATION

Validation addresses the question "Have we built the right model?" for our purpose. As opposed to the technical systems that the team is accustomed to modelling, the model of a systems technical leader describes a person in an environment (workspace) and engaged on a technical program. The model used social science methodology to ground it in the shared perceptions of the cohort. These in turn are based on their experiences and learning.

The combined model produced through the processes of grounded, experiential enquiry with a cohort of 27 international systems leaders, is a valid consensus about leadership from this group of practicing systems engineering leaders. It has 'face validity' with this group, it proved to be useful as a learning dialogue as well as a guide to reflection.

That experience, however, is still too narrow compared with what could be distilled from participation, input, and deliberations from all technical leaders globally.

A strategy for wider validation needs to be established. This strategy could include:

- Comparison with other relevant leadership models
- Comparison with case studies
- Grounding in a wider body of technical leadership experience.

Comparison with Other Relevant Leadership Models

This approach to validation takes the key concepts from the combined model and, after the style of grounded theory, explores extant literature in order to elaborate and critique the key concepts and to theorise why this model is relevant to systems engineering technical leadership. For example, during IW2016 a member of the cohort introduced the concept of "servant leadership" (Greenleaf 1970) that is founded on the idea that "The servant-leader is servant first. It begins with the natural feeling that one wants to serve, to serve first. Then conscious choice brings one to aspire to lead. That person is sharply different from one who is leader first, perhaps because of the need to assuage an unusual power drive or to acquire material possessions…" The leader-first and the servant-first are two extreme types. Between them there are shadings and blends that are part of the infinite variety of human nature. The Centre for Servant Leadership http://bit.ly/1qJd2UD claims that some of the early systems thinkers were well-known advocates of servant leadership, including Ken Blanchard, Stephen Covey, and Peter Senge. The process of exploring the links between the model developed by the INCOSE 2015 leadership institute and the wider professional and academic literature forms the second phase of this project, and it is not the focus of this paper.

Case Studies

There is a growing body of research concerning the practice of systems engineering and the implementation of major projects. This needs to be reviewed extensively to test and improve the validity of the model.

Grounding in the Wider Body of INCOSE Experience

At the same time the model needs to be grounded in the wider body of INCOSE membership.

For example, it is intended to run a world cafe session http://bit.ly/1M2cZXB at IS2016 to generate facilitated discussions on topics of relevance to the model and its use. The output from this can be used to extend the learning journey into the second cohort's experience and to develop guidance for future leadership development.

CONCLUSIONS

A technical leadership model has been created from the shared experience of the 27 members of the first cohort of the Technical Leadership Institute. The purpose of this model has been achieved. It has stimulated a shared understanding of what technical leadership is and behavioural characteristics that it should include. There is broad agreement that the leader:

1. *Holds the vision*
2. *Thinks strategically*
3. *Fosters collaboration*
4. *Communicates effectively*
5. *Enables others to be successful, and*
6. *Demonstrates emotional intelligence.*

There is more to systems engineering than decomposition and integration. Technical leaders are needed to overcome the organizational silos, and foster interdisciplinary and intercultural communication, as well as collaboration.

Whilst the first four attributes are consistent with most leadership models, they were associated with only about half of the identified leadership attributes, whereas the last two behavioural characteristics were associated with a similar number. This weight of evidence was impressive particularly in view of the technical emphasis of the Institute. The dialogue that emerged to explain why they are important, indicates the depth of understanding that drove this emphasis. Skills development in these areas may be particularly relevant for technically orientated people where systems integration is needed.

That said, this work is only a first step that will require further development and validation as outlined above. It is also clear that a one size fits all 'standardised' approach is not what is required. This appears to be consistent with an 'adaptive leadership' approach (Heifetz 2013) founded on Lichtenstein's complexity leadership theory (Lichtenstein 2007) which is based on the notion of complex adaptive systems. It is proposed that this be reviewed as part of the validation process described above.

The prospect of an approach to technical leadership that would unleash the creative genius in every team is indeed exciting as it would address the continuously increasing complexity of the problems to be faced in the future and help to deliver INCOSE's 2025 Vision. ■

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[Editor: Author biography was current when the paper was initially published in 2016.]

Patrick Godfrey was recently appointed emeritus professor at the University of Bristol and is an INCOSE Fellow. For most of his career he was a director of a large consulting engineering firm – Halcrow (now part of CH2M). In 1994 he also became visiting professor of civil engineering systems at University of Bristol where he helped to establish the system-teaching program. He provided practitioner input to various action research projects including the strategic risk management for Heathrow Terminal 5 and a best value procurement program for the Highways Agency UK. On retirement from Halcrow (2006 -2016) he was professor of systems engineering and director of the Industrial Doctorate Centre for Systems at the University of Bristol.

Professor Godfrey is a Fellow of the Royal Academy of Engineering (UK), Fellow of Institution of Civil Engineers, and Fellow of the Energy Institute and an Honorary Fellow of the Institute of Actuaries. In 2004 he was awarded an honorary doctorate in engineering by University of Bristol.

Experiments in Leading through Influence: Reflections from a Group of Emerging Technical Leaders

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■ **ABSTRACT**

Technical leadership is a skill defined in the INCOSE professional competencies. This paper presents reflections on a shared learning journey about technical leadership from the perspective of a group of emerging technical leaders. These reflections provide insights around building awareness, navigating power and influence, benchmarking personal performance, developing capacity for change, and establishing critical friends. The final section provides lessons for working as a global team in technical leadership. This paper is of relevance to any technical leader looking to develop this capacity across technical sectors.

INTRODUCTION

The scope, scale, and complexity of systems engineering projects today are unprecedented (Friedenthal et al. 2014). As the value of systems approaches to engineering becomes clearer in more application domains, there is an increased need to develop leadership skills grounded in technical expertise: this is the domain of the professional competency of technical leadership (Presland et al. 2018 and Fierro et al. 2018). Presland et al. (2018) describe many themes in providing an indication of activities related to effective technical leadership, such as collaboration, identifying best practice, accepting critique, communicating clearly, understanding the situational context, and delivering successful activities built on trust. Being able to diagnose and adapt to the situation at hand is an important skill for a technical leader to develop (Fierro et al. 2018).

In the domain of complex problems, an effective technical leader cannot simply follow the simple command-and-control approach, and requires a more holistic repertoire of experimentation, reflection, self-review, and—most importantly—learning. In this sense, we have based our learning about technical leadership in active experimentation in the complex domain: a probe-sense-respond mindset (see the Cynefin framework in Kurtz and Snowden 2003). In this paper, we describe elements of a shared learning journey over an 18-month period as participants in the INCOSE Institute for Technical Leadership (TLI). In this program, group members developed a repertoire of techniques for framing leadership and were challenged to learn through active experiments in leading through influence within their own organizations. These activities were supported by other colleagues and a number of technical leadership coaches.

Professional practice has long been a challenging domain to navigate, well situated by Schon's (1983) swampy lowlands. Understanding the role of systems approaches in complex adaptive systems of the near future is a grand challenge in engineering education (Hoffenson 2019), at a time where there is a keen and growing understanding of the need for developing the capacity of technical leaders. Activities in cohort 1 of the TLI, summarized by Godfrey (2016), describe the technical leader as someone who: holds the vision; thinks strategically; fosters collaboration; communicates effectively; enables others to be successful, and; demonstrates emotional intelligence.

Building on TLI cohort 1's work, this paper is a collection of insights about technical leadership as experienced by the group. Members of the TLI cohort 4 were presented with a range of topics and asked to respond to the prompt: how has this experience shaped your own technical leadership journey? These reflections were then clumped into thematic groups:

Building technical leadership awareness

- Navigating the tension between power and influence
- Benchmarking performance for shared development
- Developing capacity around transitions and changing futures
- Creating a group of critical friends.

These five thematic groups provide a structure for sharing our individual and collective learning journeys in the following sections.

REFLECTIONS ON EXPERIMENTS IN LEADING THROUGH INFLUENCE

These thematic five groups shown above have been used to share the vignettes of the individual contributions, which are attributed within the text. In the vignettes, respective companies and other business units are referred to generically as 'organizations'. The vignettes are interwoven with contextual notes arising from our learning journey. Each participant's reflection is shown through the pseudonym 'a cohort member (domain, nation)' to illustrate the diverse nature of this cohort; however, these individual responses are provided from a collective perspective, and reflect a view representative of many members of the group.

Building Technical Leadership Awareness

The need for technical leadership awareness is, perhaps, an obvious starting point for this journey: to be an effective technical leader, one must be aware of the context in which they are trying to lead or influence. A cohort member (aerospace sector, France) describes this need:

In complex organizations, it is impossible to simply break down product and organization, due to the high number of interactions. Technical leaders simply cannot have organizational power on all the edges they need to master. Being an effective technical leader requires the ability to have impact in the technical and non-technical domains, and within the entire scope of the organizational effort. Hence, the ability to influence outside of the technical arena is a core competency of the technical leader: the ability to "lead from the inside."

Developing leadership skills requires the tools to analyze, a mindset of self-reflection, and a network of leaders, mentors, and mentees to exchange ideas and perspectives. These provide the structure to understand, the engine to progress, and the fuel to feed the leadership journey.

Building awareness of technical leadership skills is not limited to the early career stages or future leaders: honing technical leadership skills is an opportunity to re-evaluate and identify edges to grow. A cohort member (defense sector, USA) reflects on the value of refreshing her awareness of leadership in a technical field, and the effect of doing this in a global team:

Having the opportunity to reassess your current leadership style and how others see you in that role is important in a professional team environment. This applies to all levels of technical leadership, not just emerging leaders. As a seasoned member of an executive leadership team, what I found challenging was being able to influence a group of highly technical engineers with a technical solution. I lacked technical confidence in my own experience to successfully influence others. Specifically, more often than not, I relied on the technical knowledge of others and my actual authority as a member of the executive team to move forward on technical solutions. By refocusing my awareness on technical leadership, I began to value my own technical knowledge, and build the confidence to offer my own technical opinions, hence establishing my expert power.

In the US, our technical field remains dominated by Caucasian males, and the TLI provided an opportunity to work with a much more diverse group of engineers, including nationalities, cultures, different technical backgrounds, and skills. This diversity of thinking and ideas highlights how important it is to recognize alternative leadership approaches. Each member of the group shared their ideas and contributed to our tasks using their own approach, strengths, and individual experiences.

The awareness of nuance between positional and expert power as a technical leader was an important point of differentiation for many in the group. The concept of leading from the inside highlights an important concept that shaped our journey: the tension between power and influence.

Navigating the Tension Between Power and Influence

The five types of power identified by Handy (1985) — physical, resource, positional, expert, and personal power — was a cornerstone for many experiments in leading through influence. Reflections on these experiments focused on the realization that having power of any sort does not translate clearly into a ready capacity to influence others: someone with high levels of expert power may not be effective without the resource or positional power to exercise that expertise. A cohort member (defense sector, USA) reflects on the benefits of recognizing the different power types:

In my role as a senior consulting systems engineer, I need to create a positive influence, make an impact, and influence appropriate change. This includes engaging willing and unwilling players. Acknowledging the power structures is important to influence this change. I found that without the positional power in an organization, expert power is to be earned through time by job performance and demonstrated knowledge, not merely through credentials. Further, personal power is to be earned through building relationships incrementally over time by building rapport with all concerned. However, structural challenges make influencing change difficult, such as access to key personnel and facilities. An amount of expert power can open a door to an opportunity but focusing on growing personal power is required to be effective and sustain the influence with key stakeholders.

Coupled with the five types of power are the personality types of those involved: the personality of the technical leader, and those who the technical leader is attempting to influence. On this topic, we considered the four personality types described in the DiSC profile: dominance, influence, steadiness, and conscientiousness. A cohort member (defence and transport sectors, Singapore) describes his experience in navigating personality types:

When attempting to influence co-workers, typically in the 'conscientiousness' profile, placing emphasis on technical experience, employing my know-how and experience to influence coworkers has been quite effective. Superiors, who tend to be in the 'dominance' profile, usually control the resource. However, when I apply expert power to obtain the resources to start initiatives, I have found that the 'dominance' profile is not open to other options. Customers are often in the 'dominance' or 'influence' profile. My work is based around technical matters, and my customers tend only to engage me in technical matters. Projecting technical excellence and confidence has been very effective in this situation.

However, even when a leader holds positional power, influencing members of a team who hold expert power in their technical domain can be challenging. A cohort member (building services sector, India) describes the response he achieved when trying to influence domain experts to learn systems engineering processes, so that the effectiveness of the organization could be improved:

Systems engineers in my organization are domain experts and have vast experience in their field but often lack a sound understanding of systems engineering process, which results in their respective projects being ineffective. I applied expert power to conduct in-house systems engineering process training, followed by personal power to encourage members of the team to attend INCOSE SEP exam. I connected emotionally with the members of the team by explaining the value of knowledge, certification and adherence to standards. Now, 5 out of 7 engineers are INCOSE SEP certified, allowing the organization to develop a high level of confidence in its engineers. This experiment showed me how influencing with multiple power types can add real value to the project.

These reflections in power, personality, and influence, highlight the importance of the technical leader operating in a probe-sense-respond paradigm. In this process of experimentation, it is often hard to benchmark performance against clear and consistent goals. In the following section, we explore the importance for the technical leader to benchmark their own performance as an opportunity for personal development.

Benchmarking Performance for Shared Development

We each engaged in a process of anonymous 360-degree feedback with managers, co-workers, direct reports, and a self-evaluation within our organizations to benchmark our own performance. This exposed us to the sectors in the Johari window: elements known and unknown to ourselves, and elements known and unknown to others. A cohort member (defense sector, USA) describes the value of receiving this feedback:

This feedback is a powerful tool that allows each group member to examine his or her leadership style and to determine where they need to grow as a leader. I was forced to evaluate preconceived opinions on my leadership ability and identify areas in which to grow. My biggest take-away from this experience is that leaders at all levels can benefit by using this 360° tool. My organization utilizes the LPI, but only for executive leadership positions. Membership in TLI has granted me the opportunity to take the LPI earlier in my career than I would normally experience. I recommend that technical organizations use tools like the LPI to foster a leadership training continuum throughout an individual's career.

The leadership practices inventory (LPI) focusses on five practices of exemplary leadership: modeling the way, inspiring a shared vision, challenging the process, enabling others to act, and encouraging the heart. Within our group, we each identified areas within our feedback that required development and formed small sub-groups on this basis. Each grouping discussed and supported each other to develop technical leadership capacity in that area. A cohort member (aerospace and defense sectors, USA) reflects on the process of learning together:

My personal development was assisted by the group opportunities to learn together. The leadership survey given to members of my work organization helped me to see how I am perceived by others and to identify blind spots. I worked with a sub-group with similar blind spots around 'encouraging the heart' to exchange ideas, readings, and discussion on how to effectively recognize others, meeting on a fortnightly basis over three months. One suggested reading on the topic, 'The Carrot Principle' (Gostick and Elton 2009) described that a good share of an employee's attitude toward work is internally driven by the desire for autonomy and achievement, and recognition provides reinforcement of self-image and proof of accomplishment. As the ideas in the book were discussed by the sub-group, I enhanced my understanding on how to effectively use recognition to lead.

The concept of shared development extended beyond the group for many members. A cohort member (automotive sector, Japan) describes how he has embedded shared learning within his team as an approach to technical leadership:

While being in the TLI is full of opportunity for personal reflection and identification of areas to improve on, what has been most important has been the way in which the team around me in my own organization has enabled my journey of learning. The feedback survey tool that we used catalyzed communication on feedback. I feel that I am able to proactively seek out things that I can improve on, and my colleagues do not hesitate to tell me things performance roadblocks that I may not have noticed. Furthermore, this has opened the door to discussion on good technical leadership. These discussions have provided me with opportunities to think about good technical leadership together with colleagues in the team around me.

This highlights how a culture of open technical leadership within an organization can help foster a change of culture within an organization. However, for many members of the group, these skills have been invaluable as an individual in an organization which is itself going through change or has become the catalyst for personal change.

Developing Capacity Around Transitions and Changing Futures

In a technical organization, change is the normal state of activity — be it with technology, management approach, or projects through the life cycle. Adapting to this change is a key opportunity to apply technical leadership skills. A cohort member (aerospace and defense sector, USA) reflects on his experience as his own organization transitioned management and product line approaches:

Technical leadership is not restricted to the acquisition of "hard" technical skills and the practice of accepted engineering processes and needs to be coupled with techniques in "soft" power and informal authority as applied to the technical organization. Recently, my organization transitioned from a waterfall approach to agile systems engineering, consolidation of different aircraft programs into a single, cross-platform, line of business and implementation of a culture of accountability (Connors et al. 2004) providing much more informal power to employees.

During these periods of substantial transformation into a faster, more responsive environment, there was ample opportunity to identify and analyze several forms of both formal and informal influence. During this time, I engaged different types of influence by tailoring communication to personality profiles of employees. As engineering organizations move away from a highly structured, heavily documented organizational structure to a more flexible, team oriented and model-based approach, the application of informal influence will become even more prevalent.

Technical leadership skills are useful in a transitional period within an organization, but also are transferable across organizations. A cohort member (tech sector, USA) describes how she moved to a new organization encouraged her new team members to run experiments in how to help the organization adopt systems engineering:

Shortly after taking the opportunity to change companies, I was given a team of strong systems engineers and the task to grow the systems engineering discipline within our organization. By utilizing the "probe, sense, respond" technique, we ran small experiments across the organization to see how the organization reacted. This enabled us to coalesce around techniques that work, such *as role definition within each project, and avoid techniques that did not work, such as formal diagramming or strict sequencing of activities. In many cases, this effort represents a middle ground between a full-process systems engineering implementation and no implementation at all. This has been far more effective than if I had fallen into the trap of rolling out big changes without taking time to understand the organization and the strengths and challenges specific to it. I would have also missed the opportunity to develop my team's own capacity for technical leadership.*

Recognizing that the context of broader societal factors is constantly changing is also important to the technical leader. Alongside cultural factors, generational change — and the modes of communication that go alongside it — is a large consideration of how a technical leader can be effective, as a cohort member (transportation domain, Singapore) describes:

Working in a multi-national company located in a multicultural country, where East meets West and also a good blend of Gen X, Y and Z, the diversity of culture and generation has never been more distinct at my workplace. Practicing leadership in this environment is even more challenging when trying to influence someone of a different culture and generation. Beyond understanding personality profiling, I need to be quite aware of cultural behaviors as well as the generation gaps in order to succeed.

For example, in an Asian environment, showing respectful behavior towards people, like listening attentively, speaking non-aggressively, agreeing politely to avoid embarrassing my stakeholders would all go towards increasing my chances of success. When conveying instructions to a Gen Z, it is far more effective to send a text message with mobile slang, whereas a Gen X would prefer a face-to-face briefing and an explanation of the rationale behind it.

Change can also be hard when the context and need for capability is moving faster than the organization is willing to accept, even when this capability need is apparently clear. In a constantly changing environment, cause-and-effect logic and rigorous analysis become nonsensical, as the context has shifted in the intervening time. A cohort member (aerospace, defense, and transport sectors, Australia) has applied the probe-sense-respond approach to build a business case in a rapidly shifting environment:

I was given the task in my organization to advance our capabilities in requirements management and capability design — a clear opportunity to introduce an MBSE initiative. This approach was quickly rejected, and I was left pondering the challenge of how to take the company forward.

Over the next 12 months I took a new approach based on experimentation. We executed small initiatives to develop expertise and adopt small advances in technology. We piloted these new approaches on small projects, gaining momentum every month. This quickly snowballed into a team of eight over 12 months, backed by a technology platform capable of delivering a number of digital engineering solutions for the business. By taking an approach that relied on probe-sense-respond we were able to clearly identify strategic directions to drive the capability in order to best serve the business. By showing that we can deliver increasing value month on month, as we amplify the wins and dampen our losses, and by creating services that can be applied to new markets, we have received significant investment to drive forward our digital engineering capability.

Fostering technical leadership can create great opportunities within our organizations. In the next section, we discuss how these opportunities are amplified because of the network that has been created in the group.

Creating a Group of Critical Friends

Networking is often seen as a positive activity for professionals in all sectors; however, without a purpose it can become transactional and disingenuous. In the TLI group, we have been a part of each other's learning journeys, and have in turn been able to gain a better understanding of our own situation because of the experience and guidance from others in the group. This is, in large part, due to the culture and environment created by the TLI coaches, who clearly demonstrate the 'expect'-level practices of technical leadership, such as leading "practitioners in technical and leadership issues within systems engineering" (Presland et al. 2018, pp. 47).

The supporting environment that was created so that participants could gain outside perspectives from 'critical friends' (Costa and Kallick 1993) have been invaluable in navigating our own technical leadership journeys. The INCOSE core competencies describe emotional intelligence as a key facet of the professional competencies of a systems engineer, as a cohort member (aerospace and defense sectors, USA) demonstrates:

I came to TLI to work on changing and improving my leadership skills to be more successful in a role where I was burnt out and isolated in my organization. I found that the activities alone were not enough to support growth and change: I gained the perspective I needed through discussions and feedback from my group, experiments leading our various projects, observing my fellow group leaders, classmates listening intently without judgement and acting as sounding boards in an environment of trust.

I began to recognize that, regardless of the effort I was putting into improving in my organization, some hurdles are not worth the effort of attempting to overcome. My TLI peers gave me the high level, outside perspective and support I needed. I shifted sideways in my organization from program management to engineering, and I am thrilled to be working in a role that aligns with my interests and enables me to embrace my leadership growth. My TLI group members are now my trusted advisors, with such cultural, personality and experiential diversity. Together we are vested in this journey of challenge and growth, helping each other.

This highlights the power and value of having networks of technical leaders in a variety of fields and career stages. A cohort member (defense sector, USA) reflects on the group as a safe environment to explore the concepts in technical leadership:

This experience has also introduced the mindset of purpose driven experimentation in complex environments. The blend of tools and techniques used in these experiments as ways to interpret the world around us help overcome inherent human biases that are present in our decision-making processes.

As a group, we have been able to share stories and provide insights to each other about our technical leadership journeys in an amicable and un-threatening way, as well as provide idea generation for improvement on a regular basis. The group has become a guiding tribe to review and reflect upon our experiments: a safe space to share our true feelings about each situation rather than exposing ourselves to the biases and networks of our home organizations.

Although being a part of the group has been valuable for its members, the commitment of personal time, energy, and resources has also been challenging. Running experiments within our organizations pushed us to move out of the plane of action and into the plane of reflection. A cohort member (scientific research, Italy) describes the challenges of finding time for this personal development:

I worked on developing my innovation practice in my organization. Because of the stress involved in trying to balance life and work, we often have very little time devoted to being reflective, and instead spend most of our time in a performing state. The group work forced me to stop, get off the train, and take some time to reflect and think. This *process helped me to navigate obstacles in my own work.*

I believe that the building of relationships with people from different cultures, backgrounds and stories helped me to recognize the need for considering technical leadership as a point of personal development. The perspectives we have shared during monthly catch-ups have been eye-opening. Seeing the real implementations of innovation from several colleagues in the group gave me the support to run experiments in my organization.

The effort required to invest in this personal development work—across a large group made up of multiple time zones, cultures and sectors—outside of regular requirements of work is not to be underestimated. A cohort member (aerospace and defense sectors, USA) describes how engaging in this process is similar to the experience working as a technical leader in a global company:

Since my company is a global entity, we are used to working with people across cultures and languages, which can present problems in understanding ideas or solutions because of cultural differences. These are many of the same situations we faced with group teammates. As we researched our various approaches, we are directed to "think outside the box". Where someone in the group may have a weakness, another may have a strength, so our internal assignments permit each of us to lead with our strengths and follow with our weaknesses. By creating a safe zone environment to experiment, we have been able to react and deal with change from a technical leadership position.

As a coda to these reflections, it is worth reflecting on the process of the creation of this paper as an output relevant to technical leaders. Producing an output that captured our disparate interests and that we could all be proud of has been a topic of conversation in the group since early on in our shared learning journey. A cohort member (academia sector, Australia) reflects on the effort to distill our experience:

It has indeed been an exercise in influence in the complex domain to create a framework for multiple authors to contribute equally across such diverse interests and activities. This framework for developing this paper was itself an exercise in probe-sense-respond (repeat). The original call for contribution yielded over 6000-words of reflection and identified group members who had gone astray with the assignment.

This initial call yielded some very personal and extraordinary powerful stories (the probing) but was unstructured and as a whole incoherent. Categorizing these raw stories into broad themes (the sensing) and asking each member to revise their contribution with new eyes (the response) gave some small amount of shape to these disparate ideas. I'm grateful to those members of the cohort who reached out to build the connections with our cohort members who had succumb to misadventure, with some of these later cohort members providing the most profound contributions, while others found it overwhelming to come into the process late. The greatest challenge has been working with group members to descope and sculpt each incredible contribution so that the whole could be greater than the sum of its parts: on that, you'll have to take my word(!)

These far-ranging reflections based on an 18-month period alongside the above vignettes on our experience, indicates we have learned a number of lessons of relevance for other emerging leaders, and for any organization seeking to build the technical leadership across a sector.

LESSONS FOR GLOBAL TECHNICAL LEADERS

Our group has worked through a number of projects as a full group, and as subgroups within the group. We have met face-to-face as a group during INCOSE symposia and workshops, and regularly through teleconferences. We have experimented in our own organizations, and spent countless hours supporting and dissecting each others' experiences. Although the learning has been profound, as evidenced by the reflections in this paper, it has not been without its challenges. These include:

- **Making time to participate:** group members are juggling competing priorities, such day jobs, families, life, study, and other commitments. What you get out of an experience like this depends on what you are able to put in.
- **Staying engaged outside of defined contact points:** as a large, global group connected largely in a virtual setting, the continuity of effort due to other commitments can be difficult to maintain.
- **Determining end goals and realistic plans to accomplish them:** as there are no clear leadership responsibilities or required outcomes, determining what these might look like is very important.
- **Controlling our collective ambition:** as a group of motivated leaders, our ambition has at times got the better of us, and it is often difficult to de-scope our activities.

Our shared learning has had a profound effect on each of us as individuals. When we started this journey, the concept of leadership was an individual activity: the probe-sense-respond mindset was an individual activity. As we conclude our journey, we reflect on attributes necessary for a model of a collaborative probe-sense-respond mindset. These include:

Probe: *Motivation and curiosity*. Each group member is busy, often juggling multiple activities across multiple life domains. We have to encourage and reward those members who engage, and respect those who cannot in the knowledge that they will engage and lead when they can. We left our biases at the door and showed a great amount of curiosity about everybody else without preconceptions. This curious mindset has been key to create a safe space for our experiments.

Sense: *Sharing and reflecting*. Sharing our past and current experiences in an open way through a regular monthly teleconference catch-up, as well as targeted sub-projects, has been a valuable way to understand our shared journey. We have been regularly prompted to reflect: to take a step back for a moment and seek to understand why something is not working as expected.

Respond: *Acting and delivering*. Actually doing something. It is really easy to 'want' to do something or to 'think' about doing something, but actually doing something as or for the group requires significant effort. This in itself is a fantastic achievement. Delivering on our ambition, or at least a good portion of it, is not to be underestimated.

As a final note, we recognise that we are just one cohort within the TLI initiative, and that our experience has been shaped by those before us, and will, hopefully, shape those who come after us. We are beginning to see the ripples of the impact that this initiative has had outside of the TLI, such as within our own organisations, in our local chapters, and in other spheres, as demonstrated through the vignettes in this paper. We could reasonably expect to see the INCOSE TLI as a vehicle for influencing our sector into the future.

