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Application of T-shaped engineering skills in complex multidisciplinary projects

Ida Kristin Trogstad
University of South-Eastern Norway
ida.2201@hotmail.com

Satyanarayana Kokkula
University of South-Eastern Norway
satyanarayana.kokkula@usn.no

Joris van der Aker
ESI (TNO), The Netherlands
joris.vandenaker@tno.nl

Abstract. In this research, we study the application of T-shaped engineering profile skills in complex multidisciplinary projects. Literature survey revealed a relation between the systems engineers and technical experts; we explore this relation further here. Data collection was through a survey with practicing engineers, technical managers, and academics with industrial experience. Research findings revealed that the 'systems engineering discipline' shall be used as a common language between systems engineers and technical experts in projects. We identified a gap between the design and production lifecycle stages. Questionnaire respondents confirmed this gap during validation and mentioned the lack of 'operational context' as a challenge in the system development process. There is a clear interest in acquiring T-shaped skills through training. To achieve this, the technical experts shall use training programs within their organization, by focusing on the 'systems engineering discipline' and 'system's domain & operational context' proficiencies.

Introduction

Domain. The focus of this research is on engineers, referred to as technical experts, currently practicing in complex multidisciplinary projects across industries in mature markets, such as offshore and maritime systems. These projects are often subject to dynamic environments. In these markets, the economy causes dynamics, e.g., price fluctuations. They require flexible approaches to project/product/system development, where one considers all stages of the systems life cycle. This demands a high degree of detailed engineering by multidisciplinary teams.

Background and problem statement. In 2014, INCOSE presented a future vision for systems engineering. One of the challenges mentioned was that "Knowledge and investment are lost at project life cycle phase boundaries" (INCOSE, 2014). Delicado et al. explains, "It is common in modern enterprises that knowledge, skills, and competencies required in the realization of systems of interest are distributed across multiple functions, disciplines, and organizational areas" (Delicado et al., 2018, p. 534). The cumulated impact of these two statements imply that organizations are at risk of losing knowledge and investments in complex multidisciplinary projects. Project organizations must address these challenges to mitigate the risk.

Sources such as Oskam (2009), Rogers and Freuler (2015), and Cederberg et al. (2019) describe the T-shaped competency model. The model explains how technical experts complement their area of expertise with boundary crossing capabilities to address the challenges of complex multidisciplinary projects. Existing research focuses on developing frameworks and models for specific organizations and specific areas of the industrial sector (Delicado et al., 2018). However, there is a lack of studies on how a company can bridge the gap between a project team's technical skills and the development of a complete system. Here, we observe a relation between systems engineers and technical experts. Where technical experts only possess depth of knowledge and lacks boundary crossing capabilities, how can we ensure completeness in a complex multidisciplinary project?

Goal. The goal is to present recommendations on how to address the challenge presented by INCOSE.

Research question. While we cannot deny the usefulness of T-shaped engineering profile skills, the method of application is less clear. Based on the above discussion, we ask the following research question: *How can complex multidisciplinary projects apply T-shaped engineering profile skills to secure knowledge and investments throughout the systems life cycle?*

Literature Survey

T-shaped engineering profile skills. David Guest first introduced the concept of T-shaped engineering in 1991 (Guest, 1991). Tim Brown further expanded on the concept and introduced T-shaped people as a resource for innovation. He explains the concept of T-shaped people as being people with one field of expertise, represented by the vertical bar of the T, and the ability to expand their knowledge in other disciplines, the horizontal bar of the T (Brown, 2005). Figure 1 illustrates the T-shaped profile presented by Oskam (2009), Rogers and Freuler (2015), and Cederberg et al. (2019).

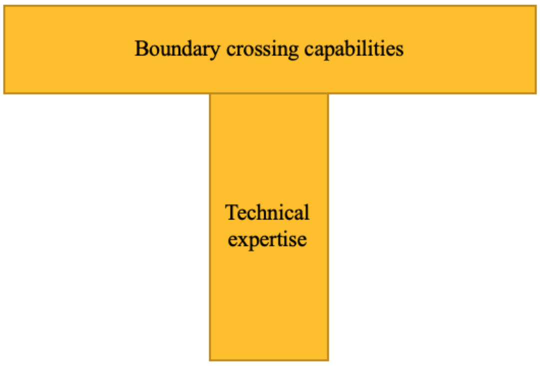

Figure 1. T-shaped Engineering Profile Skills based on (Oskam, 2009), (Rogers and Freuler, 2015), and (Cederberg et al., 2019)

Complex multidisciplinary projects. The researchers do not restrict complex multidisciplinary projects to a single industry. Rather it is an applicable term across industries and disciplines. Adamsson defines complexity as "Difficulties and uncertainties posed by the number of technologies/components/functions involved in development efforts and by the nature of the organizational tasks that individuals and organizations face in carrying out product development" (Adamsson, 2007, p. 7). Locatelli et al. writes, "Most of the successful projects in complex environments have applied certain principles and practices that can be traced back to Systems Engineering (SE)" (Locatelli et al., 2014, p. 1400). The Systems Engineering Book of Knowledge (SEBoK, 2020) explains that teams need individuals to work and perform according to the objectives of the project (Fairley et al., 2019). This illustrates the complexity of multidisciplinary projects, which requires a high degree of understanding of the project, its domain, and the context.

Systems life cycle. Sols defined the systems life cycle in eight steps from need identification through system phase-out, as seen in Figure 2 (Sols, 2014).

Figure 2. Systems Life Cycle (Sols, 2014)

Proficiencies. As described by Locatelli et al., projects in complex environments usually apply methods related to systems engineering (Locatelli et al., 2014). Delicado et al. stresses that technical experts must complement their specialty with knowledge on how to integrate their expertise in a project environment. There is a need to address the divide between technical expertise and the systems engineering methods used in projects. T-shaped engineering profile skills can help to confront this divide. Delicado et al. suggest the use of T-shaped engineering profile skills in order to close the gap between systems engineers and technical experts (Delicado et al., 2018). With this in mind, we expand on the T-shaped engineering profile by using the proficiency model on boundary crossing capabilities presented by Pyster et al. (Pyster et al., 2018, p. 73).

