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Interactive Knowledge Architecture
An intuitive tool for effective knowledge sharing

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Abstract. This paper focuses on sharing knowledge in early phases of system development. It introduces an interactive documentation tool called the Interactive Knowledge Architecture. The tool works as a knowledge base of the problem domain. We created the tool using Human-Centered Design principles. The lack of an early common understanding of the problem domain can result in increased project costs. We have experienced that we need to focus on the human aspects of project execution to successfully achieve a common understanding among the project team members and customers.

This paper presents the results of implementing the Interactive Knowledge Architecture in three system development projects. To study the tool's ability to meet the human aspects, we used an action research approach. The results of this research imply that the Interactive Knowledge Architecture offers a usable, accessible, and desirable way to document and share knowledge.

Introduction

Company. Semcon Devotek (SD) is a consultancy providing product development services across several sectors. Having expertise in mechanics, electronics, and software, using a systems engineering approach, the company delivers high tech solutions for challenging applications. SD does not deliver the physical prototype as its primary product; instead, the company develops the knowledge needed to set a system in its application. The SD mantra released in 2017 is "Product Development Based on Human Behavior", with the focus on user experience as the leading quality measure. Being a small- to medium sized company, projects are usually running with project teams with three to ten members from SD.

Problem and Approach

The lack of knowledge of the problem domain is a challenge in project development. For each new project, SD usually needs to build a knowledge base of the problem domain from the ground up. Following the Devotek Management Norm (DMN), SD's systems engineering process, the company uses analysis based on the Vee model. However, the engineers have experienced that the current processes do not provide guidelines for effective documentation in early phase project execution. Consequently, the company has improvement potential to provide an effective knowledge transfer between its systems engineers and the knowledge users such as domain engineers, project leaders, and customers. Based on the symptoms we observed in project execution, we determined problems and formulated goals as shown in Figure 1.

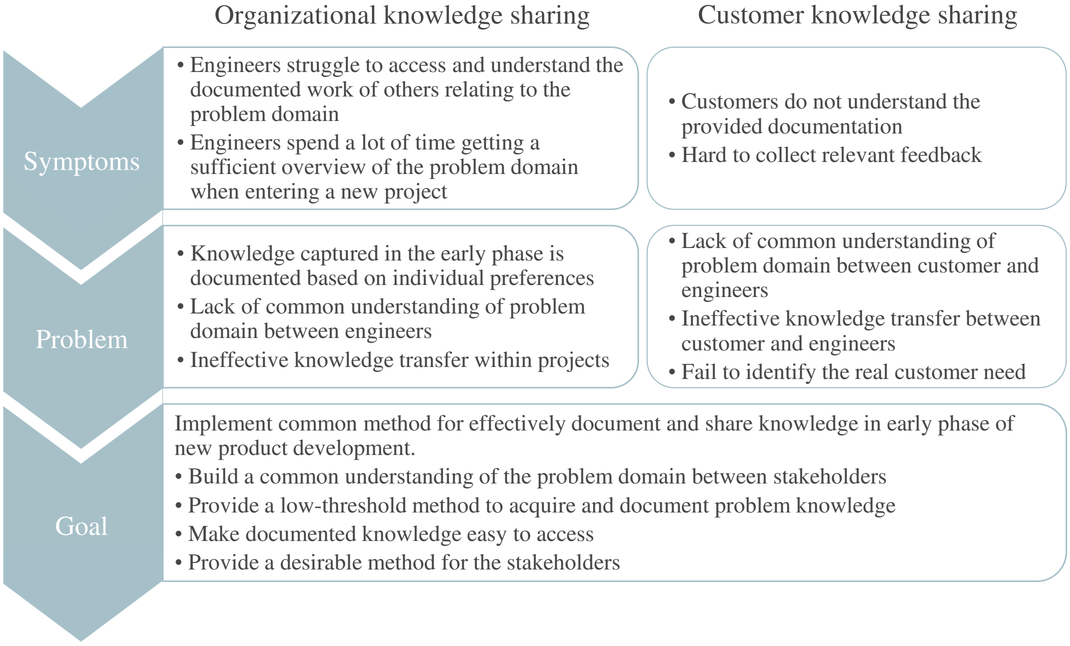

Figure 1 – Symptoms, problem, and goal.

An aspect often forgotten in product development is that product creation is a human activity, with human capabilities and constraints. Muller (2016) states that the human factors boil down to the following requirements: accessibility, understandability, and low user-threshold. The development process needs to meet these human requirements in order to integrate the human aspects. In addition to these requirements, we have experienced that desirability is an important factor when engineers choose their documentation methods. The ISO standard for ergonomics for human-system interaction (ISO, 2010a) addresses usability and accessibility as the two main requirements for software system interaction. The combination of the two requirements is vital to give the user the ability to perform effectively, efficiently and with satisfaction. Muller (2016) states that the human requirements are often conflicting with the requirements prescribed by the management process. Lack of understanding of the human requirements can have severe consequences, as poor information accessibility prevents projects to achieve early validation.

A poor understanding of the problem domain can result in late design changes with a significant impact on project cost and schedule. The committed cost against life cycle model (Figure 2) from the Systems Engineering Handbook (Walden, et al., 2015), displays the economic risk and consequences of early decision making in project execution. Having a good understanding of the problem domain is an important measure to reduce this risk and achieve early validation.

We implemented Interactive Knowledge Architecture (IKA) as the method to meet the identified problem. The IKA is a knowledge base of the problem domain for the project team and the customer. It works as a platform for building a common problem understanding among the project team and the customer to support early validation. The method originates from early phase project execution in SD, and the ongoing development started in 2017. The IKA uses principles from ISO 9241 - standard for human-systems interaction, Design Thinking, and knowledge management. The method aims to share knowledge through a desirable user experience for customers, and engineers.

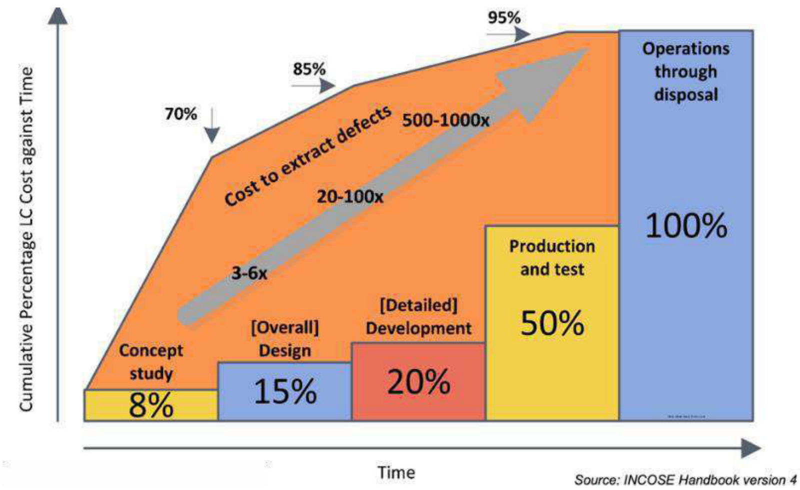

Figure 2 – Committed cost against life cycle model (Walden, et al., 2015)

The success criteria to implement a method to close the gap between stakeholders and the problem domain lies in its ability to fulfill the human requirements. Based on the requirements from Muller (2016), ISO 9241, and experience of the engineers' preferences we list the following criteria:

Table 1 – IKA success criteria

- Usability
  - The engineers must perceive the documentation process as effective.
  - The readers must perceive the navigation through the IKA as easy.
- Accessibility
  - It must be significantly easier for readers to access specific knowledge using IKA, compared to current methods.
- Desirability
  - The engineers must prefer the IKA to current methods.
  - The readers must prefer the IKA to current methods.

