Exploring a co-creative problem solving toolbox in the context of Norwegian high-tech industry

Marianne Kjørstad, Kristin Falk & Gerrit Muller
Institutt for realfag og industrisystemer - Universitetet i Sørøst-Norge

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***Abstract*—Norwegian high-tech industries face a rapidly changing market need. Staying ahead of competitors and developing significant innovative solutions are essential for business value. Systems engineering has proven to be an effective approach for developing technical (hard) systems. People, organizations, and technical functionality contribute to an increasing complexity in today's high-tech systems. This makes the traditional systems engineering approach insufficient for innovation in a socio-technical context. This paper looks towards systems architecting, systems oriented design, and participatory design for collaborative and creative ways of working to support systems engineers in developing significant innovations. We explore a rich toolbox and the outline of a new methodology for such co-creative problem solving. Firstly, we identify industry needs for the new methodology and derive success criteria for the toolbox embodied in the new methodology. Through ten industry cases within Norwegian high-tech industries, we analyze and discuss the toolbox composed of methods and tools for early exploration, validation, and knowledge transfer in the concept phase. Finally, we provide examples on how the toolbox supports the industry needs and outline the new methodology.**

***Index Terms*—Creative problem solving, concept exploration, early validation, significant innovation, socio-technical systems**

I. Introduction

Norwegian high-tech industries face a rapidly changing market need. Staying ahead of competitors and developing innovative solutions are essential for business value. Systems engineering [1] has proven to be an effective approach for developing technical (hard) systems. People, organizations, and technical functionality contribute to an increasing complexity in today's high-tech systems. Checkland [2] described such socio-technical problems as *real world problems*, and introduced the term *soft systems* to address this. Innovating in a context of soft systems using a traditional systems engineering approach has proven challenging [3]–[9].

Previous research has discussed the potential of combining design- and systems approaches [5]–[8]. However, we have not found literature that focuses on the industrial challenges for systems engineers to innovate in a soft systems context, nor the main influencing factors to address for the industry to overcome these challenges. To support systems engineers to innovate in a soft systems context, we explore collaborative and creative ways of working through a *co-creative problem solving toolbox*. The naming is referring to the act of collective creativity (co-creation) typical in participatory design [10]. In this paper we define *co-creation* using the description by Sanders, and Sanders and Stappers [11], [12]. They described co-creation in the design development process as co-design, referring to the collective creativity of designers and non-designers (such as users or customers) creating a new product or process.

Seeking to inspire systems engineers to apply more collaborative and creative ways of working than the traditional systems engineering approach offers, this paper provides our experiences using the toolbox and outlines a new methodology. The new methodology aims to support systems engineers to cope better with the complexity of soft systems to develop *significant innovations* to rapidly changing market needs. To define what we mean about significant innovation we refer to Muller [13]. Muller differentiated between incremental and significant innovation in mature companies and described the latter as "*solutions beyond the ordinary*"[1]. According to Muller, mature companies often focus on consolidation and incremental innovation to grow, while significant innovation is much harder to create.

We have conducted research through a collaborative research project including four Norwegian high-tech companies and two academic partners. The academic partners are within the field of systems engineering and systems oriented design. The companies provide innovation services and full-scale systems for the global ocean space, such as service vessels, expedition vessels, subsea systems, and off grid renewable energy systems. Through ten industry cases within the companies, we explore a rich toolbox embodied in the new methodology. In this paper, we aim to answer the following research questions:

What are the industry needs for a new methodology to innovate in a soft systems context? (Section V)

How does the toolbox address the industry needs? (Section VII)

What may be the outline of the new methodology? (Section VIII)

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The authors are with the Department of Science and Industry Systems, University of South-Eastern Norway, 3616 Kongsberg (e-mail: marianne.kjorstad@usn.no; kristin.falk@usn.no; gerrit.muller@usn.no).

[1] This terminology is inspired by the Boderc research project conducted through the Embedded Systems Institute in Eindhoven, the Netherlands [60].

By answering these questions, we contribute to the body of knowledge in three ways. Firstly, identifying the industry needs for a new methodology will guide the industry in the main influencing factors to innovate in a soft systems context. Secondly, analyzing how the toolbox addresses these needs provides a better understanding on how to cope with current challenges in the industry. Finally, identifying the outline of the new methodology will provide a good foundation for ongoing research on realization and evaluation of a new methodology.

The following two sections provide background literature on the addressed challenges and relevant literature for the toolbox. Next, we present the research design. Further, we describe the results including the research on industry needs and industry cases on the toolbox. At last, we analyze the toolbox and discuss the way towards the new methodology, before we conclude on the research questions.

II. Background

General Systems Theory developed by Bertalanffy in the 1940s has shown to provide a good basis for a general system framework in recent literature [14]. Bertalanffy [15] described systems theory as a scientific approach to understand systems in general, from biological systems to conceptual systems. Gharajedaghi [16] built on systems theory and characterized a system's behavior using the five principles of openness, purposefulness, multidimensionality, emergent property, and counterintuitivity. To define problems and develop solutions, he emphasized the importance of viewing systems through these principles. He stated that *"no problem or solution is valid free of context"* [16, p. 31]. The importance of a systems thinking mindset in engineering to solve real world problems is well documented in literature, such as [2], [14].

The lack of soft consideration in systems engineering [1] has been a topic for decades. Peter Checkland described the "*failure of systems engineering"* and the following development of the *soft systems methodology (SSM)* in the early 70s [3, p. A35]. Checkland emphasized the need to consider the political aspects of human activities to make changes in the real world that are both feasible and desirable. The main developers of SSM are Checkland, and Wilson. They have published a fair amount of literature on SSM and how it has evolved over the years [2], [3], [17]–[19].