CONCLUSION

This paper described the experiences of a shared technical leadership learning journey. This journey was framed in the probe-sense-respond mindset required to negotiate the complex domain, as defined by the Cynefin framework. The lessons that have arisen out of this process, including creating availability, staying engaged, developing a plan and curtailing ambition are applicable to any learning community. Further, we present our observations around conducting a collaborative probe-sense-respond experiment, where the 'probe' requires motivation and curiosity; 'sense', sharing and reflection; and, 'respond', acting, and delivering. ■

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We are not, as we might otherwise say, indebted to our respective organizations, the foresight of INCOSE for establishing such a program as the Institute for Technical Leadership, or the much valued guidance of the TLI Coaches: Mike Pennotti, Donald Gelosh, Patrick Godfrey, and David Long. Instead, we recognise that, as members of the TLI, we have the responsibility to "pay our technical leadership forward" within our communities, and will go about making it so.

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[Editor: Author biographies were current when the paper was initially published in 2020.]

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Ming-Wah is a systems engineering practitioner and a CSEP with over 20 years of systems engineering experience working on large-scale projects in the urban rail industry. Throughout his career, he has held various roles in systems engineering, which enabled him to practice and gain experience in the entire spectrum of systems engineering process areas. Along the way, Ming-Wah embarked on a journey of leadership, studying various leadership theories and philosophies and putting them into practice. Ming-Wah is currently serving in the INCOSE Singapore chapter as president-elect.

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Technical Leadership of Virtual and Remotely Distributed Teams

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■ ABSTRACT

The world is increasingly virtual and complex, with many relationships and teams at a global scale. The situation will not be changing any time soon. Sometimes, it is only possible to interact at a distance, of not only time zones and space, but also sometimes interpersonal distance, where names and voices make up another person. Regardless, technical teams will need good leadership to address complex situations in these virtual and remotely distributed (VaRD) environments. So, in a VaRD environment, do leadership practices and skills have to change? Do the tools, techniques, and technology make current practices for leadership in general, and the application of those practices obsolete? Maybe not.

This paper seeks to examine the nature of what is really changing when leading in a VaRD environment through the lens of engineers leading teams in global and complex technical challenges. Those perspectives are analyzed to determine the factors that go into a VaRD environment. In addition, this paper analyzes how interactions between teams compare to an in-person environment, how leadership practices are applied in this environment, and how technical leadership is tailored for these new environments.

INTRODUCTION

Technical leadership can be generally considered as actions related to inspiring, providing direction, and guiding a team focused on a technical effort. It requires understanding of both social and technical principles, and the skills to apply them. This may involve parsing through multiple factors, such as, but not limited to, culture, environment, context, behaviors, technology, and tools, each of which add their own layer of complexity to technical leadership. As many teams have moved to virtual and remotely distributed (VaRD) environments, or have been forced into one of these environments, organizations and technical teams now may have a new set of factors to consider and address.

VaRD environments are indirect, requiring working in different locations and collaborating using processes that allow individuals to work separately. It may seem that this environment will change much of how work and leadership will need to be performed in organizations. In fact, some guidance in past years on leading a virtual team states that it is not the same as leading a co-located team, and that new competencies and skills are needed (Nemiro 2004) and others call into question whether or not leadership models have changed to match a “modern business environment” (Geurts 2003). Except it appears that, at least for virtual teams in recent years, the principles of leadership have not fundamentally changed. Contrary to the idea of changing leadership models, leading a technical team in a VaRD environment will involve not changing what good leadership is, but instead involve tailoring the application and practices to the new context.

Identifying how to be effective in a VaRD environment can be explored through the following five questions:

- What are the input factors that impact technical leadership in VaRD environments?
- What are the similarities and differences between “in-person” and VaRD environments?
- How do teams develop in VaRD environments?
- How do leadership practices translate in general to VaRD environments?
- What specific behaviors have technical leaders and organizations used to adapt to VaRD environments?

These questions will be examined based on the context, experiences, and stories of the authors as systems engineering practitioners in each of their fields. This is supplemented by input from the experiences of other technical leaders who were engaged in a dedicated workshop (INCOSE 2020). These perspectives are used to evaluate if basic principles of technical leadership have changed, and what individuals and organizations can do to be effective in a VaRD environment.

INPUT FACTORS IMPACTING TECHNICAL LEADERSHIP

Success on technical projects or initiatives requires adapting leadership styles and models to different environments. Key input factors can be highlighted to help technical leaders understand how they may influence the success of their team and organization in such environments. Factors that are influential in leading teams in a VaRD environment are generally categorized as uncontrollable, organizational, and human. Uncontrollable factors, such as disruptive events, are environmental factors that technical leaders have little control over. Organizational factors, such as organizational culture, further shape leadership style and require tailored leadership models. Human factors address adaptations needed in leading and managing teams in VaRD environments:

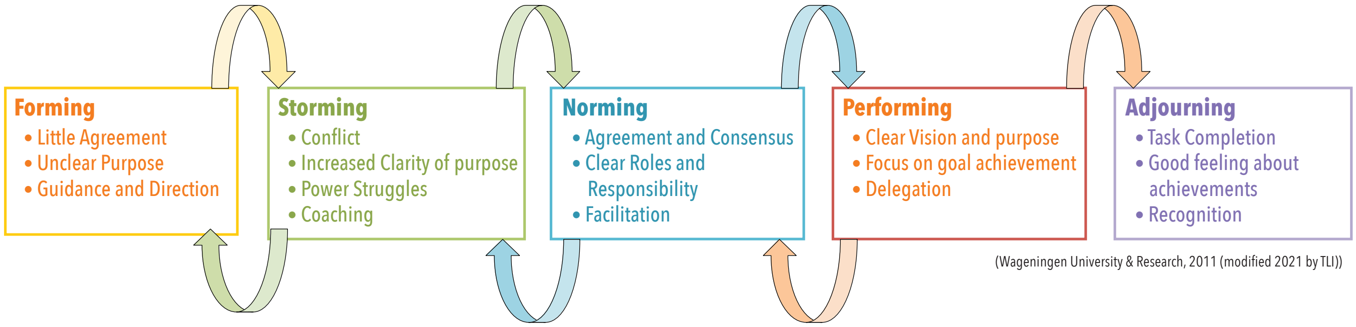
- **Uncontrollable or unpredictable events** – The economy, politics, competitors, customers, and even the weather are all examples of factors that are beyond the control of a leader or could not be foreseen. These events can influence a team's performance. Uncontrollable or unpredictable events requires technical leaders to adapt to new situational and environmental context. For example, in 2020, the Coronavirus crisis highlighted the needs for organizations and teams to adapt to restrictive measures, which have provoked new ways of leading teams in VaRD environments. Uncontrollable events shape leadership style in the face of unexpected adversity.
- **Organizational culture** – The culture of an organization is a critical factor for leaders since culture shapes leadership styles. Organizational culture consists of the shared system of beliefs, values, expectations, norms, and observable ways that members express their ideas. For example, the competing values framework of Quinn and Rohrbaugh (1983) identifies four types of organizational cultures: clan oriented, adhocracy oriented, market oriented, and hierarchically oriented. Each of these organizational types has a leadership style that tends to be more effective given the organizational culture, and some may be more effective than others in a VaRD environment. The organizational culture may also dictate what the roles are between "leadership" and "management," which can have an impact on how to lead a team in VaRD environments.
- **Human factors** – Human factors are about understanding the effects of human behaviors on performance. Human behaviors span a broad spectrum. Non-technical skills, often referred to as "soft skills", involve the negative and positive aspects of human behavior on performance. In technical environments, the principles of emotional intelligence and social intelligence are key components of soft skills. Moreover, on technical teams, leaders must practice soft skills such as the ability to influence and build trust to improve team performance. With the increased complexity in VaRD environments, soft skills become more critical, and using these skills becomes even more challenging due to the interfaces with information and communication technology (ICT).

SIMILARITIES AND DIFFERENCES IN ENVIRONMENTS AND CONTEXTS

A team is a group of individuals working together to achieve a common predefined goal. The traditional work environment, also known as an "in-person" environment, consists of individuals working in physical vicinity. The virtual teams refer to the group of individuals separated by physical distance but utilizing ICT to achieve a shared goal. Remote teams, like virtual teams, work away from each other, but usually that does not mean that everyone works remotely, or that the company distributes its team members around the world. The term "remote" in remote teams means that certain team members may work remotely away from the office or other members on the team. Remote teams can also be location based, potentially working from home, but within a specific distance to an office where they occasionally meet. When working on a remote team, rather than trying to connect across multiple time zones, there may be only one or two other remote workers while the rest of the team is centrally located. Conversely, remotely distributed teams are separated geographically and dispersed over a wide area – domestically or internationally.

Key differences and similarities between "in-person" and "virtual and remotely distributed" teams are listed below:

- **Team selection** – In person teams are often selected only based on their functional skills. VaRD teams will have the additional challenge of potentially making selections based on knowledge of technology over their necessary useful skills, like learning new ICTs, the ability to collaborate across functional and cultural boundaries, and exceptional time management.
- **Organization structure** – Compared to in person teams, which often have clear reporting lines and hierarchical organization charts, VaRD teams support a global organization structure and may be able to have weak authorities and fewer hierarchies. In fact, a hierarchical structure may be less effective in VaRD teams. VaRD teams could have trouble with collaboration if following complicated chains of command, but effective communication within the organization can address this. Communication and collaboration are key in any workplace, regardless of whether it is in-person or VaRD, especially when most interactions occur via email, chat or calls. This means ensuring a free flow of accurate information and using the right tools for the job. Both in-person teams and VaRD teams require leading by example by giving regular updates and holding check-ins with teams. If a team sees that the leader is an effective communicator, team members will follow suite.
- **Availability of information and communication technologies** – Companies cannot control where employees work in VaRD teams. But regardless of whether or not a team is in-person or a VaRD team, what they can control are in-house facilities and the physical technologies distributed teams use, including company-issued computers, smartphones, and wireless access cards. These types of technologies are tangible and bridge the gap between wherever the team members are and how they collaborate with the rest of the team.
- **Leadership or management style** – In some VaRD teams, team leads cannot control the day-to-day activities and monitor each team's activities as well. Therefore, they will need to delegate more, and will generally need to lead through influence more than directly. Frequent communication with clear delivery is critical in a VaRD team. This is in contrast with in-person teams where it is much easier for team leads to interact and participate in the day-to-day team activities.
- **Knowledge exchange and decision making** – For an in-person work environment, information exchange happens also during informative discussions. In VaRD teams, members have limited or no informal access to the data. A VaRD environment means there needs to be more frequent updates on project status and building a shared repository to provide important information to all team members.
- **Relationship building** – When in-person team members meet in the workplace, they tend to develop close



(Wageningen University & Research, 2011 (modified 2021 by TLI))

Figure 1. Tuckman five stages of team development

ties. In a VaRD team, the interactions tend to be more task focused. Lack of verbal cues and gestures in a VaRD setting does not allow for a personal touch in communication.

- **Psychological contract** – An unwritten set of expectations between the employee and the employer is referred to as a psychological contract. The foundation of psychological contract is more fragile in the VaRD environment compared to an in-person environment. Smaller instances of misunderstanding or gaps in communication result in a violation of the psychological agreement, which negatively affects the team's effectiveness. VaRD teams also tend to experience difficulties in building trust, cohesion, and commitment among its members. In a VaRD team, developing this psychological contract will not be easy.

Considering the challenges posed by VaRD teams, it is necessary to pay close attention to communication, collaboration, and cultural issues.

TUCKMAN'S MODEL OF FORMING TEAMS

Based on research conducted on team dynamic, the Bruce Tuckman's team development model shows that all teams go through the following five stages (see also Figure 1): forming, storming, norming, performing, and adjourning (Wilson 2010). All stages are inevitable in order for a team to grow to the point where its members are functioning effectively together and delivering high quality results. Once a team has experienced the forming and storming stages, they may move through the other stages in any order or return to previous stages. For example, the team development cycle can start over at any time during a project, such as a team member moving off one project and a new team member joining. The team will be back in the forming stage until the new member is settled.

This development model should result in effective teams. The members in the team must be able to work together to take part together to team results. This does not happen automatically, but it happens through this team formation. Initially, team members are individuals assigned to work together, overtime they get to know each other, what to expect, how to divide and assign tasks, and how to coordinate work. Through this process is how team members function as a team instead of individuals.

The principle behind this model applies the same for VaRD teams as well, but they might go through a more complex development process, because they solely rely on electronic communication and collaboration technology to facilitate interactions. Cultural boundaries and time zone differences add to its complex nature. Leaders need to acknowledge that each stage may develop slightly differently and take longer, but the model is applied the same.

Forming Stage

The forming stage involves a period of orientation and getting to know everyone on the team. This may take more time in a VaRD environment because team members interact less frequently. The interactions in VaRD teams are often task focused, and do not have as many opportunities to interact informally. This could result in a team awareness that is strongly contextualized and work-centric, rather than having an awareness of the other team members.

Storming Stage

The storming stage is the most critical and difficult stage to pass. It is a period marked by conflict and competition as the individual personalities develop.

For a VaRD team, it may be more difficult to express differences of opinions, and one or two people could monopolize a conversation. The approaches of different cultures in this stage for a VaRD team could complicate the situation. A clear flow of communication and regular team meetings could help, as well as an understanding of the cultural behaviors for those that make up the team.

Norming Stage

The norming stage is where the team works more effectively as a team, but not necessarily at a high level. They are no longer focused on their individual goals but are focused on developing a way of working together. They are accepting of each other's opinions and value their differences.

In a VaRD team, norming can be encouraged by putting things in writing. Talking about the norms can help everyone see what they are doing and how things work on the team. Remember: norms may not be apparent unless they are documented and agreed upon.

Performing Stage

The performing stage is where the teams are performing at a high level. Team members trust and rely on each other, and the focus is on reaching the goal as a team. The highly performing team functions without oversight, and the members have become independent at this stage. Decisions are made and problem solved quickly and effectively.

In VaRD teams, it is easy to slip out of this stage and return to earlier modes of operating. Team members can take things out of context or struggle with communication. With recognition and steady work, the performing stage can be maintained on VaRD teams.

Adjourning Stage

In the adjourning stage, the project is ending, and the team is moving off to different directions. This stage looks at the team from the point of view of the well-being of the team rather than from the view of managing a team through the original four stages of team growth.

This appears to be a difficult stage for VaRD teams. Celebrating the success of the project and sharing best practices for future use cannot be done in traditional ways, and alternative methods would need to be identified.

GENERAL TRANSLATION OF LEADERSHIP PRACTICES

A successful realization of a complex system requires abilities that go beyond the adoption of good managerial practices. Good managerial practices provide a sense of control, organization, and cause-effect rationale, and they are sufficient for the realization of known systems developed in known contexts and deployed in known environments. However, complex systems and systems of systems present emergent characteristics and pose unknown challenges. For these, good leadership practices will set the direction and guide the team throughout the adventurous and sometimes unknown journey towards the visionary destination.

The internationally best-selling book *The Leadership Challenge* (Kouzes and Posner 2012) provides the following five practices for exemplary leadership:

- model the way
- inspire a shared vision
- challenge the process
- enable others to act
- encourage the heart.

This model provides an abstract concept of the best practices a leader should adopt, independently from the nature of the team to lead, the engineered system to be realized, the surrounding environment, and the situational context. These practices are generalized and therefore useful to guide leaders in any endeavor. Nevertheless, it is important to contextualize these practices and take into consideration how the world is changing, how human interactions evolve, and the input factors affecting technical leadership described in the previous section. It is worth understanding how to translate these practices into behaviors and actions that help to lead effectively a VaRD team to successfully engineer a complex system.

Model the Way

The practice "model the way" suggests that leaders establish principles and standards on how people should cooperate and pursue goals. Leaders should then implement these establishments leading by example. Leaders of VaRD teams should comprehend the cultures of the team members, their local habits, and their needs and feelings when they interact virtually. Once they have an understanding of those items, they should find the right trade-off that maximizes team member inclusion and comfort. Leaders should establish habits for virtual interactions that help to supplement what may be missing in non-verbal communication.

In a physical environment, technical leaders use their competencies and knowledge to lead by example. In a virtual environment, social, and communication abilities may become even more important. Technical leaders should increase understanding of social aspects and their relationship with systems engineering aspects. Leaders should take the thought processes of an explorer of the interactions rather than a subject matter expert.

Leadership relies on communications, both verbal and non-verbal. The non-verbal cues are much harder to detect and transmit in a virtual environment, so it is important to be explicit about how the team should communicate.

Inspire a Shared Vision

The practice "inspire a shared vision" suggests that leaders create an appealing image of the final destination, communicate them with passion, and get the team members to envisage future and exciting possibilities.

This may be the most challenging practice to adopt in a VaRD team. Leaders should influence others and the surrounding environments with minimal feedback. Superb verbal and graphical communication skills are key to influence and inspire VaRD environments. Leaders should look at the VaRD environments with the eyes of the team members to build empathy. In addition, leaders should find alternative ways to make sure that the vision is really shared.

Leadership of VaRD teams requires more investment in inspiring a shared vision, because such teams diverge easily.

Challenge the Process

The practice "challenge the process" suggests that leaders search for opportunities and change the status quo if there is room for improvement or a need to adapt to an emergent situation. Leaders should pioneer new solutions, keep the team confidence high, and promote a mindset in which mistakes and failures are accepted and perceived as opportunities to learn when exploring and probing new situations.

A VaRD team may provide an advantage to this practice, especially for global challenges. A multicultural team will have different perspectives that would not be present within a single culture, providing different perspectives on a problem based on the different contexts of the individuals. The diversity of perspective would also encourage unique solutions to a problem. Team diversity feeds knowledge sharing and enriches the creativity of team members. Leaders should promote culture sharing via dedicated social spaces and events, where it is possible to experience habits and traditions of the team members. Forums and places to talk about things not specifically related to the engineering effort could strengthen the relationship between team members. Conversely, when diversity is seen as a challenge, the team members could feel fear and introduce barriers in communications.

As demonstrated in paper (Lee 2016), team dynamics in VaRD teams are different from collocated or in-person teams. The former generates more ideas in the same amount of time and team members may express opinions more openly, but the decision-making process may be less democratic, with the minority opinion having less influence. Therefore, in such an environment, it is easier to get new proposals for changes, but it is harder to implement them and get team members to buy in to the changes.

Finally, technical leaders should be aware that minor and apparently simple changes could have a significant impact in a new environment. Technical leaders should be quick and creative to tailor also very simple processes, such as a design review or a product acceptance, which could become complex in a VaRD environment or at least it will be different.

Enable Others to Act

The practice "enable others to act" suggests that leaders foster collaboration, build trust in the teams, and actively involve others.

In a virtual environment, reliability of both humans and ICT infrastructure are crucial to build trust and involve the team members. Leaders should envisage the adequate technological infrastructures and invest on reliability and knowledge sharing. Team members will maintain momentum and focus as long as they are not threatened by technical issues and can keep in synch if they always have access to a unique source of truth.

Leaders should organize meetings and information well in advance to avoid wasting time, support team members facing technical problems, respect the agenda, and value all interventions and contributions. Last, but not least, leaders should seek feedback, because in a VaRD environment there is not direct contact, and it is more probable that team members will get distracted and not participate to the discussion. Leaders should not show anxiety about lack of control in virtual teams, which may cause some amount of micromanagement, and destroy trust. Leaders should focus on engaging team members.

Encourage the Heart

The practice "encourage the heart"

suggests that leaders keep hope and determination alive, and recognize the contributions that individuals make.

Leaders should find alternatives to celebrations in person, such as posts in social networks, videos, and newsletters, where leaders recognize the successes of their teams. Certainly, these alternatives are often less enjoyable than a party, but they have a greater visibility and professional value. Nevertheless, it is worth introducing as an important habit the celebration of a success with a fun event every time the team meets in person.

EFFECTIVE BEHAVIORS

The fundamentals of leadership do not change because a team is remote vs. distributed vs. virtual vs. co-located. The teams require direction, guidance, coaching, decision-making, problem solving, conflict-management, team building, and everything else associated with leadership. For a virtual, distributed, or remote team, specific leadership behaviors can help the realization of good leadership practices.

Based on the personal experiences of some technical leaders, behaviors or actions that may help someone new to leading a VaRD team are the following:

- **Get to know the people**
  - Deliberately and directly talk to individuals rather than using subtext or implicit communication. Get their attention by specifically using their name and get them involved.
  - Establish a new baseline for how team members speak and write in order to use this as a sort of non-verbal communication.
  - Specifically ask how people are and ensure that everyone has a chance to talk.
  - Talk to new people in the organization regularly to get them oriented on how they “fit in.”
- **Encourage diversity**
  - Utilize backgrounds in virtual call that promote peculiar characteristics of a culture to trigger curiosity and questions on diversity.
  - Encourage diversity by organizing teams by product area in order to mix membership from different sites (Lee 2016).
- **Use the camera**
  - Whenever feasible, propose to have video on in order to allow team members to use body language. If team members are not comfortable using their camera, continue to encourage them to do so, but do not push the team member into discomfort.
- **Find tools that support on-line collaboration**
  - From the experience of one technical leader, “Do not take a chance, if it is important, pick up the phone and talk.” When writing an email or an instant message (IM), sometimes individuals will read into something that is not there or write something that they did not think would start an issue. Face-to-face communication has always been better. Things can still be talked out over the phone, and that will make it easier to hear when someone is not happy, but it will still not be as good as face-to-face.
  - Although IM may not be as reliable as face-to-face communication, it can be used as a back channel for the side conversations and comments that may need to occur during a meeting.
  - At the beginning of projects, set up a repository that everyone can get too and stress that all project related material must go into this repository.
  - Utilize pictures and screenshots in order to understand what others are seeing for troubleshooting and problem solving.
- **Leverage process and standard work**
  - Asking teams for status weekly instead of monthly and asking them for help on tasks gives them a sense of empowerment.
  - Dashboards or visual management can be used to get a better idea of what is occurring both within a team and in other teams.
- **Leverage meeting basics**
  - During virtual meetings, a moderator, a different person each time, can make sure all the required people are in attendance, reminds the host there is 15 minutes left and keeps a log of who has come in late or left early.
  - Record virtual meetings, offering off-line listening to whom did not attend the event and need to get information.
  - Whether the meeting can be recorded or not, document the results of discussions and decisions in writing and ensure that it is distributed to everyone.
- **Find alternative means of socialization, celebration, and recognition**
  - Consider using videos for acknowledgement and communication rather than emails or other written communication and sending gift cards rather than having presentation of certificates.
  - Many ICT tools have the option for “reactions” (such as emoji’s). Although these may seem unprofessional to some, they provide a passable alternative to being able to react in person.
  - Set up a virtual “coffee break” or virtual “happy hour” with the ground rules of no work being done to strengthen the bonds of the team members.

This is only an example of potentially effective behaviors. Ultimately, the specific leadership behaviors will need to be tailored to the specific organization.

POTENTIAL FUTURE ANALYSIS

As is often the case, as each of these items has been explored, additional questions and unknowns arise that need additional exploration. There are instances of conflicting processes, inconsistent trade-offs, and aspects of virtual technical leadership where no conclusion was evident in the experiences of the authors:

- **Leadership vs. management** – There are many perspectives on the differences and similarities between “leadership” and “management”, and this is no different for the application of these terms to VaRD environments. While there has been some exploration of these ideas in this paper, there is likely to be disagreement on how they are used, what each of them entail, and who performs each of these functions.
- **Virtual and remotely distributed team development** – This topic has been touched on in this paper, but there are nuances to the complexities of team development in a VaRD environment that have not been explored or tested. This paper has been focused more on teams that are already in the “performing” stage of development, so the perspective of similarities and differences in team development is limited. There are still questions on how teams form, storm, norm, perform, and adjourn in a VaRD environment, and how or if these processes change.
- **Establishing or changing a virtual culture** – Not all organizations have a culture that is both efficient and effective for VaRD teams. Changing the culture of an organization or establishing a new culture is one that is difficult to start with and doing so as part of a VaRD team is likely to present additional challenges compared to an in-person or co-located team.
- **Resolving conflicts in VaRD environments** – As with any team, there is bound to be some conflict that arises between individuals. Methods of resolving conflicts in a VaRD team may

remain the same, but this has not been examined in detail in this paper and could benefit from further evaluation.

- **Effects of different organizational structures** – Each organization will have a specific structure that will impact the effectiveness of a VaRD team. While this has been touched on in this paper, the perspectives captured and examined do not capture all types of organizational structures. Further study on multiple varieties of organizational structures could provide additional insight into the most effective ones for VaRD teams.
- **Quantitative studies** – This paper has been based on experiences in a VaRD environment, rather than any specific study. It would be beneficial in the future to examine how existing studies in soft skills tie into these leadership concepts. This could help to address and identify specific measures of effectiveness of leadership in a VaRD environment, as well as effectiveness of a team in this environment.

CONCLUSIONS

The quick shift to VaRD environments has brought on many challenges for organizations. In this suddenly almost exclusive virtual world, it is much easier for employees to become almost invisible. More than ever, leaders have to know the needs of their business and their people. The inability to bring external and internal stakeholders together in person for the foreseeable future adds more difficulty to decision-making and increases the potential for conflict. For organizations, the critical challenge in the current environment centers on how leaders can engage virtually in communication and key decision-making processes with stakeholders and internal team members in ways that enhance trust, transparency, and teamwork. It also offers a critical opening to rethink how decision-making is distributed and managed locally and globally.

Although there are differences in VaRD environments from in-person or co-located environments, teams will still require the application of good technical leadership practices, and many factors affecting teams and how teams are led are similar regardless of the environment. Fundamentally, these practices remain the same, regardless of the environment. But teams will still need to adapt to different processes for the application of leadership practices. VaRD teams will also evolve more rapidly than co-located teams, so leadership practices should be tailored and quickly adapted to respond to the unpredictable changes. The tailoring process should be executed starting from the principles, because a direct tailoring of the processes could be ineffective in such environment where the team dynamics are a critical element of the system. ■

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[Editor: Author biographies were current when the paper was initially published in 2020.]

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Collaborative Systems Thinking Culture: A Path to Success for Complex Projects

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■ **ABSTRACT**

The world is filled with hard and complex problems, oftentimes requiring involved solutions. In large organizations attempting to solve these types of problems, a mindset shift and key candidate methodologies centered on collaborative systems thinking culture (CSTC) can assist significantly. The paper explores the state of the practice, change involved with implementing systems thinking, impacts of a collaborative approach within an organization, as well as the seven phases that a reader can introduce into their organization to realize some of the benefits. The same approach was used to create this paper under collective authorship from cohort 6 of the INCOSE Technical Leadership Institute (TLI); an international group of individuals collaborating exclusively through virtual platforms. From writing papers to executing large technical programs, the CSTC approach will prepare technical teams for tackling challenging problems in an inclusive way with the intent to finish projects on time while also cultivating healthy systems engineering habits and practices. This lessens the reliance on corporate engineering procedures to drive collaborative behavior by fiat. Finally, blending CSTC into the fabric and culture of an organization is emphasized as being needed for the full benefit. That benefit includes saving programs by moving to a CSTC.

INTRODUCTION AND BACKGROUND

The world is getting more complex. For instance, most people are connected to multiple devices, which can be connected to multiple networks. This shift in the digital era shapes unique expectations of a labor market, customer needs, and values, as well as a customer's expectation on how to interact with a product. This hyper-connectivity is in part driving the complexity of the problems that systems engineers are tasked to solve. Over time, this will only increase, as new functions and modifications are applied to existing systems (Lineweaver 2013).

The INCOSE Technical Leadership Institute (TLI) Cohort Community

This paper exists through the capability of digital connection and the power of collaborative systems thinking. It is a team-based product by cohort 6 of INCOSE's Technical Leadership Institute (TLI). The theme of the paper emerged after twelve months of assignments and discussions on defining technical leadership, learning in the midst of change, and what leadership looks like under disruptive or permanently-distributed conditions. The proposed process in this paper was the result of brainstorming exercises based on the collective experience of the group, and items from the literature. This paper will present the case for improving not just team and project performance, but also product quality by adopting a collaborative, systems-thinking approach to accomplish tasks and goals. Additionally, it emphasizes that this approach must be embedded into an organization's culture for the full benefit to be realized, similar to how it manifested in TLI's cohort 6.