State of the Art

Architecting Approaches

Friedenthal (2008) states that the document-based systems engineering approach suffers from some fundamental limitations. The completeness, consistency, and relationships between the system aspects are difficult to access since the authors spread the information across several documents. The lack of access to the acquired knowledge can result in inefficiencies and potential quality issues in late stages of product development (Friedenthal, et al., 2008).

Sharing knowledge through architecture is a key element in successful development projects (Borches, 2010). However, Borches states that it is not common practice among most companies. Companies often fail with effective knowledge transfer due to poor communication of the architectural knowledge. Communicating knowledge with a variety of stakeholders across several sectors is no easy task. There are a variety of soft factors that complicate this interaction such as organizational boundaries, personal skills, mindset, and relations. It is important to remember that the goal is to share knowledge between humans and the architecture is a tool to support that goal (Borches, 2010).

Borches recommends A3 Architecture Overview (A3AO) as an effective tool for knowledge sharing. The A3AO combines elements from Model-Based Systems Engineering and A3 reports. The method presents the architecture in two sides of an A3 sheet where one side presents the interconnected structure and the other, structured textual information. Borches tested the A3AOs in Philip's Medicals MRI department and concluded that it is a powerful tool for effective communication in product development.

Brussel (2015) investigated the use of A3AO in combination with the technological development of display and user interaction. The conducted research looks into several ways to add interactivity to the A3AO using low user-threshold software. Brussel concludes that functions like zooming and internal linking add the possibility to provide more information without impending usability. However, Brussel states there is not yet any suitable software to meet all the identified user requirements from the research (Brussel & Bonnema, 2015).

Dynamic A3 Architectures are, like Borches A3AO approach, a combination of elements from MBSE and A3 reports (Singh & Muller, 2013). However, instead of implementing the architecture into two A3 sheets, Singh's approach uses numerous A3 reports distributed in a hyperlinked SysML based structure. Singh concludes that the dynamic A3 approach helps to access and extract relevant information from a common knowledge base valued by the engineers. However, there is no research measuring direct impact on project cost.

Knowledge Management

Lean thinking assumes there are two value streams that acquire value from the project development process, the product value stream, and knowledge value stream (Kennedy, 2003). Kennedy relates lean product development to be more about managing knowledge rather than managing tasks. He presents The Toyota philosophy as follows: *Product development in Toyota is not about developing cars, it is about developing knowledge about cars. Great cars will emerge from the interaction.* To validate and evolve the knowledge of the problem domain, achieving an effective interaction between the stakeholders is an essential factor (Frøvold, 2017). By standardizing how the engineers generate, collect, transform, and share knowledge, the company can support effective reuse and gain a market advantage.

Human Factors

One of the ultimate goals of product creation is to give users a great experience (Muller, 2017). However, to ensure a great experience, there is near to an infinite number of factors to explore. Different users have different characteristics, capabilities, limitations, and preferences, which build upon individual culture, experience, and learning occurring throughout life (ISO, 2010b). **ISO 9241 "Ergonomics of Human-System Interaction"** provides a series of design principles to optimize human performance in system interaction. Most essential for this paper are the principles of navigation and presentation (ISO, 2010a).

Early Phase Project Process

SD's early phase process uses principles from the Design Thinking and Human-Centered Design process popularized by the Hasso Plattner Institute of Design and IDEO (Tschimmel, 2012) (IDEO.org, 2015). The company implements these principles in the very early stages of their systems engineering process. Table 2 displays the four main stages of SD's early phase process.

Table 2 – Early phase process in SD.

- **Explore and understand.** The project team explores the customer's reality with methods such as field visits, interviews, analysis of market trends, and strategy analysis.
- **Build the problem landscape.** The team defines and interprets the customer need based on the findings of the previous phase. The team analyzes the challenges, opportunities, knowledge gaps and relevant stakeholders. The team identifies the connections and relations between the identified system aspects from the analysis.

- **Ideate.** The team does ideation on top of the problem landscape, usually performed in workshop sessions with customers and relevant stakeholders.
- **Build the solution landscape.** The team evaluates and analyzes the potential concepts to implement in the solution landscape.

Interactive Knowledge Architecture

Engineers in SD developed the IKA to be a knowledge base of the problem domain for the customer and project team. They used it as a communication platform for building a common problem understanding with the customer and support early validation. **The development** emerged through an early phase project in SD in the first quarter of 2017, together with an attempt to apply a design thinking process approach in project execution. In an effort to map the problem domain, the engineers experienced that using the hyperlink features in PowerPoint provided several benefits for effective communication and knowledge sharing. The result was an architecture of various analysis and project work in an interactive breakdown structure. The engineers based the design of the IKA on principles from ISO 9241 to support usability, accessibility and user satisfaction for the company's engineers and customers (ISO, 2010a).

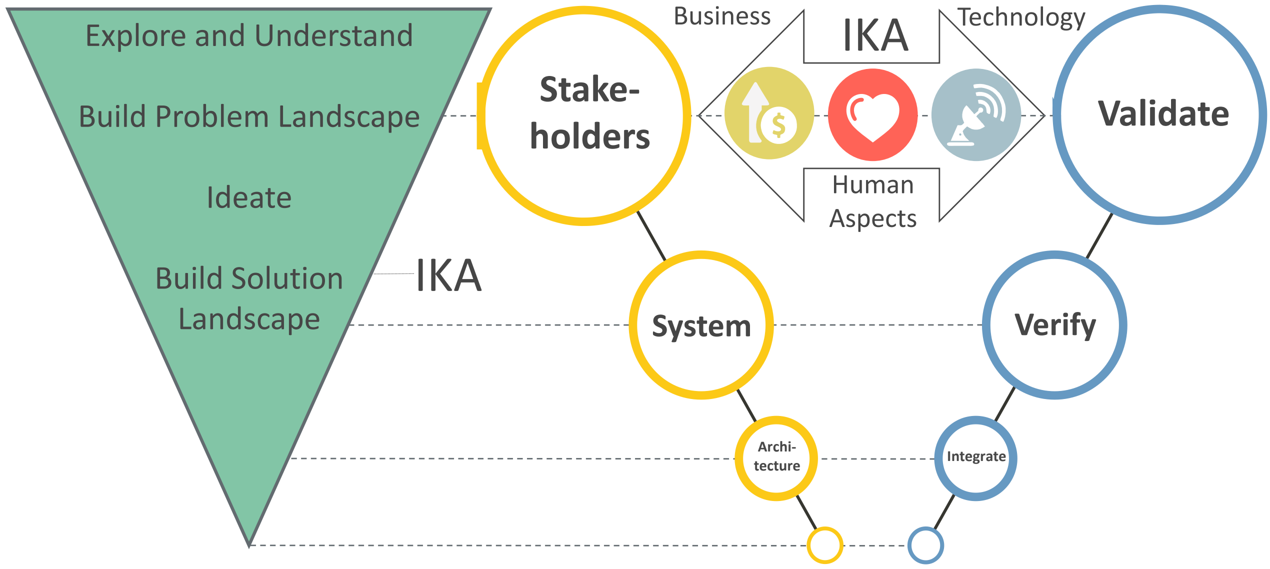

Figure 3 – Implementation of IKA in SD's project process.