Jackson provided a thorough overview of major systems approaches including SSM in [20]. He defined systems engineering as *hard systems thinking*. He recognized systems engineering as a well-proven approach coping with technical complexity. However, he emphasized the need to look towards other systems approaches for considering various forms of complexity, such as process, structural, political, people, and organizational complexity. Jackson called this *critical system thinking* with the purpose of better managing complexity.

Wade, Hoffenson, and Gerardo [5] discussed strength and weaknesses of major paradigms for designing complex systems. Their discussion included design thinking, systems thinking, systemic design, engineering design, and systems engineering. Wade *et al.* found traditional systems engineering as weaker in the concept phase compared to systems thinking, design thinking and systemic design. They proposed a unified approach combining the strengths of the major paradigms into a new *systemic design engineering*. A pilot of such a curriculum combining elements from systems thinking, design thinking and systems engineering in education has been taught at the Stevens Institute of Technology with promising results [21].

The need to explore a combined approach of design thinking and systems thinking into a new framework or methodology has been proposed in recent literature [5]–[8]. A combined systems and design methodology is assumed to better cope with *ill-defined problems* in the early concept phase with the purpose of developing more innovative solutions. Rittel and Webber [22] introduced the term *wicked problems* in the early 70ties to describe such ill-defined problems. Wicked problems are challenging problems with no optimal solutions, and a focus area in design when developing societal systems. Such systems are overly complex, and demand a different problem solving approach than for hard systems [5]–[8].

The need for informal ways of working to support exploration and context understanding in the concept phase is emphasized by Muller [23]. Muller further described the importance of managing different viewpoints to gain knowledge of multiple perspectives. Thorough understanding of stakeholder perspectives and needs are essential to design *systems fit for purpose* within a *business context* [23]. Muller described this as systems architecting. Systems architecting as a term is not that well accounted for within the literature on systems approaches. Jackson did not mention systems architecting in his overview of major systems approaches [20]. Emer, Bryan, Wilkinson *et al.* [24] found six different perspectives on systems architecting when interviewing systems architecting practitioners. In this paper, we view systems architecting as informal ways of working, complimentary to formal architecting frameworks. From this view, systems architecting presents a systems approach that can supplement the traditional systems engineering to innovate in a soft systems context.

III. Literature Review

This section reviews the literature on the methods and tools that has formed the co-creative problem solving toolbox. We look towards the field of *systems architecting, systems thinking, design thinking, participatory design,* and *systems oriented design* to explore a toolbox fit for the industrial context and industrial need in this research project.

As part of the systems architect's toolbox, Muller proposed an *illustrative concept of operations* (ConOps) [25]. Compared to the traditional ConOps [1], an illustrative ConOps is a visual representation of the sequence of operation of the concept(s), usually captured in an A3. Illustrative ConOps can be used for early validation of concepts in communication towards stakeholders. Solli and Muller [26] applied illustrative ConOps in the Norwegian subsea industry. They found that illustrative ConOps resulted in prompt responses from systems engineers on various concepts and operations, expressing concerns as well as curiosity about the operational steps.

Jensen, Muller and Balfour [27] proposed the usage of an *interactive knowledge architecture* (IKA) for knowledge sharing of the problem domain in the concept phase. They found a desirable knowledge base to work well for knowledge transfer of the problem domain between systems engineers and customers. A mutual understanding of the problem domain in the concept phase is essential for early validation to avoid late and costly design changes.

Inspired by Checkland's [2] way of visualizing systems, Boardman and Sauser developed a technique for visualizing *"readable"* systemic diagrams that capture concepts through systems thinking [28]. They called this technique *systemigram* and used it to communicate and confirm strategic intent. Boardman *et al.* described systemigram as a complement to the richness of prose, and due to its easy readability would reach out to more people enabling a greater shared understanding. Blair, Boardman, and Sauser [29] proposed using systemigram as a storyboard for stakeholder communication. Cloutier, Sauser, Bone, and Taylor [30] proposed using it for capturing knowledge about problems, while Squires, Pyster, Sauser *et al.* [31] applied systemigram to communicate a project's value proposition.

Design thinking was defined by Schön [32] in the early 1980s, and further theorized by others such as Rowe, Cross, Nelson, and Stolterman [33]–[36]. Contemporary design thinking as practiced by the Innovation Design Engineering Organization (IDEO) from the early 2000s, focuses on emphasizing with users to understand the unmet need and develop systems that enhance user experience [37]. Kelley and Kelley [38] highlighted the strong link between creativity and innovation, and described creativity as a mindset that can be trained and used to find new solutions. IDEO advocates such a mindset in a human-centered approach towards innovative solutions. Not only in design and engineering to develop more desirable products and systems, but also in management and business aiming for more creative people and organizations [39]. Inspired by design thinking, Pinto, Falk, and Kjørstad [40] proposed *visual canvases* to develop systems that are desirable, feasible and viable. Visual canvases are structured templates using visualizations to emphasize with users and extract *human values* in stakeholder analysis. In this way, it can be used for early validation of user needs in the concept phase.