Complex Systems and the Changing Organizational Landscape

As systems become increasingly complex, organizations have been evolving and changing to adapt to the change. In some organizations, a traditional hierarchical structure is being replaced with a more adaptable fully matrixed structure, where the authority network is informal and project based. Some organizations have even gone so far as to remove "middle management." How can an organization modernize itself to operate effectively in this complex modern world? There are ways in which an engineering organization can adapt to both survive and thrive through a collaborative culture enveloped in systems thinking. Basic efficiencies and processes in an organization are assumed, however. This includes a basic systems engineering process, including scope agreement among all stakeholders and the developing organization; basic project and configuration management practices, and a quality management system (QMS) especially for any manufacturing. A reasonably healthy, functional, and non-toxic work environment, although this is subjective, is also assumed. Note that a digital engineering or model-based systems engineering (MBSE) environment is *not* assumed.

Adopting a *systems thinking* mindset in a collaborative culture can help an organization navigate a landscape that is becoming decentralized, increasingly more digital, and drifting further from traditional organizational models. How does a company do this? According to computer programmer Melvin E. Conway, the first attempts would be based on a company's internal structure (which in part can drive or cement its internal culture). *Conway's Law* suggests that "organizations which design systems... are constrained to produce designs which are copies of the communication structures of those organizations" (Conway 1968). This is a great place to start for any change initiative. Adopting an organic approach to systems-thinking culture mirrored by the internal structure of an organization qualifies as a "change initiative." The cultural shift this paper proposes is not necessarily easy but can boost an organization's success in tackling modern (that is, complex) problems.

This paper uses three themes throughout the different sections to motivate the adoption of a CSTC to solve an organization's toughest technical problems:

1. Identifying the problem: desire to solve more complex problems to cost/schedule
2. Introduction of the systems-thinking mindset
3. Collaboration, healthy team dynamics, and leadership–baked into the culture, so it sticks.

It will benefit to first describe the state of the practice of collaborative-focused, systems engineering practice and culture that fully embraces systems thinking, before moving onto the proposed process and approach. The paper then moves to the tailorable process to introduce this type of mindset and culture into an organization to create the environment conducive to develop the most efficient and effective solutions. The goal is to move into enjoying some of the benefits not just to cost and schedule, but also to increased quality and customer satisfaction. As with any process, the reader is encouraged to tailor it to their needs, and to the changeability of the organization. Too much change too quickly – especially cultural change – can wind up killing the initiative.

DEFINING SYSTEMS THINKING, CULTURE AND COLLABORATIVE SYSTEMS THINKING IN THE CONTEXT OF ORGANIZATIONS

Many organizations already utilize systems thinking and have parts of their culture immersed in a collaborative environment. They have structured technical project teams from multi-disciplinary groups. For example, a single project team may have representatives from various engineering disciplines (that is, electrical and mechanical), project management, quality, safety, security, and risk, along with the team of systems engineers. The intent of these organizations is to smooth out the communication between areas of expertise and different parts of the organization by including representatives in team meetings and project flow. Even if this is not the team model, team leaders and members will have worked with others in different groups over their career to build a network of personal acquaintances and friendships with enough experience in the organizations. For example, "I know Jane, over in corporate risk – we should tell her about this design change, especially since it might affect our testing schedule" might be heard in the hallways of an organization where the informal communication flow is healthy and robust. This is where an organization with high turnover can struggle with being efficient. A culture that supports this type of cross-organization informal communication without fear of "trespassing" or butting into another's "swimlane" will support this deeper and more trusting interaction. This informal approach can answer questions more quickly by tapping one's personal networks to supplement, strengthen, or initiate more formal communication pathways.

Systems thinking has risen as an approach to embrace complexity but is also considered a critical tool for organizations in adapting rising complexity. In her book, *Thinking in Systems: A Primer* Donella Meadows explains that systems thinking can transcend disciplines and culture with the potential to cross-connect historical boundaries and specialties. What this means is that organizations are interconnected with and cut across social and sociotechnical systems (that is, disciplines and cultures) and can evolve and reshape system structures over time (Meadows 2008).

Defining Systems Thinking

Systems thinking is "*utilizing modal elements to consider the componential, relational, contextual, and dynamic elements of the system of interest*" (Davidz 2006); another good discussion of "what is systems thinking?" is in Monat's review (2015). Davidz' summary holds true for both products and systems – as well as the organizations developing and building them. Systems thinking can help us to extend our range of observation, deeper, and better analyze how we perceive the system, question what we have achieved, verify consistency of outcomes (going back to previous steps, if needed), and give us the opportunity to better understand and master the systems, while mitigating risks of negative bias. It is similar to "big-picture" thinking, but also includes a grasp of how the different elements of this big picture interact in both normal and out-of-normal conditions. Author M. C. Jackson provides clarity on the definition of systems thinking, in the book *Creative Holism for Managers*:

> *Systems thinking is the practical application of systems science concepts. In the systems thinking disciplines, systems engineering is classified into hard system thinking. Some claim that hard system thinking is worthful for technical systems but reaches the limits of the methodology once it shall address complex, social-technical systems which still are difficult to represent with mathematical models. This limits its application fields of studied systems and the coverage of the systems engineering for being a fully transversal discipline. This argument has been seen as valid and some works have been successfully conducted into INCOSE and its chapters that demonstrate progress on dealing with human and social-technical systems. The reader is referred to active INCOSE working groups that deal with these subjects for more interaction (Jackson 2003).*

Defining Collaborative Systems Thinking

The other half of CSTC is collaboration. We are not alone, and certainly few companies allow individuals, no matter how gifted, to work alone consistently. We are people and work with people. We are a team and part of a team. Can you imagine, if a company set up a sophisticated model-based systems engineering (MBSE) environment, fully embracing digital twin concepts in design and production – but only one top engineer, plus the administrator, had access? The designs created by the "lone wolf" were then rolled out to the world like Moses and the 10 Commandments. That is asking for disaster—barring that the rest of the team quickly reverts to more traditional, pencil/paper/MS Office methods to perform systems engineering. This is why the collaboration piece is so relevant.

When combined with systems thinking, collaboration helps extend previous ideas of behavior, interrelationships, and dynamics of various teams. This improves teamwork and provides space for each member of the team to improve their own performance as well as contribute to the improvement of team performance (Lencioni 2002). The team will interact more effectively when team members are adept in adopting a collaborative mindset. In most cases, this means the team accomplishes scoped technical tasks on time and on schedule by using resources (including labor time) wisely. As individuals, our capabilities are limited even for the most senior engineers; no one can keep all the details of today's complex projects "in their head." Collaboration with others drive multiple individuals together beyond their own limits. For this reason, collaboration is a core tenet of systems thinking.

A definition for collaborative systems thinking has been derived and proposed as the following through adaptation from C. T. Lamb and D. H. Rhodes:

> *An emergent behavior of teams resulting from the interactions of the team members and utilizing a variety of thinking styles, design processes, tools, and communication media to consider the system, its components, interrelationships, context, and dynamics toward executing systems design (Lamb et al. 2008).*

Collaborative systems thinking requires an understanding of systems thinking mixed with an understanding of an organization's culture. While the two might be considered separate entities – any implementation of or movement towards a CSTC requires a thorough understanding of the existing organizational culture.

Defining Culture

The culture of an organization represents its "way of life," distinguishing its unique characteristics from other organizations. Oftentimes, the organization has a defined *mission* and/or *vision* that is used to define and portray itself both internally and externally. However, this tells only part of the story. An organization's mission and vision largely define what it strives to be, reflecting its perceived self-image. However, the real underlying culture of the organization is largely embedded within the history of its organizational structure and in the norms of behavior that have been established over the course of many years.

An organization's formalizing policies and procedures (the standards for process execution and assessment) are perhaps the most tangible of company culture as they are typically captured explicitly in forms that are promulgated as requirements or guidance. However, much of an organization's inherent culture is informal and is maintained and perpetuated by habit and custom.

The existing culture can be viewed as the behavior that emerges from 1) organizational systems, including leadership structures, formal and informal, and 2) the built-in incentives for both staff and management. If an organization wants to lead its teams to a collaborative systems mindset, it needs to work with the existing organizational culture in addition to actively seeking to improve the culture toward a systems-thinking mindset. While this paper assumes that a basic foundation of systems engineering exists within an organization, the reader will find that the ideas presented in this paper will still add value even if systems engineering as a discipline and systems thinking as a mindset are not yet robustly practiced in their organization.

CULTIVATING A COLLABORATIVE SYSTEMS THINKING CULTURE

With an aggressive move to online platforms during the COVID-19 period, the cultural aspect becomes even more critical, since we must now do our jobs without the usual face-to-face interactions. It is hard enough to change culture with everyone in person; it is much harder in a virtual or hybrid working environment due to the dispersed nature of employees especially those from different geographic regions or even countries. Change is likely still needed, as the problems and the opportunities for innovation and creativity are increasing continually. INCOSE past president Garry Roedler provides a quote attributed to Jack Welch, former CEO of General Electric. "*If the rate of change on the outside exceeds the rate of change on the inside, the end is near.*" This is especially true for commercial industries working in a competitive marketplace.

Why should organizations consider moving towards a CSTC? Table 1 summarizes some of the common issues organizations face when developing complex systems, and the benefits CSTC can bring to help solve them. These issues can be complicated in their own right, but most have cross issue interactions creating a complex environment that is best suited for a systems thinking approach to solve. While it is true, there are other engineering and program management tools that can solve some of these – such as full implementation of a MBSE model, where interfaces are all clearly defined and worked – not all environments benefit from such refined systems models. A robust internal review process, along with rigorous peer-review at program gates, will also increase the project's chance of success by finding defects early. Either way, it is the authors' assertion that a CSTC will still enable smoother workflow regardless of model maturity. Note – a mature system model, where interfaces are clearly defined – is still recommended highly.

An argument can be made that all the issues presented can be solved with a less collaborative approach accompanied by well-defined processes, traceability, and handoffs. However, it is the authors' experiences that even with these safeguards in place, mistakes are made because teams are naturally focused on their work and make changes that make their product better (a good instinct in general) without informing other systems involved. Reliance on formalized communication pathways often results in more highly constrained and less adaptive interactions, limiting useful communication flow. Adopting a CSTC across all teams can provide the balance between speed and rigor; it can help solve this by ensuring designs evolve taking the entire system into consideration, not just the specific part. The value of adopting a CSTC has been visible in practice but has not been well documented, and follow-on research along with controlled studies are suggested to collect more data to validate the value proposition.

Change Initiatives and Individual Identity

Whenever adopting a new process, organizational change theory applies. These adaptations are not necessarily expensive – but may require some time (socialization) to start the shift in culture and approach. Much has been written about change initiatives in general (Kotter and Schlesinger 2008); one additional note worth mention is the potential identity shift in both staff and management with a CSTC. If the desire is to implement a CSTC in any group, from a small team to a large corporate division, the remaining questions become how do systems engineers and leaders shift their individual interaction, legitimate ambition, and current healthy confrontation, to further and deeper collaboration and systems-thinking on a larger scale? How would they establish a timeline for such a shift (assuming that not

Table 1. Problems addressed and benefits provided by implementing a CSTC

Domain	Typical Issues CSTC Can Solve	Benefits of CSTC
Interface Management	Components of your system or product were built to the correct print, but the interface had changed at the next level of assembly – forcing rework or possibly a redesign.	Interfaces are worked early, and taken seriously. System interfaces are matched by strong collaborative interfaces, either in a digital model or more traditional ways.
Testing	Cost estimates for verification and validation activities were known to be much higher than projected – but this information had not reached the systems integration team until a major design review in front of the customer, causing an awkward and credibility-reducing request for more time and money.	Less cost overall (from reduced rework) – with more accurate cost/schedule estimates along the way for both management and the customer.
Design	Designers, equipped with a decent "first draft" of the requirements, promptly worked on design prototypes to show the team, management, and the customer progress was being made. Future requirement updates were ignored, resulting in a stale prototype once the metal was cut.	Fewer technical and programmatic (cost/schedule) surprises downstream, late in the project. This also reduces rework and increased quality of the outputs.
Project Management	The project management (master schedule) effort and engineering work drifted apart mid-way through the project. While engineering work was being performed, and PM metrics collected, they were disjointed. Soon, engineers were working "off the cuff", focusing on an initial design, producing a prototype or performing testing according to their judgement and experience. Too much time was spent on design before checking back with schedule or requirements – causing a time-consuming effort to re-baseline.	Customer expectations are included in the project flow, in a formal way, reducing misunderstanding of customer intent. Customer environment, and expectations, baked into the systems engineering.
Sub-System Design	Scope was added by the design engineers, because the extra features were "lowhanging fruit"; the result was that other tasks were not completed or key testing activities were not started on time.	Designers still focus on their task, but they get the right input earlier on and at appropriate intervals.

all individuals will "see the CSTC light" at the same time, or ever)? When does the organization "carry the wounded but shoot the stragglers?"

Part of the answer is to help individuals change their identity (how they see themselves and the stories they tell) to align with the proposed CSTC. For some, the identity as "worker-engineer" may need to shift to more of a "team-engineer". A management shift might be from responsibility to maintain funding for all their people, to a more organic, abundance-based, "common good" focus. If organizations want to evolve to provide more effective ways of conducting business, then everyone involved must adapt to a CSTC perspective. If not, it may find itself trained for yesterday's way of doing business and will get left behind. The remainder of this paper takes into account the mindset shift and proposes a way to make such a change in our organization, and even ourselves.

A PROCESS TO CULTIVATE COLLABORATIVE CULTURE CHANGE

The author team has developed a process for organizations to improve project performance – assuming a baseline of capability exists with a QMS and systems engineering process – by slowly adding in CSTC elements; this process is described in this section. There are a few important prerequisites an organization must have in place in order for them to develop a system thinking culture and move forward with shifting to a CSTC. Organizations must have a proper training program that allows for new content to be added easily and can reach the organization's population effectively. Employees must have a basic flavor of system thinking culture, an understanding of systems engineering, and the organization must have some structure of systems engineering process in place. These basics include configuration management systems, knowledge retention processes, and finally a basic development and design process for requirements, architecture, interfaces, specialty engineering, and verification and validation. A basic systems engineering process is assumed, to be in place; if not, then a CSTC may not be priority one in the organization. Also, it is assumed that the systems engineering processes operate in, or at least coexist with, an existing quality management systems (QMS) framework. Finally, this paper assumes that staff and management are trained on both the systems engineering processes and the QMS used by the corporation or organization. While neither system is perfect in any real organization, some baseline is assumed for a CSTC to work most effectively.

Considering team dynamics in CSTC. A collaborative system thinking culture in relation to team dynamics, as defined by Lamb et al. (2010) as "an emergent behavior of teams resulting from the interactions of team members and utilizing a variety of thinking styles, design processes, tools, and communication media to consider the system in terms of its components, interrelationships, context, and dynamics towards executing system design."

Successful collaborative system thinking culture teams per Lamb and Rhodes (2010) have in common is team diversity, team experience, and a team culture that is common among all the members.

Table 2. Phases for implementing CSTC in an organization

No.	Phase	Description
1	Awareness and Documentation	Collect situational awareness, employee interviews, identify pain points (that a CSTC could solve).
2	Investigation of Current State	Identify existing elements of a CSTC.
3	Early Adoption and Management Buy-In	Here some small pilot projects are started, and management is approached for their support.
4	Methodology	The process for implementing the CSTC; very organization dependent and needs to be architected by leadership or the implementation core-team.
5	Removal of Barriers	Many may show up; keeping momentum is key at this phase until a tipping point in the organization can be reached.
6	Fill the Gaps	The CSTC rollout will expose gaps and holes in the new process – and maybe even the rollout itself. This is normal, and the gaps should be worked.
7	Training and Continuous Improvement	This sustains the gains and the victory, both with revised training and corporate policy if needed – and with continuous improvement efforts to keep the spirit of CSTC going and evolving.

Team Diversity and Experience

Diversity and experience are important contributors to a CSTC as they enable different perspectives and ways of thinking. Each team member has different experiences over their careers, leading to a diverse set of opinions and methods to approach the same goal. A list of considerations for both diversity and experience are below:

- Degree concentration and discipline are indicators of the type and variety of specialized knowledge on a team.
- Job role (sometimes reflected in title or level of responsibility) is an indication of the types of functional roles represented on a team.
- Social styles or personality information (Myers-Briggs, DiSC) can give an indication of team heterogeneity from a personality standpoint.
- Team roles show how well balanced a team is from a functional/execution perspective or if there is need for improvement.
- Individual systems thinking capability: If any team members have formal systems engineering degrees, or formal systems-thinking training, or problem-solving training (TRIZ, etc.).
- Corporate and industry tenure: The number of years spent in the industry is a proxy for depth of experience and familiarity with corporate procedures.
- Experience with past similar programs: The number of past similar programs worked is a direct indicator of the breadth of experience represented on the team.
- General "seasoning" of the staff. In many organizations, the majority of engineers are middle-aged or older. This represents a substantial amount of collective expertise and experience, although can be an indicator of change-resistance.

Team Culture

Collaborative systems thinking cultures deal with managing complexity, understanding interactions and interdependencies, and handling cross-disciplinary, or multi-disciplinary knowledge (the traits of experienced systems thinkers). These traits do not necessarily need to be held by one individual, but emerge through the interactions of the team, or a team of teams in a CSTC. But more importantly is a culture of open communication, willingness to listen to the experiences of all team members, and to use the diverse views to choose the best method of solving problems the team is faced with.

The Phases to Move to a CSTC

To cultivate a CSTC culture per Lamb and Rhodes (2010), an environment that values system thinking and transfer knowledge between team members is needed. If on the other hand fear and scarcity-thinking dominate the workplace culture, the road will be long, slow and arduous. Note that in some cases, the environment is in more need of urgent repair than implementing a more collaborative culture. If the environment is simply dysfunctional, or worse, toxic, that must be fixed first.

For best results, to introduce CSTC into a corporation it is suggested to implement in phases. While there are other models for organizational change, the list in Table 2 below is the recommendation specifically for CSTC in organizations. The previous recommendation, to choose a core team of staff and management to lead the change, is essential and will be assumed. Note that the process is not something that is quick – it will take sustained effort of staff-level implementation, focus, and continuous effort to realize some of the CSTC benefits – especially when progress seems slower at first from adopting the new behaviors and mindsets. The reader is recommended patience, as sharing information with groups that traditionally have not had such information, can be an exercise in vulnerability. This is in part why leadership's buy-in is so critical.

- ***Phase 1 Awareness and Documentation:***

The first phase of the implementation of the CSTC is awareness and formalization. This involves understanding the culture of the corporation by conducting interviews and/or employee research on how they perceive the organization is run. How the employees perceive the vision and mission of the corporation may not align with the goals of the VPs, CEO.

Identifying disconnects is important in the early phases. A series of questions, suggested below, can help a core team assess where an organization is, regarding awareness. This can then inform the rollout and socialization of new ways of doing work:

1. What is the mission and/or vision as defined by the corporation, and do the employees have a shared understanding of this vision?
2. Does the current vision have a system thinking mentality?
3. What are the explicit and implicit incentives that drive individuals and organizations?
4. Do any of these incentives contra-

dict or impede achievement of the organization's mission or vision? For instance, does the annual rating system, if one is used, reward individual contributor-ship over a smaller less visible role on a successful team?

5. Do any of these contradict or impede establishment of a more collaborative systems thinking culture?
6. Are company/corporation practices and policies in alignment with the vision?
7. Are they in line with a system thinking culture?
8. If not, do employees have suggestions on how practices can be improved?
9. What are the main staff and front-line management pain points?
10. Do the employees feel the organization is capable of fixing these?
11. Do any of the pain points, seem like a CSTC would solve them?
12. Are the employees, in a way asking for more collaboration, more systems-thinking without naming those terms? If so, this will help in later stages.

It is necessary to enroll an executive (Level 3 or 4 manager) in the effort at some point, ideally at the beginning; sometimes this is not possible, and a "grass-roots" effort needs to start the work. In general, the earlier an executive can be enrolled, the better.

- ***Phase 2 Investigation of Current State:***

The second phase of the implementation is the investigation. Investigate if a CSTC, or parts of it, is practiced in the corporation. While the term system thinking culture may not be widely used, the employees of the corporation could have been practicing it without knowing it. This would be a huge step forward, as any change effort should leverage what already exists that can help. Then, additional concepts of the system thinking culture could be introduced as the need is identified. The investigation should include a variety of individuals from as many different groups within the company as possible in order to get a thorough understanding of interaction between various groups. Additionally, some basic training on systems thinking for those providing input to the investigate may help discover in unveiling existing systems thinking processes as well as potential areas of improvement. Training a small group of early adaptors will also assist with the next phase. In this phase, any informal leadership structures should be identified.

- ***Phase 3 Early Adoption and Management Buy-in***:

The third phase of the implementation is the elicitation of buy-in. This is suggested to consist of two parts: a 'bottom-up' piece that contains a demo project or small well-contained sample effort where a systems-thinking approach is used, and collaboration is emphasized. This small project, when successful, would then be formalized as to how the new process, led to the success. Many change models suggest the early collection of "small wins."

Second, management can be approached with this small victory as a lead in for future support. Obtain buy-in from the management of the corporation to implement the system thinking culture if not already in place. At this point, it is suggested to build on the CSTC elements that already exist and cast the change effort as building onto what already works well. Buy-in by leadership is possibly the most critical phase for any change initiative., especially one that can change how an organization does business so profoundly like CSTC. Change is difficult and can often be resisted, therefore, it is important to focus on how a system thinking culture will not only benefit the company, but also the individual – hence the pain-point collection in Phase 1. Note that buy-in follows a progressive model, and not everyone will jump on board at once. The following are potential benefits that both management and senior staff may respond to, through the phase of getting company buy-in:

- System thinking culture may require a change in how things are done, and take an investment to implement, but will provide ample opportunities for identifying improvements. In fact, the CSTC nature will find improvements and spot gaps more quickly, leading to a faster time-to-fix in the organization.
- System thinking helps to ensure the work of an individual is streamlined by providing them with the information and tools that benefit their work (ie required information is readily available before it is needed vice only after being requested). Again, this translates into speed.
- A CSTC empowers individuals to make changes without fear of treading in someone else's lane. The communication paths are already established to prevent unwelcome intrusions. The culture paradigm requires issues and problems be voiced and worked towards improvement. Management does not have to be the font of all improvement work.
- The fruits of the demo project should be mentioned: benefits and problems discovered during the previous phases should provide specific examples of what a culture change may improve for both company and individual. Some hint or evidence of an ROI would help here.

Here and in the later phases, employees should be given a voice on the development of the methodology and implementation.

- ***Phase 4 Methodology:***

The 4th phase of the implementation of a system thinking concept is the methodology and implementation plan to introduce the CSTC. At the beginning of this phase, it is essential to establish a clear set of goals that will help to achieve your mission but should also have buy-in and reflect the input of the team/employees that will be affected by them. Continuous communication allows team members to develop ideas for process improvements and discuss them to get them approved, funded and implemented. As the methodology is developed, everything should be compared to the goals and to the system thinking ideology.

The systems engineering organization should be the core of the development of the CSTC in the organization. This implies systems engineers shall be placed at every level of the organization.

This is very organization dependent, but the methodology will likely include steps such as:

1. Establish and require certain training, including on any new tools being used.
2. Model the demo project on some chosen larger ones. Do not choose the highest visible, or most expensive project at first.
3. Assess and monitor CSTC progress, and staff morale and acceptance.
4. Prepare any communications to the sponsoring executive (one should be found, and act as the 'champion').
5. If deploying this on an active project, then establish any expectation management with the customer if the new project plan looks very different from the old one.
6. Identify and create any new engineering procedures, planning guidance, and even project cost/schedule estimation tools, to reflect use of these CSTC procedures and processes. While policy rarely drives behavior without a lot of "force majeure" – once the new behavior appears, it is recommended to backfill policy as appropriate to support the new be-

haviors. Ideally – blend in these new procedures to the existing QMS and systems engineering process system; the less that "seems" to change, the better!

7. Continue until the pre-defined 'end-point' of either activity or results are reached in the implementation effort. Measuring the effects of culture can be hard, but for the sake of employee morale it is recommend declaring some type of endpoint to the push.

Techniques and ideas from agile can be used to promote the communication and collaboration with team members. Additionally, the methodology should include a plan for positive conflict resolution in order to better enable the next phase, and existing metrics or key performance indicators should improve to indicate the effort has been successful. For instance – are projects coming in on time, at a higher rate? Are the number of defects less, for those project that are on time? What is the rate of customer returns for commercial products? Ideally these metrics exist; if not, new metrics can be explored that relate to business outcomes.

- ***Phase 5 Removal of Barriers:***

The 5th phase of the implementation is the removal of barriers. In growing a CSTC the removal of barriers may include reducing the multiple hierarchy levels and approval layers to perform a task. This should result in a more efficient team and may be the greatest source of quick wins. Other ideas include (but are not limited to):

- Rearranging the furniture to have space for group meetings to quickly discuss ideas and projects promotes collaboration.
- Remove silos by integrating different groups disciplines in key discussion and decisions.
- Perform peer reviews and working groups that include those different groups.
- Identify, and try to work with those portions of the organization that does not like this change.

It is critical for leadership to be encouraging in the removal of barriers so as not to (unintentionally) be a barrier themselves. This phase is likely to cause "storming" (from the forming/storming/norming/performing model) within the team as ideas of what is and is not a barrier will be different to everyone. It is important to keep the team open to new and possibly strange ideas. This is also a place where tailoring to the needs of the organization can take place. Some barriers like safety checks, are there for a reason. A best practice for barrier removal is to enable "trial periods" were the change initiated is given enough time to be evaluated before deciding if it should be tailored, discontinued, or if no change is needed and progress should continue. At this point, the commitment of leadership may be tested – as the natural resistance to change will have appeared by this time. Only leadership can motivate (or move? remove?) the stragglers.

- ***Phase 6 Fill the Gaps:***

The 6th phase of the implementation is filling the gaps. Gaps differ from barriers in that there is something missing that is needed which would improve a team's ability to get the work done. These gaps may be in knowledge, or in tools or even in adequate workspace. The gap could be a new team would have to be stood up, for instance a requirements task team (for interfaces). Some gaps could be solved by creating communities of practice or lunch and learns for information exchange and training. These types of groups help to fill any gaps in knowledge from systems engineering participants. In these forums participants can showcase work, research and lessons learned. Additionally, a periodic status meeting should be held between the team and leadership to communicate findings and progress. These meetings should also be used to assess the ongoing efforts and their alignment with the goals developed in phase 4. The learning along the way, will expose holes in the process; these should be worked to keep the momentum and facilitate the benefits listed at the beginning of this paper.

- ***Phase 7 Training and Continuous Improvement:***

The 7th phase of the implementation is the training of the new employees, current employees, and management on what the new processes and procedures are. This will be a thinly veiled version of what a successful system thinking culture should be for that organization. The training should explain the reason why a change on culture was needed, its impact, and stress that the cultural aspect was as important as the technical ones. At this point it is needed to establish common systems engineering terminology and concepts – some would say the new ontology needs to be established. This would facilitate its adoption and reduce confusion on the new approach to engineering work. The new way should not be more confusing than the old one! The vision is that the use of collaborative systems thinking in the team, and the larger group, becomes the new normal, establishing it as part of the corporate culture.