Pyster et al. presents proficiencies that they believe are necessary to make a good systems engineer. They present a proficiency model that relies on six proficiencies and describe systems engineers as being "pi" shaped (Pyster et al., 2018). These proficiencies are crucial when entering roles that are "knowledge intensive, varied, and complex" (Pyster et al., 2018, p. 73).

Pyster et al. define three clusters and their constituent proficiency areas as: Engineering proficiencies, systems proficiencies, and professional proficiencies. The engineering proficiencies are 'math/science/general engineering' and 'System's domain & operational context'. These are fundamental knowledge areas for engineers. Patterns presented suggest that an engineer become more senior, the 'math/science/general engineering' proficiency becomes less significant to their work as they often will not perform detailed design tasks. 'System's domain & operational context' is however significant throughout an engineer's career. The systems cluster contains 'systems engineering discipline' and 'system mindset'. These proficiencies make up the "core principles, methods, and techniques that systems engineers rely on every day" (Pyster et al., 2018, p. 110). In the professional cluster we find 'interpersonal skills' and 'technical leadership'. Pyster et al. argue that there is an increased need for these proficiencies in more senior positions.

Education. Pyster et al. describes experience as being "the most critical force that strengthens proficiencies" (Pyster et al., 2018, p. 147). Further, they describe formal education has two roles: to provide fundamental knowledge, and to develop skills and in-depth knowledge. They describe training programs within organization that typically "focus on buildings skills required to perform specific positions within the company" (Pyster et al., 2018, p. 159). Further, they observed that training would help to expand the proficiencies of the employee. This training included techniques such as lifecycle management and process improvement. Oskam claims that traditional methods cannot teach all elements related to developing a T-shaped profile. Rather, it must be experienced through collaboration and interaction (Oskam, 2009). Cederberg et al. present an example of a successful training program. The results of their study revealed, "the T-shape of the individual participants have been strengthened considerably and the participants as a group has become more homogeneous in their understanding of the challenges in the development of complex systems" (Cederberg et al., 2019, p. 15).

Knowledge management. According to Wiig, the objectives of knowledge management are "(1) to make the enterprise act as intelligently as possible to secure its viability and overall success and (2) to otherwise realize the best value of its knowledge assets" (Wiig, 1997, p. 1). Further, they state that, "To reach these goals, advanced organizations build, transform, organize, deploy, and use knowledge assets effectively" (Wiig, 1997, p. 2). In this research, knowledge management is relevant to the application of T-shaped engineering profile skills and how projects secure knowledge in order to perform and innovate.

Oskam describe a gap between ambition and implementation in the desire to innovate in the Dutch business sector. They suggest the use of T-shaped technical experts in order to secure interdisciplinary innovation. In order to perform, technical experts must possess knowledge in their own field complemented by "basic knowledge of adjacent and connecting fields" (Oskam, 2009, p. 6).

Research Method

There was no hypothesis but rather an open research question, which allowed for an unbiased analysis of the topic. Figure 3 presents the steps performed in this research.

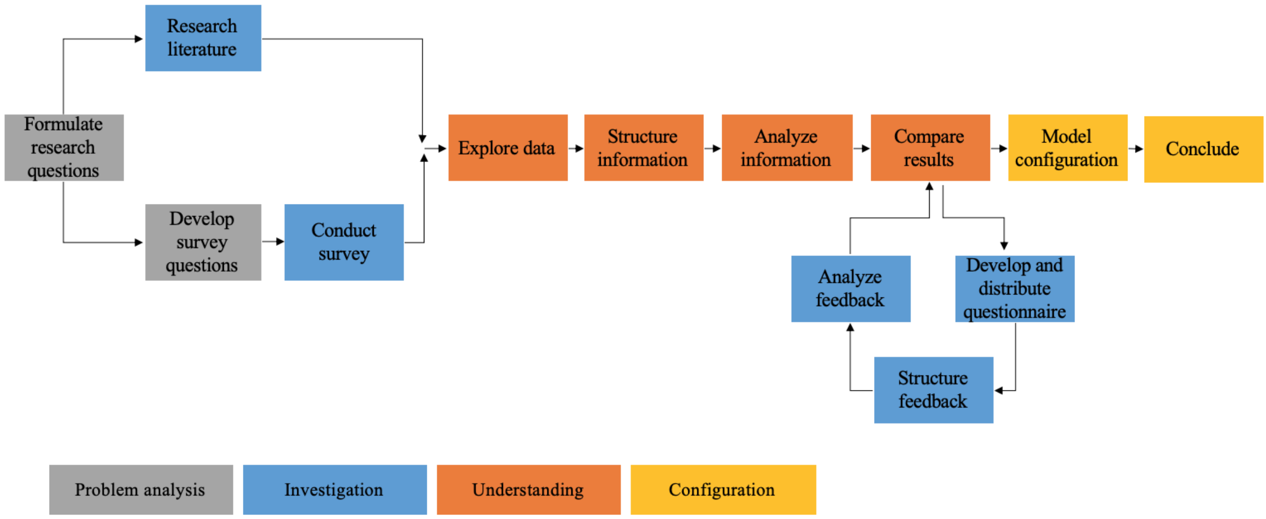

Figure 3. Research method

Problem analysis. We formulated the research question at this stage. Further, we developed a survey based on the research question and the literature. This process ensured that the information gathered was valid for the project, as well as there being a correlation between the literature and the collected data.