The project team establishes the IKA in the very beginning of a project and documents the knowledge based on SD's early phase process. Figure 3 displays how the company implements the IKA in project execution. The architecture functions, in the later parts of projects, as a knowledge base as well as an important source for validation of requirements.

Similar to Singh's (2013) approach, the IKA uses a variety of analysis structured in an interactive architecture. However, we made the analysis and interactive capabilities in PowerPoint instead of a SysML tool, due to the user accessibility and low user-threshold. Many criticize the SysML because it limits accessibility and efficiency of sharing knowledge due to its long learning curve (Borches, 2010). PowerPoint is common in industry, and the users do not need any software introduction to perform their work.

Using the IKA, we aim to share the knowledge more effectively within projects by making it easily accessible for the organization as well as the customer. Like the A3AO (Borches, 2010), we try to meet this aim by presenting the knowledge through a connected architectural overview. Figure 4 shows the documentation process of the IKA. The project team generates, collects, and transforms the knowledge through problem analysis. They share it with the architect who structures it into an accessible format, exports it as a PDF, and shares it with the relevant users. The system architect and project team use the feedback to update the project knowledge structured in the IKA continuously.

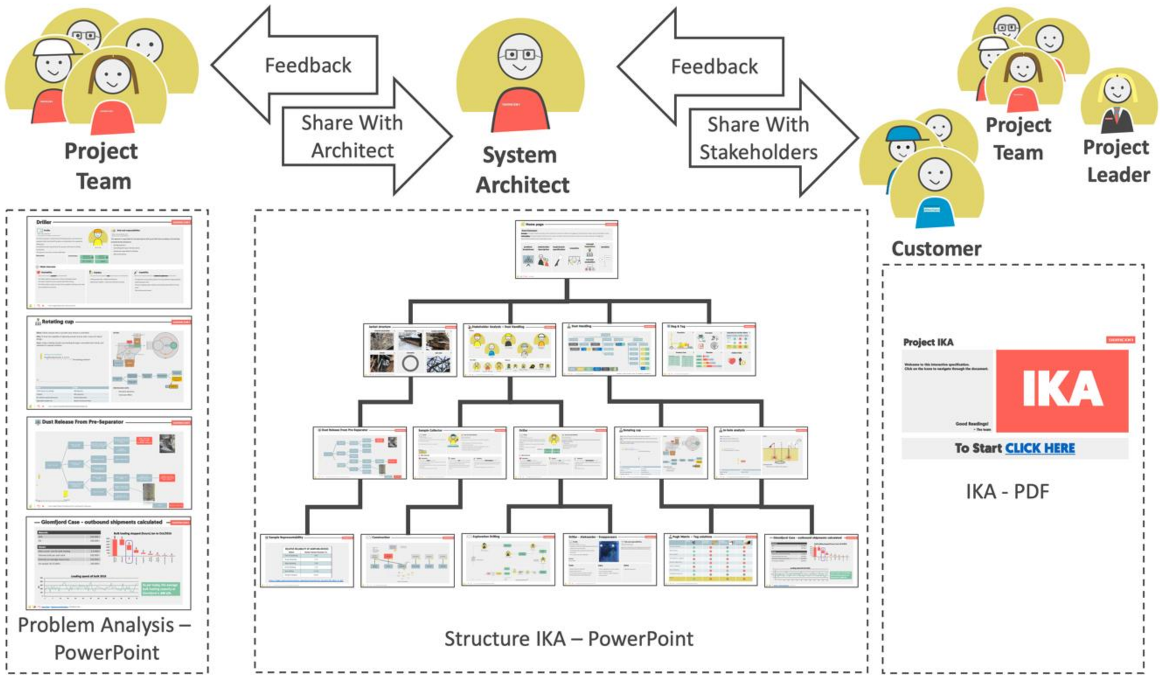

Figure 4 – Documentation process of the IKA

Presentation of user interface content should be consistent, detectable and free from distractions (ISO, 2010b). The engineers developed the IKA with a series of work templates to document early phase knowledge. They followed the ISO 9241's recommendation to present information with the same intent in a similar format. Figure 5 shows a concept analysis performed by an engineer in the TPC project. The IKA presents all concept slides with the same elements within the content area. The elements outside the content area are the same for all slides in the IKA. The status bar displays the user's location in the breakdown structure as well as giving the ability to navigate efficiently to other slides. "Home Page" is a link to the top level in the hierarchy and the "Document Map" is a link to the document breakdown structure. The "author" and "dates" table supports traceability and the area for "external links" the reference and inspiration from other files or web pages.

Navigation should be designed to help users understand where they are, where they have been, and where they can go next (ISO, 2008). The IKA aims to provide the user with the ability to navigate between the content with minimal effort. We build the architecture placing the slides in a hierarchical structure where we decompose each new level from the one above, as shown in Figure 6. The user can navigate through the level of detail in a linear order, going back and forth between levels using the navigation bar. We based the architecture on a tree structure to give the stakeholders a logical overview. However, the hyperlink feature gives the possibility to provide alternative paths between views. The architect can add links to any related slide in the document so the user can navigate without being restricted by the hierarchical structure. The user can also navigate to any part of the document with two clicks when using the document map.