Björgvinsson, Ehn, and Hillgren [41] discussed the design thinking approach as presented by IDEO, and claimed that this *"sounds like good old Participatory Design"*. Participatory design as a design practice and theoretical field originates from the 1970s. Sanders *et al.* [12] discussed co-design within the area of participatory design. They described co-design as *"the creativity of designers and people not trained in design working together in the design development process."* Further, they positioned participatory design towards *"user as a partner"*, and user-centered design towards *"user as a subject"* focus. This indicates a switch from the design thinking mindset towards a more collaborative approach. Sanders *et al*. pointed to participatory design as a fitting approach in the front end of development. They claimed that participatory design will enable a better exploration, user- and context understanding in this fuzzy phase. Kjørstad, Falk, Muller, and Pinto [42] proposed the use of *co-creation sessions* for early validation of user needs in the concept phase. Co-creation sessions are carefully planned sessions for concept exploration with customers and third parties, using tools and techniques inspired by design thinking, systems architecting, and business management.

Systems oriented design (SOD) stems from systemic design that has evolved within the design community [43]. SOD holds many similarities to conceptual modelling within systems architecting and SSM. SOD provides a method to cope with complexity using visualization, called *gigamapping* [44]. Gigamapping is used to explore complex problems and interrelations, using large sheet of papers on walls or tables and pens. Gigamapping can be used to explore freely or more structured, such as using a timeline or canvas. Structured gigamapping is typically to make a customer journey. Gigamapping is based on design practice and tacit knowledge that has evolved over time. The tacit knowledge has in recent years been captured in publications such as by Sevaldson [45]–[47]. Sevaldson [47] highlighted the main benefit from gigamapping to be sense sharing between stakeholders that co-create the gigamap.

IV. Research Design

This research is based on *action research* [48]. Action research focuses on acquiring knowledge by entering a real world situation with the intention of improving it. We find this approach as appropriate for exploring the co-creative problem solving toolbox and the outline of the new methodology. It allows us to get a thorough understanding of the industry needs and potential solutions within the context of the high-tech companies.

A. Research Methods

Using *informal interviews*, *focus groups* and *surveys* towards the industry partners, we identified the industry needs for a new methodology and derived success criteria to evaluate the toolbox. Through analyzing *empirical data* collected from industry cases, we built a problem understanding of the pros and cons of applying the toolbox.

Further, we analyzed the findings to evaluate how the toolbox satisfied the success criteria and outlined the new methodology. Final realization and evaluation of the new methodology is part of ongoing research, aiming to develop an industry guide.

B. Industry Partners

This research project has four industry partners providing innovation services and full-scale systems within the ocean space. Table 1 shows the profiles of the industry partners.

Table 1. Profile of industry partners

Company	Business	Size of company
A	Ship design	medium
B	Innovation consultancy	medium
C	Innovation incubator	small
D	Subsea EPCI supplier	large

Company A is a family-owned company with about 100 years of history designing and building ships, such as service operations and anchor handling vessels. They are well known for providing innovative solutions and have recently expanded into new markets such as expedition vessels. In recent years, they have had a strong focus on strengthening their expertise in systems engineering.

Company B is an innovation consultancy. During the past decade they have been shifting from a traditional engineering consultancy into an innovation consultancy focusing on product development based on human behavior. They have built up a profession based on design thinking tools, co-creation design, as well as systems engineering.

Company C is an innovation incubator, providing innovation services to small and medium-sized enterprises (SME) and start-ups developing high-tech solutions. They have a strong connection to several medium to large high-tech companies, providing the advantage of these connections to their customers. The incubator has a strong focus on value proposition and business models using tools such as the business model canvas [49] towards the start-ups.

Company D is an engineering, procurement, construction, and installation (EPCI) supplier of subsea systems and services with about 40 years of experience supplying reliable systems operating in a rough environment. The EPCI supplier is strong on engineering. The last decade it has in addition strengthened its systems engineering expertise focusing on effective execution.

C. *Industry Cases*

We have done research in ten cases within the industrial partners. This has been a combined effort of five systems engineering master's students and one PhD student. In each case the researchers have engaged with the systems engineers to build a thorough problem understanding and a proper evaluation of the methods and tools in a real-world context. Table 2 shows the profile of the cases.

Table 2. Profile of industry cases

Case no.	Company	Methods and tools	Publication
1	All	Gigamapping	-
2	B	Visual canvas	[40]
3	B	Visual canvas	[50]
4	B	IKA	[27]
5	A	IKA	[51]
6	D	IKA	-
7	D	Systemigram	[52]
8	D	Illustrative ConOps	[53]
9	B	Co-creation sessions	[42]
10	B	Co-creation sessions	[54]

We have published eight of the ten cases as part of the research project. The fifth column provides a reference to this work for readers with specific interests in a more detailed description of each case. For Case 1 and 6, we collected empirical data using *surveys*, *participant observations*, and collection of *benefits and concerns* reported by the participants.

D. *Limitation of research*

In this research, we had no control of the research environment. The cases have been explorative, adapted to the specific industry context and need in each case. Hence, we have had no common questionnaire nor surveys used throughout the cases. We cannot claim that the results from this research are valid for other contexts than described in each of the industry cases.

V. Identifying Industry Needs

Inspired by experience from a similar research collaboration project on knowledge based development we developed an *A3 customer-interest* [55] template for the partners at project start. The purpose of the A3s was to gain a thorough understanding of the current needs for a new methodology within each of the industry partners. We introduced the A3s to the partners in the first half-yearly workshop in the research project. Using the A3 as a guide, we performed informal interviews with company representatives from each of the industry partners. We summed up the following industry needs: *1) early validation*, *2) transfer of (human) insights*, and *3) early concept exploration* to discover "wow" innovations. "Wow" is in this paper defined using the more academic term significant innovation [13], which is the main goal of the research project. Figure 1 visualizes the main industry needs within the context of a system's life cycle [1].

