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Application of A3 Architecture Overviews in Subsea Front-End Engineering Studies: A Case Study

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Abstract. This research investigates the application of A3 Architecture Overviews (A3AOs) in subsea front-end engineering studies. A3AO is a valuable method to support multi-disciplinary communication and share architectural knowledge in complex engineering domains. The method captures key information of an overall system and displays the system overview in a standard A3 format. In this paper, we investigate the beneficial impact a global subsea supplier can gain by applying A3AO as part of their concept evaluation process in the early phase study. Through interviews and a survey, we identified company's main challenges in concept evaluation of tie-in and connection system. We then applied the A3AO method to investigate its mitigating effect in early phase concept evaluation. We found that the company resources found the A3AO to provide a holistic system overview and support knowledge sharing. Overall, our research supports the use of A3AO as a method to promote common understanding.

Introduction

Domain. To meet the world's continuously growing energy needs, offshore companies are exploring extreme territories in search of future oil and gas resources. By offering a fully submerged solution for oil and gas production, the application of subsea technology has become popular in offshore areas all around the world. After their introduction in the late 1950s, subsea technologies have increased significantly in scale and complexity over the years (Bai & Bai, 2012). In addition to this, the downturn in the industry has triggered the need for significant and sustainable improvements in project economics (Engen & Falk, 2018) (Engen, et al., 2019). These conflicting aspects have created a major challenge in today's oil and gas industry. Motivated by this, several offshore contractors have started to create alliances in order to stay competitive and provide long-term efficiency in the industry (Hurault de Ligny, et al., 2018).

Company. The company is a global oil and gas company that provides complete subsea field developments for the energy industry. The company arose from the merger of two subsea companies, one specializing in Subsea Production Systems (SPS), and one supply Subsea Umbilicals, Risers, and Flowlines (SURF), and have a fleet of vessels for offshore installation.

Problem Statement. In recently executed projects, the company has identified challenges affecting efficiency. These challenges relate to different domain philosophies, lack of common understanding, and communication issues across departments. In these projects, SPS handles subsea equipment while SURF handles sealines and offshore installation vessels. An essential part of the project is the Tie-in and Connection system. The Tie-in and Connection system's main function is to connect sealines to subsea structures, ensuring a leak-proof connection. SPS designs and manufactures the system, and SURF performs offshore installation and operation. To improve the project execution, the company needs to align its processes, promote effective communication, and share explicit knowledge across disciplines. Figure 1 shows an illustration of a typical subsea system, indicating the SURF and SPS scope as well as the Tie-in and connection system as an interface between them.

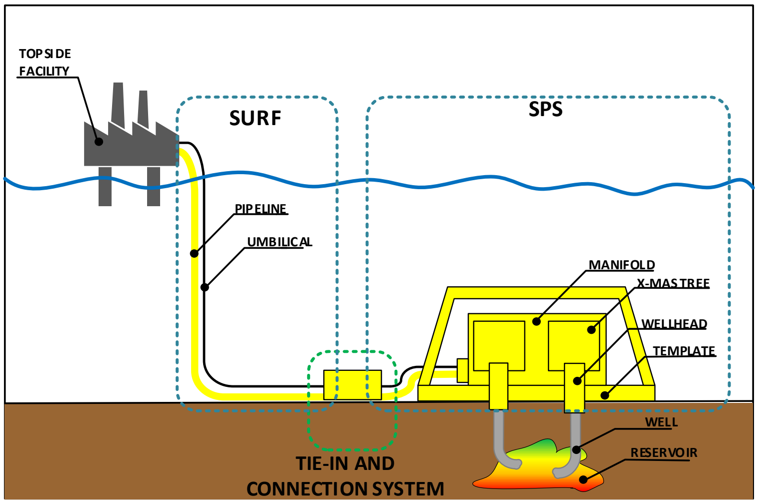

Figure 1. Illustration of the subsea system.

Applications of A3AOs. Applications of A3AOs have proven to be valuable in various complex engineering domains, such as automotive (Pesselse, et al., 2019), software (Viken & Muller, 2018), maritime (Frøvold, et al., 2017), and space exploration (Haveman, 2015). Recent studies have also shown beneficial impact of applying architectural reasoning (Muller, 2018) and the A3AO method in the oil and gas industry (Boge & Falk, 2019) (Løndal & Falk, 2018) (Muller, et al., 2015). The mentioned research studies state multi-disciplinary communication, common understanding among stakeholders, and early validation as aspects of added value in terms of A3AO usage. However, the methods need further adaption in order to fulfill specific needs and improve efficiency in the complex subsea domain (Muller & Falk, 2018).

The oil and gas industry are immature in implementing systems engineering methods (Helle, et al., 2020), and formal methods are often considered as not applicable or time consuming (Muller, et al., 2015). A case study recently conducted in the subsea domain, (Engen, et al., 2019), evaluates architectural reasoning when applied in the conceptual phase of a development project. The authors identified sharing architectural knowledge as a main challenge in the early phase of a subsea project and propose A3AO, in combination with conceptual modeling, as a topic for further investigation (Engen, et al., 2019). This proposal is supported by other case studies in the subsea domain (Muller, et al., 2015) (Boge & Falk, 2019). Inspired by findings presented in formerly executed researches, we wanted to further investigate and evaluate the application of A3AOs in the oil and gas industry.