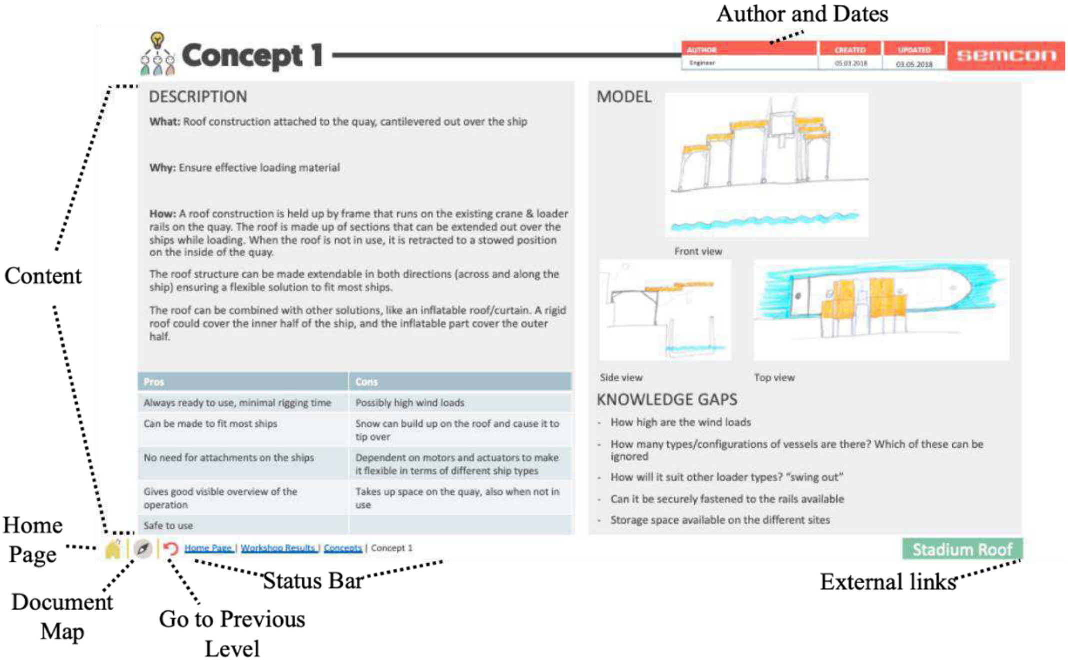

Figure 5 – IKA concept analysis. Each analysis contains the name of the author and the dates for traceability, a dedicated area for analysis content, a navigation bar, and an area for linking to external files or web pages.

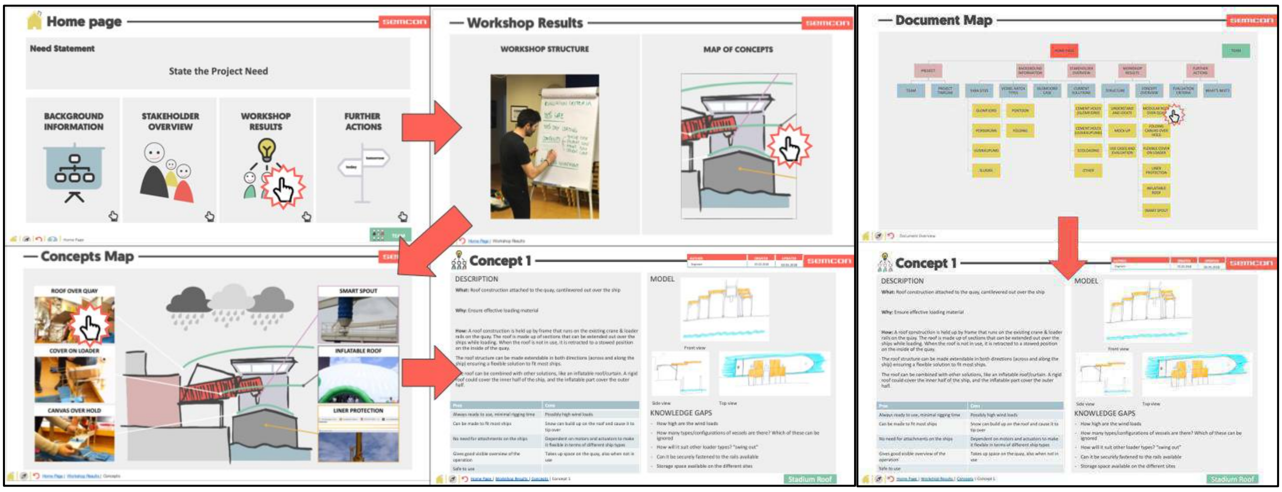

Figure 6 – Navigation in the IKA. The user can reach the concept slide by navigating through the levels or going through the document map.

Research

Cases

Projects executed in SD vary in size, industry sector, and complexity. Researching only one project would limit the added value due to the significant degree of variation that occurs from one project to another. To cope with these variations, we performed this research as a multiple case study, conducting studies of the same method in three different projects. Due to confidentiality, we do not describe the customers by their real name in this paper.

The Drilling Company (TDC) delivers equipment for infrastructure. TDC is a major international actor known for their high quality machines. SD ran an early phase problem analysis aiming to make environment protection more effective than today's solutions. The results of the study were recommendations for product development projects to enhance one of their current products and add a new segment to their product line.

The Offshore Company (TOC) recycles oilrigs. Their need is to increase efficiency and safety for recycling oil rigs. SD delivered a short problem analysis and an idea generation workshop to establish a basis from which to engaging in a larger development project with the customer.

The Production Company (TPC) is a producer with several production and loading sites in Europe. They seek a solution to be able to load products in challenging weather conditions. SD ran a project aiming to develop a solution for loading vessels regardless of weather conditions. SD delivered a short pre-study and an idea generation workshop to establish a basis from which to engaging in a larger development project with the customer.

Research Methodology

We chose action research as the approach for these multiple case studies. In this approach, we participate in the project, working as developers in the project team, and proposing new courses of actions to improve the work processes. In the role as researchers, we gather data through different research methods to seek evidence of the actions taken (Riel, 2017). Riel defines the approach to be appropriate for studies in the industrial context and lists interviews and questionnaires as recommended tools for analysis. Figure 7 represents the iterative action research process performed in this study.

Our research aims to evaluate the usability, accessibility, and desirability of the IKA. We applied the architecture in the early phase of system development for the three cases. Using structured observation notes, interviews and surveys, we evaluated the new method's ability to capture and share knowledge in early phase product development. We looked into the perspectives of internal knowledge sharing in SD and knowledge sharing with the customer. The engineers used templates from the IKA to document the gathered knowledge, and the system architect organized the work into the document structure. We interviewed the engineers to get feedback on the process and the applied tool. We delivered IKAs as results for each of the three conducted customer workshops, together with customer feedback surveys.

