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Managing Knowledge Transfer in Innovative Complex Systems Development: Case Study of Renewable Energy Project in the Oil and Gas Industry

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Abstract. Many oil and gas companies are looking for new opportunities in the renewable energy market. New energy systems, especially those with subsea large-scale hydrogen storage functions, have become an important part of the global energy transition. Oil and gas companies, like the case company, utilize experience and technologies from the subsea oil and gas sector to develop large-scale hydrogen storage systems. In systems development, there is a need for efficient knowledge transfer from the current team to new stakeholders joining the team. To meet this need, this research investigates how to use A3 Architectural Overviews (A3AOs) to facilitate the efficient knowledge transfer between the current team and the future engineer team in the renewable energy project of the case company. Drawing from the system engineering methodology, we first identified key stakeholders and their needs and studied the current knowledge transfer situation. The solution based on A3AOs has been developed and optimized in this study. This final solution has been verified and validated by the testing workshop, survey, and expert evaluation.

Introduction

Company. The case company is a leading technology provider to the traditional and new energy industry, delivering fully integrated projects, products, and services. The company operates internationally and has approximately 20,000 employees worldwide. The company specializes in subsea oil and gas engineering, installation, maintenance service, etc. In particular, the company is the forerunner, leading the energy industry's transformation, and is committed to developing a new energy system through the renewable energy project.

Case project. The renewable energy project is one of the case company's energy transition initiatives, utilizing local surplus renewable energy to deliver stable green hydrogen (H_2). For stable energy delivery from renewables, a large storage capacity is required. Despite much space to store, hydrogen is relatively easy to compress. The case company has identified an opportunity to utilize knowledge and technology from the subsea oil and gas sector to solve the storage problem by utilizing the available subsea space for possible large-scale renewable energy. The H2SubSea group in the case company is responsible for developing and qualifying the H2 storage system. As the initial H2 storage system concept matures, there are new stakeholders joining the project team due to the project scope. The full scope of the renewable energy project includes a wind turbine system, water treatment system, electrolyzers system, H2 compressor system, fuel cells system, H2 storage system, etc. When the wind is active, the power from the wind turbines is fed directly to the grid. During periods of excess electricity available, electricity will be used to split water into H2, compressed, and stored in an H2 storage system under the sea (Chen, 2022). During low or no wind, the fuel cell system converts the stored H2 back into electricity to satisfy the energy demand. As such, the renewable energy project is a complete off-grid offshore energy solution system. It can also produce, store, and deliver hydrogen to consumers at sea or export it in a pipeline to shore.

Challenges. The renewable energy project adopts the EU Technology Readiness Level (TRL) scale to support technologies' innovation and industrialization process to transform ideas to the market (Commission, 2011). The renewable energy project is under the TRL 4-6 (see Figure 1), where there is a gap between Academia and the Industry. This gap is often referred to as the "Valley of Death", where ideas go to die (Leitner, 2013). Nevertheless, it turns out that merely inventing a solution and proving the technology are not the most challenging parts. Being ready in all aspects to traverse the valley is the real work in innovation (Leitner, 2013). The H2 storage technology is the core for the renewable energy project's success in the case company. Currently, The H2 storage system concept is being developed by the core research sub-group of the H2SubSea group under Work Package 1 (WP1). After the technology is approved (under TRL 6), the WP1-H2 Storage Module is handed over to new stakeholders, such as the Manifold group, Connection group, etc. Those groups are called the (Project Execution) Engineer team, as shown in Figure 2. Hence, it is critical the knowledge is effectively transferred from the initial H2 Storage Module team to the Engineer team. As many new stakeholders join the project after TRL 6, the cost is on the rise to mature the abilities of prototype and systems development, as indicated by the red line in Figure 1.

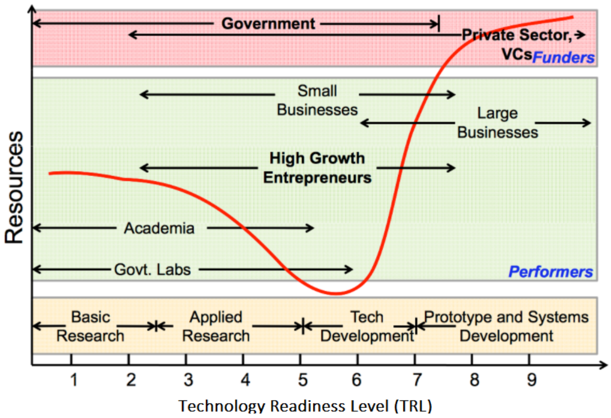

Figure 1. TRL vs. Resources

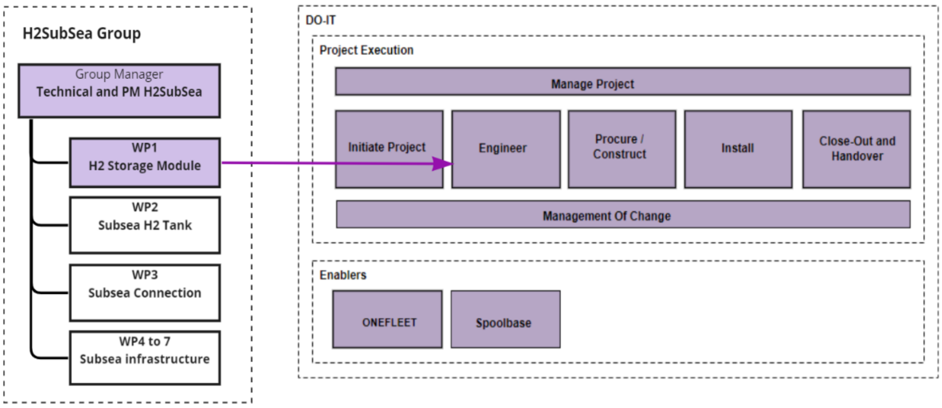

Figure 2. Knowledge Transferring Objects

Research question. This research aims to advance our understandings of the knowledge transfer from a small research group in a large conservative company (know-how in TRL4-6) to a larger group that demand lots of resources (systems development after TRL6). Specifically, this research investigates the usage of A3 Architecture Overviews to facilitate such a knowledge transfer. Therefore, this paper seeks the answer to the below research question:

How to use A3 Architectural Overviews to facilitate effective knowledge transfer of the technological know-how in the innovative complex systems project?