Research Questions. In this research, we investigate the beneficial impact a global subsea supplier can gain by applying A3AO in the early phase of a field development. The research presented in this paper focus on concept evaluation in front-end engineering studies. The paper aim to answer the following research questions:

- *What are the main challenges the company experience related to concept evaluation of Tie-in and Connection systems?*
- *How do resources in the company perceive the developed A3AO?*
- *How can application of A3AO support the company in concept evaluation of Tie-in & Connection systems*

Background

Systems Engineering (SE). SE has proven its value by providing an effective way of managing complex systems throughout their life cycles (Walden, et al., 2015). The importance of making the right decisions in the concept stage of a project, from identification of needs to concept proposal, is crucial to avoid late design changes, cost overruns, and schedule delays (Tranøy & Muller, 2014) (Engen & Falk, 2018). According to Heemels et al., the main reasons for non-optimal design choices are related to lack of common understanding between engineering disciplines and experience-based decision making (Heemels & Muller, 2006). When dealing with complex projects, such as subsea field developments, common understanding among stakeholders is essential to promote effective communication and prevent multi-disciplinary problems (Tomiyama, et al., 2007). A cross-cutting SE method used to express system principals and characteristics in an abstract manner is modeling (Walden, et al., 2015), commonly referred to as systems architecting (Maier & Rechtin, 2009).

Systems Architecting (SA). In (ISO/IEC/IEEE, 2011), SA is defined as: a process of conceiving, defining, expressing, documenting, communicating, certifying proper implementation of, maintaining and improving an architecture throughout a system's life cycle. (Maier & Rechtin, 2009) consider SA as an art based on qualitative heuristic principles and methods to tame the growing complexity of modern systems. Since the early 1990s, numerous architecture frameworks have emerged to support construction of systems architecture (ISO/IEC/IEEE, 2011) (U.S Department of Defense, 2010) (Reichwein & Paredis, 2011) (Greefhorst, et al., 2006). Throughout this paper, we use architecture terminology defined in (ISO/IEC/IEEE, 2011) due to its independency of domains.

A3 Architectural Overview (A3AO). A valuable SA method to support effective communication and share architecture knowledge is the A3 Architectural Overview (Borches, 2010). The A3AO method captures multiple high-level architecture views of an overall system and displays the system overview in a standard A3 format, 297 x 420 mm (Borches, 2010). An A3AO shall only display essential information, understood by a large variety of stakeholders, expressed in a limited number of interconnected architecture views. Typical views visualized in an A3AO include functional view, physical view, quantification view, and visual aids. Additional views, with textual explanations, support the visual representations when necessary (Borches, 2010).

Research Method

Industry-as-Laboratory. The research method applied in this case study is industry-as-laboratory (Heemels & Muller, 2006). Industry-as-laboratory, a sub-group of action research, enables the researcher to combine the researcher role with active participation in systems engineering activities in an industrial setting (Muller, 2013). To gain in-depth knowledge about the problem, we collected both quantitative and qualitative data. We extracted data in several ways, spanning from free format sessions to company's performance reports, to analyze hard engineering as well as human aspects and their influence on the problem. Figure2 presents the research approach applied in this case study and illustrates the A3AO development process.

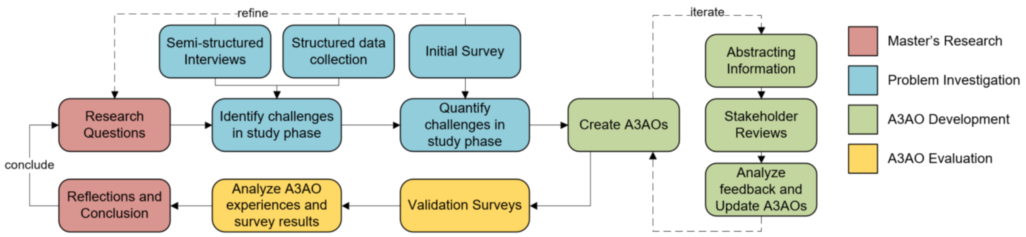

Figure 2. Research Method

Data Collection. Main methods used for data collection were semi-structured interviews, surveys, structured data collection, and research logbook. We conducted the semi-structured interviews as face-to-face meetings with key stakeholders of the Tie-in & Connection system and resources involved in early phase studies. The stakeholders were chosen as they were part of a company task force, working with aligning the systems across the disiplines. The primary goal of these interactions was to get an overview of the company's current situation and challenges. Before each meeting, the interviewees received information about the topics of discussion. Table 1 presents profiles of the resources we interviewed. In addition to this, a larger group of stakeholders received an initial survey. The purpose of the survey was to confirm observations and insights from the stakeholder interviews. The results from this survey quantified the company's current challenges in early phase studies.

Table 1: Participants in the semi-structured interviews

Role in the company (Years of experience in company)			
Chief Engineer, Front-End (29)	Manager, Chief Engineers (22)	Chief Engineer, Connections (23)	System Expert, Connection System 2 (12)
Technical Manager, Life of Field (15)	Engineering Manager, SURF (12)	Product Engineer, Connections (31)	System Engineer, Front-End (14)
Engineering Manager, Project Execution (15)	Field Development Engineer, Front-End (24)	Field Development Engineer, Front-End (18)	Field Development Engineer, Front-End (34)

The initial survey used multiple choice questions and a Likert scale to provide a quantitative measure of the company's current state. For all questions, participants had five different response alternatives, ranging from *Strongly disagree (1)* to *Strongly agree (5)* (Likert, 1932). In addition to the 5-point Likert scale, the participants had the opportunity to skip the question by selecting *Don't know* for questions that were out of their responsibility or scope of knowledge. To gather insights from experienced key personnel, we limited the initial survey's participation group to product experts and installation engineers responsible for developing and operating the Tie-in & Connection systems. 25 resources received the survey, and 18 responded within a week. The respondents have an average of 19 years' work experience in the company.