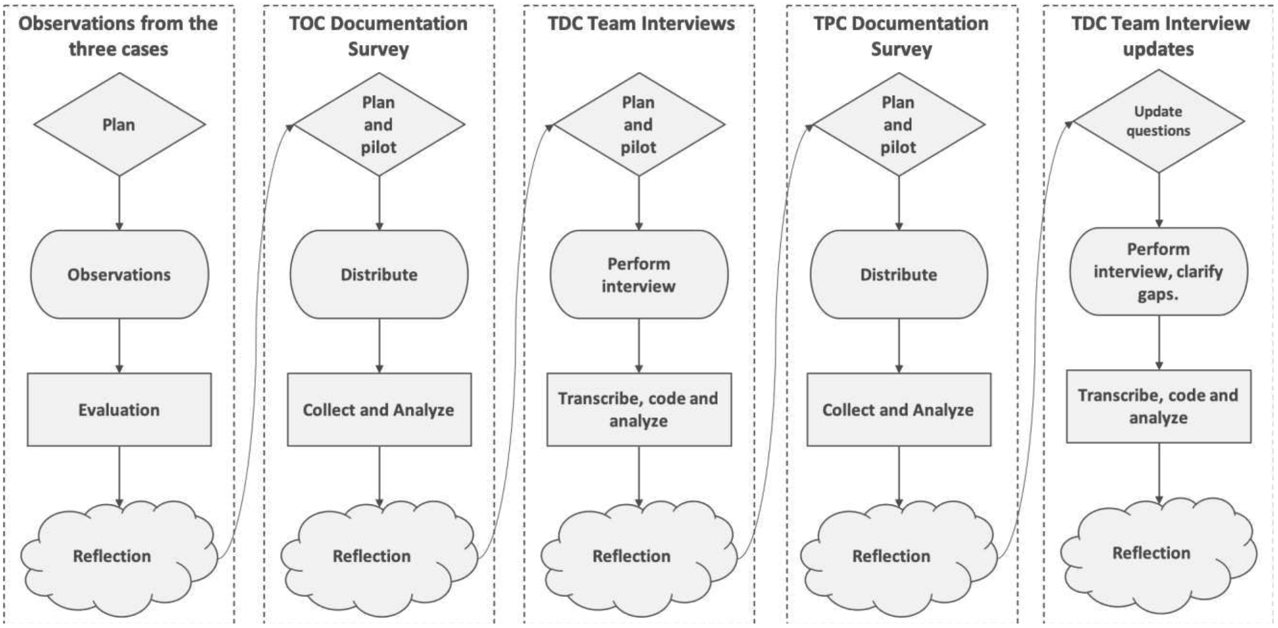

Figure 7 – Performed action research process, based on illustrations by Riel (2017)

Interviews are a good way to collect information from others. Since they are interactive, they can clarify and give new perspectives to the case (Muller, 2013). We performed interviews with the TDC project team members to gather feedback on the early phase project work. We used the interviews to map the current documentation processes of the organization and the effects of applying the new method. Using a semi-structured interview method (Kvale, 2011), a pre-defined interview guide led the interviews in similar directions. However, we conducted each interview with the opportunity to move freely to add new perspectives to the method. We formulated open questions for qualitative reflections and used a Likert scale for qualitative measures. We performed two pilot interviews, with SD's quality manager and an external engineer, before we did the interviews with the TDC project team members. We changed the formulation of some of the proposed questions, as well as directing it more towards the problem statement. After the first round of interviews, we evaluated the results and reformulated the multiple-choice questions into Likert scale statements for a second iteration of interviews.

No standard analysis method exists to extract essential meanings, or deep implications, of the content from an interview (Kvale, 2011). However, Kvale states that performing a content analysis, coding the contents of the transcript, helps to break down, examine, compare, and categorize the data. We analyzed the interview transcripts and organized the common statements between all the engineers in a table. We categorized them into the documentation process or the process of entering an ongoing project.

Surveys can be used to collect statistical data from a larger group of stakeholders. After the workshop, we delivered a version of the IKA including the workshop results together with a survey to collect customer feedback. We created the questionnaire using a Likert scale ranging from "strongly disagree" to "strongly agree" (Likert, 1932). We analyzed the results using Net Promoter Score (NPS) (Reichfield, 2003). Due to the uncertainties of how respondents perceived the scale, we used NPS to help separate the promoters from the non-promoters (Muller, 2013). We assumed respondents that answered "strongly agree" would be promoters of the idea, "agree" would be neutral, and "neutral" to "strongly disagree" would probably complain about it. The calculated results are the number of promoters minus non-promoters from each question. We validate the statement when the NPS > 0. Before distributing the questioners to the customers, we performed an internal pilot and review of the survey with three different stakeholders from SD.

We analyzed the results based on the success criteria. Usability and accessibility are, according to ISO 9241, a measure of performance and satisfaction (ISO, 2010a). We measured desirability based on what method the stakeholders preferred.

Implementing IKA in Project Execution

The study of the TDC project focused primarily on the internal effects of implementing the IKA. The project had a team of two mechanical engineers, one systems engineer, and one electrical engineer. The team was working to explore and understand the problem of environment protection on drill rigs. The goal was to come up with concepts as the basis for new development projects.

After a few months of project execution, we experienced that the team had spread the performed work across a variety of documents in a chaotic folder structure. The performed work had little connection to each other, and the engineers struggled to find the information they were looking for. We implemented the IKA in an effort to connect the acquired knowledge and make it more accessible to the team.

We documented the problem landscape in the IKA using root cause analysis, stakeholder descriptions, scenario descriptions, and key driver analysis. The input for the problem analysis came from field visits and stakeholder interviews, as well as feedback based on frequent sharing with the customer.

In the ideation phase, the team worked in an iterative process creating different concepts for the root causes identified in the problem landscape. We documented the concepts using a project concept template. The template evolved during this phase to cover different perspectives. The engineers used the template guidelines to standardize the content with the goal of enhancing communication, accessibility, and making reviews easier for the stakeholders. Two teams within Semcon, based in different locations, worked in parallel. We shared the project IKA with the Gothenburg team as the input for an internal concept generation workshop. The result was a set of concepts presented according to the concept template guidelines.

The IKA became the main media for status meeting presentations. The architect integrated the current work into the IKA before meetings. The team could go from one analysis to another during the meeting without the need for changing account or navigating through the project folder. The document overview gave a good indication of the performed tasks and the need for further work. The project team used the IKA as the primary tool for introducing the project to new team members.

SD made field visits to TOC's decommissioning site. We documented the acquired knowledge from the visit in an IKA. To validate our collected knowledge, we shared the document with the customer two weeks after the visit. The customer provided specific feedback to the IKA in a meeting three days later. They validated the observations from the field visit and suggested changes to remove or add relevant information. After the meeting, we made the changes to the IKA before sharing it with the rest of the customer team.

SD performed concept generation workshops in all the three cases. For TDC and TOC we created IKAs and shared them with the customer prior to the workshop. We printed the IKAs and placed the essential slides on the wall in the conference room, structured the same way as in the document map. We printed each sub-level in a book format for the groups to use as knowledge sources during the workshop activities. The three companies received IKAs after the workshop including workshop results.

Results and analysis

We distributed questionnaires to the participants of the TOC and TPC workshops. The participants conducted the questionnaire, through SurveyMonkey, a web-based survey portal, which we distributed through email together with the IKAs. The questionnaire contained five Likert scale questions addressing the usability, accessibility, and desirability of the IKA as shown in Figure 8. In both cases, we had workshop participants consisting of end users, project engineers, project leaders, line managers, and sales personnel to cover different aspects of the two organizations.