Knowledge Applied

This section reviews relevant knowledge applied to our research purpose, including system engineering as a generic problem-solving methodology, important issues of system architecture, and the effective tool of A3 Architecture Overviews.

Systems engineering (SE). According to the Systems Engineering Body of Knowledge (SEBoK, 2021 a), SE is a transdisciplinary approach and a means to enable the realization of successful systems development. Successful systems development must satisfy the needs of their customers, users, and other stakeholders. A stakeholder is an individual or organization having a right, share, claim, or interest in a system or in its possession of characteristics that meet their need and expectations (ISO/IEC/IEEE, 2015). Stakeholder engagement can be understood as a process of involving stakeholder concerns, needs, and values in the decision-making process (Vierikko et al., 2019). The according solutions should increase stakeholder involvement during the systems development project. As such, Vierikko et al. (2019) provided a guideline for this research to increase the effectiveness of stakeholder involvement. Besides, we also adopt the SE as a research methodology in finding a solution to an identified issue while considering the context, the stakeholders, and the rest of the world (Bonnema et al., 2016).

Systems Architecture (SA). As a methodology, SE can enable an optimal system design based on clearly defined objectives, whereby SA focus on a joint exploration of requirements and design (Maier & Rechtin, 2000). According to SEBoK (2021 b), SA is abstract, conceptualization-oriented, global, while achieving the system's mission and life cycle concepts. It also focuses on high-level structure in systems and system elements. Despite SE is more regarded as science, SA can be viewed the art part of it (Maier & Rechtin, 2000). SA applies a framework that enables early visualization of system flow and elements. This provides a common ground for communication among stakeholders (Boge & Falk, 2019). The importance of SA is to enable a way to understand complex systems, design and manage them, and provide long-term rationality for decisions made early in the project (Engen, Falk, & Muller, 2019). Decomposition is a very general principle for creating a system architecture. Whenever something is decomposed, the resulting components will be decoupled by interfaces. Many thus have perceived decomposition and interface management as the most important contribution (Muller, 2020). However, Muller (2020) pointed out the true challenge for the architect is to design decompositions that, in the end, will support the integration of components into a system.

A3 Architectural Overviews (A3AOs). The A3AOs is recognized as a valuable SA tool for effective communication of architecture knowledge (Borches, 2010). Effective communication in the architecting context means that individuals and teams understand the essential aspect of the architecture knowledge other individuals or teams share (Borches, 2010). Borches (2009) has developed the A3AOs with two sides of an A3 sheet. One side displays a structured model (A3 Model), composed of several interconnected views, for example, functional view, physical view, et cetera. The other side contains textual information (A3 Summary). It is found the visual format of A3AOs is highly accessible to diverse stakeholders (Løndal & Falk, 2018). However, not all the information obtained is equally salient. So the researchers must distill the synthesized picture to only the most vital points needed for proper positioning and understanding (Smalley & Sobek II, 2019). By limiting the amount of information to a sheet of A3 paper, the architect creating the overview has to reason carefully about what information contributes to the message and what information distracts (Brussel & Bonnema, 2015).

Application of A3AOs. Previous research has approved that the A3AOs is an effective tool for knowledge tranfer for exisiting systems in invarious heavy engineering domains. For instance, Sing and Muller (2013) developed the dynamic A3AOs and applied them in a lube oil system of a gas turbine package, Haugland and Engen (2021) applied the A3AOs in Subsea front-end engineering studies; Wiulsrød, Zhao and Muller (2022) used A3AOs in architecting Diesel Engine Control Systems, etc. However, little is know how A3AOs help knowledge transfer in the context of radical innovative systems development, i.e. new energy transition project—large-scale H2 storage systems to the case company. This research thus contributes to the application of A3AOs in knowledge tranfer by extending the application domain of an innovative systems development, i.e. our case in a large oil and gas company that transitions to new energy systems developing entering into new market.

Conceptual Solution

The oil and gas industry can significantly benefit from systems engineering methods and techniques, but they must adapt them to their setting and needs (Gerrit & Falk, 2018). It is notable digitalization is an undergoing initative in the case. Especially due to the pandemic, people are getting used to working at home, and most communication is carried out through the Internet. The conceptual solution of A3AOs to our case should be developed to be applied in a digital environment.

Although Borches (2010) suggested using both sides of an A3 sheet — structured model and textual information, prior research have shown cases successfully used only one side (Johanssen & Zhao, 2019; Viken & Muller, 2018). In our case, the concpetual soultion is proposed to mainly focus on the structured model side of A3AOs. The textural information, such as Key Performace Parameters (KPPs), is integrated into the structured model side, so that users can easily change the view between the model and text on the same page of an A3 sheet.