Investigation. The researchers initiated the process by obtaining information on current literature, current practices, and the potential for T-shaped engineering profile skills in complex multidisciplinary projects. The main methods of research were a survey and interviews with relevant industry participants. The survey was conducted as part of Systems Engineering Study Group (SESG) at the University of South-Eastern Norway (USN). The goal of the survey was to obtain background information from industry practices on the relevance and application of T-shaped engineering profile skills. The participants were from organizations in and around Kongsberg in Norway. This survey was a combination of single answer check boxes, multiple answer check boxes, and Likert scale questions. Appendix A presents the survey questions. For analysis purpose, we divided the responses into four sections:

1. Life cycle stages. Participants were asked to check boxes for stages of the life cycle that they have worked with and stages that they want to work with in the future. This allowed us to gather information on where projects loose knowledge and investments.
2. Proficiencies. We present the six proficiencies related to T-shaped engineering profile skills as suggested by Pyster's proficiency model (Pyster et al., 2018). Participants rated their pro-

ficiencies on a scale from 1 to 5. The scale allowed for a more detailed image of the T-shaped competency model and its improvement potential.

3. Methods of acquiring knowledge. Participants indicate what methods they have used when acquiring current T-shaped profile skills, and how they wish to acquire further skills. This allowed us to gather information on how technical experts can further develop proficiencies.
4. Recognition. We used Likert scale to map the participant's awareness on their T-shaped profile skills and the application in their organization, and within projects.

One risk of using survey was not achieving enough responses and not being able to obtain clarification or additional answers. This can be a threat to the external validity of the research (Muller, 2013). In order to mitigate this risk, we compared survey results to literature. We developed an additional questionnaire in order to confirm survey results or investigate discrepancies between literature and survey findings. Appendix B shows the questionnaire. Interviews with open ended questions could have replaced the questionnaires. This method allows for further exploration of the topic by allowing respondents to provide detailed knowledge (Muller, 2013). However, due to environmental circumstances, it was not possible to perform interviews at the time of this research.

Understanding. Upon collecting the data, we structured and analyzed the results. We compared the results from literature and survey in order to examine concurrent results and possible gaps or discrepancies. The questionnaire was based on the information we obtained from the survey.

Configuration. We used the results of the analysis to answer the research question. From this, we developed a model. In order to ensure that the developed model is applicable, we conducted iterations of the model configuration. This means obtaining feedback from questionnaire respondents and adjusting the model accordingly.

Survey findings

The goal of the survey was to obtain background information on industry practices on the relevance and application of T-shaped engineering profile skills. The researcher's intention is to understand the use and recognition of T-shaped engineering profile skills in the industry today. Seventeen participants answered the survey questions. The participants were gathered at an SESG event, discussing the application of systems engineering in their workplace. Survey participants include technical managers, technical experts, and academics with 0 to 15+ years of industry experience. The following sections presents the findings according to the four main topics described in the research method.

Life cycle stages. Figure 4 presents the reported life cycle stages that participants work with or have worked with, and what stages they would want to work on in the future.

We identified two discrepancies. First gap is between design and production, and the second gap between operational life and phase-out stages. There is a general reduction in respondents, who have worked with lifecycle stages beyond design. The number of life cycle stages worked with increases slightly with years of experience.

Proficiencies. Figure 5 shows two spider graphs. The blue graph illustrates current proficiency levels among the participants. The orange graph shows their desired proficiency levels. The graphs are a representation of all participants, using average values.

The research shows discrepancies between current and desired proficiency levels in 'system's domain & operational context', 'interpersonal skills', and 'technical leadership'. 'System's domain & operational context' shows the largest discrepancy, with one point difference. 'Math/science/general engineering' shows the smallest discrepancy.

Methods of acquiring knowledge. Figure 6 presents the methods in which the participants claim to have acquired their current engineering profile skills, and how they wish to expand on their current knowledge.