Figure 8 displays the results of the customer survey. The questions assess the customers' experience with the received IKA after the workshop. Question 1 and 3 relate to the information accessibility from the two different workshops and show that the IKA gives a clear overview of its contents. Question 2 and 4 cover the usability and accessibility of the architecture. Three respondents thought the IKA was easy to navigate through and one was neutral giving it a NPS of 2. Most respondents thought the IKA provided easier access to information compared to a text-based report resulting in a NPS of 5. On the last question about format preference, 7 of the 9 respondents answered they prefer the IKA to a text-based report. The survey results indicate that the customers perceived the IKA to assess all the human requirements from the success criteria.

The main interview findings relating to current documentation methods in the company, were that all engineers used their own preferred methods. However, they all found it hard to access and use knowledge documented by others. They all agreed that they perform better work when they have a good overview of the problem domain. However, current methods do not provide sufficient support to access the needed information easily.

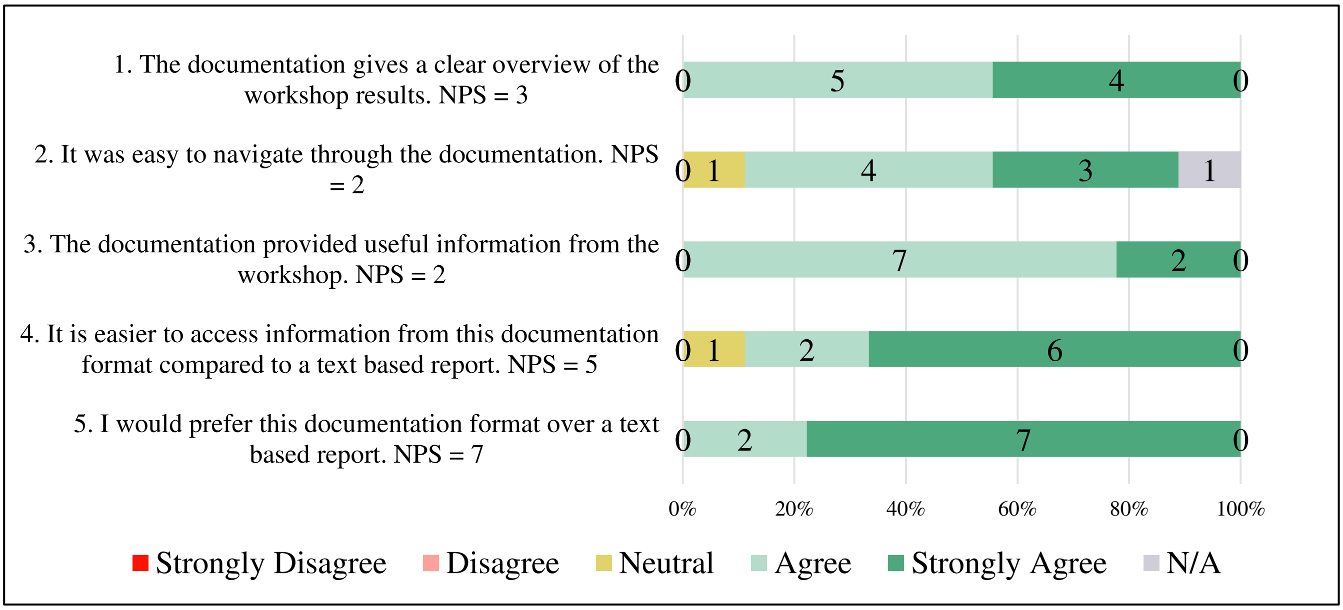

Figure 8 – Survey results

With the use of IKA in the project, the engineers agree that the standardization of the knowledge presentation supports more effective communication as well as it is easier to "know where to look and where to go". Further, the standardization of analysis templates provides a more efficient creation process as well as it ensures consistency between the team members. The engineers state they did not need any introduction on how to perform the analysis using the IKA, as the software is well known, and the templates are self-explanatory.

The engineers perceive the IKA to be a powerful tool for status and meeting activities during project execution. Since it was easy to navigate through the performed work, the meetings ended up being more effective than earlier. The engineers felt it was easier to get a good overview of project status and plan further work. Overall, the team perceived the IKA to support increased cooperation and felt they were working towards a common goal. The architecture played a significant role in building a common understanding between the engineers.

Between the open interview questions, we asked multiple-choice questions using a Likert scale format. The approach gave the possibility to compare the results between the different engineers and analyze the data in a quantifiable manner.

Figure 9 and Figure 10 sum up the quantified questions from the interview, measured the same way as the customer survey (Figure 8). The questions assess the current documentation methods and processes, compared to the application of IKA. We implemented question 4 and 4b to compare the two methods' abilities to share knowledge. The results indicate that the IKA, with 3 promoters, supports more efficient knowledge sharing compared to today's method with 4 non-promoters.

Questions 6 and 6b assess the challenge of entering ongoing projects in SD. In this case, the IKA has an NPS = 0, indicating that it is not solving the issue on its own. This match the results from open questions, stating that a good introduction from the project team is still essential for sufficient integration. However, today's methods result in a negative NPS = -4 indicating that the IKA is the preferable method of the two.

Question 7 and 7b assess the accessibility of documented knowledge in SD's project execution. The use of IKA results in a NPS of 2 compared to 4 non-promoters of the current methods. The score indicates that the engineers evaluate IKA to improve the accessibility of the documented knowledge.