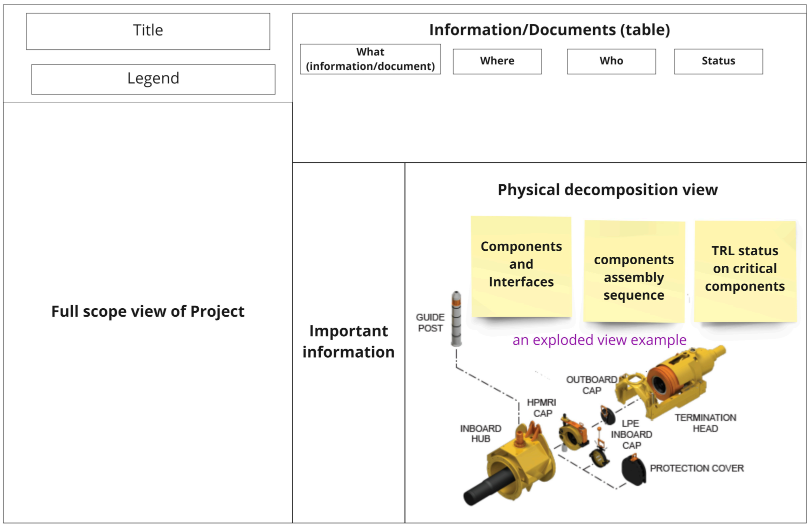

Figure 3. Conceptual Solution: An Early A3AO example

Based on literature review, we define a conceptual solution that includes several key elements that can benefit the case situation. The one-side focused A3AO solution includes four key elements: the full scope view of the project, physical decomposition view, information/document table, and important information. Furthermore, this top-level system is demonstrated by a functional model in the full scope view of the project (Borches, 2009). The system components are shown in the physical decomposition view, especially the interface by decomposition. To address the challenge of system architecture (Muller, 2013), we use the 3D design modeling program NX to create a exploded view of the system (shown in Figure 3). The exploded view provides the design decomposition including the 3D picture of individual subsystems/elements, dashed lines to connect individual subsystems/elements in assembly order and the locations of subsystems/elements in the system.

Research Methodology

Research Methods

We adopted a case study as the main research methodology. Moreover, during the development of A3AOs, some key stakeholders started using the conceptual solution for the project and generating feedback for improvements. Hence, we jointly used both case study and action research in this study.

Case study. A case study is a qualitative research method that involves empirical investigation of a particular contemporary phenomenon within its context using multiple sources of evidence (Robson, 2002). The renewable energy project in the case company provides a specific context for us to investigate the stakeholders' needs, the current situation of knowledge transfer between the initial H2 Storage Module team and the project execution engineer team, and the appliaiton of the conceptual solution on the knowledge transfer between the two teams.

Action Research. Action Research seeks to introduce and evaluate change that generate knowledge to inform improvements and future practices, originally in organizations and programmers but increasingly in design (Blessing & Chakrabarti, 2009). Action Research involves a research method with iterative actions among solution development, implementation and critical reflection (i.e. feedbacks) (Blessing & Chakrabarti, 2009). We employed action research through user participation to improve the conceptual solution based on user feedbacks after their implementation.

Research Design

Based on the systems engineering methodology, we designed our research process into three phases: the exploration phase, the experimentation phase, and the testing phase, shown in Figure 4.

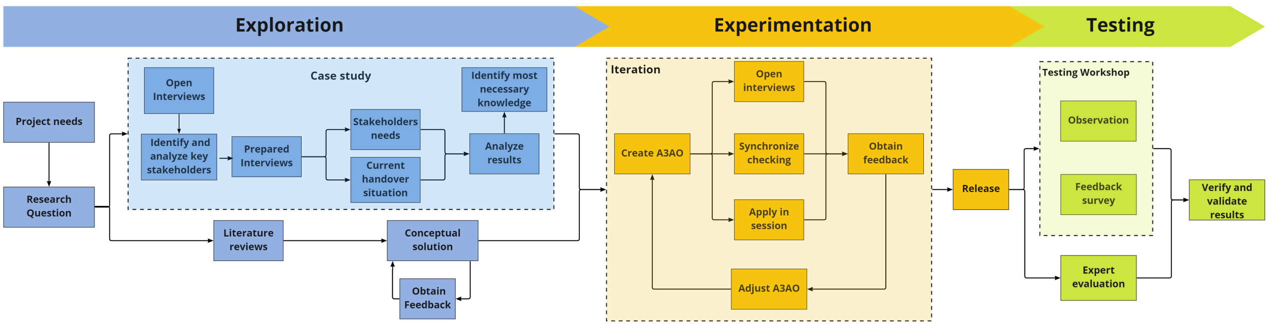

Figure 4. Research Design

During the exploration phase, we began with the identification of the research needs of this case project which leads to our study focus –the research question. To address the research question in the case study, we firstly investigate who the key stakeholders (Vierikko et al., 2019). Based on the interview data, we identified all relevant stakeholders and further analyzed their influence, level of interest or concern to the case (Vierikko, et al., 2019). Based on that, we cataloged stakeholders' level of engagement and identified a list of key stakeholders. Next, we performed interviews with all key stakeholders with an aim to understand their needs and current situation. To further identify the most critical needs the key stakeholders may have, we performed one more interview. Concurently, the literature review is performed to understand the state of the art of the application of A3AOs on knowledge transferring. Based on the literature review, we proposed the conceptual solution. The identification of key stakeholders and their needs and the conceptual solution serve as the basis for improving the application of the conceptual solution in the next phase.

Based on the findings in the exploration phase, we created the specific A3AOs that can operate over the internet in the experimentation phase. It is developed towards an efficient way to work when people were busy working from home during the pandemic. Under this phase, we aim to improve the A3AOs through action research method. The feedbacks obtained from the implementation of the A3AOs by the key stakeholders are the source for improvement. We obtained feedbacks from key stakeholders after their each time using the A3AOs. Based on the feedback we received, we continously improved our solution. We ran four iterations to get direct feedback through interviews with key stakeholders. Moreover, two key stakeholders had access to the A3AOs creation tool and gave feedbacks by adding stickers. When they put stickers on the A3AOs creation tool, we were notified and the stickers were synchronized. Those feedbacks were also included in improving the solutions.