To gain deeper knowledge about the topic of investigation, we performed a structured data collection. We gathered and thoroughly evaluated performance data and system documentation from several former subsea projects executed by the company. Analyzed documentation includes, among others, former study reports, offshore installation timings, evaluations of tie-in systems, and lessons learned. To capture data references, observations, experiences, and personal reflections occurring throughout the case study process, we kept an electronic logbook.

Creation of A3AOs. When creating the A3AOs, we applied the reverse architecting process to consolidate and capture implicit knowledge (Borches, 2010). Based on information extracted in the structured data collection, we abstracted relevant information and captured it in an A3 paper format. Due to the multi-disciplinary nature of the Tie-in & Connection system, the A3AO only displays essential system aspects and insights. We grouped the abstracted information into different architecture views to present the information in a structured manner.

After creating draft versions of the A3AOs, we presented the structured information in one-to-one sessions to 6 individual stakeholders. Each review session followed the same approach; present A3AO, receive feedback from stakeholder, and finally, discussion of further improvements. We analyzed stakeholder's feedback after each review session and changed the A3AOs accordingly. We repeated this iterative process until all stakeholders were satisfied and approved the captured information. Table 2 below shows the key stakeholders that contributed in this process. In total, we performed 7 iterations of connection system 1 and 6 iterations of connection system 2.

Table 2: Participants in the review sessions

Role in the company (Years of experience in the company)		
Chief Engineer, Front-End (29)	Manager, Chief Engineers (22)	System Expert, Connection System 2 (12)
Technical Manager, Life of Field (15)	Chief Engineer, Connections (23)	System Engineer, Front-End (14)

A3AO Evaluation. To evaluate the final A3AOs, we conducted a validation survey. In this survey we involved a more diverse group of stakeholders, from different departments and disciplines. The purpose was to capture insights from multiple sources in order to increase confidence and reliability of the research findings. The type of resources invited to the survey include managers, chief engineers, systems engineers from field development and project execution, and domain experts from SPS and SURF departments. In total, 77 resources were invited and we received 44 responses. The resources had one week to review the attached A3AOs and respond to the survey. The respondents have an average of 19 years' work experience in the company.

As the initial survey, the validation surveys also used multiple choice questions and a 5-point Likert scale to provide quantitative measures of the results. In addition to this, the validation surveys included open comment sections, allowing the stakeholders to provide any additional feedback about the A3AOs and their views. The validation survey contained two main parts for evaluating the A3AO method and its impact in early phase studies. Part A focuses on personal experience and understanding, system overview, common understanding, and concept evaluation related to the Tie-in & Connection systems. Part B evaluates the A3AOs, their respective views, elements, and characteristics.

Data Analysis. To evaluate and compare Likert data from the surveys, we use the Net Promoter Score (NPS) (Reichheld, 2003). Participants that respond *Strongly agree* function as promoters of the statement, *Agree*-responses are passives, and participants answering *Neither agree, nor disagree*, *Disagree*, or *Strongly disagree* function as detractors. According to NPS, a valid statement shall have an overall score larger than zero. The overall score is number of promoters minus number of detractors (Muller, 2013). In addition to the NPS, we use median and frequencies to properly analyze central tendency and variability of the Likert-type items (Boone & Boone, 2012).

Case Study - A3AO Application in the Subsea Industry

Study Process in the Company

From receiving study award to study approved for submission, there are several tasks to execute in order to perform a subsea field development study. The company study process initiates with reviewing study contract documentation and closes by approving the overall solution and technical deliverables before submission. The purpose is to evaluate potential concepts, by conducting risk and mitigation assessments, in order to define the best overall solution according to the selection criteria. Typical engineering aspects to consider include design, manufacturing, installation, and operation. Before submitting the study, the Study Manager performs a Submit Meeting to present the technical solutions and approve their associated costs. Figure 3 illustrates an overview of company's study process.

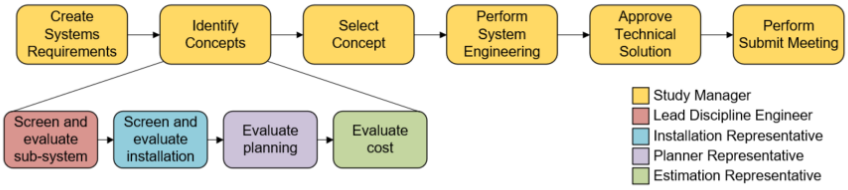

Figure 3. The company's Study Process

In a subsea production system, subsea flowlines are transporting production fluid between subsea structures on the seabed (Bai & Bai, 2012). To provide safe and leak-proof subsea connections between flowline ends and structures, the company uses a Tie-in & Connection system. This system is a vital part of a subsea field development. For that reason, the company has developed a range of remotely operable Tie-in & Connection systems over the past decades. The company has two common solutions for connection systems. Both connection systems are operated by a standard Remotely Operated Vehicle (ROV). Using ROV handled tooling, the connection systems connect sealines in a safe and efficient manner.

Current Challenges in the company

Findings from Semi-Structured Interviews. To gather insights about the company's current challenges in early phase studies, we conducted semi-structured interviews. Table 3 presents some interesting insights and quotations extracted from the individual stakeholder interactions.