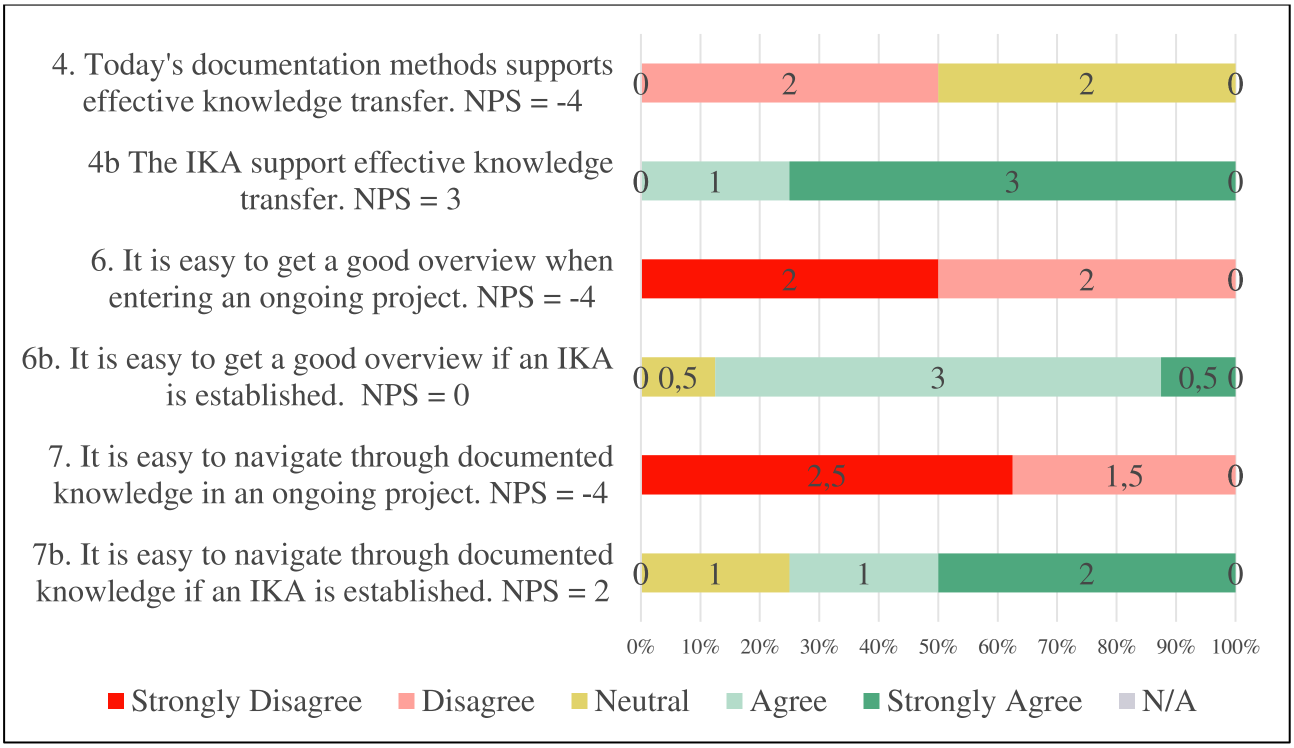

Figure 9 – Interview results for current method and IKA assessment in projects.

Questions 14 and 15 (Figure 10) are both greater than 0. The results show that the IKA is a preferable solution for the engineers. We can presume they will be promoters of the method in their next project.

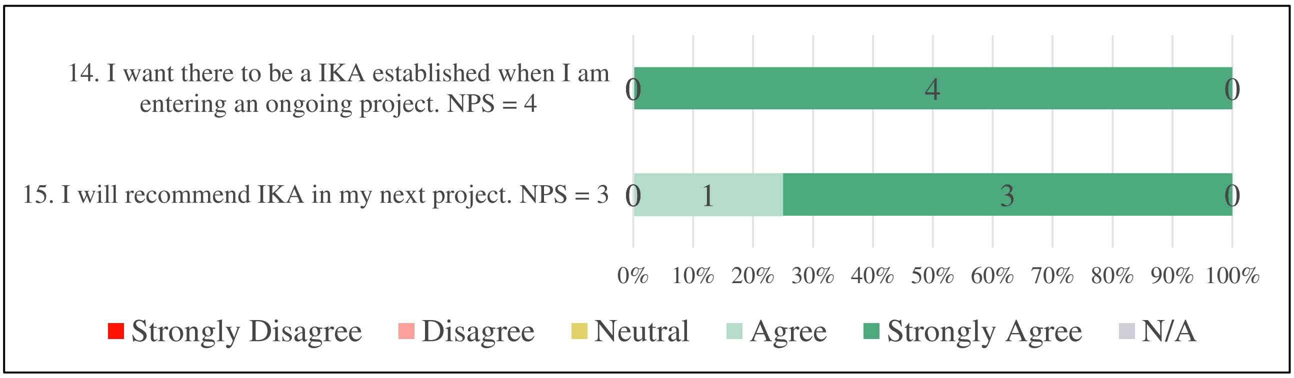

Figure 10 – Interview results: IKA desirability

Measuring Performance and Satisfaction

We measured the level of usability and accessibility as a product of user performance and satisfaction (ISO, 2010a). In this study, we measured performance of the IKA based on observations during the project work. In the customer knowledge sharing perspective, we observed that TOC was able to give relevant and specific feedback despite short time for review. In the perspective of organizational sharing, we observed that the engineers from Semcon Gothenburg were able to come up with 12 concepts based on a short introduction of the TDC IKA. TDC team members perceived the IKA to integrate well with the development process. The engineers perceived that document structure and standardized templates increased efficiency in meetings. Overall, we experienced that stakeholders using the IKA were able to perform specific work in an effective and efficient manner.

Attitudes, preferences, and perceptions represent the cognitive responses, which are essential in user satisfaction (ISO, 2018). We measured these through all the research activities in this study. By comparing the IKA to current methods in the survey and interview, we found IKA to be the preferred method by the users. The common statements from the interview indicate that the perceptions and attitudes to the current methods are not satisfactory. The research data indicates that users of the IKA perceive the method as easy to use, as well as they preferred it to current methods. The overall results indicate that the users perceive the IKA to provide high usability, accessibility, and desirability.

Discussion

Research Credibility

The data credibility varies in the different methods applied in this study. We sent the survey to the customers after we delivered the workshop results in an IKA. From the workshops, we got 9 out of 30 potential answers from the customer stakeholders. The answers were consistent, which could indicate that additional answers may be in the same part of the scale. We do not have control over the research environment, and we do not know the eventual biases of the different respondents. We used NPS to limit some of these biases. The respondents were not related to the researchers, so we presume they provided honest feedback.

The respondents received the survey together with the IKA and provided most answers the same day. They did not spend much time on the architecture and base their answers primarily on first impressions. Since most respondents agreed it was easy to navigate through the structure, and that information was easily accessible, we can expect the IKA to have a short learning curve. To add more value to this aspect, we could have stated a question regarding the time the respondents spent in the document.

The engineers from the interview are all close colleagues to the researchers, which can affect the credibility of the answers. We limited some of the credibility issues using NPS as well as only collecting the common statements of the engineers through coding. A credibility issue we were not able to limit, was the variation in the engineers' age and company role. All participants were between 27 and 35 years old and worked in the same environment with small discipline variations. We can assume that the rather young user group is more positive to new methods.

All the cases in this study provided research data primarily from the mechanical domain. We performed almost exclusively work for mechanical applications. In the interviews, we identified that the engineers feel the electrical and software departments in the company usually have more structured documentation methods. The feedback could indicate that the measure of performance between the current and purposed method would be different if the projects had been more electrical or software oriented.

Challenges and Opportunities

Keeping the IKA up to date can be a challenge. New input and understandings can result in changes to the documented architecture. However, regardless of documentation methods, we need to update the knowledge base when it is outdated. The IKA makes the content more accessible and makes it easier to spot outdated or wrongly stated information. This ability can have a positive effect on validation and prevent the documentation from being outdated.

Like Brussel's (2015) interactive A3AO, the IKA lacks a suitable software for all its needs. Using PowerPoint as the primary tool for creating the IKA introduces some limitations to the architecture. It does not have basic "if, then" programming functions or automatic updates of crossed referenced elements. Other architecture approaches, like SysML, tend to provide a more multidimensional view as well as a relation between system elements. There are several powerful tools with much functionality we could use to build more sophisticated architectures. However, the main trade-off lies in low user-threshold for the variety of stakeholders. We experience that the implementation of more functions can quickly increase the learning curve and the need for "expert users". PowerPoint is well known by the stakeholders and accessible on most computers. We experience that the IKA is a useful tool for early phase project development, while more complex architectural software, like SysML, are more suitable for a more detailed technical design architecture.