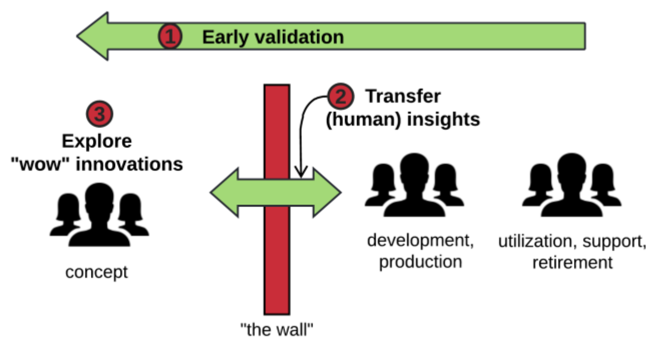

Figure 1. Industry needs in the context of a system's life cycle

Point 1 in Figure 1 shows the industry need to perform early validation of concepts towards a system's operational life cycle (utilization, support, and retirement). This describes the need for better understanding the usage of the system in the concept phase. Point 2 in the figure shows the need to transfer insights gained in the concept phase towards later life cycle phases. The company representatives described this challenge as *"throwing concepts over the wall";* hence, there is a lack of knowledge sharing between concept and development phases. Point 3 in the figure represents the industrial need to create significant innovations through concept exploration. Norway being a high-cost country, the companies need rapid ways of doing this to stay competitive in a global market.

In parallel with the early interviews with company representatives, we performed a literature review on *design thinking* and *systems engineering* as part of early case studies within the industry partners [42]. Thereafter we synthesized the knowledge gained from the literature and interviews, and derived *success criteria* to evaluate the toolbox. For triangulation purposes, we further evaluated the criteria using a survey towards the company representatives. We provided the survey to the eight company representatives in the research project in one of the half-yearly workshops. Prior to the survey, we presented the rationale behind the success criteria to the company representatives. Table 3 shows the profiles of the respondents.

Table 3. Profile of respondents

Role	Company	Relevant work experience (years)
Project manager	A	11
Ux-designer	B	6
System architect	B	4
Department manager SE	B	20
General manager	B	25+
Program manager	C	20+
Technical manager SE	D	13
Chief product developer	D	25

Using Likert scale [56] with the options *very low, low, medium, high,* and *very high*, the respondents answered the two statements:

S1) How important do you think the different properties below are for a new method for the project team in early phase innovation?

S2) How well are the different properties satisfied by the current way of working in early phase innovation in your company?

We analyzed the survey results using a Net Promoter Score (NPS) [57], [58]. We consider the promoters as the ones replying *very high*, while the detractors are the ones replying *medium, low* and *very low*. *High* is neither promoter nor detractor, and hence left out of the NPS score. Table 4 shows the identified success criteria and the NPS results of the survey.

Table 4. Success criteria with NPS results

Success criteria	S1: perceived important for a new method	S2: satisfied by current way of working
Striving to fail early	-3	**-8**
Grasping complexity	**2**	**-7**
Showing business potential	**4**	-4
Sharing knowledge	**1**	-4
Visualizing	**4**	-4
Focus on customer	**4**	0
Enabling creativity	0	-3
Focus on user	**1**	-3
Adaptable to project need	**2**	-4

Table 4 shows the promoted success criteria (NPS > 0) and the most challenging criteria in current work processes (NPS < -5) in bold. For S1, the industry partners were surprisingly not promoting the two criteria; *striving to fail early* and *enabling creativity*. These are factors often highlighted as important for innovation, such as in literature on design thinking [37]–[39]. Reformulating the criterion “striving to fail early” into the more positive “rapid learning” might have provided a more positive NPS score from the industry partners. A negative NPS score for “enabling creativity”, might be related to company culture and history. Based on the solid foundation in literature, we choose to keep these two criteria.

Further, for S2 the companies identified *striving to fail early* and *grasping complexity* to be the most challenging criteria to fulfill in current way of working. The companies also perceived that they currently have enough *focus on customer*.

The last criterion in Table 4; *adaptable to project need*, is at a meta-level with respect to the other criteria, describing the success criterion about the toolbox (irrelevant of its content). The NPS score of -4 indicates that the companies perceive their current way of working as not fit and too rigid for the various needs within a project team. The new methodology needs to be flexible enough to fit the various needs of the systems engineers working in the concept phase.

VI. EXPLORING A TOOLBOX

This section describes the industry cases on the methods and tools. We conducted ten cases, applying six methods and tools. Table 5 shows the methods and tools in the toolbox, industry cases, and the theoretical field for positioning the methods and tools.

Table 5. Overview of methods and tools in the toolbox

Methods and tools	Case (company)	Theoretical field
Gigamapping	1 (all)	Systems oriented design
Visual canvas	2 (B), 3 (B)	Design thinking
IKA	4 (B), 5 (A), 6 (D)	Systems architecting
Systemigram	7 (D)	Systems thinking
Illustrative ConOps	8 (D)	Systems architecting
Co-creation sessions	9 (B), 10 (B)	Participatory design

A. Gigamapping

We applied gigamapping in one case covering nine sessions within all the four companies. Gigamapping stems from systems oriented design. It is a session-based method used to explore complex problems through sense sharing [47], using large sheet of papers on walls or tables.

In **Case 1**, an experienced gigamapping facilitator introduced the method to the companies [59]. From there on, members of the research team facilitated the sessions. We applied gigamapping in idea generation, concept exploration, and concept development. The number of participants in the sessions varied from 4-12 participants. Figure 2 shows small teams doing gigamapping on table and wall (in the back).