Table 3: Quotations from semi-structured interviews with key stakeholders

No.	Quotations	Role
[A]	*We need to integrate engineering of connection systems with the needs of installation projects and vessels.*	Chief Engineer, Connections
[B]	*We don't follow a particular approach when evaluating concepts, we basically gather experts around the table and agrees upon a solution.*	Field Development Engineer, Study
[C]	*Unfortunately, decisions are often made on previous experience and personal preferences.*	Technical Manager, Life of Field
[D]	*We need to get rid of subjective decision making and evaluate concepts objectively.*	Manager, Chief Engineers
[E]	*In my opinion, we lack a mutual understanding about each other's needs and drivers.*	Engineering Manager, SURF
[F]	*We need to overcome silo-thinking and align processes to optimize our execution.*	Chief Engineer, Front-End
[G]	*It is essential to get away from the SPS vs. SURF thinking on the tie-in system.*	Chief Engineer, Front-End
[H]	*Prepare a simple document that states the main drivers for selection the connection system for a prospect.*	Chief Engineer, Connections
[I]	*The SPS & SURF sides work much differently at the tender/FEED stage. I would suggest this is where the attention should be.*	Engineering Manager, SURF

Findings from Initial Survey. Figure 4 presents 10 important findings related to concept evaluation challenges in early phase studies. These results function as the zero-state measurement of this research, by mapping out and quantifying the company's current challenges. Results show that main challenges in concept evaluation are related to finding relevant system information (#1, #2 and #3), lack of holistic perspective (#4), knowledge sharing across departments (#5, #6 and #7), and multi-disciplinary communication (#8 and #9). In this figure, the Tie-in & Connection system is referred to as T&C system.

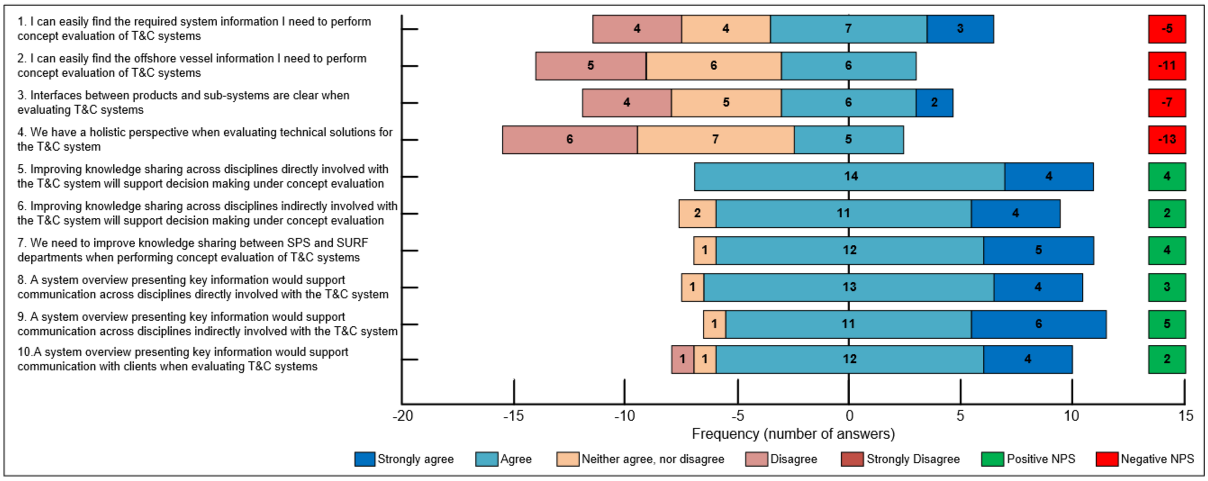

Figure 4. Survey results: Concept evaluation challenges in early phase (18 respondents)

From the findings presented in this section, we extract 3 needs of improvement that can support concept evaluation of Tie-in & Connections systems in Front-End Engineering studies. These needs are related to:

- Easy-accessible format stating key information and main drivers
- System overview to support knowledge sharing and multi-disciplinary communication
- Holistic view – integrate SPS engineering and installation needs from SURF

A3AO Development

Based on the challenges outlined in the previous section, we created two A3AOs that present high-level system overviews of the two most common Tie-in & Connection systems provided by the company. Both A3AOs capture essential aspects related to system operation and sealine installation. The A3AOs includes four essential views, including functional, physical, operational, and quantification view. These views were chosen based on recommendations from literature that have previously applied conceptual modeling in the early stages of systems engineering (Haveman, 2015) (Borches, 2010) (Heemels & Muller, 2006). In addition, we included a view presenting pros and cons of each concept, based on needs extracted from the interviews. In the following sub-sections, we give a brief introduction of each view and present the final A3AOs.

Functional View. This view presents the functional flow of sealine installation and acts as the backbone of the A3AO model (Borches, 2010). The flow illustrates an overview of the main functions involved in an offshore operation when performing installation of flexible sealines. Main functions are related to lay vessel preparation, lay vessel operation, relocation of vessels, support vessel preparation, subsea connection operation, and post-operation. Furthermore, top-level functions are decomposed into more detailed functions to highlight specific activities required to achieve a successful subsea connection of flexible sealines.

Physical View. The physical view visualizes the Tie-in & Connection system´s architecture structure in an abstract manner. Major building blocks and key interfaces of the respective systems are captured in this view. Abstractions presented in this case are offshore vessel, ROV, subsea structure, flexible sealine, and physical elements of the connection system. This building block view supports the functional view by providing visual representations of the physical elements listed in the workflow.

Operational View. In this view, we visualized the usage scenarios of flexible sealine installation to capture system's dynamic behavior (Muller, et al., 2019). The operational view contains simplified models, like the physical view, to promote better understanding of the installation sequence. The usage scenarios use high-level visualizations to focus on challenging installation activities from an operational standpoint. From SURF's point of view, system concerns are mainly related to vessel flexibility, installation time, and cost. For instance, the vessel rate for a lay vessel is more expensive than for a smaller support vessel. For that reason, the operational view highlights interactions between the Tie-in & Connection system and the various offshore vessel types.