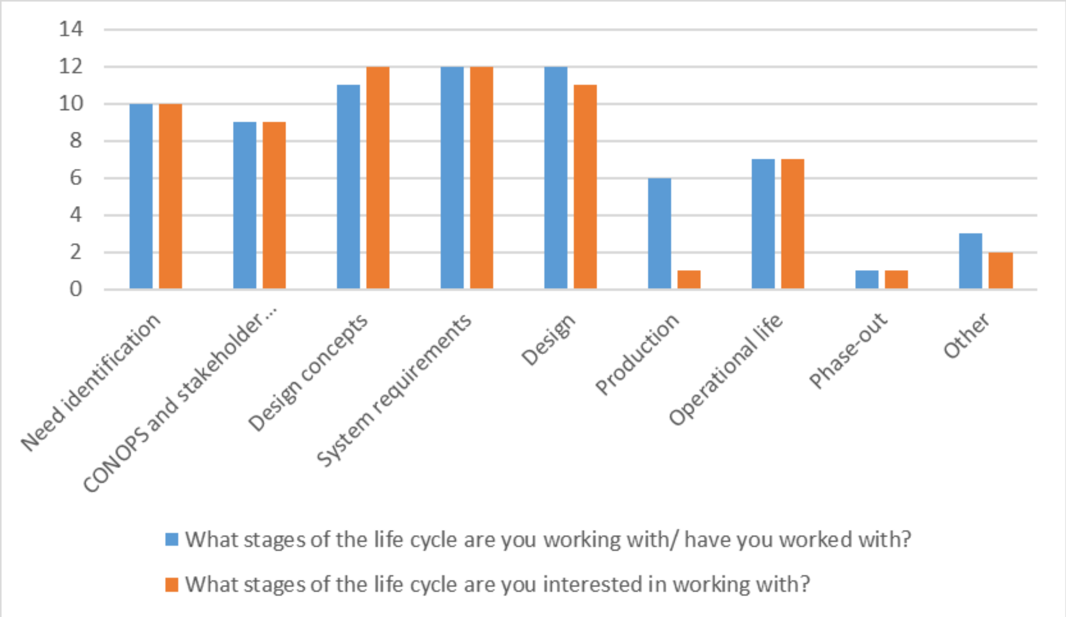

Figure 4. Life cycle stages worked on and want to work with

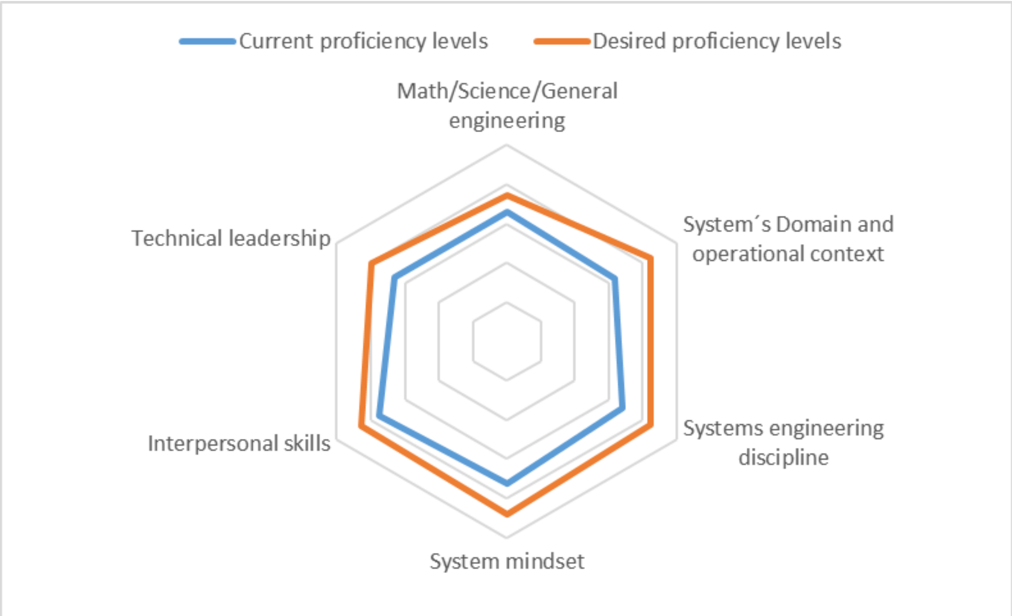

Figure 5. Profile for current and desired proficiency level

Experience and formal education are the most popular methods of having acquired skills, whereas training is the least popular method. There is slightly less interest in acquiring T-shaped engineering profile skills through formal education. The research shows the largest discrepancies in how participants have acquired and how they wish to acquire knowledge in formal education and training. However, for formal education there is a decrease in interest while there is an increase in interest for training.

Recognition. Figure 7 shows the results of the Likert scale questions that addressed recognition of T-shaped engineering profile skills.

We observe a pattern where the first three questions, which addresses the general application of T-shaped engineering profile skills, have higher scores than the questions related to the respondents' current organizations.

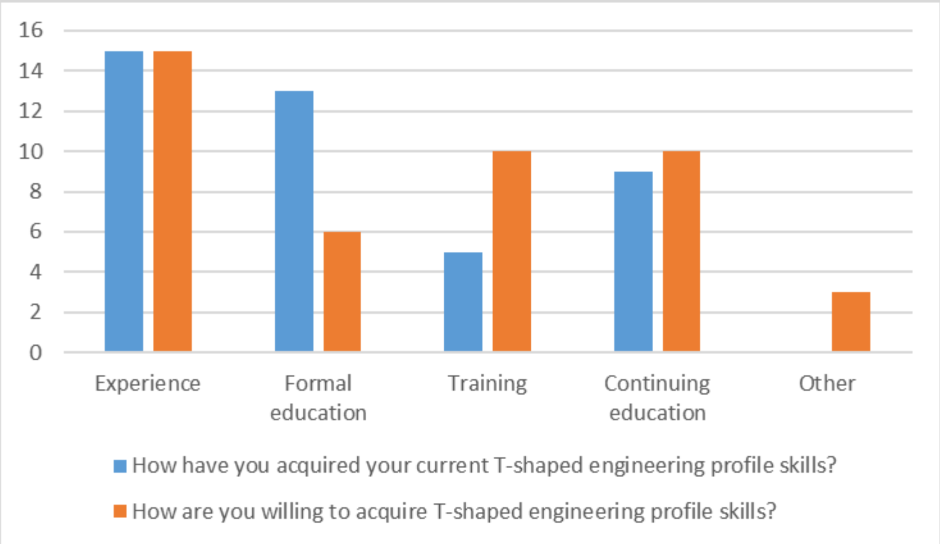

Figure 6. Methods of acquiring knowledge

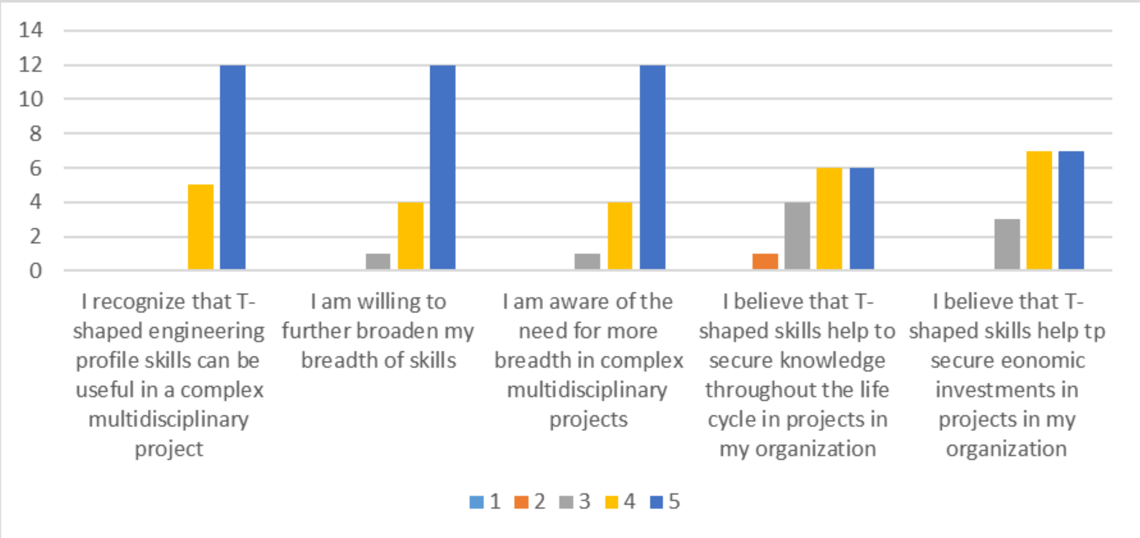

Figure 7. Recognition of T-shaped engineering profile skills

Validation using Questionnaire

Questionnaire was used to validate the findings from survey with industrial experts. There were only two respondents who responded to the questionnaire. Table 1 present the roles of respondents.