At this point, the intent is that even with an imperfect rollout, and obstacles to some of the CSTC goals – there is consensus on the value of the effort among staff and management. This looks like less rework, smoother communications among teams, and fewer management surprises for much of an organization's project work. Additional benefits from a CSTC include the early feedback in the design and with the concurrence of the customer. This makes early design prototypes, either in hardware or in a modelling tool closer to what the customer will want; this reduces the need for extensive rework. This approach helps establish good relationships with customers while completing the project on budget and as scheduled.

With systems engineering becoming more collaborative within the organization, it becomes more customer centric as well. The "engineering" work expands into more than the technical realm – customer relations, program management, communications planning. Intangibles like trust, collaboration, customer satisfaction, and even quality become part of the systems engineering-mix. This process is of course tailorable based on the organization's need and appetite for (tolerance to) process improvement. A culture change or shift is not an easy task, but sometimes it is necessary to adapt to a changing environment and the needs of the customers. An organization that embraces CSTC completely is more prepared to listen to tough customer and employee feedback. This can increase retention rates of both groups. This courage to listen openly, and the mindset that good ideas can come from anywhere inside, even outside the organization, lead to the long-term health and sustainability of the organization, and its ability to win business now and in the future.

Understanding Enablers and Barriers to CSTC

This paper strives to lay out a thorough foundation and motivation for a CSTC. The last part of this (extensive) background is to share some enablers and barriers to implementing a CSTC to equip the reader with as much collected insight as possible for success. Most of these are part of communication and mindset, the third concept weaved through the document.

The right mindset, mentioned earlier, along with the ability and willingness to communicate thoroughly and effectively both individually and as a team, form the third concept mentioned at the start of this section. Also, it is proposed that the process

Table 3. Summary of enablers and barriers to CSTC

Enabler	Barrier
Effective Communication	"Hero culture"
Engaging in Convergent and Divergent Thinking	Team fragmentation
Internal and external situational awareness	Time pressure, driving "head to the desk, blinders on"

alone – without the background, motivation, or context – is not enough to inspire either the reader, or their colleagues, to undergo the hard work of change.

Enabler: Effective communication is a necessary condition for CSTC. Communication among engineers is not limited to the written and spoken word. Part of good communication in a design team is the use of sketches, drawings, mathematical equations and models. While the use of computer modeling tools may be called out in standard processes, informal sketching is very important for the creative process during early design and to help team members share ideas with one another – especially in "blue sky" or brainstorming sessions. Even late in the program, during root-cause analyses, many types of communication methods are used. While improving communication is beyond the scope of this paper, as a skill this should be in every systems engineer's toolbox.

Enabler: Ability to engage in divergent and convergent thinking. Engineers excel at convergent thinking—beginning with a problem and finding a solution. Divergent thinking begins with a requirement or need and asks questions to explore the design space and to generate a large number of design possibilities. The challenge is in fostering open and critical discussion of design alternatives during the divergent phase without premature convergent thinking. Both skills are important.

Enabler: Team internal and external situational awareness. CSTC is about identifying and leveraging interactions, interfaces and cross disciplinary knowledge. Team awareness is an individual trait that indicates awareness of what others on the team are working on and what others on the team know. This knowledge, when universally held, enables team members to preemptively share information with those who need it and better coordinate efforts toward improving a system design. High-level knowledge of what other teams are responsible for and can do is also helpful – and can facilitate finding the right subject matter expert (SME) on short notice.

Barrier: The 'hero' culture, or other unhelpful incentive structures. While the role of the hero is less prevalent than perhaps it used to be, the cultural aspect of the "lone engineer" or lone SME, working late nights to heroically finish the project does still exist in some organizations (again, anecdotally). Another facet of this culture is the reliance on one or two senior engineers for all the design decisions – this can happen especially on teams with few seasoned engineers and many new ones (less than 3 years' experience). Engineering culture also fosters a tendency to procrastinate. The tendency to reward the "hero" who comes through in the end is a barrier to teamwork and to identifying and addressing concerns early in a program through team interaction, proper systems engineering discipline, and sharing of information. There is lack of insights of aggregation of cross-domain knowledge in the 'hero' culture, and the dependencies between key system interfaces may not be resolved on time. The project information received by all cross-domain teams should be consistent at all stages of project life cycle.

Barrier: Team fragmentation. Teams may segment, or form subgroups, along functional lines, because of differences in opinions, or differences in goals. Some of this can be healthy, as all the structural engineers, co-located, can discuss projects and share expertise. In any large project, the decomposition of work into subprojects or disciplines is required to realistically achieve the project's goals. However, whenever a team forms subgroups, information flow could be impacted, and care must be taken to prevent these subgroups from undesirable divergence. This is where a strong lead systems thinker can help. Additionally, the ability to openly discuss and debate interactions and alternatives might be hampered by allegiances to the subgroup. Functional alignment was the most commonly sighted reason for teams forming subgroups (Torabi 2019). The resulting 'turf protecting' results in missed opportunities to leverage cross-domain knowledge. Active and savvy leadership – technical and line – can create a safe environment that minimizes the downsides of fragmentation.

Barrier: Time Pressure. Nothing squashes innovation like a pressing deadline where the team is already behind schedule. The irony is that new and more expansive thinking can get work done quicker, and beat schedule estimates based on past projects and a given percentage of rework.

Worse yet is a situation where the schedule is not realistic – and then everyone is under a general time pressure knowing the schedule cannot be met, so there's certainly no time for exploration, new approaches or innovation. The only difference here is that the team (perhaps no-one) really knows how late they are.

CONCLUSION

To create CSTC this paper has covered the concepts of collaboration, systems thinking, and how they can (and should) interact in a systems engineering environment. The need for a collaborative approach along with and combined with a systems-mindset and systems-thinking mentality was presented, along with a process to help the reader bring about such a transition in their organization. We return to the question of why would we pursue a collaborative systems-thinking culture in the first place? Can't the old methods, eventually, solve the complex problems we face today? What about all the great engineering in the 60's and 70's, which was done before much of formal systems theory was developed? More pertinent to today's environment – budgets are not expanding, and customers across industries consistently push for "more for less."

We can claim to act in the CSTC direction if we can adopt not just practices but also *mindsets*: needed to reduce rework; cut development time, increase customer satisfaction; as well as boost our organization's overall contribution to society. It can be asserted that the current economic and global business environment forces organizations to adapt in this direction, or it becomes defunct or permanently irrelevant. It is not only our organizational solvency that is at stake but also lives. Examples abound – from the logistical effort seen to distribute the COVID-19 vaccine – to the recent tragedies in air travel that have been traced back to failures in the systems engineering (specifically, the human factors aspect), therefore adopting a systems-thinking mindset and culture has become even more pressing. This says nothing about the potential of engineering to solve some of the most vexing problems of humankind: fresh water for all, food distribution, disease prevention, and control among others.

We as systems engineers and leaders have an opportunity to contribute substantially, and to do this we need to evolve to a collaborative systems-thinking culture in ourselves and our organizations as most of the simple problems have already been solved. A large bibliography describes the future challenges of the systems engineering – including INCOSE's own forthcoming Vision 2035. With a collaborative systems thinking culture, both at an organizational level and even adopted as an individual mindset, a system engineer will be armed to address these problems and grow in our position of leadership in engineering domains. The CSTC approach allows us as systems engineers to progress in this important work. Systems engineering involves leadership — with this tool, we can continue our leaders' journey, and continue to contribute to our project, organization, and society as a whole. ■

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[Editor: Author biographies were current when the paper was initially published in 2020.]

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Future Trends Influencing Technical Leaders and Technical Leadership

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■ ABSTRACT

This paper summarizes the authors' reflections on global trends and key factors influencing systems engineering in the post-COVID era. The discussion builds upon INCOSE's *Systems Engineering Vision 2035*, as well as multiple virtual workshops and peer discussions conducted by the authors as part of their experience in INCOSE's Technical Leadership Institute (TLI). The authors focus on three key factors affecting technical leaders and their technical leadership role: 1) the heightened societal awareness of environmental concerns along with the associated demand for more environmentally friendly products, 2) the increasingly interconnected, multicultural, multigenerational work environment, and 3) the increasing capability of advanced digital tools, techniques, and processes. The authors' analysis acknowledges the need for technical leaders to think green, build an inclusive work environment, welcome differing viewpoints, avoid stereotyping, and expand their virtual tradecraft. Ultimately technology changes how technical leaders do their jobs, but not the job itself. Leaders must still set the vision and direction of the organization, communicate that vision to their stakeholders, and provide the resources and support that the team needs to achieve the vision. Emerging technologies offer leaders new and innovative means to do this in a more inviting and inclusive manner.

INTRODUCTION

INCOSE's *Systems Engineering Vision 2035* (hereafter referred to as Vision 2035), published in 2021, describes a "world whose global social, economic, political, and physical environment continually changes, alongside advances in technology and new scientific discoveries." Perhaps more than any other event in our lifetime, the coronavirus disease 2019 (COVID-19) pandemic epitomizes these unprecedented changes. COVID-19 not only changed how we work, but even how we live, both during the pandemic and afterwards. In response to the pandemic, people around the world did not just stop going to work, they stopped going to dinner! As gasoline consumption went down. The supply chain broke down. As their lives changed, so did their priorities. Rather than resigning themselves to accepting unsatisfactory work environments and unfulfilling work, many simply chose to resign from our current jobs and seek fulfillment elsewhere, resulting in the Big Quit of 2021 (Curtis 2021).

Even as employees increasingly realize that life is too precious to let it be completely consumed by work, corporate stakeholders are likewise adjusting their values and priorities to reflect a larger, more global, more interconnected marketplace where environmental stewardship can no longer fall prey to the bottom line. Employers must increasingly adapt to this new world order, and various technologies are emerging to facilitate this adaptation. This is especially true for leaders in technology-centric organizations, where finding and retaining specialized talent was often a challenge, even before the epidemic. Put simply, technical leadership must evolve to adapt to the changing demands of the technical leadership environment. These changes are fundamentally altering the technical disciplines themselves (how we work) as well as the technical products and full-scale solutions generated by these disciplines (what products we build and how we build them).

As part of the INCOSE Technical Leadership Institute (TLI) experience, the authors conducted multiple workshops, interviews, and peer feedback, in addition to a literature search, to better understand the changing leadership environment, how technical leaders are responding to these changes, and how they must continue to evolve. Findings from the interviews included ever-increasing complexity in new product design, an increasing need for people with cross-cutting vs. specialized skills, and a growing need to understand the interconnectedness between the product, the process, and the environment. After aggregating the information resulting from this research, the authors identified three key factors impacting technical leadership: 1) the heightened societal awareness of environmental concerns and the associated demand for more environmentally friendly products, 2) the increasingly interconnected, multicultural, multigenerational work environment, and 3) the increasing capability of digital tools, techniques, and processes.

On October 4, 2022, the authors conducted a workshop with other TLI members to further examine these three factors, with breakout sessions for each factor. On April 6, 2023, the authors conducted another workshop with systems engineers at a large systems engineering firm, focused specifically on digital tools, techniques, and processes. The next three sections of this paper, which correspond to the three key factors listed above, capture the results of those workshops in a non-attributional manner. A summary of the authors' conclusions from this body of research is presented in the final section of this paper.

LEADING IN A CHALLENGING SOCIETAL ENVIRONMENT

The world is living unprecedented times. In his speech to the 2022 General Assembly, the UN Secretary-General, Antonio Guterres adeptly summarized several of the global high priority challenges society is facing: the supply chain crisis and the ongoing climate crisis. Regarding supply chains, the Secretary-General noted that the COVID-19 pandemic and war in Ukraine strongly impacted global supply chain systems in the recent years. Distribution and availability of goods are leading to a sharp increase in costs, placing countries at risk of facing severe shortages in food and energy supplies, especially for the most vulnerable. This fragile situation is compounded by the increasing frequency of extreme climate events, which, in turn, are disrupting people's lives, reducing wildlife population, and impacting economies, with the most vulnerable societies suffering the most, even when they are not the ones generating large levels of carbon emissions (Guterres 2022).

INCOSE's Vision 2035 acknowledges that the world is highly interconnected and interdependent, with a constantly changing environment (INCOSE 2021). Advances in technology are affecting society in both positive and negative ways. On one hand, technology has enabled us to get food, water, and medicine to many parts of the globe that were previously unserviceable (World Economic Forum 2022). The average lifespan is increasing, and the quality of life, in general, is improving (World Health Organization 2023). However, this increase in lifespan and quality of life is also leading to increased consumption and increased competition for resources, which often yields to political and economic upheavals (European Environment Agency 2020). Warlords and dictators are using the very technologies created for the betterment of mankind to expand their control over their respective regions (Pledger 2021), criminals are using their enhanced access to information to steal identities and commit fraud (National Council on Identity Theft Protection 2023), and hate groups are using social media to disseminate misinformation and hate speech, threatening human rights and democracies (SafeHome.org 2021).

Both the Secretary-General's speech and Vision 2035 recognize the growing need for leaders who are willing to collaborate and build collective solutions, as individual effort will not be enough. Vision 2035 acknowledges that "collaboration and leadership across industries, academia, and governments [will be required] to meet these challenges" (INCOSE 2021). A systematic approach, led by systems thinkers, is needed.

During our October workshop, we conducted a breakout session with diverse technical leaders from around the world to discuss the awareness of environmental concerns and the associated demand for more environmentally friendly products within the broader systems engineering community. Discussion topics included new consumer expectations about environmental stewardship, battling inequality in organizations, preventing negative political influence, and addressing the supply change breakdown due to challenging societal environment. The convergence of various views from diverse perspectives pivoted offered workshop participants a broader perspective with new insights for all. Participants agreed that a safe, fair work environment with positive leadership influence and open lines of communication between stakeholders is essential. The set of dynamic and difficult subjects discussed provided a path for finding equitable solutions that can be implemented to achieve and sustain optimized outcomes for both the individual and the organization.

Participants also unanimously agreed on the need to support "green" processes that protect the environment by reducing greenhouse gas emissions, saving water and energy, recycling and reusing materials, etc. One point of interest in the discussion was that expecting the organization to roll out green initiatives is not enough, and that the responsibility to champion planetary lifeform preservation efforts rests upon the individual, as well as the organization. Without individuals working together to make their desires known, corporate interests can outweigh sound environmental choices. Even with the strong consumer push for green initiatives, some organizations remain recalcitrant. To aid such organizations in recognizing the negative impact of non-biodegradable products, an employee could raise awareness by speaking about the matter with their management. Along the same lines, increasing reuse and supporting local green initiatives outside of organizations is another great way to decrease negative environmental impact of waste.

An individual can also help create a more caring work environment within organizations by asking their employer for diversity, equity, and inclusion (DEI) training. Figure 1 above contains definitions for these terms, as documented in DEI-100: Diversity, Equity and Inclusion policy statement [INCOSE 2023]. Additionally, each organizational leader should promote equity and inclusion in their work facilities via communication, training, and making equality part of the organization's vision and values. Technical leaders have the power to influence conversations and should feel safe speaking up about any inequality observed in their work environment. Furthermore, organizations should consider establishing a diversity panel to examine internal policies and processes, and to address DEI-related grievances. A diverse DEI panel could also be helpful in strategic messaging by helping to identify and minimize unintentional bias

Diversity is the range of human differences, encompassing the characteristics that make one individual or group different from another.

Equity is the fair treatment, access, opportunity and advancement for all people, achieved by intentional focus on their disparate needs, conditions, and abilities.

Inclusion is the intentional, proactive, and continuing efforts and practices in which all members respect, support, and value others.

Note – INCOSE uses the compound term ***Diversity***, ***Equity***, and ***Inclusion*** (often abbreviated as ***DEI***) when referring to the broad subject matter.

Figure 1. INCOSE's standard definitions for diversity, equity and inclusion

or potentially inflammatory language in the work environment.

The group also discussed how work environments can play a role in an individual's perspectives on global matters, their willingness to speak up when inequality is observed, and their trust in the organization to do the right thing. When leaders fail to discourage violence, promote diversity, and uphold sound values, their followers take note and respond accordingly. Technical organizational leaders bear the responsibility to create a safe environment where individuals feel safe to speak up when injustice occurs. Such safe environments not only aid employee retention, but also increase productivity, since employees are less distracted by environmental issues and more able to focus on the job at hand.

Another key point in the group discussion was the reality that few companies work in total isolation. Thus, managing the relational interface between different stakeholders and organizations is critical to cross-organizational success, especially when the organizations have disparate values. Such a document, if planned and executed well, could enable continued productivity even if communication between organizations breaks down. Such a document would define the interfaces between systems of a project, end user procedures for interacting with a product, or a contract between nations to prevent supply chain breakdowns.

LEADING IN A GLOBAL SOCIETY

The authors hosted a second workshop breakout session during our October workshop to examine the leadership dynamics associated in an interconnected, multicultural, multigenerational environment. These dynamics create both challenges and opportunities. As one pundit stated,

> "When we fundamentally can't relate to someone due to generational gaps, we often resort to using harmful stereotypes and blame solvable problems on each other instead of working to understand — and value — the differences that distance us. Our job performance and productivity are negatively impacted as a result." (Waldman 2021)

Although the context of this statement was generational gaps, the authors believe it is equally true for cultural and other barriers. We also believe these same differences can – and should – be leveraged to create a more effective team since each brings unique skills and valuable perspectives that, when combined, enable a more holistic approach to solving society's toughest challenges.

INCOSE's TLI is a microcosm of this reality. TLI members live in different countries and cultures, have different educational backgrounds, use different languages and technologies, and represent different generations. Although they share common interests (that is, leadership and systems engineering), each TLI member has a different communication style. As they work remotely and globally these days, they need to learn how to lead in a global society. TLI demonstrates what Aesop endeavored to communicate many years ago in his fable about the bundle of sticks – we are stronger when we work together (DaBoss 2013).

During the workshop, session participants recognized that differences in the global society (such as culture, generation, communication style, education, and language) can lead to difficulties coping with each other when working together on a project. The key to becoming an outstanding technical leader is to recognize and understand these various cultural and generational differences, to respect and learn from each other, and to leverage our differences to build a more effective team. As Deming consistently emphasized, permanent change in organizations comes from the top (Deming 1982, 2012, 2018). Thus, these behaviors must start with technical leaders, who must ensure their team members adopt the same behaviors described above if the changes are to be impactful across the organization.

Workshop discussions focused on cultural leadership challenges in three specific areas: 1) the multigenerational environment, 2) communication and technology, and 3) future trends in global society. The following subsections expand on these three areas.

Multigenerational Environment

Waldman (2021) describes five generations in today's workforce: The silent generation (born 1925 to 1945), baby boomers (1946 to 1964), generation X (1965 to 1980), millennials (1981 to 2000), and generation Z (2001 to 2020). Each of these generations has been shaped by differing world events, social situations, and technological advancements, creating differing preferences for communication and working styles; The savvy technical leader should understand these preferences and adapt their leadership style accordingly.

Waldman warns of the dangers of generational stereotyping, which occurred during the October workshop. Participants, composed primarily of mid-level and senior engineers, described the younger members of the workforce as a "YouTube generation" that is "very risk adverse," requiring "more hand holding" and "instant gratification." Participants also bemoaned the younger engineers' desire to work "fully remote."

In interviews conducted prior to the workshop, the younger generation offered a different perspective, stereotyping the more senior generations as risk averse and reluctant to change. The younger generation considered existing processes and procedures, often established by the senior generation, as ineffective and outdated – reflecting an outmoded mindset that needed to change to keep the organization competitive in a changing marketplace. Note that each demographic saw the other as risk averse.

The younger generation suggested centralizing and sharing information in the cloud to improve development efficiency, promote automation, and facilitate artificial intelligence (AI) development. Having studied the latest technologies in college and regularly using the latest computing devices and social platforms, they are more inclined to adopt the latest technology. On the other hand, senior technical leaders have experienced decades of challenges associated with adopting new technologies throughout their careers.

As the creators of the concept of Gentelligence implore, modern society – to include the modern workplace – needs to abandon the "us vs. them" mentality, and instead champion diversity of thought to better optimize productivity and innovation (Gerhardt, Nachemson-Ekwall, Fogel 2021). Likewise, technical leaders need to recognize the benefits of both sides and bring younger and older generations together to create better more innovative solutions for their projects.

Communication and Technology

Session participants agreed that generational differences affect the communication between generations. As "new generations of students 'live their lives vastly digital'" (INCOSE 2021), younger generations are often eager to use new technologies while senior generations are more reluctant to do so. The younger generation tend to favor asynchronous communications via email, text messaging, Discord, Slack, Yammer, etc., whereas older generations tend to default to more synchronous communication forms such as phone calls, office visits, and in-person meetings. Different communication styles between older and younger generations often complicate intergenerational communication. The compromise solution is often virtual meetings using applications such as Microsoft Teams, Cisco Webex, and Google Meet.

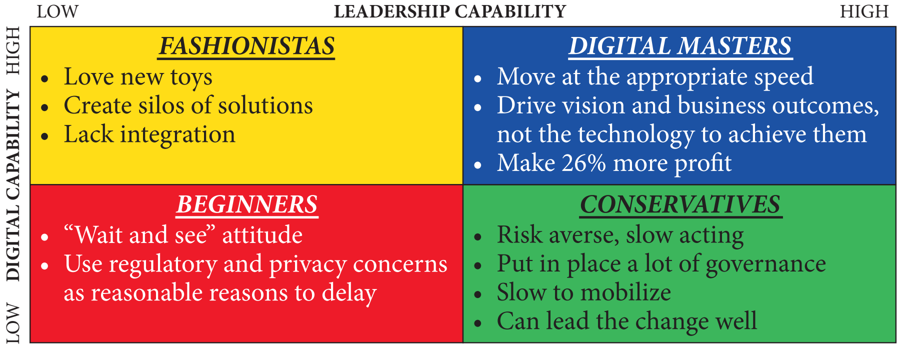
Language and Culture

One of the more obvious, and yet often overlooked, challenges to communication in a global society is language barriers. Just as English has become the language of choice for technology, diplomacy, and aviation, we speak in English to communicate with systems engineers in INCOSE. For non-native English speakers, the mental translation process requires time and effort to communicate effectively. The language barrier challenge is exacerbated by the cultural differences that underlie the language differences, making it more difficult to communicate and understand with the same ease and nuance enjoyed by those who share a common culture and native language.

As Polaszewski-Plath noted, the business world has recently realized that overcoming this barrier opens up a much larger pool of available talent (2021). Being open to this larger pool of talent has become more important in the aftermath of COVID-19 and the associated Big Quit, during which a record four million people quit their jobs in a single month (Curtis 2021). As a technical leader, it will be necessary to learn cultural differences and eliminate cultural unconscious bias for better communication. Thankfully, technologies such as language translations software and remote work environments such as Zoom, Slack, Microsoft Teams, and Google Suite are helping to overcome gaps in both language and latitude.

Future Trends in a Global Society

Vision 2035 states that "enterprises will continue to move toward greater globalization, embracing diversity, innovation, and new collaboration methods in search of competitive efficiencies" (INCOSE 2021). During the October workshop, participants explored the future trends in a global society and how to lead it as outstanding technical leaders. Session participants agreed that tomorrow's global environment will require systems engineers to develop increasingly complex systems to adapt to increasing changes. One example of this is remote work, which many participants have been doing since the COVID-19 pandemic began. The necessity to maintain continuity of operations despite the pandemic forced many organizations to rethink their work processes to make them more virtual-friendly. Participants agreed that virtual work is here to stay, that virtual meetings are the new normal, and that we should leverage the potential benefits it offers. Such benefits include the opportunity geographic diversity in recruiting, since employees no longer need to live near the organization they work for. This, in turn, creates opportunity for diversity in other areas since the pool of candidates is much larger, which, in turn, creates opportunity for greater diversity in thought. Greater diversity in thought leads to better probability of selecting the most effective strategy for success in the 'Meta-verse' environment.



LOW LEADERSHIP CAPABILITY HIGH

HIGH DIGITAL CAPABILITY LOW

FASHIONISTAS • Love new toys • Create silos of solutions • Lack integration	***DIGITAL MASTERS*** • Move at the appropriate speed • Drive vision and business outcomes, not the technology to achieve them • Make 26% more profit
BEGINNERS • "Wait and see" attitude • Use regulatory and privacy concerns as reasonable reasons to delay	***CONSERVATIVES*** • Risk averse, slow acting • Put in place a lot of governance • Slow to mobilize • Can lead the change well

Figure 2. Westerman, Bonnet, and McAfee's digital leadership assessment model

LEADING IN A DIGITAL WORLD

During the TLI journey, the authors investigated a third area of interest: how advances in technology are affecting the workplace and its leadership. The authors focused on three main areas: 1) the virtual work environment, 2) digital engineering (DE) and model-based systems engineering (MBSE), and 3) automated intelligence (AI) and machine learning (ML). A common thread throughout the discussion was the unchanging role of a leader in the digital world. This may at first seem counter to the theme of this paper until one considers the essence of leadership: setting the vision and direction of an organization, building a plan to achieve that vision, creating excitement and unity of effort in support of the plan, and then successfully executing the plan – all the while taking care of the employees, who are the very resource that makes successful execution possible.

Based on anecdotal findings from the October 2022 workshop, the authors conducted a second Leading in a Digital World workshop with systems engineers from a large systems engineering company on April 6, 2023, to further investigate these findings with a larger number of participants to produce more statistically significant results. Informal poll questions used during the October workshop were refined and expanded for the second workshop. The 30 workshop participants rated 69 questions using a modified Likert scale to measure opinions and perceptions regarding the three aforementioned focus areas.

The consensus from participants at both workshops was that our increasingly digital world changes how a leader performs his/her mission, not the core of what he/she does as a leader. This is a key finding that indicates innovation, quality, and change management techniques proposed by Deming (1982, 2012, 2018), Gladwell (2000, 2005), Kotter (2012, 2016, 2021), and others remain viable in the virtual workplace, although the application of these tools may require refinement for better applicability in the digital world. As such authors frequently note, those leaders best able to adapt how they lead to address the ever-changing environment, while remaining focused on their vision, are far more likely to continue succeeding than those who do not.

To frame our discussion in the workshops, we considered the model from Westerman, Bonnet, and McAfee's Leading Digital (2014), which assesses leaders along two dimensions – their leadership capability and their digital capability – and then used this assessment to place the leader into one of four leadership quadrants, as depicted in Figure 2.

Participants were asked to assess themselves, their bosses, and the senior leaders of their organization based on this model. Participants saw themselves as either conservatives or digital masters, but none of the participants assessed the leadership in their respective organizations as digital masters. To gauge their perceptions of outside organizations, participants were also asked to assess the senior leaders in government, industry, and academia, respectively. Interestingly, the participants unanimously placed the majority of leaders in academia in the Fashionista category. Most agreed that engineers, as "early adopters" of technology, often fall into the Fashionista category, as well. Although some workshop participants expressed concern that this model was perhaps overly simplistic, it nonetheless provided a common framework for discussion for the remainder of the breakout session.

Subsequent discussion in the breakout session concentrated on three main areas: 1) the virtual work environment, 2) digital engineering and model-based systems engineering, and 3) automated intelligence and machine learning. Surveys were conducted in each of these areas using a modified five-point Likert instrument that ranged from "strongly disagree" to "strongly agree." Although the breakout group was not large enough to derive any statistically significant findings, the following subsections detail the discussion and general survey trends for each of these topics.

The Virtual Work Environment

Given the explosion of virtual work in response to the COVID-19 lockdowns, it seemed appropriate to investigate participant views on telework during both workshops. Participants in the October workshop agreed that, despite the clear progress seen in telework tools over the last few years, much work remains to be completed. The proliferation of incompatible tools and organizational firewalls, and conjunction with other cybersecurity restrictions, and bandwidth limitations, have greatly restricted the freedom of information across collaborating teams, especially multiorganizational teams. Greater still are the organizational culture challenges as leaders must adjust to reduced face-to-face communication and decreased managerial oversight of employees, which requires more strategic guidance, greater trust, and less micromanagement.