When the optimized version was ready after the four iterations, we released it for final testing. We conducted the testing workshop to evaluate it under the testing phase. During the testing workshop, the two representatives from H2 storage team used the optimized version of A3AO to present the project know-how to the project execution engineers, and we did the observation during the presentation. After the presentation, we openly discussed the concern of using this version of A3AO with the key stakeholders and conducted surveyed with them at the end of the workshop. In addition to the workshop, we also sent this version of A3AO to experts for evaluation. Data collected from the observations, feedbacks and surveys help verify and validate the solution.

Data Collection

We used mixed methods in data collection. We performed interviews, observations, surveys and workshops which are detailed below.

Interviews. Interviewing is a powerful way to get information from others (Muller, 2013). The method offers an opportunity to interact with the person being interviewed and reduces the possibility of misunderstandings (Muller, 2013). We used both Open Interviews (OIs) and Prepared Interviews (PI) in the data collection. Unlike PIs, OIs do not have a pre-defined set of questions, which is the main difference from PIs. Table 1 presents all interviews we conducted in this research.

Table 1: Interview Type and Participants

No.	Type	Participant (s)	Experience	Objective	Phase
OI-01	Open Interview	1 Project manager, 1 Manager of Marketing and Branding, 1 Director of Marketing and Branding, 1 H2 Storage Manager	30+ years	Explore all stakeholders	Exploration
OI-02	Open Interview	1 H2 Storage Manager and 1 H2 Storage Module Lead	10+ years	Further explore the key stakeholders	Exploration
PI-01	Prepared Interview	1 Manifold Manager	10+ years	Understand the need and current situation	Exploration
PI-02	Prepared Interview	1 Manifold Design Manager	10+ years	Understand the need and current situation	Exploration
PI-03	Prepared Interview	1 Lead Engineer Manager 1 H2 Storage Module Lead	10+ years	Understand the need and current situation	Exploration
PI-04	Prepared Interview	1 Lead Control Engineer	10+ years	Understand the need and current situation	Exploration
PI-05	Prepared Interview	1 Manifold Lead Engineer	10+ years	Understand the need and current situation	Exploration
PI-06	Prepared Interview	1 Chief Engineer (with tender experience)	10+ years	Understand the need and current situation	Exploration
PI-07	Prepared Interview	1 Senior Project Engineer	10+ years	Understand the need and current situation	Exploration
PI-08	Prepared Interview	1 Lead Engineer (with work experience in renewable energy project)	10+ years	Understand the need and current situation	Exploration

PI-09	Prepared Interview	1 H2 Storage Manager and 1 H2 Storage Module Lead	10+ years	Analysis of the interview result; Identify the most necessary knowledge for transferring and explore the concept and feedback.	Exploration
OI-03	Open Interview	1 H2 Storage Manager and 1 H2 Storage Module Lead	10+ years	Feedback about the A3AO and the contents	Experimentation Iteration 1
OI-04	Open Interview	1 H2 Storage Module Lead	10+ years	Feedback about H2 storage module knowledge on part 3 of the A3AO	Experimentation Iteration 2
OI-05	Open Interview	1 H2 Module Lead Engineer, 1 H2 Storage Manager, 1 Manager of Marketing and Branding	10+years	Feedback about how to optimize part 2 of the A3AO	Experimentation Iteration 3
OI-06	Open Interview	H2 Subsea group	10+ years	Review and feedback about the overall knowledge (Part 1, Part 2, and Part 3) on the A3AO	Experimentation Iteration 4
OI-07	Open Interview	1 System Engineering Industry Ph.D.	10+ years	Evaluate on the A3AO	Testing

Observation. It is one of the most common ways of data collection (Blessing & Chakrabarti, 2009). Observational methods involve the researchers recording what is happening either by hand or using recording or measuring equipment. This research conducted the overt observation under the testing workshop. Overt observation means all involved know that observations are being made and who the observer is (Blessing & Chakrabarti, 2009). However, a full explanation of the observation purpose will not be provided not to influence the design process to be studied (Blessing & Chakrabarti, 2009). Our purpose was to investigate the use of the A3AO and how people responded to it.

Surveys. Surveys are typically performed as one-way communication. The survey is sent to the recipient, who answers the survey without the possibility of interaction; clarification of intent is not possible (Muller, 2013). This research conducted one survey that includes Likert Scale Questions and Open Questions. Likert Scale Questions with five alternative answers: Strongly agree, Agree, Neutral, Disagree, and Strongly Disagree. The benefit of a Likert Scale is that researchers can accumulate and compare respondents' answers (Muller, 2013). In addition, the Open Question will allow the participants to spend time forming their opinion and providing more information, mainly can collect data from the participants who do not like to speak out. Table 2 presents the details of this research survey. We used the mean and percentage to analyze the survey results, and we also used the Net Promotor Score (NPS) to check which question was promoted or detracted. Muller (2013) provided fundamental knowledge for applying the mean and NPS in this research.

Table 2: Survey Questions and Objectives

Survey	**Type of Questions**	**Objectives**
Section 1	11 Likert Scale Questions	To investigate the value of the A3AO
Section 2	1 Open Question	To understand stakeholders' concerns with the A3AO for knowledge sharing in the renewable energy project so that we can do better in the future

Workshop. To validate and verify the final version of A3AO in this study, we conducted a testing workshop with five key stakeholders. Two are from the H2 Storage Module team, and three are from the project execution engineer team. We sent out the final solution to three (two knowledge owners and one knowledge user) before the workshop so they had time to read it; the others would see the A3AO for the first time during the workshop. Participants with or without pre-see the A3AO could be valuable for us to observe how they reacted to the A3AO during the workshop.