Quantification View. In terms of the quantification view, we have included an installation timeline and a list of key performance parameters (KPPs). The timeline illustrates a visual overview of the main functions' order and estimated duration during an offshore installation of a flexible sealine. A table supports the timeline by highlighting the various installation stages and their duration in hours. The values are a generic representation, as the actual number are depending on various factors such as operator experience, water depth, weather conditions etc. The purpose is to display how long each offshore vessel needs to be present during the operation, to serve as a comparison of the two systems. The key performance parameters view presents a list of key data about the Tie-in & Connection systems', such as typical design ratings, requirements, and main values.

Pros and Cons. The purpose of this view is to present the Tie-in & Connection systems' advantages and disadvantages in terms of offshore installation and operation. There are many influential factors that affect concept evaluation, and some of them are not stated in current system documentation. In order to perform a thorough evaluation of Tie-in & Connection systems, resources must possess specific knowledge and experience from offshore vessels. To mitigate this, we introduced a pros and cons view. This view provides an overview of important factors that affect the Tie-in & Connection evaluation.

Complete A3AO. At the end of this process, we captured the presented architecture views in an A3 format. Furthermore, we linked the operational view to the functional view and placed a list of abbreviations in an available space. Finally, we included a legend with notation in the top left corner and A3AO information in the top right corner. Figure 5 illustrates one of the A3AOs created in this research. Due to confidentiality reasons, key data are left out.

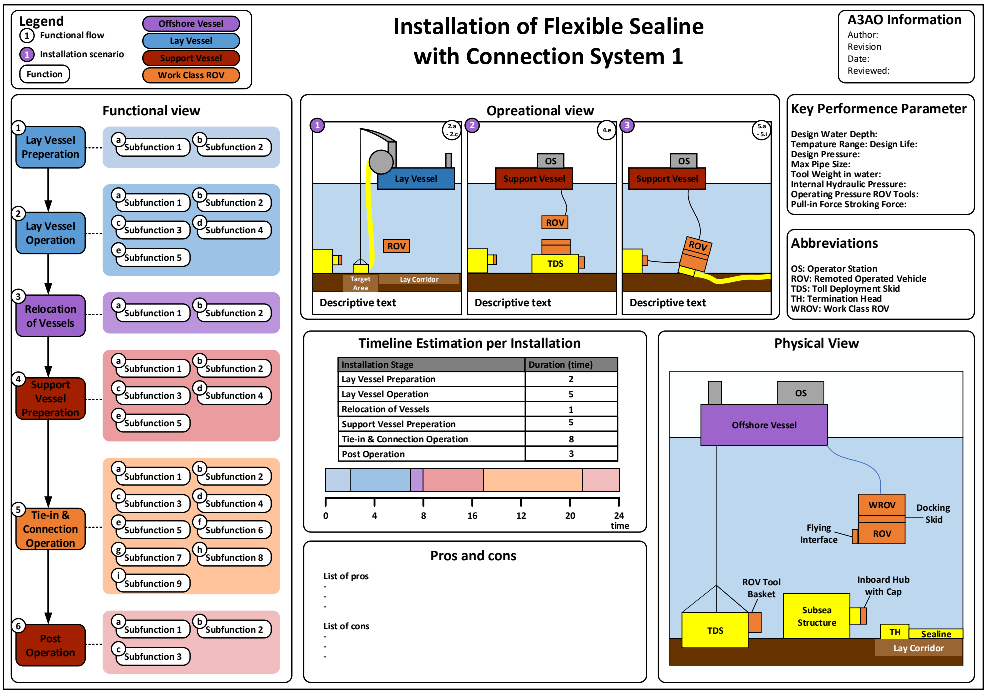

Figure 5. Illustrative example of one of the A3AOs

Results

To evaluate how the A3AOs can support the concept evaluation and how the resources perceive the A3AOs, we performed a validation survey. We gave the respondents the A3AOs for review and invited them to a survey to evaluate the impact of the A3AOs and their content.

Due to resources' different roles and responsibilities in a subsea field development, we created two validation surveys that contained slightly different questions. The two target groups are Connections and SURF, and Front-End and Systems Engineering (FESE). In the following section, we present the key findings from the validation survey.

Personal Experience

Figure 6 shows the participating resources' personal experience with the Tie-in & Connection and the A3AO method. In general, respondents are familiar with the subsea connection systems and the offshore installation aspects of flexible sealines. They are not familiar with the A3AO method from previous subsea developments.

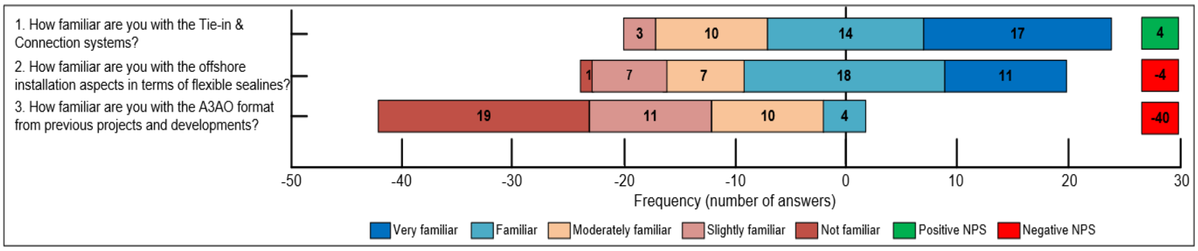

Figure 6. Survey results: Personal experience (44 respondents)

Impact of A3AOs

All respondents. Figure 7 presents survey results used for evaluation of A3AOs and their impact in early phase studies. Results show that respondents are positive to the visual A3AO presentations as they provide a holistic overview of the system of interest (#2, #3 and #7). Respondents agrees that the method can support communication in discussion with external clients and support concept evaluation of Tie-in & Connection systems (#8 and #10). The survey results show that the most respondents agree that that A3AO improve respondents' system understanding. Still 25% of the respondents, do not find the A3AO supportive, giving them negative NPS values (#1, #4, #5, #6 and #9).