Figure 2. Small groups doing structured gigamapping

The team in front was exploring a new concept over its lifecycle using structured gigamapping with timeline. Most participants expressed enthusiasm during and straight after applying the technique. Participants of two early sessions using gigamapping were replying to the following Likert scale [56] statement after the session: *"I will try out the techniques we used in this workshop in my future work."* All 22 participants replied agree or strongly agree to this statement, with an NPS [57] of 13. The ship designer cleared off a separate room for gigamapping just after the introduction, determined to further test this way of working.

Main benefits that the participants replied after gigamapping were a better understanding of complex problems and stakeholders. They also reported that gigamapping enabled communication and ensured that all participants were on the same page. Main concerns that the participants replied after gigamapping were whether all necessary participants were present, if the actions would be followed-up, and how to ensure using gigamapping as part of the daily work. Another challenge mentioned by participants was that gigamapping was suited for extrovert people.

B. Visual canvas

We applied visual canvas in two cases in company B. Inspired by design thinking, visual canvases are designed to extract human values enabling design of systems that are *desirable, feasible, and viable* [40].

In **Case 2**, Pinto *et al.* [40] implemented two visual canvases in a system development project in the innovation consultancy. The project team used the canvases for stakeholder analysis and use case scenarios. Pinto *et al.* found the tool to increase the project team's focus on human values. The team developed system requirements reflecting the identified human values.

Sjøkvist *et al.* [50] conducted further evaluation in **Case 3**. They implemented visual canvases in an early concept study for a customer in the construction industry. In addition to Pinto's canvases, they implemented visual canvases for stakeholder mapping and stakeholder interviews. The project team used the canvases for documentation and communication towards customer and within the project team. Sjøkvist *et al.* observed that the project team found it challenging to maintain the focus on human values throughout the concept phase. However, they found that visual canvases contributed to a stronger awareness of human values among the systems engineers. The team successfully managed to transfer human values into stakeholder requirements.

C. IKA

We applied IKA in three cases in companies A, B, and D. IKA [27] is a tool developed in MS PowerPoint for knowledge sharing in the concept phase in company B. It is documenting knowledge captured by tools such as visual canvases or co-creation [40], [50]. Inspired by design thinking and informal methods in systems architecting, IKA uses visualizations and interactive links to provide a usable and desirable interface for the systems engineers.

In **Case 4**, Jensen *et al.* [27] found IKA to support effective documentation and communication within the project team and to customer at the innovation consultancy. The systems engineers perceived IKA as more desirable than current way of working. Jensen *et al.* also found the tool to be effective in status meetings, as a structured knowledge base for building the problem and solution landscape within the project team.

In **Case 5**, Vanebo and Kjørstad [51] found IKA to be beneficial for creating a mutual understanding of customer needs within the project team. The format and layout of the IKA showed potential for presentations to customers. Vanebo *et al.* also found the IKA as a potential knowledge base for the project team in the concept phase and for knowledge transfer to teams in the following life cycle phases. The concerns reported by the systems engineers were the amount of work required to develop and maintain the IKA. They also reported the need for a document owner and revision control.

Case 6 applied IKA in a project team at the EPCI supplier (company D). Figure 3 shows the IKA front page.

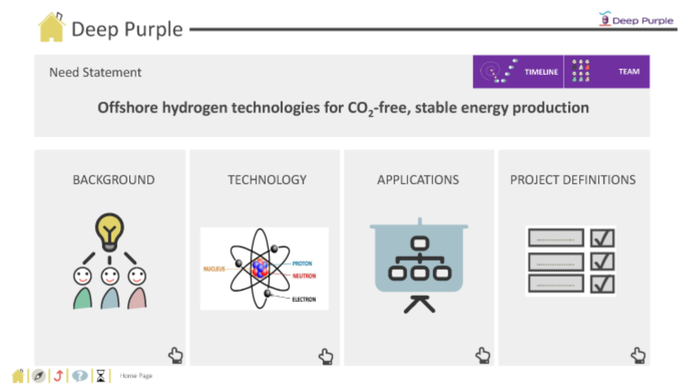

Figure 3. Front page of IKA applied in company D

The team was doing concept design of a renewable energy system to provide off grid, stable, emission-free energy to maritime applications. As three new team members entered the project at that time, the team used IKA as a knowledge base and for knowledge transfer to new team members. The team tested IKA for eight months.

The main benefit observed during development of the IKA, was that to communicate in this format the systems engineers needed to be specific and simplify concepts. The navigation links also gave a rapid knowledge transfer for new team members. The main concerns reported by the team members was that the IKA layout suffered from a lack of quality check and that it required a lot of maintenance. Another comment was that the value of IKA depended on its design. The IKA did not necessarily increase the understanding of customer needs but ensured the transfer of the knowledge gained. We observed that the IKA did not replace any of the other documents in the project. The systems engineers perceived maintaining IKA as added work.

D. Systemigram

Systemigram was applied in one case in company D. Systemigram [28] is a systemic visualization for capturing concepts through a systems thinking mindset, and used for communication of strategic intent.