Expert Evaluation. The expert evaluation was a backup plan in addition to the workshop. Our workshop had been postponed several times due to participants' schedules and sickness; therefore, we decided to do the expert evaluation in case we could not hold the workshop before the deadline. The expert selected is the System Engineering Industry Ph.D. with renewable energy project and systems engineering knowledge, working as an H2 Storage Module lead and an H2SubSea group manager at the case company.

Case Study Findings

Key Stakeholders. Based on the data from OI-01 and OI-02, we identified all the relevant stakeholders and evaluated their influence/interest on the case project. We conducted the evaluation of their influence/interest on a scale from 1 (lowest) to 5 (highest) in order to prioritize who are the key stakeholders with higher-level of influence/interest. Those key stakeholders (eight in total) are usually the go-to resources when a knowledge transfer happens during the case project. The evaluation results were mapped into the relevant stakeholders' location on the two-dimensional matrix, as shown in Figure 5. Moreover, the stakeholders were cataloged into two groups for transferring knowledge: knowledge owners (senders) and knowledge users (recipients).

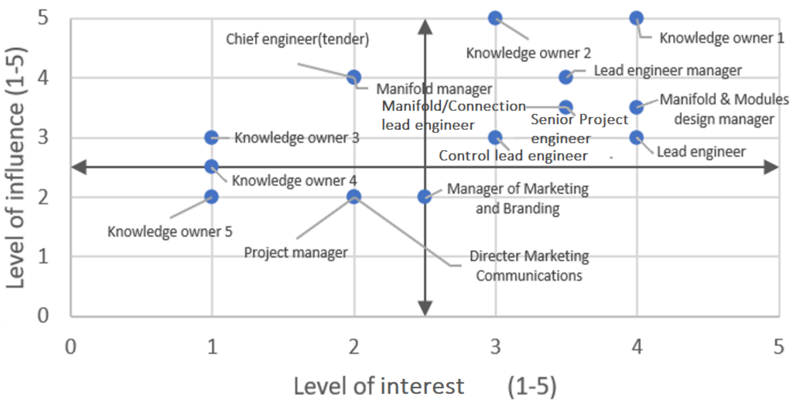

Figure 5. Results of Stakeholder Mapping

Table 3: Key Stakeholders' Needs on Required Knowledge

Information/knowledge	Interviewee 1	Interviewee 2	Interviewee 3	Interviewee 4	Interviewee 5	Interviewee 6	Interviewee 7	Interviewee 8
Consept					x			
Scope of work			x					
Project plan	x	x						
GA					x	x		
Schematic	x	x				x	x	
TRL of components		x	x		x	x	x	
All requirements for design	x	x	x	x	x			x
Subsystem specification	x	x			x	x		
Function description	x							
Analysis report						x		
Qualification documents						x		
Interfaces	x	x			x			x
Between storage and other systems	x				x			x
Between subsystems(components)	x				x			x
Interfaces with rig and Vessel	x	x						x
Suppliers		x						
Equipment and tool		x						
Standard					x			x
Location(to place the storage)					x			
Local requirements (e.g. factory choosen)					x			
How to install			x		x			
Deviation to client requirements			x					
Contract			x		x			
Budget								
Information for the qualifying product team		x						

Key Stakeholders' Needs. We conducted one-on-one interviews with the eight key stakeholders (PI-01 to 08) to understand their needs and the current sitation of knowledge transfer. The identifed needs mainly focus on what knowledge is needed when H2 Storage Module team handovers and after TRL 6. To further analizing the interview results, we conducted PI-09 interview for the most critical knowledge needed after TRL 6. The result of the interviews and analysis are shown in Table 3. The blocks in blue represents the most requested information/knowledge (based on PI-09; the red colors what the interviewee thought was most important to them (based on PI-01 to 08).

Current Situation. Based on the interview data (PI-01 to 09), it is found the knowledge needed is know-how in our case which is mostly tacit and carried only by the core knowledge owners. Whenever new engineering team joined the project, a lot of time and resources are needed for them to acquire required knowledge to carry on the project. In addition, due to the limited project budget, many stakeholders, including knowledge owners, have multiple projects simultaneously, thus the knowledge owners are not always available. Despite the attempt to document required knowledge, the according documents are difficult to be located due to different storage places. At the current moment, the case project is under TRL 4-6 and conducting the main activities of technology testing and qualification, shown in Table 4. As the technology matures, more and more execution engineers will join the project. Many stakeholders have pointed the need for a more efficient knowledge transfer to newly joint engineers from the H2 Storage Module Team.

Table 4: The Project Activities and Technology Readiness Levels Scale

Consept	Proof of Consept		Prototyping 1		Prototyping 2		Field Qualified	
TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL9
Basic principles obwerved and reported	Technology concept and or application formulated	Experimental proof of concept	Technology validation in lab	Tech valid in relevant environment	Demonstration in relevant environment	Denmonstration to operational environment	Actual system completed and qualified	Successful mission operation

There are no existing lessons learned from previous projects. It is because this project is about radical innovative systems development to the case company. But there are similar issues of knowledge transfer in previous oil and gas projects in the case company. In oil and gas projects, there is a similar need of knowledge transfer between the tender team and the project execution engineer team. In the past, after the tender team completed the intial project activties, the team held a handover meeting with the project execution engineer team for knowledge transfer. In handover meeting, they presented a technical wrap-up, General Arrangement (GA), and overview of customer requirements (in PowerPoint or Excel), which often took about one hour. During the interviews, many engineers complained that they often lost knowlege after the handover meeting in previsous oil and gas projects. The reason is the knowledge capture within the handover meeting was limited and the documentation of according knoweldge was located in different places such as Teamcenter, D-drive, etc. Sometimes even the critical information to the project execution engineer team, such as Subsystem Specifications, is not documented and thus unavailable. It thus leads to the increase of project cost as more time spent for project execution engineer in locating and learning the required knowledge.