Results from the second workshop tended to be more positive in this area, with the preponderance of participants agreeing that both they and their customers have sorted out most of the technical issues associated with teleworking, and that the transition to telework applications has enhanced their ability to communicate with stakeholders. Given the company's technology-centric focus, this result was not surprising. However, participants acknowledged that they and their customers still have cultural issues to resolve.

Digital Engineering and Model-Based Systems Engineering

Well before COVID-19, DE, and MBSE had become common themes in the vision for the systems engineering discipline. The history of MBSE can be traced as far back as 1958, when Dr. Wayne Wymore was tasked to stand up the nation's first department of systems engineering; modeling and simulation was a key part of his curricula (Wymore 2004). Despite several decades of promising research since that time, MBSE remains a nascent tool in the system engineer's quiver. Discussion during both workshops revealed strong support for DE and MBSE among the leadership of many prominent organizations, particularly in the aerospace and defense industries. This support often included significant investment in tools and training. Respondents at the first workshop indicated that adoption was sometimes stymied by midlevel management officials who were averse to accepting the risk associated with a model-based design package. Since these products did not have the "look and feel" of traditional design documentation, they felt the design solution was incomplete. Despite such anecdotes on the cultural challenges of fully implementing DE and MBSE, participants believed that the greater challenge was technological, with implementation being hampered by inconsistent standards across the supply chain, incompatible digital toolsets, and insufficient workforce training and experience.

Respondents at the second workshop saw their organization as clearly committed to adopting digital engineering processes but acknowledged the need for additional progress in sorting out both the technical and cultural aspects of implementation. Respondents saw their customers as less committed, with slightly more work needed to sort out the technical and cultural issues. When asked whether MBSE is a standard part of how they do their jobs as systems engineer, the responses were evenly split. When asked whether they possess the MBSE skills needed to thrive in the digital engineering arena, the response was slightly more favorable. When asked whether they were leveraging continuing education opportunities to enhance their skills in MBSE and digital engineering, over 75 percent responded positively – a strong indication that at least among this sample population, the employees see the value of digital engineering and are committed to the self-improvement needed to remain productive as digital engineering processes become more commonplace throughout the engineering community.

The second workshop also incorporated a series of additional questions asking about the general timeframe that various issues associated with MBSE and digital engineering would be resolved for their organization, their customers, and the larger systems engineering community. Respondents projected that their company would likely resolve the technical and cultural issues associated with implementing MBSE and digital engineering within five to ten years, but that their customers and the larger systems engineering community would need ten to fifteen years to reach that milestone.

Automated Intelligence and Machine Learning

No discussion on emerging technologies with great potential for affecting how we live, and work would be complete without a sidebar on AI and ML. Both workshops investigated participants' perspectives on how AI/ML will be used for talent management, communications, knowledge management, workplace optimization, and decision empowerment. Although most workshop participants agreed that AI/ML will significantly improve how organizations find, hire, and retain talent, one participant described how the misapplication of AI in his organization's hiring process was resulting in the elimination of highly qualified candidates with diverse backgrounds in favor of those with more traditional experience, demonstrating how the misapplication of a viable tool can have an adverse effect on productivity. Participants also agreed that AI/ML will significantly improve how organizations capture, find, share, and maintain knowledge; capabilities that will become increasingly pivotal to success in tomorrow's technology-centric marketplace. AI/ML offer great promise in ensuring information is valid, accurate, trusted, and certified – all key attributes to an authoritative source of truth.

The second workshop incorporated a second set of timeframe-centric questions addressing various issues associated with AI/ML, again inquiring about when these issues would be resolved for their organization, their customers, and the larger systems engineering community. For the self-assessment portion of the questions, responses were primarily divided between zero-to-five years and five-to-ten years. For their customers and the larger systems engineering community, responses were primarily divided between five-to-ten years and ten-to-fifteen years. In other words, respondents felt that AI/ML issues would be resolved before MBSE/digital engineering issues.

CONCLUSION

As the global response to COVID-19 adeptly demonstrated, the only constant in modern society is change. Societal change not only affects how we live and work, but how we must lead in a technology-centric environment. This paper documents the authors' examination of how technical leaders must adapt to be successful as they juggle the many challenging facets associated with the heightened environmental awareness in an increasingly virtual, multicultural, and multigenerational work environment empowered by "smart" tools, techniques, and processes. Although the workshops were too small to collect statistically significant findings, we sincerely appreciate the qualitative insight offered by the participants which are captured herein. Those insights include the following recommendations for tomorrow's technical leaders:

- Think green in product design and development; your customers, employees, and other stakeholders demand it.
- Be intentional in building an inclusive work environment, where diversity of opinion is not just allowed, but rather encouraged.
- Break out of your thought silo by actively engaging those with differing cultural, generational, and experiential backgrounds; their insight might be the missing piece to solving your latest puzzle.
- Beware stereotyping, which can lead to diminished communication within diverse organizations and the rejection of good ideas for bad reasons.
- Become multilingual in the virtual world. Diversify your virtual communication to leverage both modern and traditional tools. You may prefer email, but your Gen Z superstar may prefer instant messaging. Why not use both?!
- Never forget that technology changes how technical leaders do their jobs, but ultimately not the job itself. The leader is still responsible for setting the strategic vision, building excitement around it, giving the team the flexibility, resources, and support to accomplish it, and providing any needed course corrections along the way.
- Remember to learn from failure and to celebrate success.

We look forward to the opportunity to expand this body of research through additional surveys and workshops in the months ahead. ■

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A Systems View of Career Development for Systems Engineering Leadership

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■ **ABSTRACT**
Systems engineering leaders' career development journeys are primarily driven by their experiences that shape their capability, qualities, and perspective; however, the pathways that individuals take are not only broad and varied, but also equally affected by personal life decisions and external factors. This paper describes a two-fold study that aimed to: a) provide insight into commonalities in the career journeys of systems engineering leaders, and b) ascertain how key areas affect career development. Five key areas were explored: education, technical experience, soft skills experience, job satisfaction, and work-life balance. A mixed and multi-method approach was taken, gathering data from sixty-one participants through interviews, surveys, and facilitated workshop. The study found that although there was no 'blueprint' that yields successful systems engineering leadership, there were themes/trends that were common. An influence model was developed to highlight these trends in the form of the key areas, factors affecting them, and the interrelationships between them.

■ **KEYWORDS:** systems engineering leadership, technical leadership, competencies, leadership development

INTRODUCTION

The INCOSE Technical Leadership Institute (TLI) is an initiative that provides support and coaching to systems engineering leaders (SELs). The TLI seeks to '*accelerate the development of systems engineering leaders who will exemplify the best of INCOSE and the SE profession*' (INCOSE 2017). Systems engineering technical leadership sits at the nexus of systems engineering and technical leadership. Since 2015, over 100 systems engineering leaders have completed and been inducted into the Institute. As part of the workshop program there is a two-year induction process, where SELs are encouraged to explore their leadership journeys and to identify projects of common concern that will provide insight and empower the leaders into pursuing the next stage of their own development.

Throughout the first year of the INCOSE Institute for Technical Leadership workshop, cohort 7 (2021-23) engaged in understanding the systems engineering technical leadership model developed as a collaborative learning initiative by the fifth cohort (Browne 2020). The second year was a chance for cohort 7 to build upon the foundation of TLI, "learning together", explore a technical leadership topic, and contribute to the greater body of knowledge. As cohort 7 embarked on a learning journey through self-awareness, leading through influence, complexity and uncertainty, storytelling, engaging emotion, and active listening there were a few questions from the group that kept emerging:

- How do you know when it's time to advance in your leadership journey?
- How much are you prepared to compromise in your personal life in order to progress your leadership career development?
- How can I reach my career goals yet still maintain the right work-life balance for me?

With each question the team leaned more towards understanding the ideas around career development/leadership focusing on, *harmony* (as opposed to balance), *stagnation* (understanding when it's time to move on), aspects that may be *additive* and *complementary* rather than competing for a limited amount of time or energy.

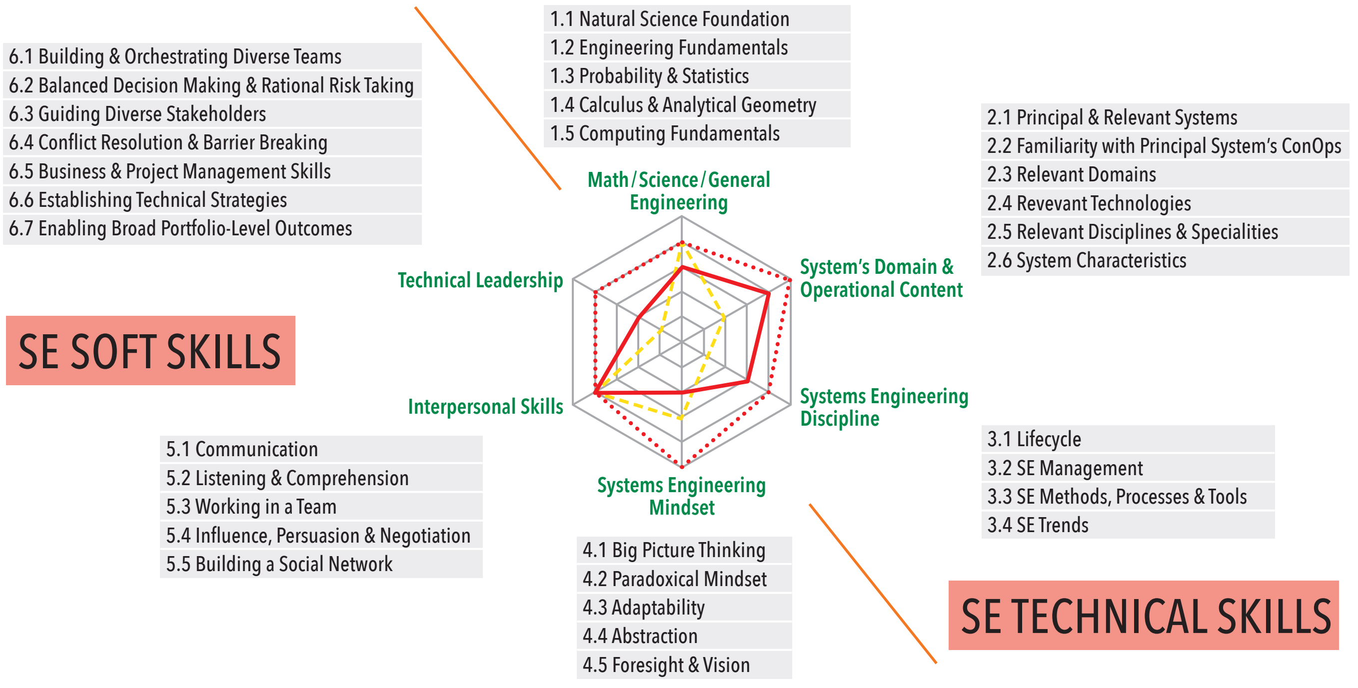

Figure 1. ATLAS 1.1 proficiencies – the theory of effective systems engineers (Hutchison 2018)

The result of this study extends the knowledge for discerning various "leadership journeys" involving the experiences that drive the strategic career development of SELs via insights into their systems engineering roles and competencies (both technical and soft skills), education and training, work-life balance, and job satisfaction. There is no single solution to a successful leadership journey and all individuals' leadership journeys are unique, both in terms of an individual's pathway, opportunities, and their working/social environment (teams, mentors, and organizations). However, breaking up the journey into inflection points and categories to create a quantitative rating will help determine if there are patterns and commonalities that individuals can gain insight from and use to avoid stagnation, create balance and purposeful progression in their own leadership journey. These ideas created the project, *A Systems View of Career Development for Systems Engineering Leadership*.

The paper is structured as follows: firstly, a brief project background is provided that explains the impetus and aims for the study, alongside a summary review of the existing literature, the project methodology is then described, outlining a traceable set of steps and methods used to ensure a fair outcome. An overview of the results from the mixed method data gathering is shown (via interviews, survey, and workshop), and a comparative and summative analysis is provided. Using the insights from the data, a systems view of systems engineering technical leadership is then presented in the form of an influence model showing the key factors affecting SEL career journeys and how they are interrelated. Finally, a discussion around the findings and implications is given and concludes with a reflection on the study's overall aims.

PROJECT AIMS

The overall aim of the project was to investigate the experiences of SELs from a broad range of domains in industry, academia, and government institutions in order to:

- Ascertain whether there are common types of career pathways
- Determine to what extent various key areas shape the experiences and development of systems engineering leaders.

Throughout interviews and a workshop, the team aimed to:

- Identify common themes and significant differences
- Co-create a shared model around these patterns, commonalities, and key learnings from a systems perspective.

The data gathered and presented addresses the professional and personal characteristics that contribute to SE leadership, concerns regarding development and stagnation, as well as ideas of harmony and change over time as personal and environmental conditions change.

EXISTING LITERATURE

Systems engineering competencies have long been an interest to define the skills of a systems engineer, and also to provide a framework for competency and career development in general (INCOSE 2018). In particular, it is recognized that in addition to technical engineering, soft skills are also essential to develop in systems engineers (Beasley 2019). Furthermore, systems engineering leaders are not simply a rebadged form of managerial role but require a specific set of leadership skills and worldview (Holzer 2014).

Whilst there are varying opinions on how best to attain and achieve competency in systems engineering, there is a growing acknowledgement that it is an essential part of engineering leadership; whether it be explicitly part of wider engineering leadership development (Crumpton-Young et al. 2010; Pitts 2013), provided as a development pathway in organizations (Ryschkewitsch et al. 2009; Holzer 2014), as taught offerings from tertiary education providers (Duliba et al. 2017; Graessler 2018), or as a standalone leadership program such as the TLI (Godfrey 2016).

In this last decade or so there have been three key bodies of work that have extended the knowledge around the development of SEL:

1. NASA's systems & engineering leadership (development) program (SELP) based on *The Art and Science of Systems Engineering* (Ryschkewitsch et al. 2009) that sought to identify competencies and skills, as well as explored the behavioral characteristics of SEL at NASA
2. INCOSE systems engineering compe-

tency framework (ISECF) (INCOSE 2018) that prepares a global baseline of roles and competencies for systems engineers to develop (having originated from the INCOSE UK chapter's efforts to define systems engineering competency)

3. The Helix project from the Systems Engineering Research Center (SERC) at the Stevens Institute of Technology, driven from US defence. It is this latter body of work that this paper draws upon.

Although the three areas of work have been derived independently, there is much cross-correlation between their findings and there have been subsequent work that show the overlaps/mappings between them, particularly the ISECF and Helix (Hutchison 2019). The field is still evolving with new competencies being proposed as the skills and needs from SELs evolve (Harding 2022).

The Atlas 1.1 Theory of Effective Systems Engineers (part of the wider SERC Helix project) describes a consistent body of research that interviewed a large sample of 335 systems engineers from 2013-2017 (Hutchison 2018). As part of the work, they identified six proficiency areas (Figure 1) collated into two main skill super-categories: technical skills and soft skills. This project builds further upon these two super-categories and focusses specifically on SELs and their experiences in attaining these types of skills rather than the total population of systems engineers.

METHODOLOGY

The study described in this paper used a mixed- and multi-method approach to the research; mixed-method through the gathering of quantitative and qualitative data, and multi-method through three different sets of data gathering approaches. The three approaches are described as follows:

1. A 1 hour semi-structured interview that involved questions led by a project team member.
2. A 20 minute online survey that was self-paced and featured a proforma of a reduced set of questions.
3. A 2 hour workshop exploring the high-level questions in a focus group style setting.

The three approaches were not strictly independent because a summary of the findings from approaches 1 and 2 were used as a stimulus for the discussions in the workshop (approach 3). For all approaches, the questions were focused around five key areas (KAs) and quantified as per metrics in the brackets shown below:

- KA1. Education (proficiency level)
- KA2. Technical experience (proficiency level)
- KA3. Soft skills experience (proficiency level)
- KA4. Job satisfaction (5pt Likert agreement scale)
- KA5. Work-life balance (5pt Likert agreement scale).

The Atlas 1.1 proficiency levels were used for KAs1-3 (see Appendix A). KAs 4-5 were derived based on the initial cohort 7 questions described in the introduction, however these were more personal-based reflections. In particular there was discussion around KA5 work-life balance; what constituted work or life (or life outside of work that is closely related, for example volunteering in a professional society) and is "balance" really about equal measures of each? As the project progressed a need to clarify the definition was required and further descriptors were used to extend the meaning to "harmony," leaving it up to the individual to assess what was right for them during their career. McMillan (2011) describe similar difficulties in expressing the work-life interface (from conflict, enrichment, and balance constructs) using the term harmony to include all these constructs. As the understanding of harmony within this project evolved during the process, the reader will find the terms "work-life balance," "balance outside work," and "work-life harmony" used interchangeably.

Semi-structured Interview. Participants were asked to identify between 3 and 5 inflection points that they have experienced during their career development. This could be a change in job or role or could be a set of pivotal milestones that shaped their careers. Data was gathered using a pre-interview questionnaire around the participant's experience, systems engineering practitioner status, and other demographics. Interviews were undertaken on an individual participant basis and used question prompts as a springboard for discussion. At logical points in the discussions and in each of the five KAs, the participants were asked to rate themselves for each inflection point so that a comparison of relative change over their career could be derived.

Online Survey. An anonymous online survey was administered using Google Forms and participants recruited via INCOSE online social media platforms such as Yammer, and the project coauthor's professional networks such as LinkedIn. The survey featured the same demographics questionnaire as the interview group; however the inflection points were limited to a maximum of 3 steps in their career, and there was a greater focus on the quantitative rating, alongside an open text field for qualitative description (rather than the full set of prompt questions that were used in the semi-structured interviews which would take too long for a self-paced online survey).

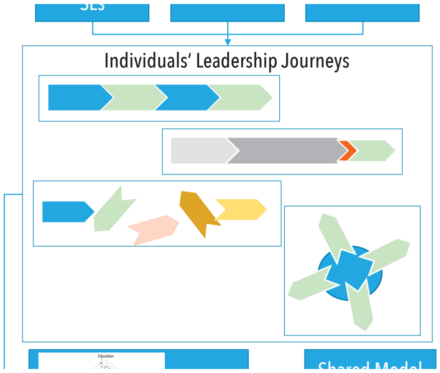

Figure 2. A systems view of systems engineering technical leadership study methodology

Workshop. An online collaborative workshop was held in September 2022 with participants invited from the previous and existing TLI cohorts and coaches. Small focus groups were created using zoom breakout rooms, with each room discussing one of the KAs.

Reviews of the three data sets were undertaken by the project team, with a grounded theory approach adopted, using inductive reasoning to draw out patterns, concepts, and interrelationships between them. This was then used to develop a shared model of systems engineering technical leadership in the form of an influences model.

Figure 2 depicts the methodology described in this section. In summary, the team started with the TLI cohort 7 questions, the Atlas theory of effective systems engineers and our own personal experiences. From there the team gathered input from other systems engineering leaders. Due to the uniqueness of everyone's individual stories, the data gathered varied from orderly and linear to chaotic (as shown in the arrows in Figure 2). Ultimately, this data is used to develop the shared model discussed later in this paper.

DEMOGRAPHICS

A total of 61 individuals participated in the study, with participants fairly evenly spread across the three different methods (interview, survey, or workshop). Table 1 shows a summary of the demographics of the participant population. In terms of gender diversity, the interviews and workshop were slightly skewed towards male attendees, however the online

Table 1. Participants overview

	Approach 1: Interviews	**Approach 2: Online Survey**	**Approach 3: Workshop**
Participants (N)	19	20	22
Male-Female Ratio	58:42	94:06	55:45
Mean Age (years)	51	47.5	n/a
Career Duration (min-max years)	10-46	3-42	n/a
Mean Career duration (years)	27.46	22.45	n/a

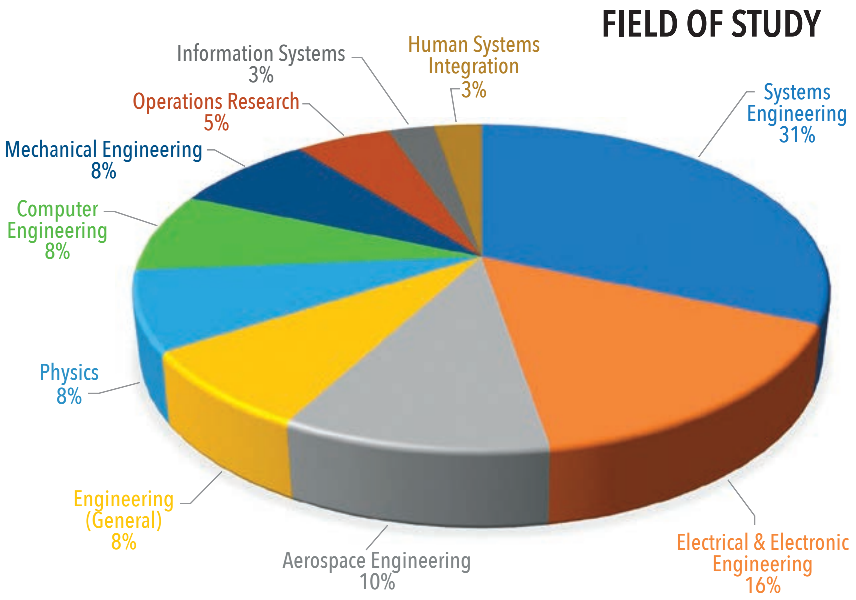

Figure 3. Field of study of interview and survey participants

survey saw only 1 female respondent. The interview group was on average marginally older and more experienced than the survey group. [NB Workshop participants were not required to complete the demographics form]. Figure 3 shows the background of the interview and survey participants according to their qualification field. Unsurprisingly, the highest grouping was those who studied systems engineering, followed by various other engineering disciplines; physics, computing, operations research, and human systems integration.

RESULTS

A total of 19 interviews were conducted between August and September 2022 across a cross-section of SELs ranging from 10 to 46 years of systems engineering experience, from a range of industry sectors, government, and academia. A template was created to guide the interviewers and provide a consistent recording mechanism to gather the data. After conducting the first sets of interviews, the team undertook a mid-project review of the data and benchmarked between interviewers to ensure a consistent approach. After all the interviews had been performed and recorded, the team aggregated the data from the interviews into one common location in order to identify common themes and significant differences between the results. Radar charts were also created to serve as a visual representation of the data obtained during each interview. Examples of two radar charts that were produced to assist with the visual/qualitative results can be seen below in Figure 4. After combining the data all of the radar charts were organized together so the team could visualize the results by comparing the differing shapes and sizes of the charts. This helped provide a holistic view of the data and allowed general discussion of the results prior to detailed analysis of the quantitative results. The qualitative data was important to discuss as there were numerous factors that were learned throughout the interviews that could not be assigned a value, such as whether the interviewee was involved in academia, a professional organization or industry, or if they were formally trained as a systems engineer versus growing into a systems engineering role throughout their career. A summary diagram showing more of the radar charts can be seen in Appendix B as well.

The biggest trend that was noticed across all the radar charts diagrams was how different they all looked – there were a few trends that looked similar, but in general everyone's diagram was very unique and showed how much career paths vary from person to person. It was also interesting to see how various people broke down their careers into inflection points - distinguishing these anywhere from number of years within job titles, to programs worked, to changing companies. Everyone had a different definition of how inflection points applied to their careers which made it interesting (and at times challenging) to compare all the interview results.

The team noted a few commonalties after looking at the radar chart results between all the interviews:

Education (KA1) increased as people progressed through their careers/inflection points. Education also did not tend to decrease over time, meaning most people continued in their education and applied it to their daily work throughout their entire

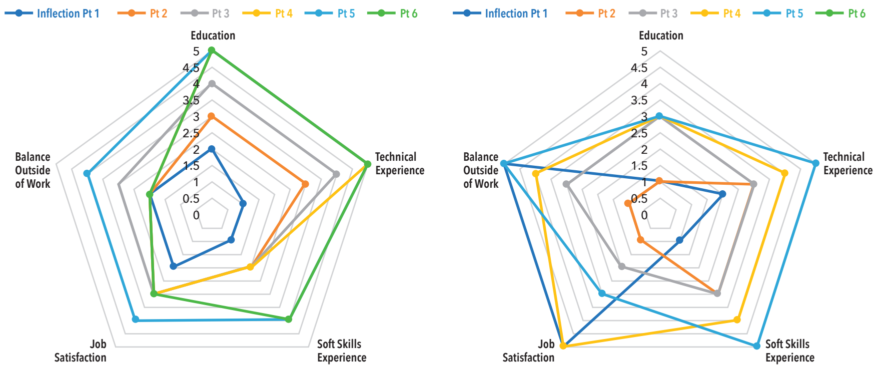

Figure 4. Example radar charts for two contrasting interview participants

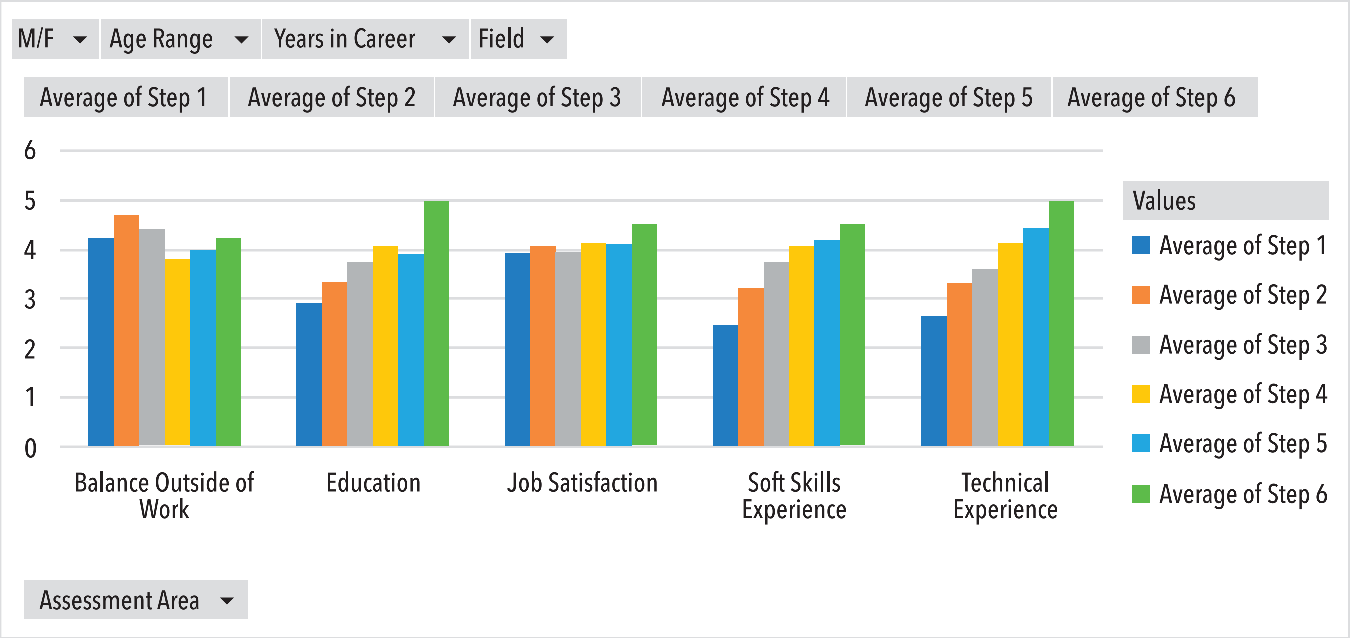

Figure 5. Data separated by key areas

career. *Technical experience (KA2)* increased as people progressed through their careers/inflection points as well, meaning people were constantly learning new things with respect to their technical paths and were always progressing with on-the-job training. They were less likely to lose those skills over time, therefore the radar charts did not show many decreases in technical experience. Technical experience was also prone to grow the most early on in peoples' careers, similar to education – most people learn the most early on in their careers with respect to formal education and on the job training. Later in careers, people's focus switched more to building *soft skills experience (KA3)*, which were prone to be the inflection points where people transitioned into more leadership roles. Some of the most interesting data trends fell within the *job satisfaction (KA4)*, where this category tended to be the highest (best job satisfaction) later in peoples' careers (higher inflection points). This is most likely due to people figuring out what they want to do in their careers early on, starting with less appealing jobs but setting goals and reaching toward jobs that actually appeal to them later in their careers. With this increase in job satisfaction, however, comes a variation in work-life balance. *Work-life balance (KA5)* varied quite a bit over most people's careers. It was hard to visually identify trends in this category. It was recognized that this category had contributions based not only on people's career inflection points, but also what was happening in their personal lives outside of work (that is, starting a family, moving, starting a new hobby, etc.).