In **Case 7**, Kjørstad, Mansouri, Muller and Kjenner [52] investigated how systemigram could benefit the renewable energy project at the EPCI supplier (company D). At the time of the case, the renewable energy project was still in concept exploration phase with high focus on communicating business case towards internal and external stakeholders. Kjørstad *et al.*

developed a systemigram visualizing the business case with focus on user needs. The systemigram was included in the IKA. Kjørstad *et al.* found the systemigram to provide an effective way of communicating the business case towards external stakeholders, allowing the presenter to highlight the important aspects instead of diving into confusing details. The external stakeholders, not previously exposed to systemigram, found it to be an informative and fascinating way of communication. Developing the systemigram was a time-consuming process; however, the process itself increased the systems engineers' understanding of the system and its context.

E. Illustrative ConOps

Illustrative ConOps was applied in one case in company D. Illustrative ConOps [25] is a visual representation of the sequence of operation of the concept(s), usually captured in an A3 format. Illustrative ConOps can be used for early validation of concepts in communication towards stakeholders.

Case 8 designed an illustrative ConOps of a maintenance operation for the renewable energy system in company D. Inspired by the focus on human values in Case 2 and 3, Aarsheim, Falk and Kjenner [53] developed a semi-structured interview guide to find how the users perceived the maintenance tasks. Combined with the illustrative ConOps, the project team conducted interviews with users holding operational experience from offshore subsea systems. The project team considered this as a feasible option as the company had no access to users of similar systems. Aarsheim *et al.* found the illustrative ConOps to increase the systems engineers understanding of human values. Furthermore, they successfully transferred this knowledge into stakeholder requirements not previously identified by the project team. They also observed that the interviewees reacted with surprise to the focus on human values, clearly expecting a more technical and business focus.

F. Co-creation sessions

We applied co-creation sessions in two cases in company B. Co-creation sessions are carefully planned sessions for concept explorations. The sessions are carried out in collaboration with customers with the intention of early validation. Through facilitation, the participants apply tools and techniques inspired by design thinking, systems architecting and business theory.

Case 9 investigated a co-creation session in three different innovation projects within the innovation consultancy (company B). Kjørstad *et al.* [42] found the main drivers for co-creation sessions to spark creative ideas and explore early phase concepts, enable customer ownership of chosen concepts as well as create a mutual understanding of the user needs. Further, they found the main impacting factor of the effectiveness of the method to be the skill of the facilitator.

In **Case 10**, Guntveit, Kjørstad and Sevaldson [54] did further research on how co-creation sessions contributed to early validation of stakeholder needs. They planned and facilitated three sessions with three different customers. Guntveit *et al.* found that the co-creation contributed to anchor, align, and validate stakeholder needs. However, they also found that the sessions themselves did not necessarily help for eliciting stakeholder needs. The project team needs to identify this insight upfront and include it in the session.

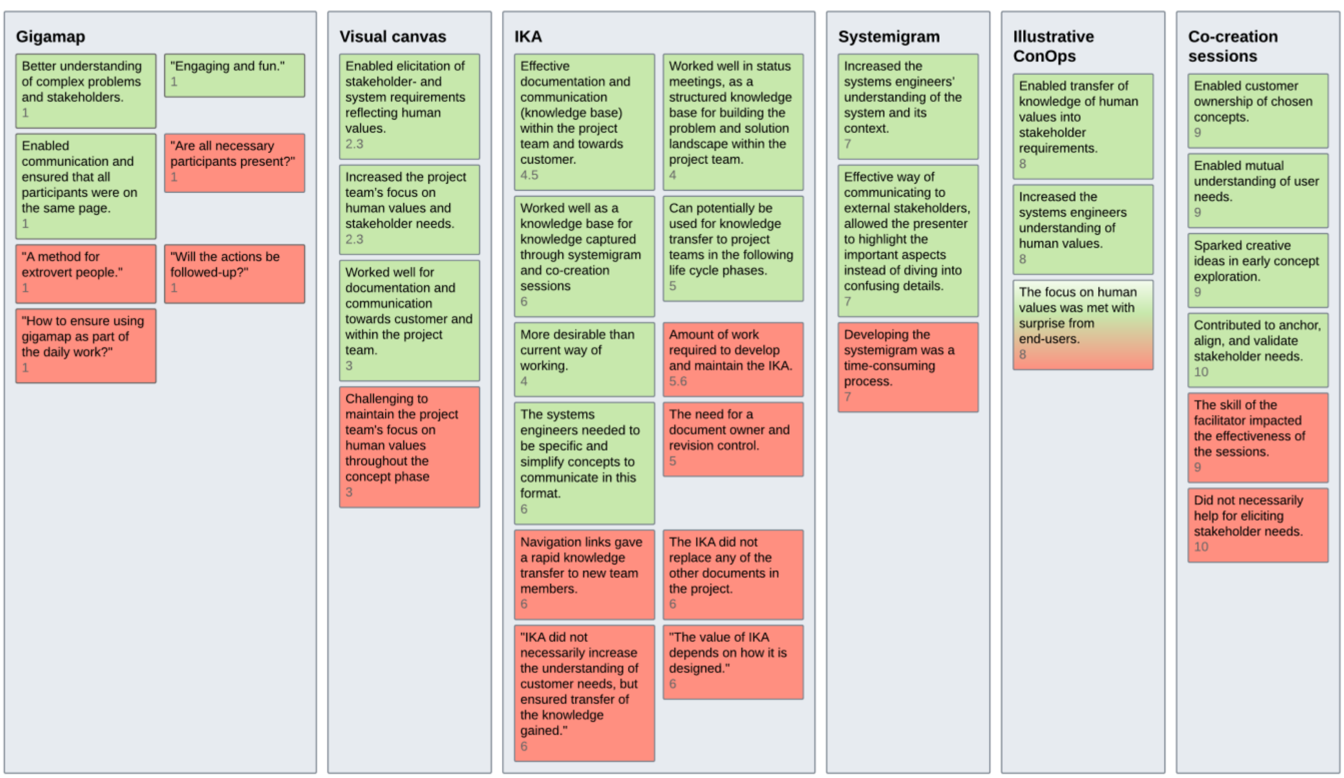

Figure 4. Pros (light green) and cons (dark red) of the methods and tools in the toolbox (including reference to case no.)