Furthermore, we conducted the Root Cause Analysis (RCA) on the two primary issues by using the 5-Why. The results of RCA are presented in Figure 6. Based on the current understanding of the oil and gas projects, we found out the main root causes for the knowledge transfer are related to the availbility of the knowledge owner - H2 Storage Module Team. Therefore, the solution should resolve such root causes. As such, we propose a new tool based on the A3AO to help facilitate the knowledge transfer.

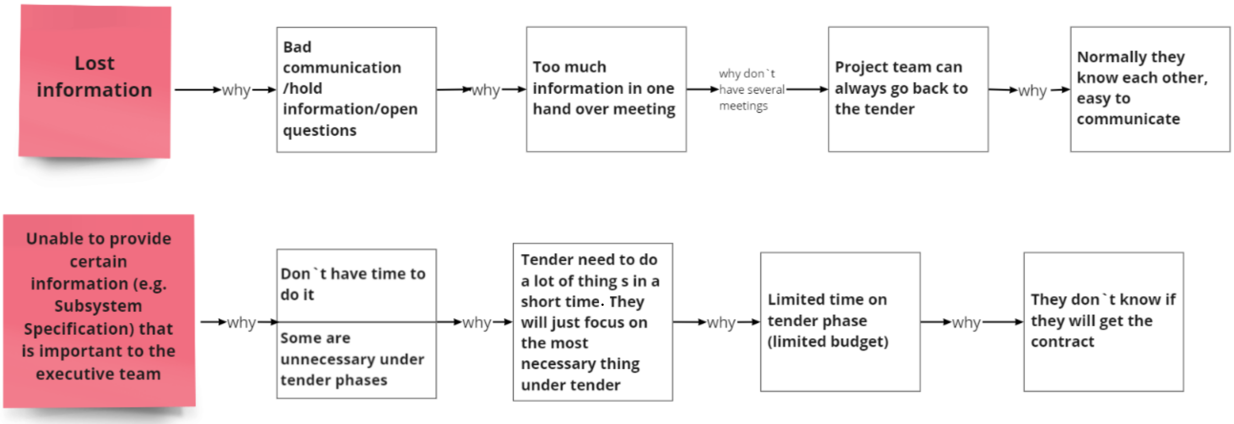

Figure 6. Root Cause Analysis

Solution. There are several iterations of solution optimization based on the conceptual solution – the one-side A3AO. Table 1 presents the four iterations that optimized different parts of the solution according to the feedbacks received from key stakeholders. In the first iteration, we reviewed the entire A3AO with the key stakeholders and discussed where to get all required information, who support it, how to do better, etc. In the second iteration, we focused on optimizing the H2 Storage Module decomposition view and the important information. As the module was still under development during the research project, there existed uncertainty of the architecture design and important information. Hence, the H2 Storage Module lead initiated several reviews to ensure that architecting design and important information in the solution were desirable. In the third iteration, we focused on optimizing the full-scope view of the project in the solution. Since the renewable energy system development in this case project is a complex system development, the case company has experienced the difficulty to explain the system's dynamic behaviors. Herein, the video was found that has been created by the case company to explain the system behaviors. Thus, we added it together with the functional diagram in the full-scope view part of the solution. Based on the collective feedbacks, we also improved the functional diagram by adding the system boundary and subsea scope boundary. In the fourth iteration, all the parts of the solution were reviewed for quality check.

Based on the iteration results, the final solution of the A3AO includes three parts. Part 1 lists information/documents the future project execution engineer team needs. The list consists of the document number, document name, storage place, owners, experts, and status of documents. Because documents are stored in different places for different purposes, we also have add-in links to the document for aiding the knowledge accessibility. Part 2 is about the functional view of the top-level renewable energy concept, which is named as renewable energy technology. In our case, it is essential to include the high-level system. After TRL 6, different work packages of the renewable energy project will be handed over to the different sub-groups of execution engineers and most engineers will focus on their subsystems/elements of the H2 storage system. Thus, to avoid missing the full scope of Deep Purple (top-level system), it is necessary for engineers to understand the top-level system when developing subsystems/elements. In order to aid the understanding of how the complex system works, we also have the link to the video that explains the dynamic behavior of the top-level system efficiently. Part 3 focuses on interfaces between subsystems/components of the H2 Storage Module. Meanwhile, the important information like KPPs, TRL, etc. are integrated into Part 3. Figure 7 shows the example of the final solution, whereby Part 3 has been simplified and used boxes instead of actual modules in this figure due to confidentiality.