Overall Observations

In general, a few "big picture" trends were observed:

1. Whichever direction the radar charts "leans" toward or away from (that is, one assessment area tended to have higher/lower values assigned to it overall) tended to show what the interviewee prioritized in their life. For example, the diagram in Figure 4 above on the right leaned "away from" education, which aligned with that person's focus throughout their career on having a mentor and on the job training rather than formal education.
2. It can be concluded that the method of ranking also affects the results – people tend to not rank below 2 (novice or disagree). The maximum value of 5 was presented for all 5 areas in all inflection points, but the lowest rank has not per-se been 1. Respondents have not ranked below 2 on *work-life balance (KA5)* and *job satisfaction (KA4)*, and the average minimum over the remaining key areas *(education (KA1)*, *technical experience (KA2)* and *soft skills experience (KA3))* is also around 2.
3. The inflection points were hard to compare as there was limited to no consistency between the various interviewees. They were all varied with respect to job position and time duration in career, making it difficult to draw inferences across various radar charts.

In order to get a deeper look into the data, however, more quantitative analysis was performed on all of the interview and survey data to arrive at better conclusions and trends with respect to the 5 KAs and how they changed over peoples' careers/inflection points. Details of this analysis and how it was conducted will be described more in the Analysis section.

ANALYSIS

In order to dive deeper into the data, the team assembled all data collected from interviews and surveys into a single data set. The plot below depicts all assembled data as averages at each inflection point (called a "step" in the chart below for brevity) of a respondent's leadership journey.

The trends discussed in the interview results section above are generally true within this data as well. We see a steady increase in *education (KA1)*, *technical experience (KA2)* and *soft skills experience (KA3)* throughout all inflection points. However, the team did observe some differences from the previous discussion in interview results. Ratings within *soft skills experience (KA3)* increase the most in earlier infections points which differs from the earlier discussion. The chart above shows an increase in *soft skills experience (KA3)* of 0.76 rating points which is the second largest increase of any category between any step. The team assessed that this early growth in soft skills is due in part to the definition of the first inflection point by interviewees. Those first one or two inflection points were often when interviewees began to transition from individual contributor roles to roles that

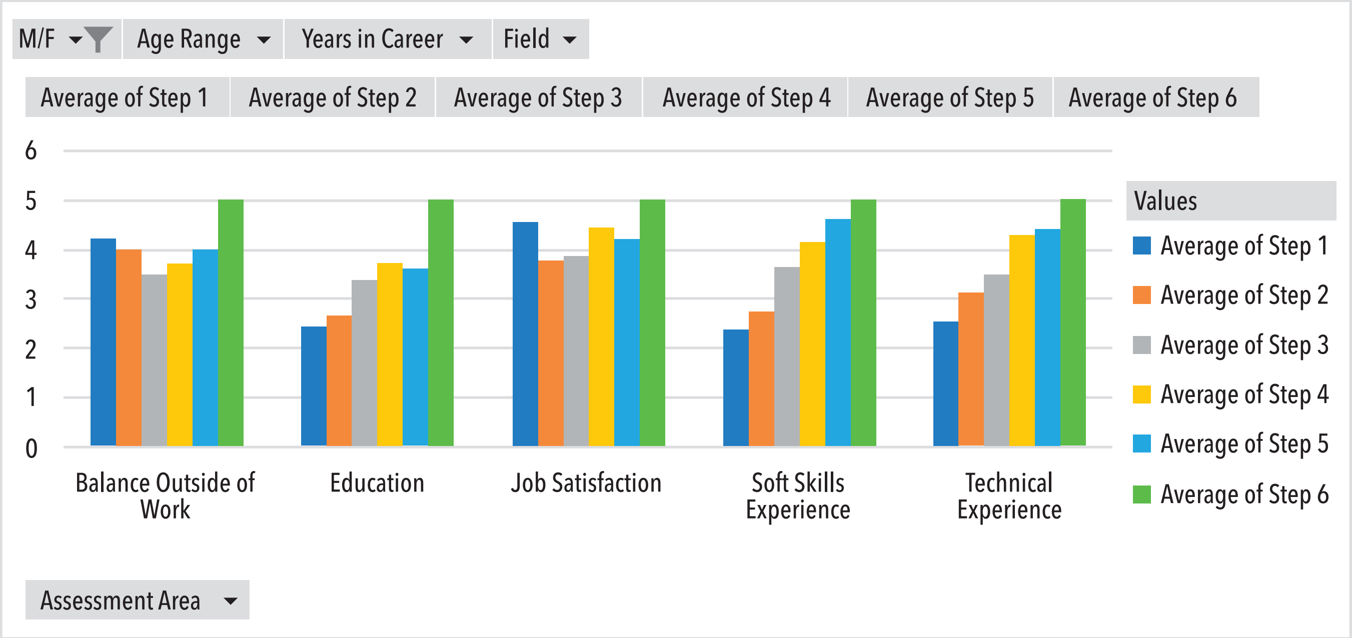

Figure 6. Data filtered by female respondents

had more interaction with other groups or were moved into small leadership roles. This ultimately led interviewees to assess the need to improve soft skills with these new roles.

While *soft skills experience* (KA3) jumps more in early inflection points, *education* (KA1) ratings had a large jump in the 6th step/inflection point with an increase of 1.1 rating points. This is the largest increase in the dataset. The discussion in a subset of interviews indicated that early career leaders were focused on increasing technical experience and soft skills that were directly related to their role within their company. Once those skills reached a higher rating, participants then desired to expand their education.

Neither *job satisfaction* (KA4) nor *balance outside of work* (KA5) showed the same increase as the other categories. Interestingly, *balance outside of work* (KA5) was the only category that showed a significant decrease between inflection points with a decrease of 0.3 points between steps 2 and 3 and a decrease of 0.6 points between steps 3 and 4. Interviews seemed to indicate that this decrease was a result of increased responsibilities and the desire to grow as a leader within the associated new roles. However, over time, this yielded to more balance throughout interviewees lives as seen by the subsequent rise in the *balance outside of work* (KA5) rating.

The discussion in this section generally holds true when filtering the data on different age ranges, industry and gender. For example, the plot below shows female responses to surveys and interviews. The trends observed in this plot are largely the same as the plot above, albeit with different magnitude of changes to the size of between inflection points. Of particular note, the *job satisfaction* (KA4) rating for our female participants decreases .78 points between steps 1 and 2 which is larger than any single drop observed in all of the unfiltered data. The magnitude of these changes, particularly in mid-career *job satisfaction* (KA4) among our female participants warrants future investigation but is not discussed in this paper.

Workshop Outputs

A two-hour workshop was held in September 2022, with 22 participants drawn from the population of TLI past and current cohorts and the TLI coaches. Following a brief overview of the project and introduction to the methodology and draft results, a facilitated focus group approach was used via a Miro online collaboration board. Four main activities were undertaken by the group: i) an icebreaker activity around effective SELs, ii) focus groups on each KA, iii) small-group storytelling and self-reflection, and iv) shared model building around systems engineering leadership. The first two activities are described within this section, activity and the shared model building is described in the following section. The storytelling and self-reflection are not within the scope of this paper as these were personal in nature and are not described explicitly (although some aspects have been used within the overall discussion).

Ice breaker activity. The participants were posed a starter question ‘what makes an effective SEL?’ and asked to add short one-to-three-word immediate responses, following this they were given up to three votes to place upon the full set of words added to the board by all the attendees on those aspects they perceived as most influential in effective systems engineering. Figure 7 shows the output word cloud, It can be seen that being an ‘active listener’

Figure 7. Word cloud – what makes an effective SEL?

Stimulus Questions:
1. Did you feel you learned your technical experience on the job?
2. Did you feel that your education was useful in your job?
3. Was there a point in your career that you felt you had "sufficient" technical experience? A defining moment?
4. How have you increased your technnical experience/proficiency throughout your career?

Different phases of the program life cycle and how decisions effect down stream.

Enhanced technical experience by doing stretch assignments

Increase in proficiency throughout career has come through diversity of problems, application domains, and experiences. Key driver was leveraging INCOSE for greater connection to global community (where global is far more than just geographic)

There was a point where knew the basic process – but my company wanted me to expand into small team leadership, to achieve SE goals: reviews, create and revise technical documents w/ a team, etc.

Formal education taught us how to learn but "sufficient" technical experience can only last so long before reaching for the next step (enhance and grow)

I "honed" my tech experience on the job, building upon academic foundation. The "sufficient" questions implies "sufficient…for what?" I do feel like there have been times in every assignment where my tech experience is sufficient for that job, but never quite sufficient for the next one or the next promotion. In the Air Force, I have been able to routinely add to my technical education, which led to opportunities to increase my tech experience/proficiency

I am doing nothing of what I technically learnt in my undergrad and grad school directly howeber there were many skills I learnt along the way that helped me

My Maths degree has given me a unique perspective and approach to problem solving — I've been able to use that nearly daily.

I took SE classes, and am doing SE work. Taking SE courses, staying active in INCOSE, reading up on SE Handbook

(1) Education provided the foundation, but the real technical experience came on the job itself. "Systems engineering is a contact sport"

I felt I learned my technical experience on the job. I feel I learned where to find material and how to learn in school.

By being close to the product–walkaround/touch & feel instead of demos

It was very helpful to learn the technical experience OTJ, It is also necessary to learn new technology through my job.

Technical experience by doing both in my job and through INCOSE events/webinars.

Mandatory corporate training with modest budget, but that tends to shrink over time, hence some training is up to me. They do recognize and appreciate, that I take initiative on training – and especially that I share it with others back at the desk. Same with participation with INCOSE – they are glad I do it, will fund some of it – otherwise, all on my own time.

I find I need to boost my technical expertise, in MBSE, traditional SE topics (mod/sim) – even Lean/6sigma processes; My workplace is more development focused and wants more leadership.

Moving out from under my mentor and stretching my legs on my own, I feel that is when I had a turning point in my technical experience

Figure 8. Workshop output – technical experience in systems engineering technical leadership

and 'good communicator' were deemed of most influence along with a more specific systems engineering attribute of having a 'big picture understanding.'

Focus group activity. The participants were randomly assigned to four breakout rooms (4-5 members per group + 1 facilitator from the project team). Two teams discussed I (KA2), one team discussed *soft skills experience* (KA3) and one team discussed *balance outside of work* (KA5). The groups were given the same stimulus questions that the interviewees were given as a springboard to discussion. Participants were asked to i) reflect on the questions, ii) add 'sticky notes' onto the shared Miro board with their thoughts, and iii) verbally discuss as a group around the contents of the 'sticky notes'. Following the breakout group activities, all workshop attendees were brought back into the main group and each focus group took turns to share and summarize the discussions they had.

Figures 8, 9, and 10 show the outputs from the focus groups. The 'sticky notes' are those created by the participants, these were then synthesized by the project team later to identify key themes and connections between the concepts discussed. 'Sticky notes' are shown in colored notes (colors are arbitrary), and derived themes in bold font.

The discussion around *technical experience* (KA2) (Figure 8) followed similar themes that had been identified in the interviews and surveys. In general, the systems engineering technical skills described in Atlas were gained through a combination of technical or systems engineering education in conjunction with on-the-job training. Due to the range of educational backgrounds some participants did not believe that their technical education field was useful to their systems engineering career, but they had gained skills through their ed-

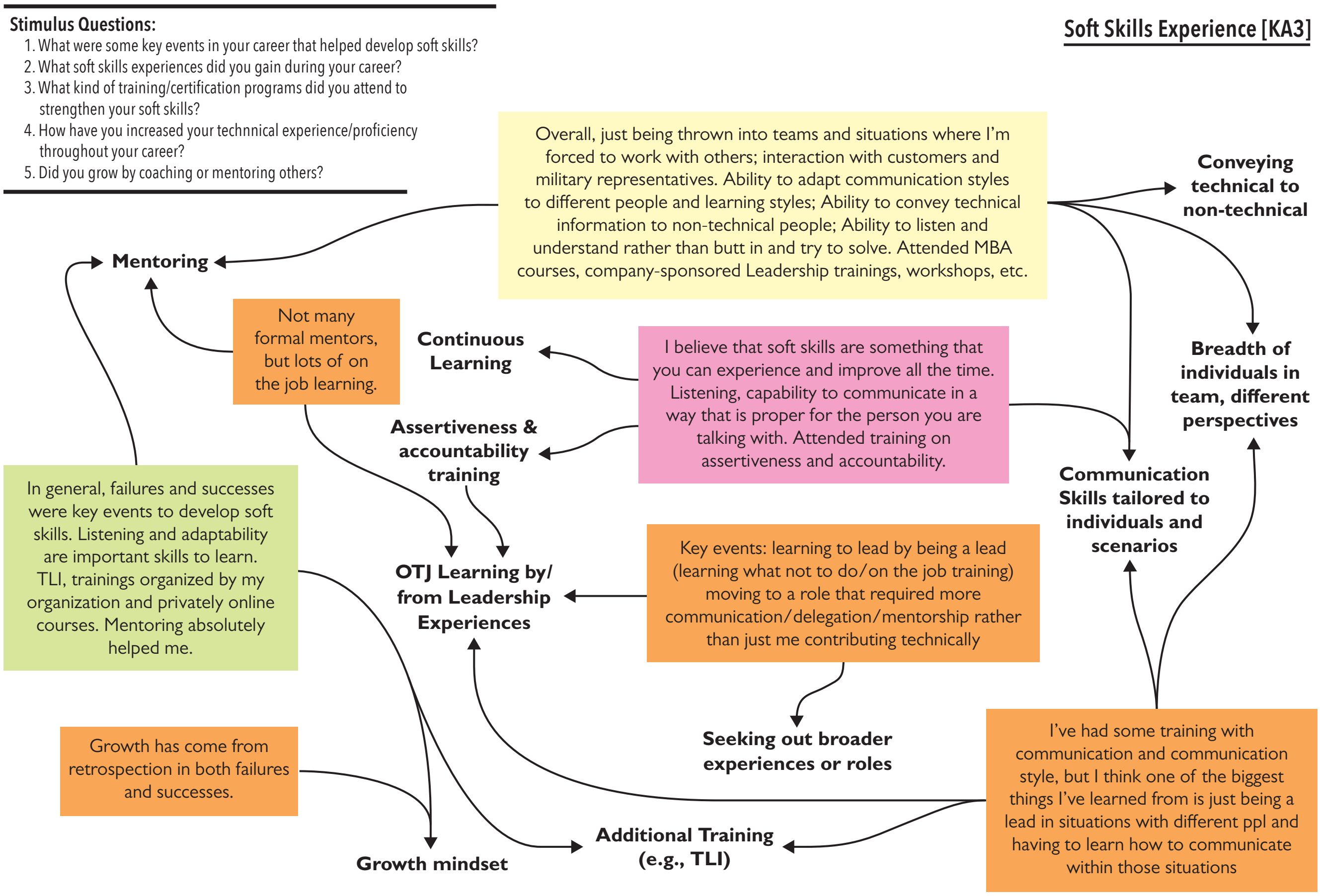

Figure 9. Workshop output – soft skills in systems engineering technical leadership

ucation that could be translated. Further to on-the-job training, there was also an acute feeling that technical skills development requires exposure to tangible and varied technical work and contexts and could be planned to "stretch" or extend the individual. There was also an appreciation that a lot of the systems engineeering technical skills could not be gained only through work activities, and education/training via INCOSE offerings were a common mechanism (however the use of these tended to be self-initiated by the individual).

The *soft skills experience* (KA3) focus groups (Figure 9), although independent of the *technical experience* group had some overlap in themes such as on-the-job learning and seeking out of different experiences to grow. However, it can be seen that soft skills do not tend to come from education, other than specific training courses. There was a mixture of soft skills that were identified with some more internal to the individual (for example, assertiveness) and some more external-facing improvement (for example, communication skills). There seemed to be more proactiveness in terms of learning themes such as continuous learning and growth mindsets.

Balance outside of work (KA5) is a common concern for many leaders, in particular finding the right level or harmony that is "right" for the individual at that stage of their life and career (Figure 10). This group identified many of the tensions that exist in maintaining an acceptable balance. Worryingly, many in this group were 'volunteering' their out-of-work hours to complete work, whether that be through heavy workload, or through competing priorities during the day (for example, supporting your team during the day and resorting to 'catching up' with work after hours). The group also identified some potential advice for maintaining balance through time management, limiting activities/commitments, and communicating a healthy cut off time when work is not expected to be done. Caring responsibilities and flexible work were also concerns.

The themes and relationships identified during the workshop, alongside the interview and survey qualitative findings were then used to develop the systems model of systems engineering leadership described in the next section.

MODEL-BUILDING

During the workshop the project team leveraged the concept of causal loop or influence diagrams to further describe the relationships between the identified key areas. The diagrams help model the relationships between elements in a system and those relationships influence the behavior of the system over time. They aid in representing the mental models we hold and enhance learning of the dynamic nature of complex systems. As can be seen from the analyses, the radar charts above indicate that each respondent had a unique career development as a SEL. The project team facilitated a shared model build exercise considering career development as a complex system and mapping out various factors that influence the identified key areas. An initial model (Figure 11) was provided to the participants as an example to build upon.

The workshop participants were guided to identify variables that influence the key areas that were centrally placed in the diagram space. Once the variable was identified and placed in the variable space, the participants were asked to link the variables to one or many depending on their influence. Sometimes in our mental model we have one-to-one correlation, but when represented diagrammatically we are able to identify correlations one to many or vice versa. It was also discussed whether the link connecting the two variables is a positive or negative influence. The polarity of influence

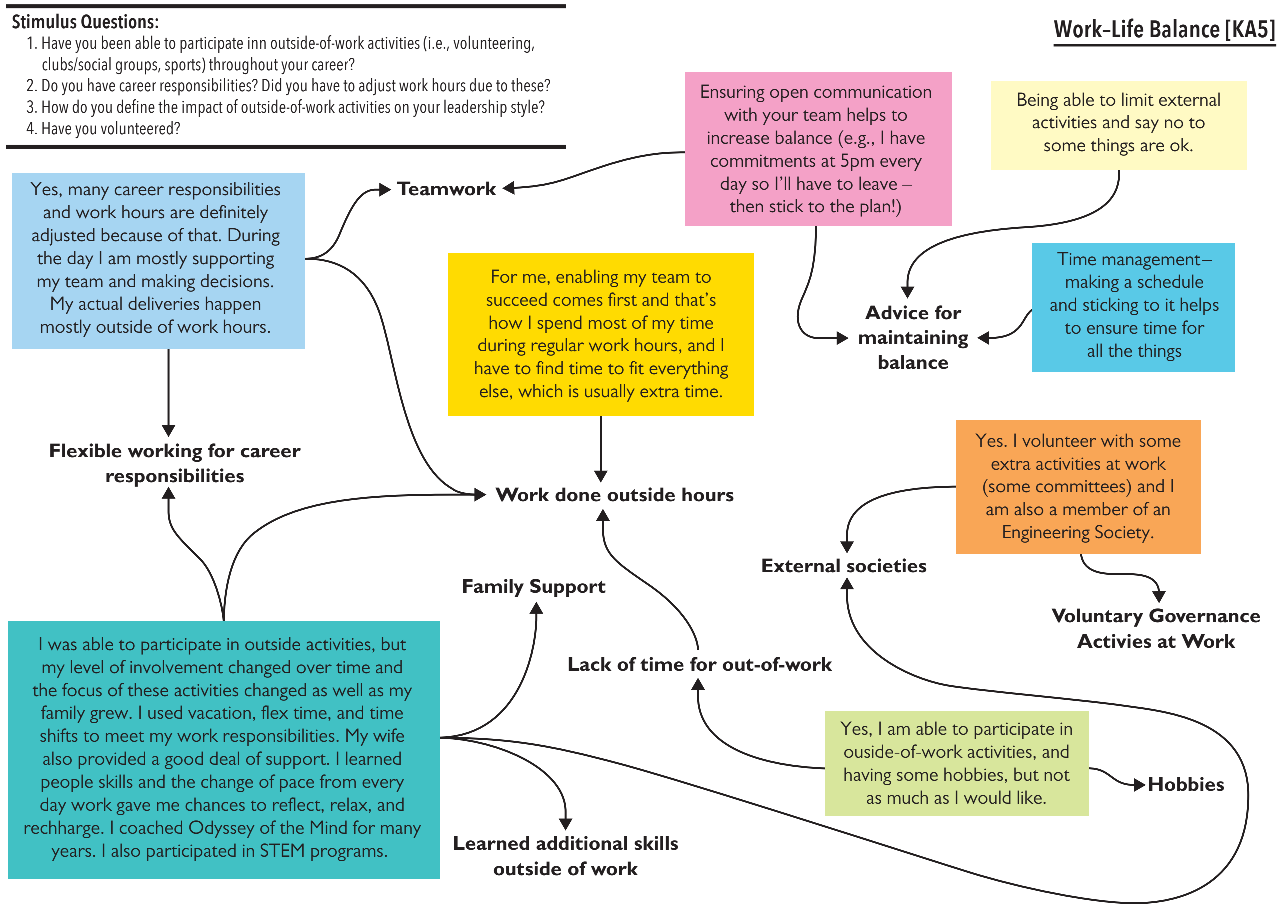

Figure 10. Workshop output – balancing outside of work in systems engineering technical leadership

is not added to the current scope of work, only discussion was enabled. Similarly, weightage of dependency is not identified at this time as this is an initial study through interviews, surveys and workshop discussions. When more data is available the links between the variables can be provided weightage based on trends observed.

Figure 12 describes the influence diagram developed based on the discussions in the workshop as well as other methods of data gathering. From the diagram we can draw the following inferences:

- Day job alone does not make one an effective SEL
- On-the-job training is the most popular way to develop experiences
- Continuous learning through education or via coaching and ment oring is recommended
- One can plan a career path trajectory but chance encounters can bring opportunities as well.

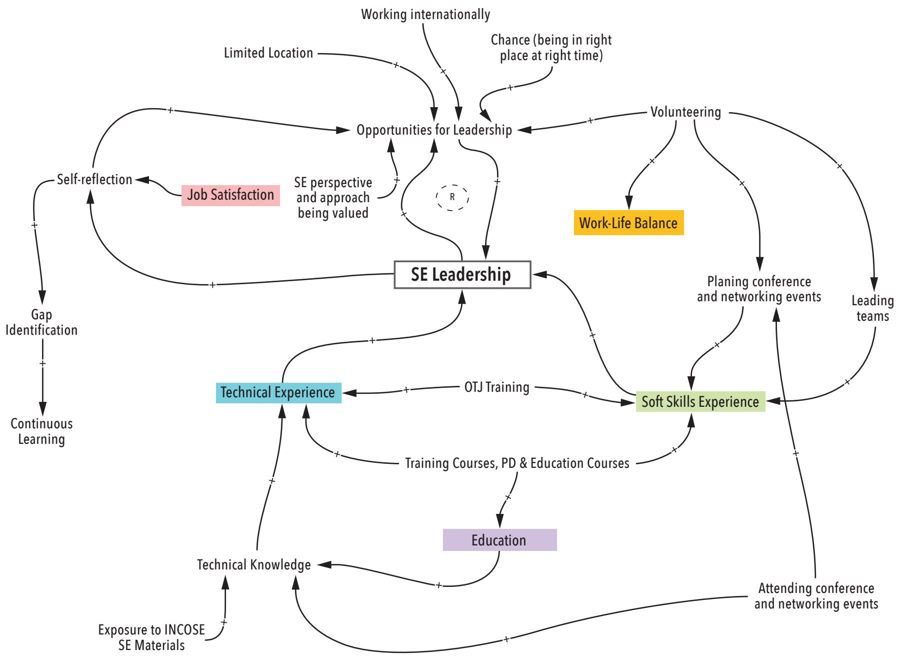

Figure 11. Initial model

DISCUSSION

This paper aims to provide *a systems view of career development for a systems engineering leader* by conducting a literature review, specifically the SERC research contributions on Helix and Atlas, identifying the gap between literature, and our personal learnings from TLI to form a new research idea, fill the gap by research – in our case by conducting semi-structured interviews and additional surveys, to finally sharing and validating our results with our target group via a workshop converging in a single shared model.

Our literature research (presented in section *Existing Literature*) identified a number of relevant research areas and

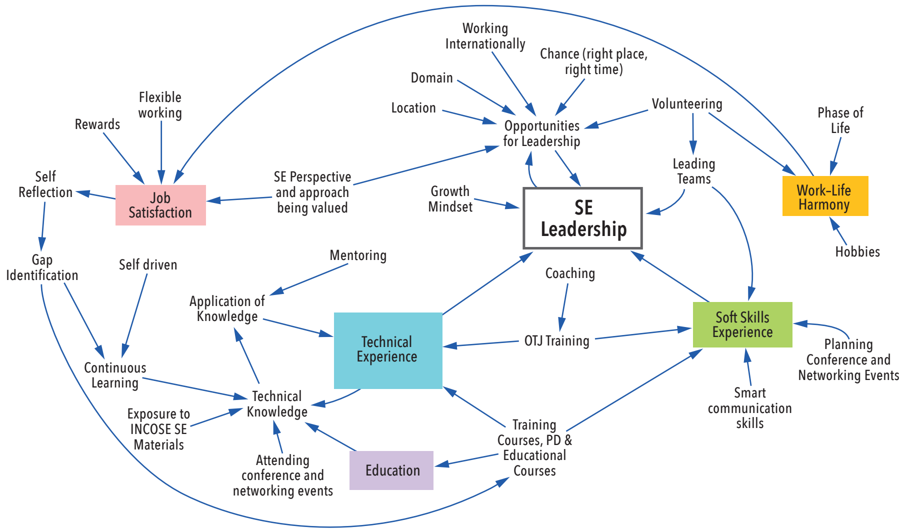

Figure 12. SEL influence diagram

methodologies for measuring systems engineering leadership growth. By combining our interest in the TLI cohort questions with literature, two (2) new axes for measuring leadership growth were proposed to provide additional context to the studies performed in the context of Atlas and Helix: *job satisfaction* (KA4) and *work-life balance* (KA5). During the semi-structured interviews and workshop, it became evident that there was a common struggle to find harmony between an individual's private and professional lives. Most of the people interviewed – either via ranking low or providing more details in their way of answering, presented this challenge within the axes of *job satisfaction* and *work-life balance*. During the workshop the initial model was tuned heavily towards the effectors of work-life balance, namely hobbies, phase of life, and volunteering. The effectors of *job satisfaction*, centered around flexible working, rewards, self-reflection, self-drivers, and systems engineering perspective and approach being valued.

Improving harmony is also shared via a conscious choice of family or work based on what is appropriate for the individual at that point in their lives and careers. For example, deciding to focus heavily on a professional career at the earlier stages gave way to seeking a different form of harmony at later points in life when individuals had families. Work-life balance was mostly viewed as positive or negative, and their experiences shaped the participant's overall satisfaction in life, with some consciously identifying changes in career (inflection points) as a strategy to remedy the lack of harmony.