Connections and SURF. Figure 8 presents survey results from the Connections and SURF group. Respondents agree A3AOs promote common understanding, improves knowledge sharing, and support decision making when evaluating concepts in early phase studies (#5, #6, and #7). They also find that the A3AO presentations will support communication when training new resources (#10). In terms of supporting communication across directly involved disciplines, they are less supportive (#8).

FESE. Figure 9 shows survey results from the Front-End and Systems Engineering (FESE) group. In general most respondents agree that the A3AO promote common understanding and support decision making when evaluating Tie-in & Connection systems (#1, #3 and #5), but comparing the NPS scores we find that they are less supportive than the connection and SURF group. We also find that the respondents agree that the A3AO captures key aspects of flexible sealine installation and provides rapid access to key information from SPS and SURF (#2 and #4).

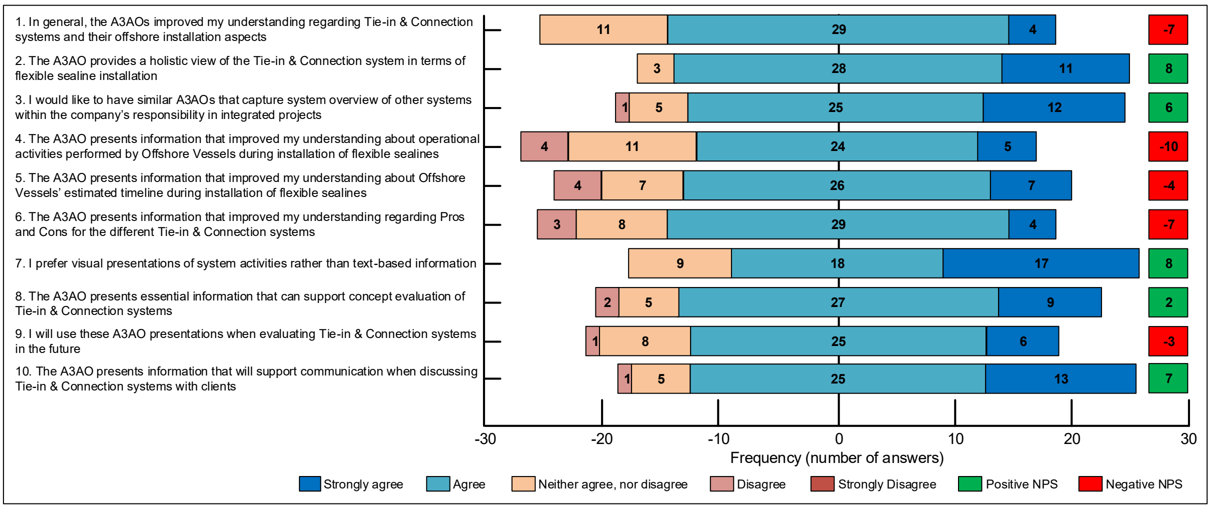

Figure 7. Survey results: A3AOs and their impact in early phase studies (44 respondents)

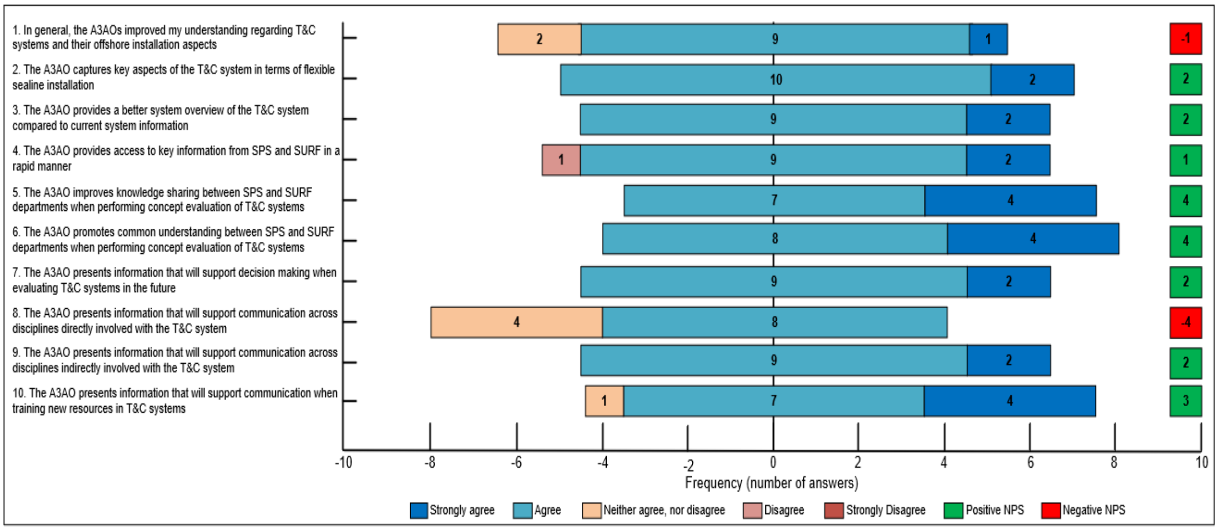

Figure 8. Survey results: Connections and SURF group (12 respondents)