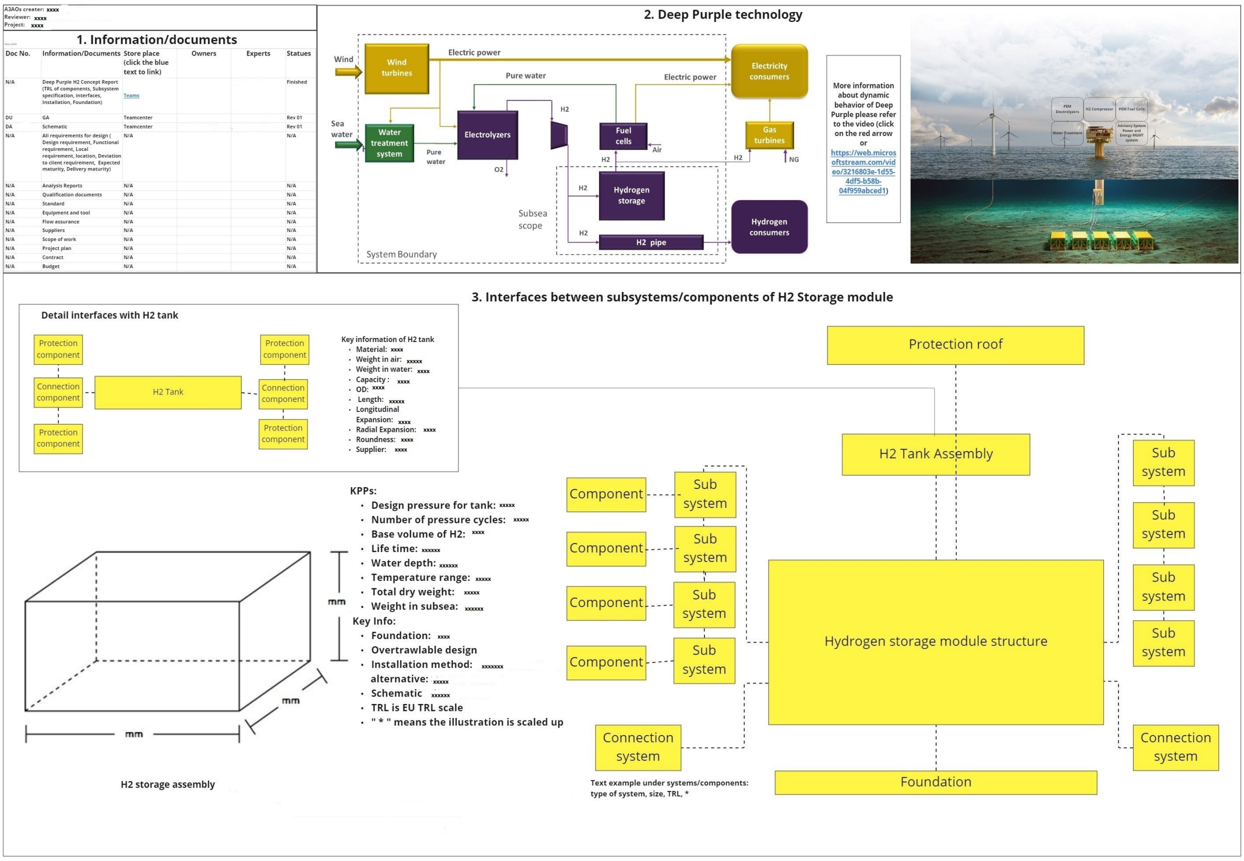

Figure 7. Example of the Optimized Solution

Verification and Validation

Based on the testing workshop, survey and expert evaluation, we verified and validated the final solution. The according results are summarized, as follows:

- All the participants (including both knowledge owners and users) in the testing workshop responded to the survey. From the point view of workshop of participants, the result (Figure 8) shows that all of them agree or strongly agree that the solution can provide the essential knowledge needed to support the communication and execute the project related to the H2 Storage Module (#1 and #2 from the survey). Compared with other documents, 80% of respondents agree or strongly agree that this solution offers an overview of knowledge (#5), better understanding for the start of the project (#6), better information accessibility (#7), alternative views of the text and illustration (#8). Besides, 60% of them agree that this solution can make it easier to understand systems/subsystems and reduce the possibility of needing to ask tender questions (#4 and #10). It is notable all of them agree or strongly agree that the final solution can lead to better communication and more efficient knowledge transfer during the handover (#9 and #11). Although all respondents agree that the solution can bring much value, we found some negative NPS values that they detract from the value in their answers to questions #4, #5, and #10. We also observed from the testing workshop that execution engineers, who are totally new to renewable energy technology and only saw paper version of the A3AO, pointed out that "*the Abbreviation is unfamiliar… In addition, it is not easy to understand part 2 (Deep Purple technology) without any explanation, but the video… then it is good.*" Conversely, those who have involved in the project think that "*This is good, easy, and informative.*" Moreover, they also empathized that *"part 1 is beneficial; gathering all documents in one place would save much time searching for them."*