The engineers requested guidelines and tools for early phase project execution. A suggestion was templates for all the different analysis, ready for implementation in the IKA. We should use templates with caution as they can have several pitfalls (Muller, 2017). Having too leading templates can result in reduced innovation. Engineers can end up filling out the template without fulfilling the purpose of the document. However, the engineers perceived good templates to drive efficiency in the project. We observed that standardizing the layout for related content, like using a concept inspiration template, had positive effects on communication and accessibility, as the users knew where to look for specific information. The templates can be effective, but we need to make sure they do not restrict creativity or possibility to add new perspectives. We should be able to tailor the templates to fit the purpose and make sure they provide open guidelines for the content rather than restricting it with rules.

In the TDC project, by collecting feedback from the customer, we discovered that our approach had triggered internal discussions in the customer organization. Mapping the customer's knowledge of problem domain, helped to build a common understanding within the company leading to new insights and enhanced internal communication. A direct impact was a redefined project need. The structured documentation form and frequent knowledge sharing with helped build a common project understanding between the project team and the customer.

Conclusion

This study presents how the IKA can be used to share knowledge effectively in early phase product development. The identified success criteria for the solution were its ability to meet the identified human requirements. Table 3 show how the engineers and customers participating in this study perceive the IKA to fulfill the success criteria.

Table 3 – IKA's ability to meet the success criteria

- Usability
  - The engineers perceive the IKA to support effective knowledge documentation with clear guidelines as well as create consistency in the performed work.
  - The engineers agree that the layout standardization supports effective communication.
  - The customers and engineers consider navigating through the structure as an easy task.
- Accessibility
  - The engineers and customers feel the acquired knowledge is more accessible through the IKA compared to previous methods.
- Desirability
  - The customers and engineers prefer the IKA to current methods in early phase project execution.

We discovered that the IKA had an impact on the effectivity of status meetings. Structuring the work into one common knowledge base provided the engineers the perception of building a common understanding of the problem domain. The engineers stated that standardizing how we present knowledge through structured templates increased the accessibility and supported effective communication. We observed that the structure and standardization of the IKA were important to build a common project understanding between the team and the customer. Acquiring a complete overview of documented knowledge in projects is still not an easy task. However, the engineers perceive the IKA to be significantly better compared to current methods.

Future Research

There are several factors making project communication challenging. One essential factor is the difference in aspects such as nationality, culture, and work disciplines within the various stakeholders. The collected research data in this study lacks the perspective of user variety. The interviewed engineers are within a small range in age, work in similar disciplines and environment. We made the surveys anonymous and did not have control of the background of the respondents. To make the solution more viable, we should study the IKA's impact on communication with a larger and more diverse user group.

SD developed and tested the IKA with promising results in internal project execution. Engineers have tested the method in different projects with good feedback from the customers. However, SD is a unique actor in the Kongsberg industry, and we need to test the method in other companies to add value to the systems engineering body of knowledge. In a workshop performed with several industry stakeholders, we observed that knowledge sharing of early phase knowledge was a known issue for all the represented organizations. The survey results showed that 7 out of 9 customer respondents strongly agreed that they prefer the IKA over a text-based report. These observations indicate that the method can add value to other companies, despite the organizational differences to SD. We should study the method in other organizations to add more value to the Systems Engineering body of knowledge.

References

Borches, P. D., 2010. *A3 Architectual Overviews.* Enschede: Univercity of Twente.

Brussel, F. F. & Bonnema, M. G., 2015. Interactive A3 Architecture Overviews, INTUITIVE FUNCTIONALITIES FOR EFFECTIVE COMMUNICATION. *Procedia Computer Science,* Issue 44, pp. 204-213.

Frøvold, K., 2017. *Applying A3 reports for early validation and optimization of stakeholder communication in development projects.* Adelaide, Australia, INCOSE.

Friedenthal, S., Moore , A. & Steiner, R., 2008. *A Practical Guide to SysML.* s.l.:s.n.

IDEO.org, 2015. *The Field Guide to Human-Centered Design.* 1st ed. San Francisco: IDEO.org.

ISO, 2008. *ISO 9241-151 Guidance on World Wide Web user interfaces,* Geneve, Switzerland: ISO.

ISO, 2010a. *Ergonomics of human-system interaction - Part 100: Introduction to standards related to software ergonomics,* Geneva, Switzerland: ISO.

ISO, 2010b. *Ergonomics of human-system interaction - Part 210: Human-centered design for interactive systems,* Geneva, Switzerland: ISO.

ISO, 2018. *ISO 9241-11 Ergonomics of human-system interaction - Part 11: Usability: Definitions and concepts,* Geneva, Switzerland: ISO.

Kennedy, M. N., 2003. *Product Development for the Lean Enterprice.* Richmond, Virginia: The Oaklea Press.

Kvale, S., 2011. *Doing interviews.* 2007 ed. London: SAGE Publications, Ltd.

Likert, R., 1932. A technique for the measurement of attitudes. *Archives of Phychology,* Volume 22, pp. 3-55.

Muller, G., 2011. *Systems Architecting: Abusiness Perspective.* Boca Raton: CRC Press.

Muller, G., 2013. *Systems Engineering Research Methods.* Atlanta, Elsevier B.V. proceedings of Procedia Computer Science.

Muller, G., 2017. *Architecting for Humans; How to Transfer Experience?,* Kongsberg: Retrieved from: http://www.gaudisite.nl/info/ExperienceTransfer.info.html.

Muller, G., 2017. *Template How To.* [Online]
Available at: http://http://www.gaudisite.nl/TemplateHowToPaper.pdf
[Accessed 18 May 2018].

Reichfield, F. F., 2003. The one number you need to grow. *Harvard Business Review,* Issue December 2003.
Riel, M., 2017. Understanding Action Research. *Arts in Learning Technologies,* p. 11.
Singh, V. & Muller, G., 2013. *Knowledge Capture, Cross Boundary Communication and Early Validation with Dynamic A3 Architectures.* Philadelphia, Incose.
Tschimmel, K., 2012. *Design Thinking as an effective toolkit for innovation,* Barcelona: XXIII ISPIM Conference: Action for Innovation: Innovating from Expericence.
Walden, D. D. et al., 2015. *Systems Engineering Handbook: A Guide For System Life Cycle Processes and Activities.* 4. Edition ed. Hoboken, New Jersey: John Wiley & Sons, inc..

Biography

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Halvor Røed Jensen studied mechanical construction at South-Trondelag University College, where he graduated in 2015. From fall 2015, he worked in Semcon as project engineer alongside taking his Master's in Systems Engineering at the University College of South-Eastern Norway. He received his Master's degree in spring 2018 and has since then been working as a system architect for Semcon.

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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 system architect, followed by two years at ASML as manager systems engineering, returning to Philips (Research) in 1999. Since 2003, he has worked as 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 full professor of systems engineering at University of South-Eastern Norway in Kongsberg, Norway. He continues to work as senior research fellow at the Embedded Systems Innovations by TNO in Eindhoven in a part-time position.

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