Life cycle stages. Respondent-1 mentioned that they experience a loss of knowledge and investments in handovers between persons or between functions. Respondent-2 mentioned that the loss of knowledge and investments are *mainly production and service related*.

The questionnaire asked the respondents to address the gap between design and production lifecycle stages (See Figure 4), later on how they are willing to invest resources in order to bridge this gap. Respondent-1 replied that they would want to attract people with a practical skillset and/or operational experience into product development. They mentioned a mindset that focuses on *a) total cost of ownership or b) lifecycle management, and c) use of (project/development) processes pre-scribing* *cross-functional presence throughout the product (creation) process*. Respondent-2 states, the use of traineeships and exposure to job tasks performed in different life cycle stages.

Table 1: Questionnaire respondents

Respondent	Position
Respondent-1	Technical manager from the Kongsberg industry
Respondent-2	Technical manager and trainer/consultant

Proficiencies. We noticed discrepancies between team's proficiency levels and individual's proficiency levels. Generally, the technical manager ranked their team lower than survey respondents ranked themselves. Exceptions are the 'systems engineering discipline' and 'system mindset' proficiencies. We also observed that when asked about desired proficiency levels, the same proficiencies ranked higher for teams than for individuals.

We asked respondents how they secure people with a 'system mindset' for projects. Respondent-1 mentioned the *ability to actively select viewpoints* and *to capture and communicate these viewpoints*. Respondent-2 mentions frequent job changes in the start of their career as well as reflections, peer discussions and networking.

Methods of acquiring knowledge. Respondent-1 mentioned training and experience as the methods in which teams have acquired their knowledge and further wish to acquire their knowledge.

Recognition. When asked about how they recognize and secure T-shaped engineering profile skills in their projects, Respondent-1 underlined the importance of having people with practical experience or a practical mindset. They look for people who represent a solution to the issue of *balancing plans, needs, requirements across tasks and teams*. They often refer to these people as systems engineers or technical managers who sometimes perform well and sometimes not.

Discussion

Life cycle stages. Findings from the survey suggest that technical experts rarely work with or are interested in working with life cycles stages after design. The questionnaire confirms this observation. The researchers relate this to the INCOSE statement of losing knowledge and investments in life cycle boundaries (INCOSE, 2014). We assume, this loss occurs when the design is complete and the technical expert(s) move on to another project, and production starts. This is a process where there is an exchange of information; technical drawings are handed over from the engineers to the production team. The drawings are now the basis for production processes. Respondent-1 mentions the lack of operational input as a challenge in the engineering process. The boundary between design and production is where we move from a conceptual to a pragmatic mindset. As brought to our attention from Respondent-2, this is also where education of the workforce moves from theoretical to practical. We present these observations in Figure 8.

The information transfer from design to production requires an understanding of production practices from the engineer for the transfer to be successful. If technical experts cannot translate a functional design into specific components, the project will lose knowledge and investments.

We also observed another gap between operational life and phase-out life cycle stages. According to Sols, we must consider that the processes related to phasing out a project or product may require costs in the early life cycle stages (Sols, 2014). He underlines the importance of a "global view" in product development. We will discuss this in relation to the proficiency model.

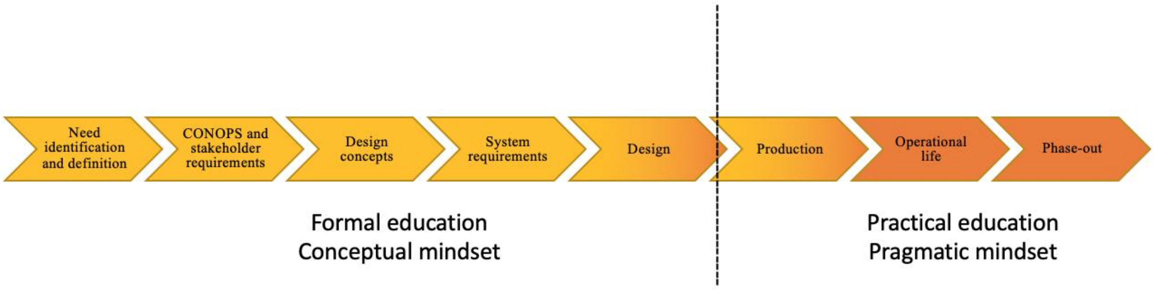

Figure 8. Life cycle stages and boundary gap

Proficiencies. Based on information from the literature, the survey and the questionnaire, we present an adaption of the proficiency model from Pyster et al. Figure 9a shows the "pi" model for systems engineers and Figure 9b shows the adapted model for technical experts.

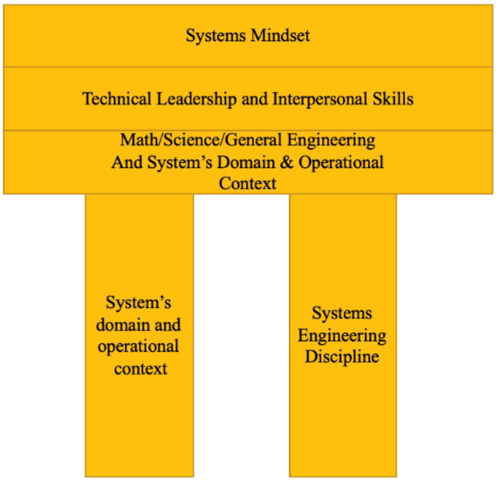

Figure 9a. The "pi" model for systems engineers (Pyster et al., 2018)