Our expectations were not to validate a fixed statement or hypothesis, such as "the way to find harmony between private and professional life is…." Or "how have you continued development even at later stages of your career?," but more to become reassured in the fact that there is no given track; humankind, SELs specifically, solve their challenges creatively and consciously. At the outset of the project, it was anticipated to find varied opinions and outliers during the interviews, however not many presented themselves. An exemplar outlier are the results from interviewing a SEL, who presented a "2" on *balance outside of work* for most inflection points, including his current. The interview shows reasoning for this number.

The interview process itself has also been evaluated and improved during the first interviews. We concluded that an interview team (minimally two team members) was more effective than a one on one interview. One team member would focus on the interview while the second or third would take notes and present the final results for evaluation. The interview questions template proved useful for openness to those interviewed, however also distracted some. As a result, keeping pace was difficult. Our focus was to find the nuance and capture the experiences of experienced SE leaders, this meant that the one-hour timeslot was often overrun.

The team wanted to gather additional data from outside our immediate networks in order to get a broader view on career development for SELs. The quantitative results (radar charts) from the online survey were compared to those from the interviews. The survey was more challenging to piece data results together because it was left up to the survey respondent to choose how many inflection points they wanted to provide. Because the survey was not as guided, 19 out of 20 participants only focused on one or two specific inflection points rather than inflection points across the spectrum of their entire career, making it impossible to ascertain which were equivalent points.

The SERC Helix project describes the challenge for systems engineers to identify key training, and the benefit of training opportunities that really stood out as helping develop further. These included trainings such as week-long leadership retreats or two-week rotations into other parts of the organization. Theoretically our interviews could've shown inflection points around a training that has been particularly impactful, however this has not become apparent during our study. This suggests future work, especially while Helix points out unclear career paths for systems engineers. Defining inflection points themselves showed difficulties. The team had to evolve the interview methodology after the initial pilot interview, by providing a stimulus set of questions to provoke thought around suitable inflection points ahead of the interview and spent the first quarter of the planned interview time to really focus on the definition of inflection points together. This change led to better defined inflection points, but might have also introduced additional bias (for example, after the change, participants were more likely to choose inflection points that chronologically matched their job position changes, but epoch of a job is not necessarily a good indicator for growth as it can depend on external forces and types of roles). By forcing our stakeholders to think into the fixed 4 to 6 inflection points it might be that we've missed less significant – or over defined – datapoints. Further work is required to ascertain the appropriate level of granularity in addition to identifying a way to provide consistency across the various interviewees to assist with comparisons. A suggestion for improvement on this topic is to provide literature, possibly a white paper, upfront of such interviews to help the interviewee in thinking ahead and preparing, but also not leading them towards the strict number of points. A clear limitation is the limited number of interviews which has led to a statistical problem. By calculating the standard deviation (sample standard deviation) and variance (data type, text, and logicals removed) from our survey and interview data, it must be concluded that the dataset does not hold statistical significance. The StdDev and Var are around 1.0 and 0.5 where the dataset ranges from the values 0 to 5. Therefore, the previous and following findings must be seen as trend analysis and not significant statistically.

The literature research and collected data have been used to inform our thinking on a systems view of career development for a SEL resulting in the creation of a shared model, which was validated during a 2-hour workshop with TLI alumni and coaches. Introducing our principles during the first part of our workshop helped to guide towards the final exercise, by 5-person breakout groups toward to final exercise: namely to improve our shared model. By using Miro^{TM}, an online visual collaboration platform, we've been able to creatively and commonly work on a single model. Working together with alumni helped to find gaps in the initial model and fine-tune it toward the experiences and perceptions of those that took part in the workshop. The SEL influence diagram presents these results.

Four important limitations exist for this study: i) the sample size of participants was limited (N=61), if systems engineering practitioner (SEP) status is used as a proxy to the population, there are 365 registered expert SEP (ESEP) and 2,371 certified SEP (CSEP) worldwide (INCOSE 2022), therefore our study represented <17% of the potential ESEP population or <2% of CSEP/ESEP combined), a minimum sample size of N=93 participants would be required to meet 95% confidence level (at 10% margin of error), ii) there is potential homogeneity in the population, particularly in the workshop where the attendees were constrained to being INCOSE TLI members, iii) the variability in self-rating scores made it difficult to truly compare different individuals (for example, individuals tended to rate themselves based on their current worldview so those who reflected on longer careers might have rated themselves lower relatively at the earlier stages of their career than those who were mid-career, and iv) the variability in career lengths and numbers of inflection points meant that one person's point/step was incomparable to another's (this was particularly acute when comparing interview data with survey data).

Possible future research in the field of systems view of career development for a systems engineering leader lies in the expansion or continuation of the principles presented in this paper. By conducting a higher number of interviews (or other means of data collection) to form a statistically sound dataset our analysis can move from trend to proven. From our interviews and workshop, we conclude that what we're presenting is recognizable for current leaders but also relevant for future leaders from INCOSE.

CONCLUSION

This understanding a study undertaken as part of the INCOSE TLI designed to provide insight and understanding into the career development of SELs. Building on the work of the Atlas project, a series of measures were derived in five key areas: *education (KA1)*, *technical experience (KA2)*, *soft skills experience (KA3)*, *job satisfaction (KA4)* and *work-life balance (KA5)*. A mixed and multi-method approach gathered data using semi-structured interviews, online survey, and an online workshop. The project has shed light into the key areas and how they influence the development of systems engineering leadership, and a shared influence model has been developed as an output. Although it was acknowledged that each of the key areas are important in career development and a shared model was derived using the common interrelationships, the project did not find consistent patterns in terms of leadership pathways and growth, therefore it is fair to suggest that systems engineering leadership development is very much an individual process of experiences, opportunities, preferences, and decisions that shape the ongoing capability and outlook of the SEL at any one point in time during their career. In conclusion, this is best demonstrated by readdressing the original questions that were the impetus of the study:

How do you know when it's time to advance in your leadership journey?

— You don't. You should be prepared to jump when opportunities arrive.

— Once you're at ease make sure to move on. Place yourselves in challenging environments to test and prepare.

How much are you prepared to compromise in your personal life in order to progress your leadership career development?

— Work funds private [life] however I only realized this later in life.

— For me my professional life is what matters most.

How can I reach my career goals yet still maintain the right work-life balance for me?

— Life lessons contribute to successful leadership (for example, self-evaluation and communication).

— Volunteering helped to compensate for the lack of work-based leadership opportunities.

The study is a significant piece of work that extends the current knowledge around systems engineering competencies in technical and soft skills development to wider systems engineering leadership career development factors that are focused on the experiences of how SELs have developed and personal factors that have driven their careers such as job satisfaction and work-life balance. The beneficiaries of the research are organizations seeking to develop systems engineering leaders, the systems engineering leaders themselves to enable self-reflection in their careers that will inform both decisions for planning new experiences and maintaining harmony with their personal lives/needs, and finally the wider global population of systems engineers to be nascent that there are varied and different paths to systems engineering leadership. ■

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[Editor: Author biographies were current when the paper was initially published in 2023.]

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Jonathan Keim. I was born and raised in the suburbs of Atlanta, GA. I obtained my bachelor’s degree in aerospace engineering at the Georgia Institute of Technology. After college, I accepted a job in the aerospace/defense industry as a system engineer in the Denver, Colorado area. I’ve spent the past twelve-plus years in the aerospace/defense industry at Raytheon and more recently at Ball Aerospace. In Colorado, I met my amazing wife, Natalie. We have two boys: Ethan (5 years old) who is incredibly energetic and questions everything and Jameson (1.5 years old) who is bright eyed and smiling a ton. In my (quickly disappearing with the newborn) free time I enjoy working out, rowing, reading, and playing my guitar.

Grace Kennedy is a research fellow in systems engineering in the SMART infrastructure facility at the University of Wollongong researching applications of MBSE for the Australasian rail industry. Grace holds a master’s in systems engineering from Loughborough University, UK. She has expertise in organisational systems engineering (modelling enterprises as systems, in particular the integration of “soft”/human aspects of organisations into these models). She started her career working in Air Systems at BAE Systems, UK. Prior to immigrating to Australia, Grace was a researcher at the Systems Engineering Innovation Centre at Loughborough University. Grace is a CPEng (systems engineering) through Engineers Australia and has attained CSEP status with INCOSE. She is a cochair of the INCOSE Human Systems Integration Working Group. Grace is a member of Engineers Australia, INCOSE, IEEE and the Human Factors and Ergonomics Society of Australia (HFESA). She is currently undertaking a part-time PhD investigating the application of MBSE and digital engineering for organisational change through the lens of organisations as systems.

Brandi Opland. I specialize in requirements and verification engineering. With 12 years of in industry experience and a master’s in systems engineering from John Hopkins University, I understand the complexity of requirement traceability and the multi-disciplinary aspect of it. It has become my passion to document, mentor, and continue to learn how each program balances the right amount of rigger via risk, scope, cost, and schedule for a systems engineering solution that increase efficiency and communication between all team members, both internal and external. I believe that a key to successful systems engineering is not only validation of the product, but validation of the process.

Yoeri Ramon Sigterman is an engineering delivery manager at Thales Nederland B.V. His formal education is industrial design engineering and bio medical engineering at the University of Delft, Netherlands. After experiencing project management in the automotive section he was intrinsically motivated to learn more about systems engineering and how this discipline provides guidance in complex development projects. He is part of twins; our parents decided to name the first born Yoeri referring to Yuri Gagarin the first cosmonaut to journey into outer space.

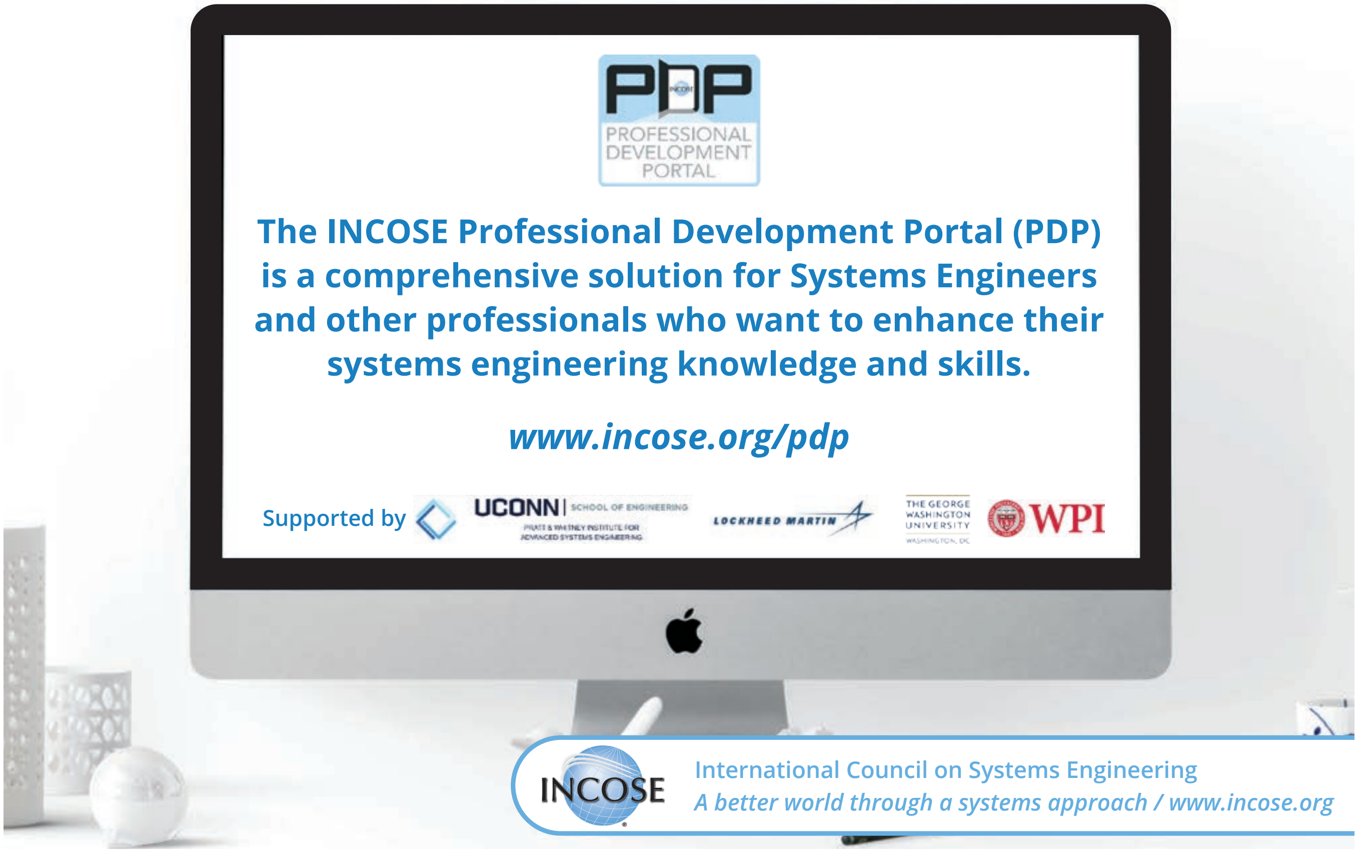
Brandi Wingate is a systems and test engineer at Ball Aerospace, working 10 years on various roles for the company. She graduated from Penn State University with a B.S. in aerospace engineering in May 2012 and earned a Masters in systems engineering from the University of Colorado – Colorado Springs in August 2020. She joined Ball Aerospace as a systems engineer in August 2012 and transitioned into test engineering in 2018, working on numerous spacecraft payload and bus programs within the national defense and civil space. She lives just outside of Boulder, CO with her husband and daughter!

APPENDIX A

Table 2. ATLAS 1.1 proficiency levels (Hutchinson 2017)

#	Level	Level Description
1	Fundamental Awareness	Individual has common knowledge or an understanding of basic techniques and concepts. Focus is on learning rather than doing.
2	Novice	Individual has the level of experience gained in a classroom or as a trainee on-the-job. Individual can discuss terminology, concepts, principles, and issues related to this proficiency and use the full range of reference and resource materials in this proficiency. Individual routinely needs help performing tasks that rely on this proficiency.
3	Intermediate	Individual can successfully complete tasks relying on this proficiency. Help from an expert may be required from time to time, but the task is usually performing independently. The individual has applied this proficiency to situations occasionally while needing minimal guidance to perform it successfully. Individual understands and can discuss the application and implications of changes in tasks relying on the proficiency.
4	Advanced	Individual can perform the actions associated with this proficiency without assistance. The individual has consistently provided practical and relevant ideas and perspectives on ways to improve the proficiency and its application and can coach others on this proficiency by translating complex nuances related to it into easy to understand terms. Individual participates in senior level discussions regarding this proficiency and assists in the development of reference and resource materials in this proficiency.
5	Expert	Individual is known as expert in this proficiency and provides guidance and troubleshooting and answers questions related to this proficiency and the roles where the proficiency is used. Focus is strategic. Individual have demonstrated consistent excellence in applying this proficiency across multiple projects and/or organizations. Individual can explain this proficiency to others in a commanding fashion, both inside and outside their organization.

APPENDIX B (next page)



APPENDIX B

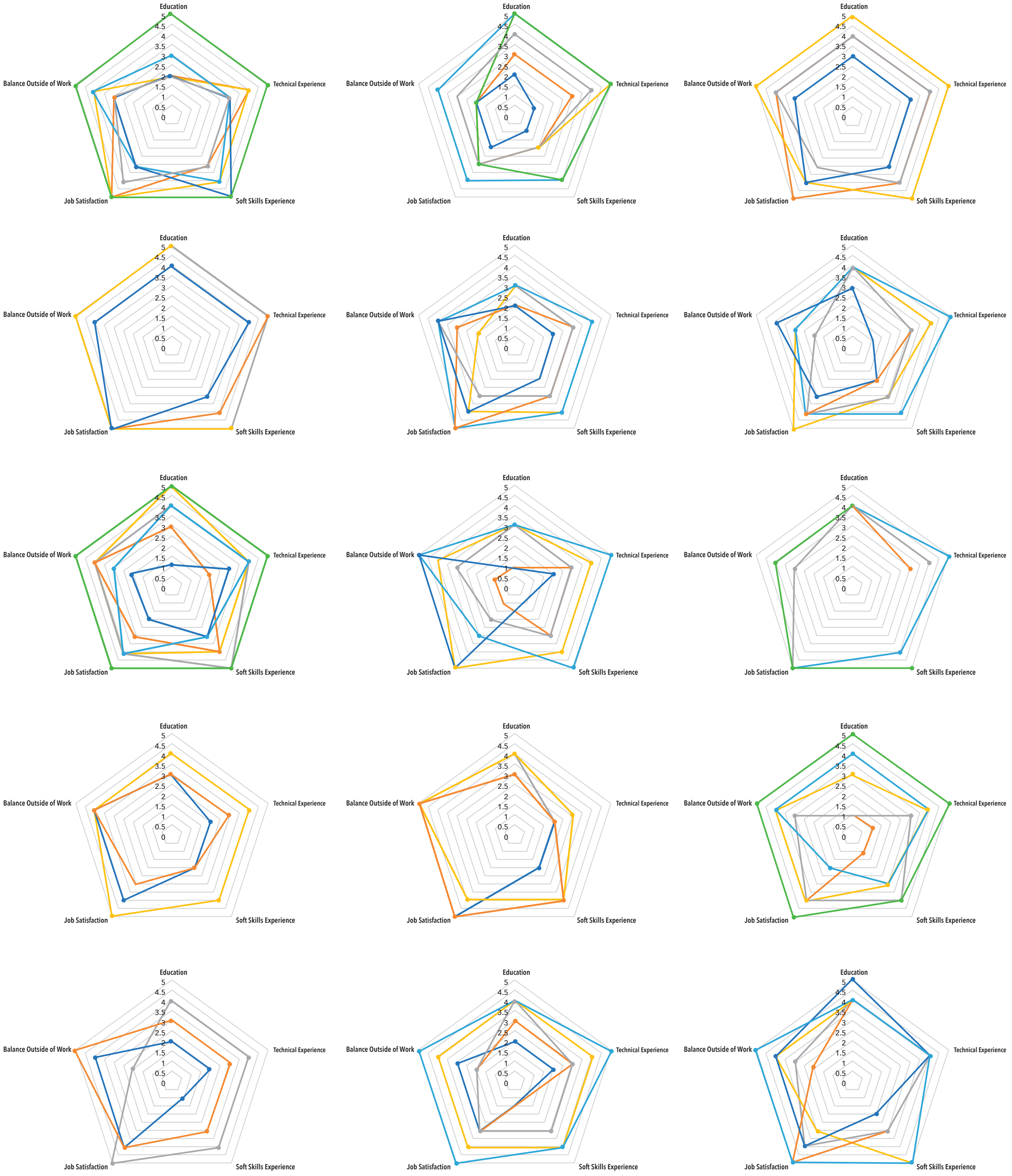


Figure 13. Summary view of various radar charts created from interviews

A Tinkerer's Mindset: Lessons from the Technical Leadership Institute's Cohort 8 on Safe-to-Fail Probing as a Tool for Informing Judgement

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■ ABSTRACT

Tinkering — or making small changes to experiment toward an improvement in performance — is seemingly a natural characteristic of many systems engineers. As such, systems engineers are uniquely qualified to develop complex solutions necessary to overcome lack of clarity, achieve order, and avoid failure. Further, there is a much broader conversation surrounding the possibility of "failure" being beneficial in systems engineering projects. In response to the needing to inform judgment in situations shrouded in uncertainty, members of INCOSE's Technical Leadership Institute (TLI) cohort 8 examined the role of safe-to-fail probes play in informing judgement for systems engineers. Within the constraints of the TLI's major project, virtual workshops and qualitative interviews were two data collection mechanisms established to empirically investigate the role(s) of safe-to-fail probing in systems engineering. Overall, the data sets offered conclusions describing the potential role(s) of safe-to-fail probes for systems engineers working in uncertain environments. Resulting from this (limited) empirical exploration are additional insights and implications for how systems engineers may invoke safe-to-fail probes to improve decision-making in uncertain and challenging situations. Such a tinkerer's mindset can help systems engineers transition from the constraints of "intolerable failure" to the opportunities related to probing-sensing-responding to "responsible failures."

BACKGROUND AND INTRODUCTION

INCOSE's Technical Leadership Institute (TLI) seeks to build a global learning network of active INCOSE members seeking to improve their leadership skills in an open, collaborative environment. By engaging in an (initial) two-year experience composed of virtual/in-person workshops, coaching, collaborative projects, and asynchronous assignments, TLI participants gain knowledge and experience to become systems engineering leaders in the face of ambiguity and uncertainty. To date, the TLI has provided nearly 150 participants from six continents and approximately 20 countries with a tailored, rigorous, and collaborative program to support the development — and evolution — of systems engineers as *leaders* in addressing complex problems.

As an intentional and strategic effort by INCOSE to apply the unique skillset of the system engineer to intersection of "technical excellence" and "leaderships skills," TLI assigned group 3 from cohort 8 (aka, "the warm skeptics") to examine how to inform judgement in situations shrouded in various types of uncertainty. Related discussions within TLI/cohort 8 navigated how the uncertain and the unknown can delay and deteriorate the relationship between judgement (or, evaluating a situation toward an opinion) and decision (or, making a choice). More specifically, group 3 was assigned a 6-month long major project to examine the role of safe-to-fail probes play in informing judgement to deliver effective systems engineering decisions.

According to some systems engineering experts, current interpretations of the word "fail" is potentially problematic. For example, a 2010 panel of systems engineering experts asserted that:

> *Society has been developing a hubris that we know how to do everything and that, every time we make a mistake, it is something we should have known better about…There is a perception in society that demands success the first time and every time. In contrast to perception, it is not possible to always avoid failure; therefore, it is vital to think and talk about what it means to learn from failure. (Slegers et al. 2012)*

The experts on this panel continued to review several major cases in which different types of failure occurred, ultimately concluding that only is failure an option at every system lifecycle step (until the final goal), failure *can provide* opportunities to reassess and improve (Slegers et al. 2012). Perhaps more succinctly, Elon Musk is often quoted as saying: "If things are not failing, you are not innovating enough" (Satara 2018).

Though just a few anecdotes, this TLI group found that there is a much broader conversation surrounding the possibility of "failure" being *beneficial* in systems engineering projects. Despite attempts to manifest order, structure, and coordination, systems engineers experience failures resulting from uncertain situations, indeterminate environments, or unknown scenarios — or a combination of all three. In response to suboptimal system performance, systems engineers often begin to make small changes to affect a repair or improvement in system performance — or tinker. Here, systems engineers naturally tinker to navigate a range of potential solutions necessary to overcome lack of clarity, achieve order, and avoid failure in complex problems. Though often seen as a difficulty (particularly in terms of decision-making), a systems engineers' tinkering can help reframe failures as opportunities to understand complexity. Such a tinkerer's mindset can help systems engineers transform a focus on avoiding failure to learning from controlled failures to navigate complexity.

After introducing safe-to-fail probes, situating them among leadership and complexity concepts, and mapping them to decision-making in complex and uncertain operational environments, this paper will describe two parallel — but related — data collection opportunities. Next, this paper will evaluate these empirical data to identify common themes and interesting trends describing how safe-to-fail probing may inform judgement to successfully execute systems engineering solutions. Lastly, this paper will review conclusions and offer insights from this empirical exploration, as well as suggest implications for how systems engineers may invoke safe-to-fail probes — similar to a tinkerer's mindset — to improve decision-making in uncertain and challenging situations.

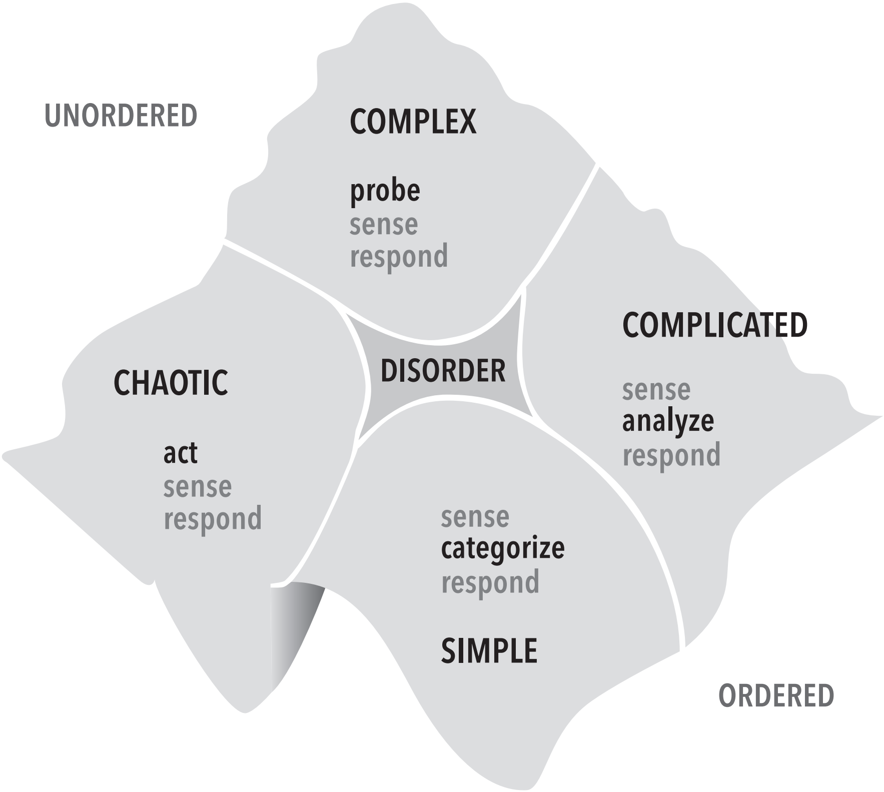

Figure 1. Original visual representation of Snowden's Cynefin framework (Snowden and Boone 2007)

"SAFE-TO-FAIL": INTRODUCTION TO THE CONCEPT

"Safe-to-fail" refers to actions taken when attempting to make sense of complex situations or systems that result in suboptimal performance. Considering its broadest meaning, this study used the term "system" equally for engineered and natural systems — where both can produce uncertain outputs based on interactions between environmental and internal components. The potential for such uncertain outputs accentuates the challenge for systems engineers to make decisions in uncertain situations, indeterminate environments, or unknown scenarios. Yet, several approaches to informing judgement and sense-making related to complexity exist. Consider, for example, Snowden's Cynefin framework (Cynefin.co 2023) that was introduced the TLI's cohort 8 early in their program. This framework has been employed successfully across many professional disciplines and routinely enhances the ability for decision-makers to evaluate their challenges, opportunities, and decisions in the correct context of their situation. More specifically, the Cynefin framework (Figure 1) categorizes systems (and situations) into five distinct groups (Cynefin.co 2023):

- Simple: There is a linear and clear relationship between cause and effect and the relation is identifiable by most observers.
- Complicated: There is a linear relationship between cause and effect, though that relation is not obvious and is likely only identifiable with proper application of expertise and analysis effort (Note: reductionist approaches and traditional scientific methods are most suitable here).
- Complex: The relationship between cause and effect can only be observed in hindsight, as the number of interactions among internal elements and between the system and its environment creates emergent properties causing low or absent levels of predictability.
- Chaotic: There is no relationship between cause and effect, as the interactions among internal elements and between the system and its environment results in absent levels of predictability or explainability.
- Disorder: This is the state of not knowing where the system fits in, sometimes referred to as a state of ignorance.