VII. Analyzing the Toolbox

Figure 4 presents a summary of the pros and cons applying the toolbox. Table 6 shows how the toolbox addresses the success criteria. Based on the findings in Figure 4, this section analyzes the industry cases on the toolbox and discusses how the methods and tools satisfy the success criteria (highlighted in *italic).*

Table 6. How the toolbox addresses the success criteria

Methods and tools	Success criteria
Gigamapping	Grasping complex problems, sharing knowledge, enables creativity
Visual canvas	Focus on user
IKA	Sharing knowledge
Systemigram	Showing business potential, focus on customer, sharing knowledge
Illustrative ConOps	Striving to fail early, visualizing
Co-creation session	Enabling creativity, striving to fail early, focus on customer, share knowledge
All (the toolbox)	Adaptable to project need

In Case 1, we observed that **gigamapping** works well for *grasping complex* problems and *sharing knowledge* through interactive sessions. It is a visual tool for exploration and in this way, it *enables creativity*. Participants perceived gigamapping as a tool for extrovert people, and a question often popping up afterwards was how to proceed. Facilitators must ensure that introvert participants engage too.

In Case 2 and 3, we found **visual canvases** to increase awareness of human values through *focusing on the user*. The project teams used the canvases to identify needs and transforming them into stakeholder and systems requirements. In Case 8, we observed that direct contact with end-users is not always possible nor even known nor prioritized in the early concept exploration phase.

IKA seems to work well in small-sized companies used to flexible work processes, such as in Case 4 and 5. It is a rapid way of communicating concepts. All cases on IKA found it to work well for *sharing knowledge*. It was acting as a knowledge base for the knowledge captured by the other methods and tools. Case 4 also proposed to use IKA for knowledge transfer towards systems engineers in subsequent life cycle phases.

Systemigram as applied in the renewable energy project in Case 7, is a slow but helpful tool to *show business potential* and *focus on customer*. We also found the systemigram to work well as a communication tool for *sharing knowledge* towards external stakeholders. The case shows that the process of developing the systemigram is as least as important for knowledge sharing as the result itself.

In case 8, we found **illustrative ConOps** to be effective for early validation of user needs, and in this way offers a good approach *to fail early* and to learn rapidly. Designing *visual* representations of operational scenarios forces the systems engineers to *focus on users*. We found that the focus on human values enabled systems engineers to elicit new stakeholder requirements.

Case 9 and 10 found **co-creation sessions** with a planned agenda and carefully chosen tools to work well to engage customers, create trust, *enable creativity*, and explore the problem and solution landscape. Through exploring concepts in collaboration with customers, the session *strives to fail early* and learn fast, as well as *focus on customer* and *share knowledge* through interaction. Case 9 found the outcome of the sessions to be depended on the skill of the facilitator. This sets certain requirements to the facilitation skills of the systems engineers.

We found most of the methods and tools in the toolbox to be flexible and *adaptable to project need*. Visual canvases are not that easily adapted if contact with end-users is not possible. However, this challenge can be mitigated using visual canvases towards feasible options, such as in Case 8. The co-creation sessions as used in Case 9 and 10 are not necessarily adaptable to a project without a customer. For such projects, a modified co-creation session using similar tools and approaches might be beneficial for internal concept exploration. It is also interesting to note that focus on human values and emotions is less expected in some domains than others (as experienced in Case 8). Further, we see that the IKA in Case 4 and 5 (company B and A) seem more promising than in Case 6 (company D). We assume that the size of the company might affect these results, as medium sized companies usually have more flexible ways of working than larger companies with rigid work processes.

VIII. Towards a Methodology

This section outlines the new methodology as the authors envision it at the current point in time. The outline is based on the experiences from exploring the toolbox through the ten industry cases.

To support exploration and validation of early phase concepts, we find that systems engineers may benefit from applying more collaborative and creative ways of working than supported by traditional systems engineering. Collaboration expands the perspectives of the systems engineers and ensure stakeholder and context understanding. Knowledge of multiple perspectives supports a systems thinking mindset to develop a system fit for purpose. Creativity enables exploration of the problem space towards significant innovations. Co-creation sessions focus on both collaboration and creativity by applying techniques for exploring the problem and solution domain. Such sessions require careful planning and strong facilitation skills. Rather than facilitate co-creation sessions in its full, we propose to find inspiration from the techniques applied in the sessions and make use of shorter and more iterative sessions.

To further support systems engineers to explore and early validate concepts towards a system's operational life cycle, we see the need for systems engineers to explore user needs and operational scenarios. Tools such as visual canvas and illustrative ConOps are suitable for this purpose. Making visualizations forces the system engineers to simplify ambiguous concepts. The outcome of the illustrative ConOps and systemigrams is a tangible artifact that eases discussion in the team and with customers. Using a knowledge base, such as IKA, to store this kind of artefact supports the transfer of insights towards later life cycle phases. Based on the findings from the cases applying IKA, we propose to integrate such a knowledge base to a more formal architectural framework, similar to what proposed by Cloutier, Sauser, Bone, and Taylor [30]. A digitized IKA will reduce the need of maintenance and revision management. The knowledge base should still strive to keep an intuitive and desirable format for the systems engineers to make use of it.