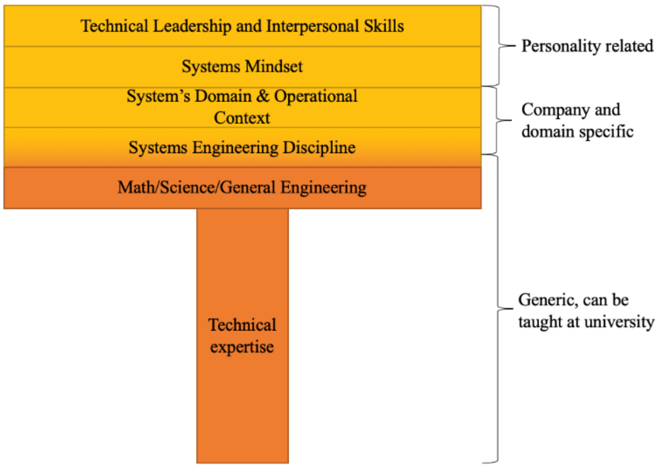

Figure 9b. T-shaped profile for technical experts adapted from (Pyster et al., 2018)

The survey findings reveal that 'math/science/general engineering' has the lowest discrepancy between current and desired proficiency levels. This is also the case for the questionnaire. These findings support the statement that technical experts acquired their 'math/science/general engineering' proficiency at a university level.

According to the model presented by Pyster et al. the 'systems engineering discipline' is a vertical proficiency for systems engineers. In the adapted model presented for technical experts, we believe that the 'systems engineering discipline' is a boundary crossing proficiency. We suggest the use of this proficiency as a common language to bridge the gap between systems engineers and technical experts. Results from the questionnaire support this statement. Respondent-1 writes that they look for the missing link with *the ability to balance the plans/needs/requirements across tasks/teams in the project*. The survey findings reveal discrepancy between current and desired proficiency levels in the 'systems engineering discipline'. Technical experts need to strengthen these proficiencies for them to develop a common language with systems engineers.

The authors suggest adding the 'system's domain & operational context' skill to the horizontal bar for technical experts. The survey results show that 'system's domain & operational context' is the proficiency with the largest discrepancy between current and desired proficiency levels. According to Pyster et al., this proficiency means having knowledge and awareness of relevant systems and the domain in which these systems operate (Pyster et al., 2018). We consider the system's operational domain in relation to the three last life cycle stages where a more pragmatic mindset is essential. The development of the 'system's domain & operational context' proficiency includes the development of knowledge on the later life cycle stages, including phase-out, which will help to bridge the gaps presented in the survey findings. We relate this to Sols suggestion of a "global view". Pyster et al. claims that this is a fundamental proficiency for systems engineers, but our findings suggest that this is not the case for technical experts. Respondent-1 supports this statement and mention that *the product development teams are generally lacking operational input.*

The discrepancy between team and individual proficiency levels suggest that individuals do not place the same emphasis on 'systems engineering discipline' and 'system mindset' as technical managers do. We observed discrepancies between current and desired proficiency levels in both 'technical leadership' and 'interpersonal skills'. Both of these proficiencies that Pyster et al. present as being more relevant for senior technical experts. These proficiencies are also more dependent on personality rather than education and experience, along with the 'system mindset'.

Methods of acquiring knowledge. From the model in Figure 9b we argue that formal education is not sufficient when developing a T-shaped profile. The survey findings support this and reveal that although many have acquired their current proficiencies through formal education, there is little interest in further pursuing this method. Oskam also supports this finding. They claim that interaction and collaboration are methods of teaching many of the aspects of the T-shaped profile (Oskam, 2009).

Survey results reveal that the most interesting methods among technical experts are experience, training, and continuing education. The questionnaire supports this finding. Respondent-1 reports training and experience as the preferred methods of acquiring knowledge. In this research, we choose to focus on training, as this can be used to teach proficiencies to practicing technical experts. Technical experts can acquire both experience and training within their organizations, which allows for a development of the 'system's domain & operational context' proficiency. Teaching the 'systems engineering discipline' within the context of the organization and its projects will also strengthen the 'system's domain & operational context' proficiency.

Recognition. The survey findings reveal a gap between current and desired application of T-shaped engineering profile skills. The participants recognize the need for T-shaped skills in order to preserve knowledge and investments, but they do not recognize current practices in their projects. Findings from Oskam support the survey findings. The gap between ambition and execution is evident in the survey findings. Observations support the development of the 'system's domain & operational context' proficiency through training within organizations.

Conclusion

The survey revealed gaps between design and production lifecycle stages, and the current and desired proficiency levels. Gap between the life cycle stages in design and production can be bridged by understanding the 'operational context' in the system development process, whereas gap's in the current and desired proficiencies are more dependent on personality rather than education and experience, along with the 'system mindset'.

The 'systems engineering discipline' works as a common language among technical experts and systems engineers. While we cannot expect technical experts to have the same proficiency level as systems engineers, a basic knowledge will enable better communication between systems engineers and technical experts. This will allow for an exchange of information that can help to secure knowledge and investments. Training within organizations allows for development of proficiencies that are relevant for the organization and its projects.

A further understanding of relevant domains and interfaces can increase the recognition of T-shaped engineering profile skills in complex multidisciplinary projects.

Future Research

Future research should focus on a larger variety of industries and domains. This will allow for a universal model. We recommend focusing on verification of survey participants proficiency levels. This can be done through feedback from their managers and coworker. Researchers can distribute surveys and questionnaires to technical experts and technical managers in the same projects. This will allow for a deeper investigation of discrepancies.

Acknowledgements

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Biography

Ida Kristin Trogstad received her Master of Science in Systems Engineering with Industrial Economics from the University of South-Eastern Norway in 2020. She is currently employed as a Systems Engineer at Kongsberg Defence & Aerospace, Norway.

Satyanarayana Kokkula received his Master's degree in Applied Mechanics from Indian Institute of Technology (IIT), Delhi in 2000. He worked for one year as an Assistant Systems Engineer at TATA Consultancy Services, India. In 2005, he received his PhD from the Norwegian University of Science and Technology (NTNU), Trondheim, Norway. After finishing PhD, he joined FMC Kongsberg Subsea AS as a Specialist Engineer in Structural Analysis from 2006 to 2016. At present, he works as an Associate Professor of Systems Engineering at the University of South-Eastern Norway.