Int.	Domain	Current Role	~ Years of Experience	INCOSE Involvement
A	Academia	Consultant	50+	Y – Working Group Leader
B	Defense [G,R]	Line/Program Manager	15	Y – Member
C	Defense [G,R]	Director	30	N
D	Aerospace	Major Projects Manager	15	N
E	Aerospace	General Manager	23	N
F	Food Packaging [C]	Technical Product Owner	26	N
G	Aerospace [G,C,R]	Assembly, Integration & Verification Lead Engineer	25	Y – Sector Director
H	Food Packaging [C]	Specialist Food Packaging	30+	N
I	Software, Academia	CEO/President & University Professor	30+	Y – Local Board Member
J	Food Packaging [C]	Quality & Product Creation Director	24	N
K	Aerospace	Retired	30+	Y – Former Board Member
L	Defense	Vice President Systems Engineering Ecosystem	30+	Y – Member
M	Transport	Product Development Director	20	N
N	Imaging	Retired	30+	Y – Local Chapter Past President
[G] = government, [C] = commercial, [R] = research				

Figure 2. Demographic summary of interviews conducted to explore the "safe-to-fail" concept

For each of identified quadrants, the framework offers a pathway for sense making and informing judgment. For example, sense making for the complex quadrant is through *probe-sense-respond* cycles. In complex systems, there will be unintended consequences flowing from interactions in the systems. (Snowden et al. 2022). To that end, safe-to-fail experiments are targeted probes with the objective of minimizing any unintended outcomes toward making sense of complex behaviors. In other words, they are small-scale "experiments" designed from different perspectives with the intent to gain visibility on emergent properties of the system without significant damage (National Health Service 2021).

While the Cynefin framework offers probing as a first sense-making step for complexity, safe-to-fail experiments have some specific characteristics. First, they are not random attempts to stimulate the system and are targeted toward a set of learning objectives. Second, safe-to-fail probes need to be executed with caution and awareness of unacceptable outcomes. Lastly, the outcomes of safe-to-fail probes need to initiate additional actions—with a focus on recovering from a "failure" and amplifying a "success" (National Health Service 2021).

Safe-to-fail experiments provide a method to identify the unknown "unknowns" — including poor decision-making, unnecessary rework, and (potential) mission failure that can result from incorrect sense-making. For instance, performing reductionist analysis — what is appropriate for the "complicated" Cynefin quadrant—on a complex system or situation as a mechanism for mitigating uncertainty can be quite costly and produce results with poor reliability. Yet, better understanding the roles and implications of probing into the unknown — even when what results could be classified as a failure — was the focus of this study.

DATA COLLECTION TO EXPLORE THE CONCEPT

In response, this TLI major project required each group to collect data within the constraints of 1) drawing from fellow systems engineers (and, in some cases, only active and former TLI members) and 2) some form of interaction. Group 3 decided to leverage (and extend) initial interviews suggested by TLI for one data set. The interviews targeted business and technical leaders within (or adjacent to) INCOSE and characterized the current status of safe-to-fail probes across a broader array of systems engineers. The second data emerged from virtual workshops conducted with members of the INCOSE TLI community. The workshops provided a natural experiment by which to evaluate the potential utility of safe-to-fail probes in future systems engineering applications. Both data collection mechanisms were established to empirically investigate the role(s) of safe-to-fail probing to inform judgement in systems engineering within the assignment description set by TLI and operational constraints set by group 3 members.

Description of Interview Data

Data set I consisted of qualitative interviews (Figure 2) because of their ability to support dynamic interaction, provide additional insight, capture nuance, and further explore unexpected responses (Weiss 1995). Following a semi-structured process, these qualitative interviews provided for deeper descriptions of interviewees' true beliefs and interpretations of *how* and *why* failure is (mis)understood. Though not a traditional academic set of interviews, this qualitative interview data provides additional coherence, depth, and clarity with which to evaluate the role(s) of safe-to-fail probing. The team developed on a common set of guiding questions to be used during the interviews, which included aims to learn:

1. The interviewee's type of organization, domain, and

professional background

2. Examples of interviewee making decisions in the face of complex scenarios
3. What decisions needed to be made and how the interviewee arrived at the conclusions
4. The difference between the expected and actual results
5. Any changes the interviewer would have made their approach in hindsight
6. The interviewee's (and organization's) perception of failure and when failure was accepted
7. If the interviewer could provide an example of a safe-to-fail probe that could have helped.

Prior to question 2), each interviewer presented a description of the Cynefin framework that focused on the difference between the four quadrants but omitting the pathways for sense making and informing judgment. More specifically, a version of the Cynefin framework diagram (Figure 1) was presented without the action words (for example, "complex" quadrant did not have the words "probe," "sense," "respond"). This characteristic of the interview design was aimed at maintaining authenticity and reducing interviewer bias toward probes if that was not the actual decision-making technique employed by the interviewee. Toward the end of each interview, prior to question 7), the interviewer then presented the complete description of the Cynefin framework, now including the words "probe," "sense," and "respond" for the complex quadrant.

Logistically, interviews lasted approximately one hour each. As possible, interviews were conducted in person; others were conducted virtually via Microsoft Teams or Zoom. Depending on availability of the technology, interviewees were asked for verbal consent for recording, note-taking or transcribing the meeting. Each interviewer then wrote a summary of their interviews, organizing the "raw data" according to the guiding questions, and shared them with other group 3 members. For this study, all names of people, organizations, products and projects have been anonymized (Figure 2). In total, 14 interviews were included in this data set, including representation of systems engineering (or adjacent) professional roles from the academic, defense, transport, food packaging, and software domains. Approximately 50% of all interviewees are involved in INCOSE (to varying degrees), while all but two had more than 20 years of professional experience. While not a comprehensive grouping, these interviews do provide a representative sample of domains from which to draw useful conclusion and insights on safe-to-fail probing for systems engineering decision making.

Description of Workshop Data

This data collection mechanism was designed to immerse participants in a hands-on experience in developing fail-to-safe probes for a complex scenario. The virtual workshop was conducted via Zoom, included virtual breakout rooms (for group-facilitated workshop activities), and utilized Miro as a virtual interactive space. The workshop was conducted in mid-October 2023, lasted 90 minutes, and was repeated in two different time-zones to support worldwide participation. Due to TLI-based constraints for this major project, participants consisted of members of from other TLI cohorts. The participants were split into two groups and the set of probes from each group were evaluated by the other. This mechanism simulated a complex scenario where responses are difficult to forecast and probes can play a relevant role in informing decisions in uncertain situations.

The scenario at the heart of this data collection mechanism included the following characteristics:

- A main customer is claiming (perceived) safety issues on several production lots
- The suspect lots are partly delivered on the market and partly available in stock for quality checks
- Relationships with the customer is good but the long-standing customer manager recently retired
- The company specialist has engaged with legal, communications, and first alert technical personnel
- The customer is making a claim to take the road of harsh litigation
- Technical information is limited, non-structured and partly contradictory.

In response, the participants were required to:

- Clarify the impact and the extension of the issue in terms of severity and actual occurrence
- Identify root causes and responsibilities so to eliminate the risk further occurrences
- Minimize the risk of losing customer confidence and avoid stakeholder reputational risks.

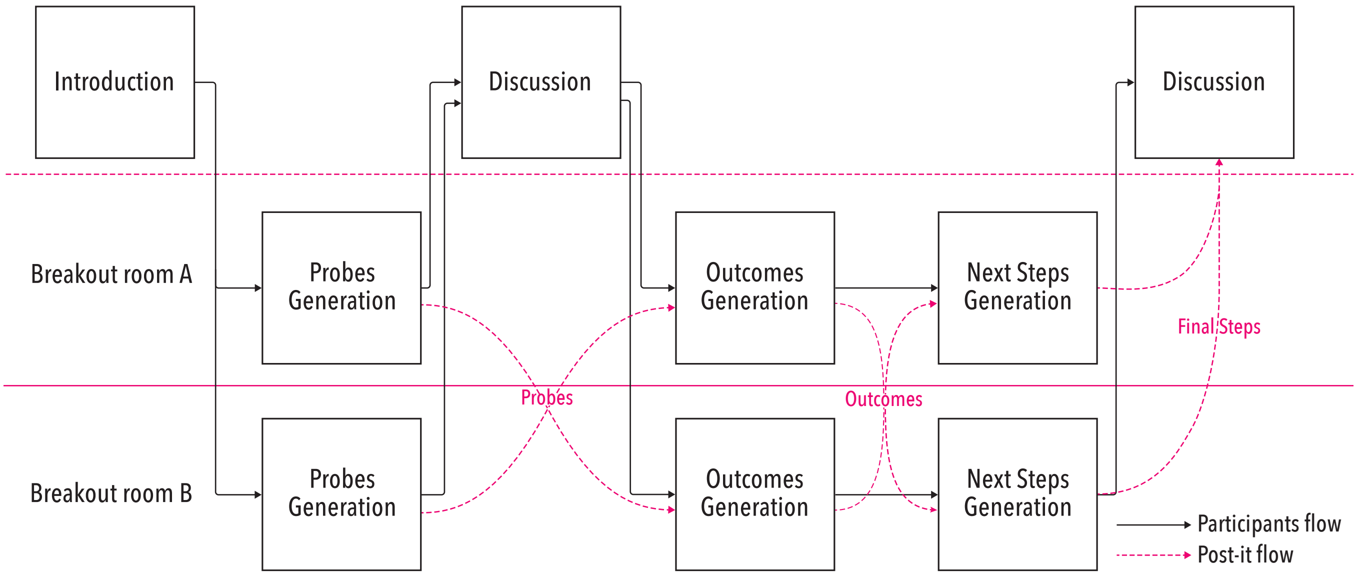

Figure 3. Conceptual design for the safe-to-fail workshop structure

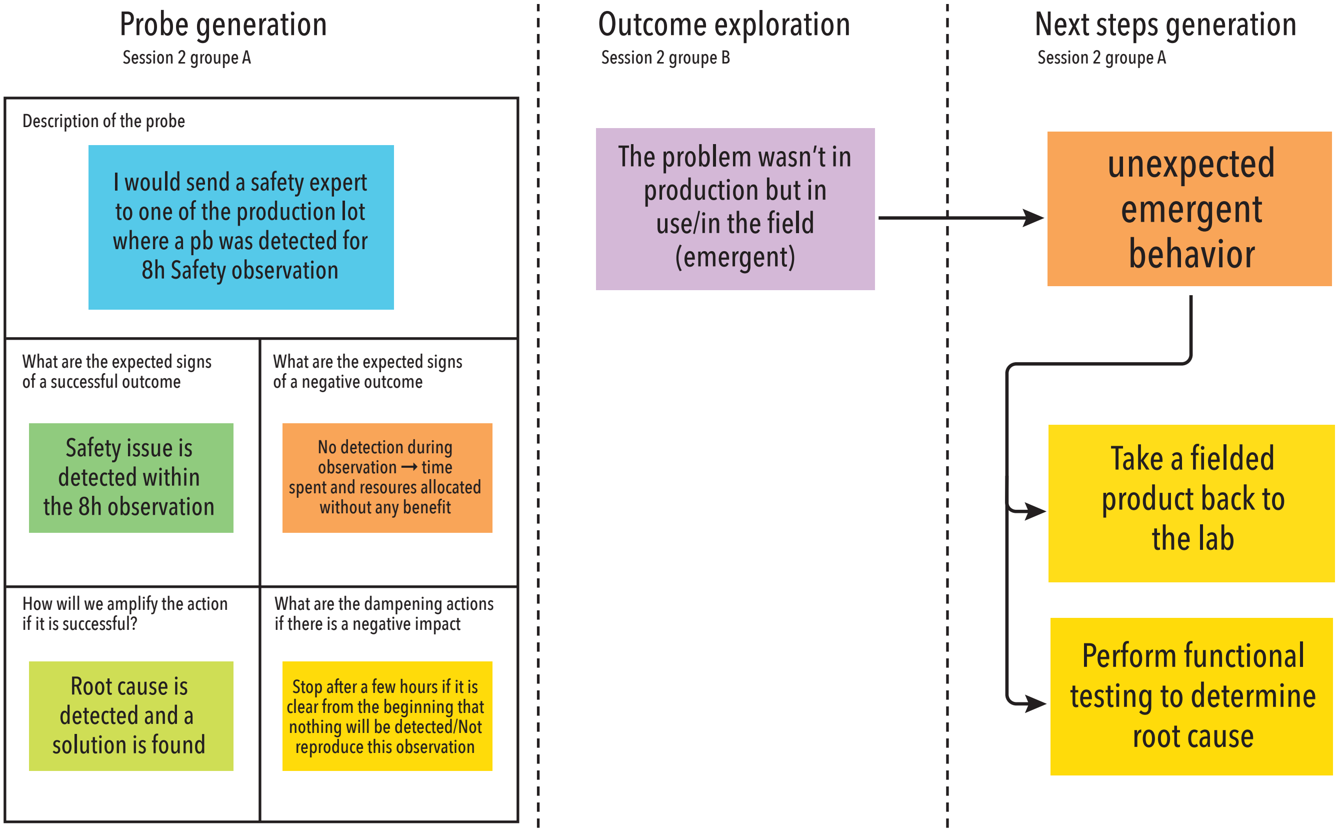

Figure 4. Example of the data collection from the virtual workshop on safe-to-fail probing.

Session (Group)	Number of Participants	Number of probes [# in complex quadrant]	Number of outcomes	Number of next steps
1(A)	2	4 [2]	10	8
1(B)	3	7* [6]	13	9
2(A)	2	4 [3]	5	7
2(B)	2	4 [1]	8	3
*one had all four quadrants completed and two had only the prompt				

Figure 5. Summary of workshop results, including the number of probes derived and outcomes generated

Participants were provided with a structured template for probe generation on the Miro board. The template included a space for the probe prompt and four quadrants: signs of successful outcomes, expected signs of negative outcomes, strategies to amplify successful actions, and strategies to dampen negative outcomes. The workshop activities consisted of (Figure 3):

- *Probe generation*: individually and collaboratively create and produce safe-to-fail probes
- *Outcomes generation*: collaboratively generate possible outcomes to the prompts proposed by the opposite teams
- *Response generation*: Collaboratively compare outcomes to anticipated signs and generate final mitigation actions.

The safe-to-fail probes generated by the participants were classified according to Cynefin framework quadrants by evaluating their use of good systems engineering practice for finding root causes (for example, the complicated quadrant) or if the probes were more exploratory in nature (for example, the complex quadrant). Per the workshop design, each probe elicited at least one response from the parallel team. The result was a rich diversity in the range of possible outcomes, particularly in terms of expectation and polarity. Some responses went beyond expectation and several responses used complexity to clearly reframe the problem space. Similarly, both positive and negative outcomes were generated in response to safe-to-fail probes. Lastly, each team prepared dampening and amplifying actions to address the probes and response.

The workshop was a success in terms of creating the condition for participants to experiment with the concepts related to safe-to-fail probes. The generated outcomes allowed participants to revise their mindset and feel more comfortable exploring complexity and uncertainty.

DATA ANALYSIS TO EVALUATE THE CONCEPT

Both data sets were iteratively analyzed with a focus on identifying trends, common themes, and areas for further exploration. Given the qualitative — and representative — nature of both data sets, the unit(s) of analysis were individual statements describing various aspects of probing, failure, complexity, uncertainty, and systems engineering. Here, analysis relied "less on counting and correlating and more on interpretation, summary and integration"

(Weiss 1995, p. 3) to investigate the potential role(s) of safe-to-fail probes for systems engineers.

TRENDS & COMMON THEMES

Probing is common, safe-to-fail is not. For the first common theme, perhaps unsurprisingly, emerging from the data sets is that *probing* and tinkering are a natural and regular occurrence in this representative set of systems engineers—but *safe-to-fail* experiments were not. This is reflected in the workshop by most probes stemming from common systems engineering problem finding methodologies than exploratory experimentation. Overall, 57% of the interviewees expressed that probing and experimenting is one of the more immediate and obvious tools systems engineers use when dealing with complex systems. More specifically, consider the following examples:

- "I have a trial-and-error mindset" (Int A)
- "It's just how my brain works, I probe" (Int B)
- "Question everything, start prototyping per the scientific method." (Int C)
- "The key information derives from a combination of formal and standardized tests, focused on the interactions with the stakeholders …" (Int H)
- "Complex systems already naturally tend to show emergent behavior of amplitude difficult to be predicted. Daring to afford a potentially huge impact even if somehow controlled is not reasonable" (Int H)
- "Incremental validation of the emerging consensus …" (Int K)
- "We did try to allocate other resources, but that probe failed. After one or two weeks, it was clear they needed the experts on the problem." (Int M)

This is not an unexpected finding since the iterative process of experimentation and testing is commonly applied in systems engineering and scientific practices. Where probing was a natural reaction to exploring the uncertainty for a path forward, there was not a consensus among the interviewees on *how* to conduct such probing. Among our selected interviewees, the limits of each probe and their next steps seemed to be discovered spontaneously. In the workshops even when next steps were identified, participants usually differed in the final strategy when the outcomes were revealed. Conversely, none of the interviewees described more intentional probing strategies. For example, consider those exemplified in the Cynefin framework, such as identifying tailored learning targets, defining acceptable failure levels, and implementing recovery (or amplification) strategies. Similarly, many of the probes proposed by the workshop participants stayed in the complicated quadrant—highlighting the natural tendency to resort to the complicated viewpoint rather than embrace the complexity of the situation (for example, safe-to-fail probing). In this manner, one major theme in the data is that while probing may come naturally, safe-to-fail experiments do not.

Common sense and intuition are still powerful tools. A second trend emanating from the data relates to the roles of common sense and intuition for informing judgment and addressing uncertainty. Even though some situations described by our interviewees required probing to inform judgement, approximately 50% of the decisions evaluated were based on common sense and intuition built on past experiences. Again, this trend is consistent with the experience of many systems engineers, as human beings are "machines for jumping to conclusions" (Kahneman 2011). This behavior is efficient if the conclusions are likely to be correct and the cost of an occasional mistake is acceptable. Jumping to conclusions is risky when the situation is unfamiliar, the stakes are high, and there is insufficient time to collect additional information. These are the circumstances in which intuitive errors are probable (Kahneman 2011). Yet, both interview and workshop data illustrate that systems engineers are (roughly) equally likely to rely on past experiences — despite the possibile impacts of cognitive biases — and more formal analytic approaches to inform judgment under uncertainty. Consider the following statements as examples:

- "We didn't see the number of dumb things that were happening [resulting from intuition]" (Int. C)
- "[Arrived at the decisions] primary through discussions withs stakeholders achieving consensus on these ideas" (Int D)
- "Because there was a strong sense of duty tied to both ethical and moral considerations; I tried to listen to my conscience. I imagined myself from a distance, visualizing another person in my situation" (Int E)
- "The key information derives from a combination of formal and standardized tests … and the fifth sense deriving from long and recognized experience in the role" (Int H)
- "Confidence was the way to overcome complexity" (Int K)
- "… stand by the decision and even today I remain skeptical of whether the integration effort would indeed bring improvements" (Int M)
- "These [decisions] were all common sense to me." (Int N).

From the collected data, systems engineers are quick to invoke common sense and intuition. And, similar to the first common theme, there does seem to be a clear strategy, plan, or end game for navigating complexity and uncertainty. That only 50% of the interviewees indicated taking this approach suggests that there is an (at least equally) effective approach available for supporting strategic probing and a tinkerer's mindset.

Failure seemingly has conflicting interpretations. A final common theme emerging from the data related to perceptions of and connotations for the term "failure" — resulting in an overwhelming aversion to the term. Invariably, when asked about their opinions about failure, almost all interviewees agreed that controlled and measured failures are a consequence of learning and should be embraced. Whether failing under controlled, experimental situations (Int. D, Int. E) or as part of an intentional technical/design activity (Int. H, Int. M), interviewees did not default to being averse to failure. Yet, nearly all interviewees qualified these responses in terms of the perception of failure by their organizations. Overall, 43% of the interviewees reported their organizations would negatively view failures even in the context of informing judgement:

- "Perception is that failures will not be forgotten" (Int B)
- "Difference between 'safe to fail' and having the 'courage to fail' are executive leaders willing to be the 'bullet catcher'" (Int C)
- "Nevertheless, within the company, a mistake in a non-technical area is not well-received" (Int E)
- "A subcontractor is not expected to fail, just to execute what is required, on time" (Int F)
- "Although the processes encourage to dare potential limited failures (fail fast, fail safe), it is difficulty to break the glass ceiling of the historical 'jump to solution and fix it' practice" (Int I)
- "A lot can be learned by failure, but failing ends up getting a bad reputation" (Int N).

More specifically, interviewees further explained that tendency for failure aversion within their organizations stems from fear of safety impact (Int. H), reputational damage (Int. M), or financial loss (Int. D, Int. E). Yet, several interviewees stressed that "a lot can be learned by failure" (Int. N) and that "failure at the 'right' time...is part of the game" (Int. G). Thus, the aversion to failure seems to be a function of organizational culture and operational pressures around fears of unacceptable losses. Here, strategic and focused probing (like that proposed by the Cynefin framework) offers opportunities to situate both interpretations of failure — namely by using targeted probes with well-defined and accepted levels of failures to explore uncertainty and learn complex solutions.

AREAS FOR ADDITIONAL EXPLORATION

To conclude each data collection exercise, three questions were posed to the participants to investigate opportunities to operationalize safe-to-fail probes for mitigating uncertainty and complexity, namely:

- Under what conditions — or with what characteristics — can safe-to-fail probes be successful?
- How can safe-to-fail probes be successfully implemented?
- What benefits can be anticipated with or experienced from safe-to-fail probes?

While there was not a clear consensus, the data revealed some candidate conditions and characteristics that support the successfully implementation of safe-to-fail probes. Some responses were explicit and clear, like Int. C's statement that safe-to-fail-based strategies can only be successful when provided with the necessary— and sufficient— authority, resources, and responsibility to adequately learn from shortcomings. Other characteristics were more philosophical, like Int. A' assertion that safe-to-fail probing requires stepping across the boundaries of what is known to work and Int. D's claim related to the psychological fortitude necessary to handle "failing."

Overall, safe-to-fail probes were deemed likely to be successful under two broad conditions. First, the associated "failure" does not involve safety, reputation, or financial losses. For example, in workshop session 2, one of the probes led to a catastrophic outcome, with participants noting that "[since the] probe has changed the situation [it was not a] safe-to-fail [experiment]". Second, the anticipated information or knowledge return seems worth the risk. Across both data sets, a positive interpretation of failure — similar to the basis of safe-to-fail probes —was associated with local actions or framed in terms of "traditional research."

The data also revealed additional considerations related to implementing safe-to-fail probes for systems engineering applications. One such consideration is offered by Int. C and Int. G, who both noted the need to gain stakeholder consensus and buy-in for defining acceptable failures. Int. M offered the ability to validate such consensus within a well-chosen core team — as well as the flexibility to revisit any such consensus as the stakeholder group grows — in implementing safe-to-fail probes. Lastly, Int. A suggested that need to "question everything" and "start prototyping" early and often, where Int. C asserted the need for a "did we learn from it" organizational and team paradigm to institute safe-to-fail probes.

Taken together, the conditions and actions that support safe-to-fail probes presuppose several benefits for decision-making in uncertain and complex situations. For example, an overwhelming majority of the statements supporting safe-to-fail probes highlighted the ability for systems engineers to explore a set of quasi-established, incomplete, or preliminary solutions to gauge which would provide the best next step. Stated more simply, safe-to-fail probes provide a mechanism for the systems engineer to learn from uncertain or complex situations without sacrificing substantial resources on more formal, detailed analysis. Such small, measured, and targeted probes can also assist in overcoming a full range of cognitive biases — despite the tendency for systems engineers to rely on "common sense" and intuition. Seemingly, the primary benefit of safe-to-fail probes is not to find why a situation is inadequate or uncertain, but rather to focus tinkering on where and how to apply novel recovery or amplification strategies to address complexity.

CONCLUSIONS, INSIGHTS AND IMPLICATIONS FROM THE CONCEPT

Overall, the data collected was sufficient to address the potential role(s) of safe-to-fail probes for systems engineers working in uncertain environments. Throughout both the interviews and workshops, the different interpretations of "failure" manifested an oxymoron, or an apparently contradictory figure of speech. More specifically, the data revealed that failure is only "bad" when nothing is learned —which suggests a logical consistency with the Cynefin "probe-sense-respond" approach where learning is a natural extension of responding. The data also illustrated that while failure can emerge in many different forms, the exploratory nature of safe-to-fail probing is a tool that can help identify drivers of uncertainty and complexity. And, one of the more consistent outcomes from the data was the realization that — particularly in complex situations — "failure is an inseparable part of learning" (Int. A). Though, likely not suitable in time-sensitive situations and decisions, the data suggests that systems engineers can invoke the "probe-sense-respond" ethos of safe-to-fail probing with planning, iteration, and time to explore the results.

Yet, the TLI requirements for data collection and analysis somewhat limit the generalizability of these conclusions. More precisely, limiting participating in the workshops to members of INCOSE's TLI and focusing interviews on systems engineers in leadership roles artificially restricted the different perspectives collected in the data.

The concern of potential unidentified bias in the analysis from these limitations is (somewhat) mitigated by the juxtaposition of more experienced (interviewees) with earlier career (TLI members) systems engineers. Similarly, requirements for identifying interviewees (which loosely followed the logic of snowball sampling) may not provide truly representative results for all systems engineers. The use of open-ended interview questions using terms with multiple interpretations (for example, "failure" or "safe") and "idealistic" workshop scenarios (for example, less aligned with real decision-making) may have confused some participants. This kind of workshop seems a promising tool to teach system engineers about safe-to-fail probing to inform judgment. Despite these limitations, the conclusions of this study support further exploration of safe-to-fail probing.

Additionally, these conclusions offer several insights germane to system engineers. First, the data showcased how many systems engineers are "natural tinkerers" who consider failure as a normal and accepted element of innovation. While this tendency can positively impact systems design and deployment, the data highlighted that there is a distinct difference between *knowing* that it is "safe-to-fail" and *having the courage* to fail (Int. C). As previously described, there are both individual and organizational characteristics that can increase both this knowledge and this courage. Another insight relates to how safe-to-fail probes can offer clarity to systems engineers in uncertain or complex situations. Where systems engineers may naturally explore different potential pathways out of uncertainty, safe-to-fail probes remove the focus on "succeeding" and reframe it toward identifying actions to recover lost or amplify current system functionality.

Lastly, several implications stem from these conclusions and insights. First, there is a clear need for — and likely significant benefit from — deriving a clearer and more precise ontology and lexicon. Establishing a set of commonly accepted concepts, terms, and definitions will help instill safe-to-fail probes as a regular tool for systems engineers to use in informing judgement in the face of complexity and uncertainty. Second, there are richer insights to be gleaned from continuing these interviews with a broader set of participants, including from different countries, professional backgrounds, and philosophies. Here, there is an opportunity for systems engineers to identify the impact of culture differences on the interpretation of "failure" and conditions under which safe-to-fail probes are successful. Ultimately, the implication is that systems engineers can be benefit from safe-to-fail probes by eliminating "intolerable failures," tolerating "responsible failures" (Int. C) and exploiting the tinkerer's mindset to improve decision-making in uncertain and challenging situations. ■

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Sep 2024 09
SWISSED24: Building Bridges
Zurich, Switzerland

Sep 2024 19–21
INCOSE's Annual Western States Regional Conference (WSRC)
Albuquerque, New Mexico, USA

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SESA's Systems Engineering Test & Evaluation (SETE) Conference
Melbourne, VIC, Australia

Sep 2024 23–24
Systems Analysis & Modelling (SAM) Conference
Linz, Austria

Nov 2024 05–06
INCOSE UK's Annual Systems Engineering Conference
Edinburgh, Scotland

Dec 2024 12–13
Complex Systems Design & Management (CSD&M) Conference
Paris, France

Feb 2025 01–04
INCOSE's Annual International Workshop (IW)
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Jul 2025 26–31
INCOSE's 35th Annual International Symposium (IS)
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