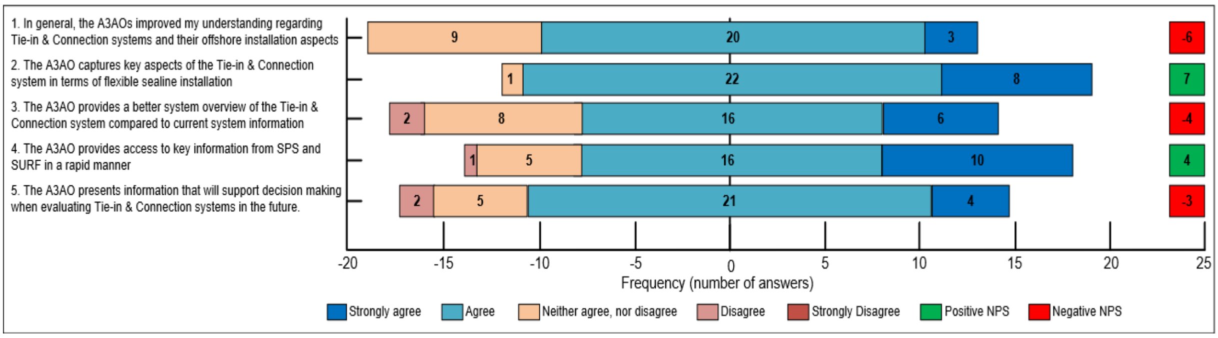

Figure 9. Survey results: FESE group (32 respondents)

Reflections. The open comment sections in the validation survey provided some interesting view-points from respondents. The results showed conflicting opinions between respondent groups and their roles in the company. In terms of presenting system information that will support decision making in the future, Front End and Systems Engineers were less supportive (NPS= -3) than Con-nections and SURF personnel (NPS= 2). This is interesting since it is the product experts' respon-sibility to perform concept evaluation in early phase, due to their specific knowledge about the connection systems. Within the FESE group, system engineers working in project execution were less supportive than field development engineers. System engineers stated that A3AOs lack specific information, while field developers stated that they contained too detailed information, as shown in the following two statements:

System Engineer: "A3AOs are simplifying the information to the extent that I consider it unfit to serve as the only source of information when making decisions about choosing which system is most feasible."

Field Developer: "The A3AO drawings gives a good understanding of the operations involved - but may be somewhat detailed for early phase work (we rarely go into details such as laying sequences, timing and operations)."

Another interesting finding from the survey is that even if the statements regarding improved understanding receives negative NPS scores, most respondents agrees to the statements (#1, #4, #5 and #6 in Figure 7). As shown in Figure 6, most respondents are very familiar with the Tie-in & Connection system. Overall, the respondents recognize the value of the A3AO and its holistic overview of the system. According to respondents, A3AOs are useful to support communication and share knowledge with resources that are less familiar with the system. This is illustrated by this statement from a chief engineer within the Connections and SURF group;

Chief Engineer: "As an expert in this area, the understanding of the product/operation involved is presented in an excellent way to show involved people not familiar how tie-in operation works."

Views in the A3AOs

Figure 10 presents survey results on the A3AO method, its views and characteristics, in general. In terms of architecture views' usability, results show that respondents are positive to the functional view, installation timeline, pros and cons, and key performance parameters. Respondents are less enthusiastic about the physical and operational view. The characteristics of the A3AOs receive positive feedback on readability, understandability, and usability. Most responders state that the A3AOs contain adequate amount of information.

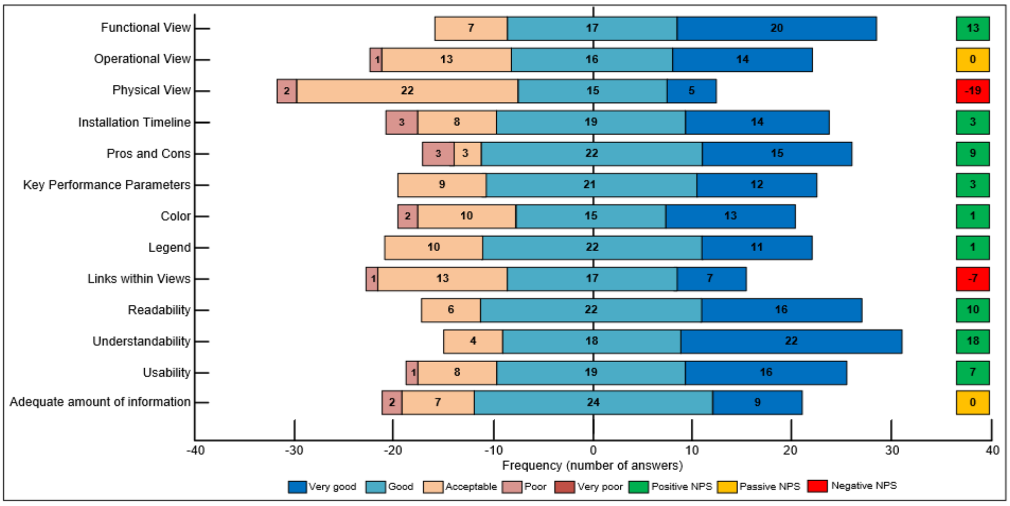

Figure 10. Survey results: A3AO views and characteristics (44 respondents)

Discussion

To maximize their potential in the subsea industry, the company needs to improve collaboration between departments. Former research has enlightened the A3AO method as a beneficial tool to cope with challenges when developing complex systems, such as subsea field developments. In the early phase of a subsea development, it is important to have a holistic perspective and define the best overall solution in an objective manner. For this reason, we analyzed company´s concept evaluation challenges and examined the beneficial effect of applying A3AO in subsea front-end engineering studies. We investigated this in three research questions.