Dr. Kokkula is a Certified Systems Engineering Professional (CSEP) by the International Council on Systems Engineering, and a Senior Member of the Institute of Electrical and Electronics Engineers.

Joris van den Aker studied economics and organizational science at Tilburg University, The Netherlands. He works as systems engineering program manager at TNO-ESI (www.esi.nl). Development and execution of inhouse competence development programs for systems engineers and architects in high-tech industry are two of his core activities. Keywords in these programs are leadership, mindset, strategy, systems thinking, systems engineering, business context, and culture.

Appendix A- Survey form

As part of my master's thesis, I am conducting a survey that investigates the application of T-shaped engineering profile skills in order to examine how knowledge and investments can be secured throughout the project life cycle. T-shaped engineering profile skills refer to engineers that possess both depth of expertise and boundary crossing capabilities. I would appreciate if you could answer the following questions.

Section 1- Operational context

Check boxes (single answer)

Years of experience

- o 0-5
- o 5-10
- o 10-15
- o 15+

Education level

- o Bachelor
- o Master
- o Doctorate
- o Other: ______________

Team position

- o Manager
- o Engineer
- o Other: _______________

Check boxes (more than one per question)

What stages of the life cycle are you working with/ have you worked with?

- ☐ Need identification
- ☐ CONOPS and stakeholder requirements
- ☐ Design concepts
- ☐ System requirements
- ☐ Design
- ☐ Production
- ☐ Operational life
- ☐ Phase-out
- ☐ Other: ___________

How have your current T-shaped engineering skills been acquired?

- ☐ Experience
- ☐ Formal education
- ☐ Training
- ☐ Continuing education
- ☐ Other: ___________

Likert scale (adapted from Pyster, Hutchinson & Henry, 2018)

Current proficiency levels in boundary crossing capabilities	1.	2.	3.	4.	5.
Math/Science/General engineering					
System's Domain and Operational Context					
Systems Engineering Discipline					
System Mindset					
Interpersonal Skills					
Technical Leadership					

1. Fundamental awareness	2. Novice	3. Intermediate	4. Advanced	5. Expert

Section 2- Recognition of T-shaped engineering profile skills

Likert scale

Questions	1.	2.	3.	4.	5.
I recognize that T-shaped engineering profile skills can be useful in a complex multidisciplinary project					
I am willing to further educate myself in boundary-crossing capabilities					
I am aware of the need for more breadth in complex multidisciplinary projects					
I believe that T-shaped skills help to secure knowledge throughout the life cycle in projects in my organization					
I believe that T-shaped skills help to secure economic investments in projects in my organization					

1. Strongly disagree	2. Disagree	3. Neutral	4. Agree	5. Strongly agree

Section 3- Application of T-shaped engineering profile skills

What stages of the life cycle are you interested in working with?

- ☐ Need identification
- ☐ CONOPS and stakeholder requirements
- ☐ Design concepts
- ☐ System requirements
- ☐ Design
- ☐ Production
- ☐ Operational life
- ☐ Phase-out
- ☐ Other: ___________

How are you willing to acquire T-shaped engineering skills?

- ☐ Experience
- ☐ Formal education
- ☐ Training
- ☐ Continuing education
- ☐ Other: _____________

Likert scale (adapted from Pyster, Hutchinson & Henry, 2018)

Desired proficiency levels in boundary crossing capabilities	1.	2.	3.	4.	5.
Math/Science/General engineering					
System's Domain and Operational Context					
Systems Engineering Discipline					
System Mindset					
Interpersonal Skills					
Technical Leadership					

1. Fundamental awareness	2. Novice	3. Intermediate	4. Advanced	5. Expert

Appendix B- Questionnaire

Interview questions

We have performed a survey with 17 respondents from organizations in and around Kongsberg. The questions in this interview are related to this survey. The goal is to research the validity of the survey results and collect any other relevant information from practicing managers in complex, multidisciplinary projects. Please answer the following questions with your current project team in mind.

Life cycle stages

1. What stages of the life cycle are you working with in your project?

- ☐ Need identification
- ☐ CONOPS and stakeholder requirements
- ☐ Design concepts
- ☐ System requirements
- ☐ Design
- ☐ Production
- ☐ Operational life
- ☐ Phase-out
- ☐ Other: ___________

2. INCOSE has stated that knowledge and investments are lost in life cycle boundaries. In which boundaries do you believe that knowledge and investments are lost in your project?

3. From the survey findings, we observe that the numbers of respondents who have worked with different life cycle stages after design are reduced. See Figure 1. If we relate this finding to the statement made by INCOSE, we can assume that much knowledge and investments are lost between design and production and in phase-out.

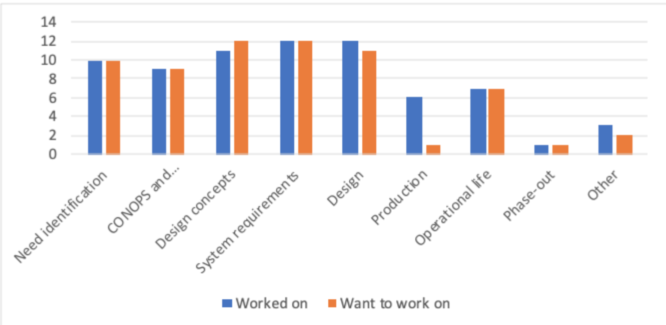

Figure 1. Life cycle stages worked on and want to work with

How would you be willing to invest resources in T-shaped engineering skills and life cycle management in order to bridge this gap?