We have found knowledge sharing, with the purpose of transferring insights to be multidimensional. Session-based tools, such as gigamapping and co-creation sessions, support sense sharing between people as part of a sense-making process. Sense sharing is important for a team to make sense of complex problems. However, the insights gained during such sessions also need to transfer to people not being part of the process. We see a need to capture and transfer the insights gained from sense sharing into the knowledge base. This requires systems engineers that have this insight, as well as the skill to order and visualize it. The process of making systemigrams supports sense sharing by the people part of the process, and the systemigram itself enables knowledge sharing to people not part of the process. Our findings from the case show that systems engineers may perceive the process of making them as time consuming. The value of systemigram needs to be clear for the systems engineers to apply it in their daily work.

The new methodology needs to be flexible, to support systems engineers holding various skills and ways of working. The methods and tools in the toolbox support the main industry needs in several ways and are complementary. The toolbox is a proposal, other methods and tools with similar purpose may be equally beneficial when combined in the same way. For the new methodology, we propose a balance of concept exploration and early validation of concepts moving towards significant innovation at a rapid speed. The systems engineers need to hold a strong focus on capturing insights in a visual format. Tangible concepts decrease uncertainty and enable rapid learning. In future research, we will elaborate on further realization and evaluation of the new methodology and aim to provide an industry guide.

IX. Conclusion and Future Research

Norwegian high-tech industries face a rapidly changing market need. Staying ahead of competitors and developing significant innovative solutions are essential for business value. We find that systems engineers may benefit from applying more collaborative and creative ways of working than traditional systems engineering offers. This paper explores a toolbox and the outline of a new methodology for such co-creative problem solving. The new methodology should support systems engineers to cope better with the complexity of soft systems in the development of significant innovations. Through ten industry cases within four Norwegian high-tech industries, we have analyzed and discussed a rich toolbox embodied in the new methodology, aiming to answer three research questions.

1) What are the industry needs for a new methodology to innovate in a soft systems context?

Through informal interviews and surveys within the four industry partners, we have identified three main industry needs for a new methodology. Figure 1 captured the main needs as *1) early validation of concepts* towards a system's operational life cycle, *2) transfer of (human) insights* between concept and development phases, and *3) early concept explorations* for significant *"wow"* innovations.

2) How does the toolbox address the industry needs?

We explored a toolbox consisting of six methods and tools to be embodied in the new methodology. *Visual canvas* and *illustrative ConOps* support systems engineers to explore user needs and operational scenarios. Visual canvas, illustrative ConOps, and *systemigram* produce visual artefacts that enable discussions, early validation, and rapid learning. The artefacts can be used for knowledge sharing to ease transfer of insights through an intuitive and desirable knowledge base, such as *IKA*. Session-based methods, such as *co-creation sessions* and *gigamapping*, provide multiple perspectives and transfer insights in the form of sense sharing through concept exploration.

3) What may be the outline of the new methodology?

The methods and tools in the toolbox complement each other in supporting the industry needs. The toolbox is a proposal, other methods and tools with similar purpose may be equally beneficial when combined in the same way. The new methodology needs to provide flexibility to support systems engineers with different skills and ways of working. We propose a proper balance of exploration and validation of concepts, as well as a strong focus on creating tangible artifacts to decrease uncertainty and enable rapid learning. In future research, we will elaborate on the realization and evaluation of the new methodology, aiming to provide an industry guide.

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Marianne Kjørstad received the B.S. degree in mechanical engineering from the University of South-Eastern Norway in Kongsberg, in 2003 and the M.S. degree in product design and manufacturing from the Norwegian University of Science and Technology in Trondheim, in 2005. She is currently working towards the Ph.D. degree within systems engineering from University of South-Eastern Norway.

From 2005 to 2016, she worked as an engineer and systems engineer with engineering, testing, and commissioning of complex systems to the ocean space. In 2016 she became assistant professor in systems engineering at the Department of Science and Industry Systems at the University of South-Eastern Norway in Kongsberg, before she started her Ph.D. studies in September 2017. Her research interests include early phase systems engineering and systems architecting, focusing on innovation within Norwegian high-tech industry.

Kristin Falk received the M.S. degree Industrial Mathematics in 1994, and the PhD in Petroleum Production in 1999, both from the Norwegian University of Science and Technology.

From 1999 to 2015, she led technology teams in start-ups as well as SMEs and large corporations, primarily in the energy industry. Since 2015, she has been with the Systems Engineering Program at the University of South-Eastern Norway, as a full professor in Systems Engineering and Subsea Technology since 2019. She is the author of more than 50 papers and patents. Her research focus is “how to create systems fit for purpose in a volatile, uncertain, complex, and ambiguous world”.

Gerrit Muller, originally from the Netherlands, received his master’s degree in physics from the University of Amsterdam in 1979. He worked from 1980 until 1997 at Philips Medical Systems as a system architect, followed by two years at ASML as manager systems engineering, returning to Philips (Research) in 1999. Since 2003, he has worked as a senior research fellow at the Embedded Systems Institute in Eindhoven, focusing on developing system architecture methods and the education of new system architects, receiving his doctorate in 2004. In January 2008, he became a full professor of systems engineering at University of South-Eastern Norway (USN) in Kongsberg, Norway. He continues to work as a senior research fellow at the Embedded Systems Innovations by TNO in Eindhoven in a part-time position. Since 2020, he is INCOSE fellow and Excellent Educator at USN.