What are the main challenges the company experience related to concept evaluation of Tie-in and Connection systems? Through the semi-structured interviews and the initial survey, we identified that the main challenges affecting the concept evaluation. These include: difficulties in finding relevant system information, lack of holistic view, ineffective knowledge sharing, and multi-disciplinary communication. From literature, we observed that these challenges are quite common when engineering complex systems (Heemels & Muller, 2006). To mitigate these challenges, the company needs to align their process to promote common understanding across SPS and SURF departments. SPS is responsible for the Tie-in & Connection system, and SURF is responsible for installation and operation. Separate domains have different needs, working methods, and even domain-specific languages.

How do the resources in the company perceive the developed A3AO? From the validation survey we found that overall, the respondents found the A3AOs and their characteristics to be easy to read, understand, and use. Respondents were able to understand their content without any explanations or guidelines. Results proved that we managed to capture valuable key aspects of the installation sequence and present them in a holistic manner. The survey showed that they responded well to the functional view, installation timeline, key performance parameters, and pros and cons. The least valued views were physical view and operational view. The company resources appreciate detailed illustrations, such as CAD/3D models or real-life photos, rather than abstract models. However, the main value of an A3AO is in its simplicity (Borches, 2010). Or as stated by Muller: *the devil is often in the detail* (Muller, et al., 2019). Survey results proved that very few respondents were familiar with the A3AO format from previous subsea developments. The same respondents stated that they would like an A3AO format of their own system of interest.

How can application of A3AO support the company in concept evaluation of Tie-in and Connection systems? The validation survey showed a clear link between the company´s main challenges previously defined and the benefits of the A3AOs. Hence, we expect that A3AOs will support the company in the early phase concept evaluation. The A3AO captures key information and main drivers in an easy-accessible format, and hereby promote common understanding across SPS and SURF departments. To illustrate the importance of evaluating concept in a holistic perspective, the A3AO format displayed an SPS system from SURF´s point of view. According to respondents, this was very valuable. The A3AO´s intention is not to replace existing documentation in concept evaluation, but to serve as a supportive tool in discussions and evaluations of the Tie-in & Connection system. The A3AO´s role in concept evaluations is not to function as a single source of information, but to share key aspects about the respective system in a rapid manner. For that purpose, it can support discussions and concept evaluation in early phase studies.

Validity of Data. Multiple stakeholders with extensive industry experience contributed in this research, spanning from product experts to department managers. To capture personal and honest opinions from each stakeholder, we conducted individual interviews and review sessions. To improve reliability of survey results, we distributed surveys to multiple resources in different disciplines. In total, 62 participants with an average of 19 years of experience responded to the surveys. A validation threat can be that respondents influence each other´s opinions and drag the result in a specific direction. To mitigate this threat, we gave the respondents a short response time to review and answer the survey. Respondents answered the surveys from their home office, so we can assume that we captured their objective opinions.

Value of Work. Through this research, we have demonstrated the benefits of using A3AO to efficiently share knowledge and present insights about a system in an industrial setting. "*One insight is worth a thousand analyses"* (Maier & Rechtin, 2009). Few stakeholders were familiar with the A3AO method from previous projects and developments, despite their extensive work experience. Most of the respondents were positive to the A3AO method and wanted a similar overview of their own system of interest. From an academic perspective, this research contributed in the work of identifying patterns of systems engineering methods applied in the subsea domain.

Limitations of Work. We have not tested the A3AO method in an actual study, hence the evaluation depends on stakeholder opinions. Stakeholders´ opinions are often biased due to different mindsets in the different departments. The conflicting opinions we received in the validation survey illustrates this. As human beings, resources interpret messages and information in different ways based on their personal experience. Additionally, the information presented in the A3AOs are simplified models and estimated values. In terms of concept evaluation, subsea installations and their respective timeframes depend on various factors such as operator experience, water depth, weather conditions etc. Specific factors are not included in these abstract presentations. Subsea projects are complex and depend on specific information in order to investigate potential concepts thoroughly.

Further Work. The company should mitigate the challenges in order to prevent late design changes, cost overruns and schedule delays caused by poor design choices (Engen & Falk, 2018). The first step on their way can be application of A3AO in front-end engineering studies. Further work is needed to test the A3AOs in an actual study in order to evaluate its supportiveness in a real case. To further benefit from the A3AO, the company should develop A3AOs on lower levels and link them back to the top-level view (Haveman, 2015). Lower-level views should contain specific information and more details about the connection system and its surrounding elements. Architecture views capturing specific information about offshore vessels and their installation constraints should be an interesting topic for further work.

Conclusion

To maximize their potential in the subsea industry the company needs to align their processes and improve across the organization. In this paper, we investigated the beneficial impact the global subsea supplier can gain by applying A3AO as part of their concept evaluation process in early phase studies. To evaluate the impact of the method and its mitigating effects, we performed a case study on the company´s subsea connection systems.

The main challenges affecting the company´s current concept evaluation are difficulties in finding relevant system information, lack of holistic view, ineffective knowledge sharing, and multi-disciplinary communication. To mitigate these challenges and support concept evaluation in front-end engineering studies, we defined three needs of improvement:

- Easy-accessible format stating key information and main drivers
- System overview to support knowledge sharing and multi-disciplinary communication
- Holistic view – integrate SPS engineering and installation needs from SURF

Furthermore, we developed two A3AOs that provided system overviews of the company´s Tie-in & Connection systems. We analyzed company resources´ perception of these A3AOs and investigated how they could support concept evaluation. Overall, the respondents found the A3AOs and their characteristics easy to read, understand, and use. By capturing essential information of the Tie-in &

Connection system, and share it in a holistic manner, A3AOs can mitigate the company´s current challenges and support concept evaluation in early phase studies.

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Biography

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