Methods of acquiring knowledge

4. How have the engineers in your project acquired their T-shaped engineering skills?

- ☐ Experience
- ☐ Formal education
- ☐ Training
- ☐ Continuing education
- ☐ Other: ___________

5. How are are you willing to invest in order to develop further T-shaped engineering skills?

- ☐ Experience
- ☐ Formal education
- ☐ Training
- ☐ Continuing education
- ☐ Other: ___________

6. We observe that many respondent are interested in developing skills through training and continuing education. See Figure 2. Are these methods that you would be willing to apply in your project team?

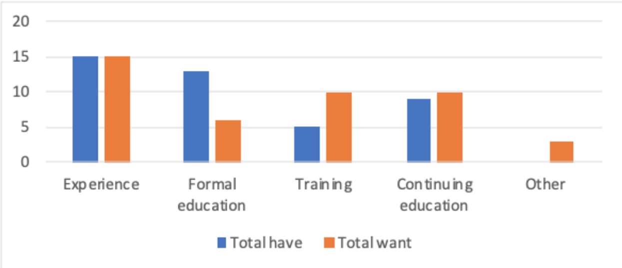

Figure 2. Methods of acquiring T-shaped engineering profile skills

Proficiencies

We have developed a model based on Pyster et al. This model presents the T-shaped profile of engineers. See Figure 3. These proficiencies are the foundation for the following questions.

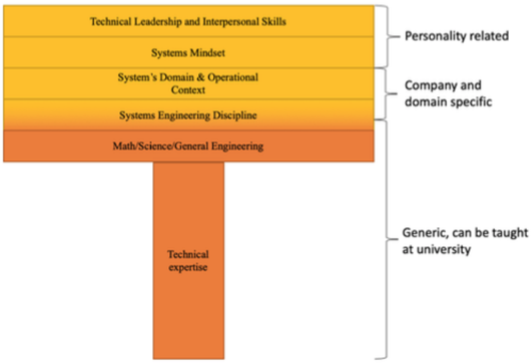

Figure 3. T-shaped profile for engineers, adapted from Pyster et al. (2018)

7. Teams current proficiency levels

Current proficiency levels in boundary crossing capabilities	1.	2.	3.	4.	5.
Math/Science/General engineering					
System's Domain and Operational Context					
Systems Engineering Discipline					
System Mindset					
Interpersonal Skills					
Technical Leadership					

1. Fundamental awareness	2. Novice	3. Intermediate	4. Advanced	5. Expert

8. Teams desired proficiency levels

Desired proficiency levels in boundary crossing capabilities	1.	2.	3.	4.	5.
Math/Science/General engineering					
System's Domain and Operational Context					
Systems Engineering Discipline					
System Mindset					
Interpersonal Skills					
Technical Leadership					

1. Fundamental awareness	2. Novice	3. Intermediate	4. Advanced	5. Expert

9. Our previous survey results are presented in Figure 4. We see that that the largest discrepancy is found in systems' domain and operational context. According to Pyster et al, this is a fundamental skills for systems engineers. However, our observations suggest that this is not the case for technical experts. How can you relate this to your current project team?

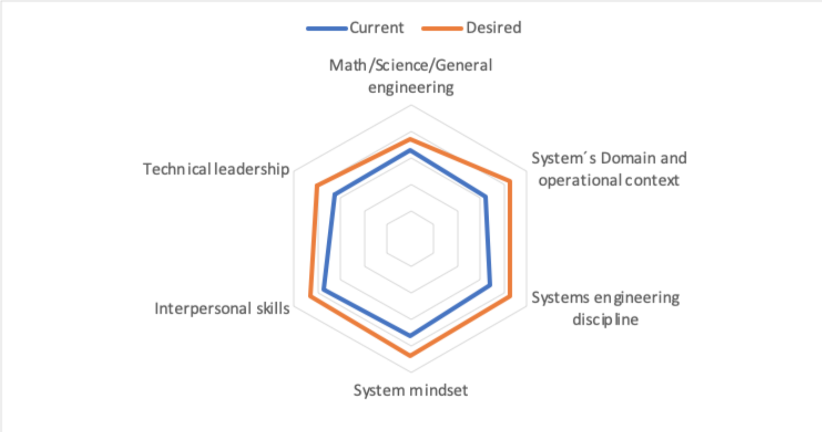

Figure 4. Current and desired proficiency levels in boundary crossing capabilities

10. From Figure 3 we see that the system mindset is related to personal attributes. This proficiency encompasses the engineer's approach to a task, patterns of thinking and ability to see the bigger picture. How do you secure people with the system mindset in your project team? How can you connect engineers with systems mindset to you system's domain and your operational context?

Recognition

In the survey a Likert scale was presented in order to map the respondents recognition of T-shaped engineering skills. See figure below for the results.

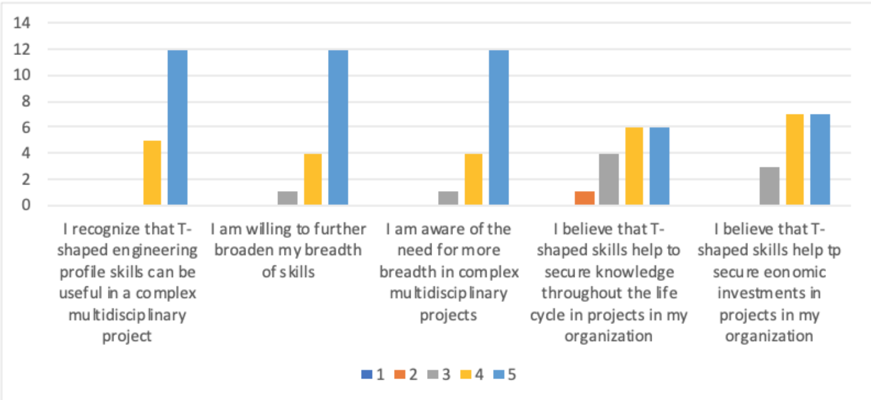

Figure 5. Recognition of T-shaped engineering profile skills

11. Questions that address the general application of T-shaped engineering profile skills score higher than questions related to the respondents' current organizations. This could imply that T-shaped engineering skills are not prioritized in projects today. How are T-shaped skills recognized and applied in your project?