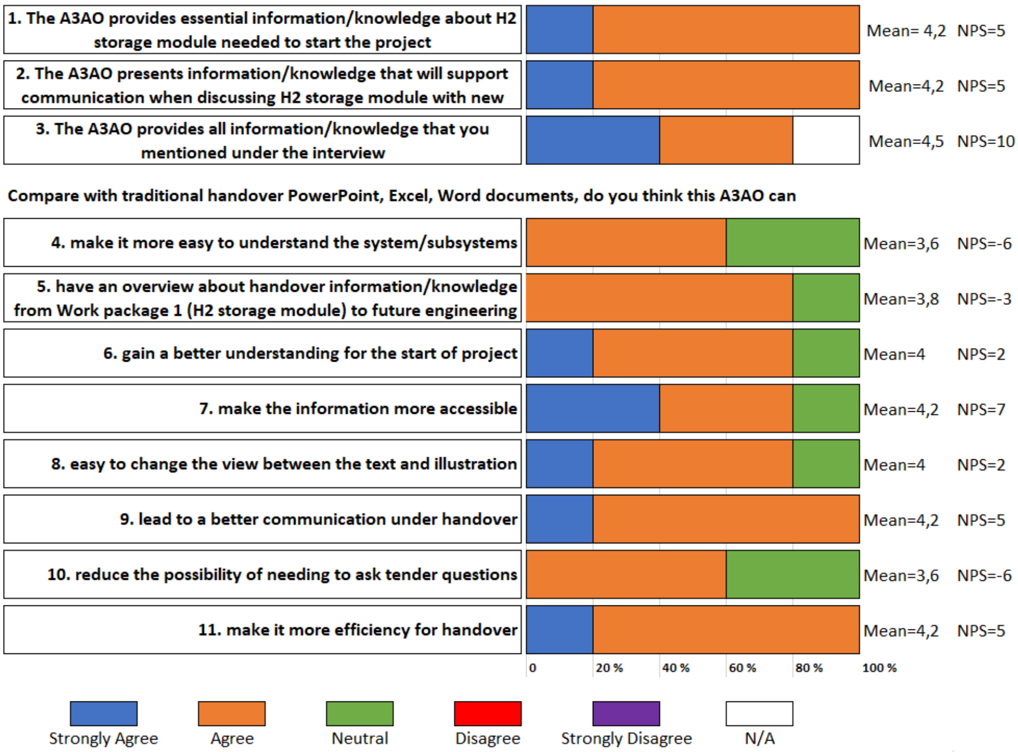

Figure 8. Results of the Survey

- From the user point of view, this solution is found easy to be used and can help facilitate knowledge transfer. The solution, particular part 3 of it, has been implemented in the case project. For instance, the H2 Storage Module lead used it to report and explain the H2 Storage Module work, so that the senior management could easily understand how many engineers are needed to continue the H2 Storage Module development. The user said: "*I planned to use 30 minutes to explain, but in the end, I was able to spend only 10 minutes using this A3AO. Now I see the value of A3AO.*"

- From the management's point of view, this tool is productive and worth investing time in. As the H2Subsea group manager said: "*We have been very busy but supporting this definitively helps me/us get less busy and more productive, so squeezing that time for these sessions to support was motivating and worth it! This is great work!*"

- From an expert point of view, this tool is found useful, but requires maintenance as the project progresses. The evaluation from an industry system engineering Ph.D. who works in the case company with the case project experience, in her own words, is: "*It is very good to have not only the subsystem view but also including overall system. I think it would be useful for the future engineering team. The biggest challenge might be maintaining. For example, if the documents are not ready yet, make sure to update them.*" Regarding maintenance, we got the same feedback from the testing workshop when discussing the concern of the solution usage.

Reflection and Discussion

The above verification and validation results show that the final solution based on A3AOs can solve the intended research question and improve the efficiently of the knowledge transfer. To enable the better solution or usage of the solution, we also investigated the possible concerns based on the survey results of section 2 (Open Questions). We summarized the main concerns into two categories (shown in Table 5). Regarding maintenance, the first concern is the "*installation of the system*." The project has not decided which installation method will be used yet and only the options of installation methods are included in the solutions. However, after TRL 6, as the project progresses, the installation method will be decided, then the installation information can be updated. There exists the same concern for other information as well. For instance, the components TRL described in Part 3 will be updated as the project progresses, and many documents will be only ready after TRL6. Moreover, the solution is under release on Teamcenter, where the revision will be controlled. Based on the comments received from the testing workshop, we have already added an abbreviation list to the solution. However, the traceability of requirements and covering all aspects of information and knowledge needed is out of the scope of this study but important to be considered for future work. This solution focused on the most needed information for the execution engineer team from the H2 storage module team and it is impossible to cover all aspects as much information/knowledge is simply not ready yet. In the event of covering all aspects in future work, we suggest creating several A3AOs for different focused areas. For instance, the installation method and interface with H2 Storage Module can be one A3AO, and the project schedule can be another, etc.

Table 5: Catalogue of the Main Concerns

Catalogue	**Main Concerns**
Maintenance	Installation of the system
	TRL
	Update it according to the project
	Update during project execution, for example, Part 1
	Revision control: risk of using an old version
New part	Abbreviation
	Traceability of requirements (Link to input documents)
	Cover all aspects

In reflecting to the research process, we applied systems engineering methodology in solving the real-life challenge of knowledge transfer in the case project. We firstly created the conceptual solution of the A3AO and used it to present information or communicate with stakeholders. We experienced that many stakeholders were unfamiliar with A3AOs and did not expect them to use A3AOs-based solutions right away, but at least we hope the recognition of the value of A3AOs in knowledge transfer in the case project. As the director of marketing communications in the case company said, "*it is important to influence people when involving stakeholders in this case".*

It is also worth mentioning that engineers with a system engineering background thought it was excellent to have all-scope Deep Purple top-level systems in the A3AO. However, engineers without a system engineering background tend to focus on the system they develop. Many engineers have worked in their way for a decade, and it is a challenge to introduce a new method to them. Thus, we may have to consider their work habits and acceptability when choosing a method.

Furthermore, we found sending out the A3AO before the testing workshop can help participants better prepare for the workshop. We observed that participants who saw the A3AO for the first time asked more questions than those who had seen before. Answers to some questions can be found in the A3AO. If participants can have the access and time to go through the A3AO, we believe it could be more efficient in conducting the workshop.

We were committed to collecting valid data, however, limitations remain. We involved stakeholders from multiple disciplines during the data collection. We conducted one-on-one interviews with key stakeholders for in-depth information and the following interviews/sessions to review the data we collected. However, RCA results were derived from the data collection but not reviewed. The review should be performed to the RCA results for improved validity of the analysis.

Conclusion

In this research, we investigated how to use A3AOs to facilitate efficient knowledge transfer between the current H2 Storage Module team and the future project execution engineer team in the Deep Purple project. We identified key stakeholders and their needs and investigate the current situation of knowledge transfer of the Deep Purple project and the oil and gas projects in the case company. In line with the prior art, we developed the conceptual solution, the A3AO, which was optimized through four iterations. The final solution was verified and validated by a testing workshop, survey, and expert evaluation. The verification and validation results show that the A3AO can facilitate efficient knowledge transfer, which is mainly manifested in improved communication, more accessible access to information, provision of essential knowledge to initiate the project, a better understanding of project initiation, and improved quality handover efficiency, etc.

By the time of completing this research paper, the A3AO had already been used in the Deep Purple project and has been released in Teamcenter. The solution developed in this study has now become an official tool for more engineers to use in the Deep Purple project. We can conclude that the A3AO is applicable in large oil and gas companies transitioning to new systems, such as large-scale H2 storage systems in new markets in our case. We recommend the continuously improvement of the solution by further investigating the ongoing implementation in the case company. Future research is also possible for other industry contexts in similar situations.

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