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Asset Information Model to Increase Traceability in Offshore Wind Projects

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Abstract

This study aims to prepare for the development of an asset information model to increase traceability in offshore wind projects. The goal of the information modelling framework is to increase information flow between projects as well as the quality of the project delivery. Literature review describes traceability in a wide variety of cases and industries, and points to both challenges and benefits with the definition and implementation of traceability practices. However, a successfully maintained asset information model can help engineers make quick and well-designed development decisions and solutions. The development of an asset information model shall contribute to an accelerated design process with higher accuracy and less deviations. Being able to create a product that answers the relevant stakeholders' expectations in a more accurate and efficient way can give the company a valuable advantage in a competitive market. Furthermore, a research design has been defined to form the basis for further research in the spring 2022 semester.

Keywords: Traceability; Information flow; Asset information model; Standardized structure; Requirements; Energy industry; Offshore wind

1. Introduction

In recent years the renewable electricity growth has seen a significant acceleration, driving renewables to new records. In the next five years, the global renewable capacity is forecast to increase by over 60%. By then offshore wind additions are expected to account for one-fifth of the global wind market[1]. The global shift from fossil energy resources to renewables pushes the energy companies into focusing on developing renewable energy facilities. These types of projects are still somewhat new to the industry, and the methods of managing these projects are still maturing.

Aibel[2] is a service company providing engineering, construction, modification, and maintenance to projects within

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the oil, gas, and offshore wind industries. Because of the increased focus on renewables, Aibel has seen an increase in the amount of early phase offshore wind projects in recent years. The methods for requirement traceability and transfer of knowledge between projects used in oil and gas projects within the company are both outdated and not directly transferable, which defines a need for a better solution for traceability in and between similar projects. Early phase offshore wind projects also have a short time frame, often making it challenging for the engineers to document specific developments and the connected scope affected by changes made to any parts of the complex system. A possible solution to mitigate these challenges is to implement a 'traceability solution'.

The process of filtering out relevant requirements for each discipline is done through tedious gap analysis, often creating confusing lists of data that is managed manually, allowing for an increased number of human errors and the risk of missing the implementation of important requirements. This can drastically pull down the overall quality of the delivery as well as increase the cost. The lack of traceability also often leads to bad information flow, which in turn results in a waste of time and resources by having to repeat engineering activities initially completed in earlier phases.

Clients are also expressing an increased interest in the implementation of systems engineering and traceability when providing contracts. New requirements regarding coding systems for increased traceability based on standards such as IEC 81346[3,4] are being implemented, forcing Aibel to adapt to new methodologies and implement systems thinking.

In this study, an Asset Information Model (AIM) (see Fig. 1) visualizing the complex system is proposed. The AIM builds upon the industry-standard IEC 81346[3,4] and provides a visualization of the complex system and the relationships between the artifacts within the system. The main categories are function, product, and location. The AIM will be supported by a reference designation system for power systems which will tie the categories to the artifacts with a tag visible in documentation and 3D-models. When the relationships between the categories are established, requirements tied to the categories will also be applied to the artifact. A function related to a product placed in a specific location will inherit all location requirement for that specific location.

For the AIM to retain the required level of quality to effectively offer traceability, the model must be updated and maintained by the engineers daily by integrating it into the engineers' everyday workflow. If done so, the AIM can help engineers gain a holistic understanding of the dependencies between the system aspects, offering a better basis for making good decisions based on the stakeholder requirements.

1.1. Research Questions

In this study we will investigate the AIM and how it may help Aibel through increase their traceability. The research question (RQ) this study will explore is as follows:

RQ: How can an Asset Information Model contribute to increased requirements traceability?

When developing the AIM, it is necessary to further investigate the requirements. Offshore wind systems are complex and often have too many interrelated requirements. The sub-research questions (SRQ) are as follows:

SRQ1: How do we cope with different requirement inputs?
SRQ2: How do we create and maintain focus on the requirements that are critical for success?

There are many dimensions to traceability. In this study the focus will be on tracing from high level to low level decisions and tracing the changes that take place anywhere by introducing models as means to cope with requirement traceability.

2. Literature Review

Traceability was first mentioned in the mid-1990s in the agri-business sector and refers to the ability to trace the history, use or location of an object through documented identifications[5].

Almefelt et al.[6] investigate requirement management in the automotive industry. The study aims to bring forward new experiences regarding the management process used in an industrial case. Because the study focuses on a practical case, it also investigates the social system dealing with the development, which makes the process more complex than the development projects described in the literature. Almefelt et al.[6] investigates the identification of progress,

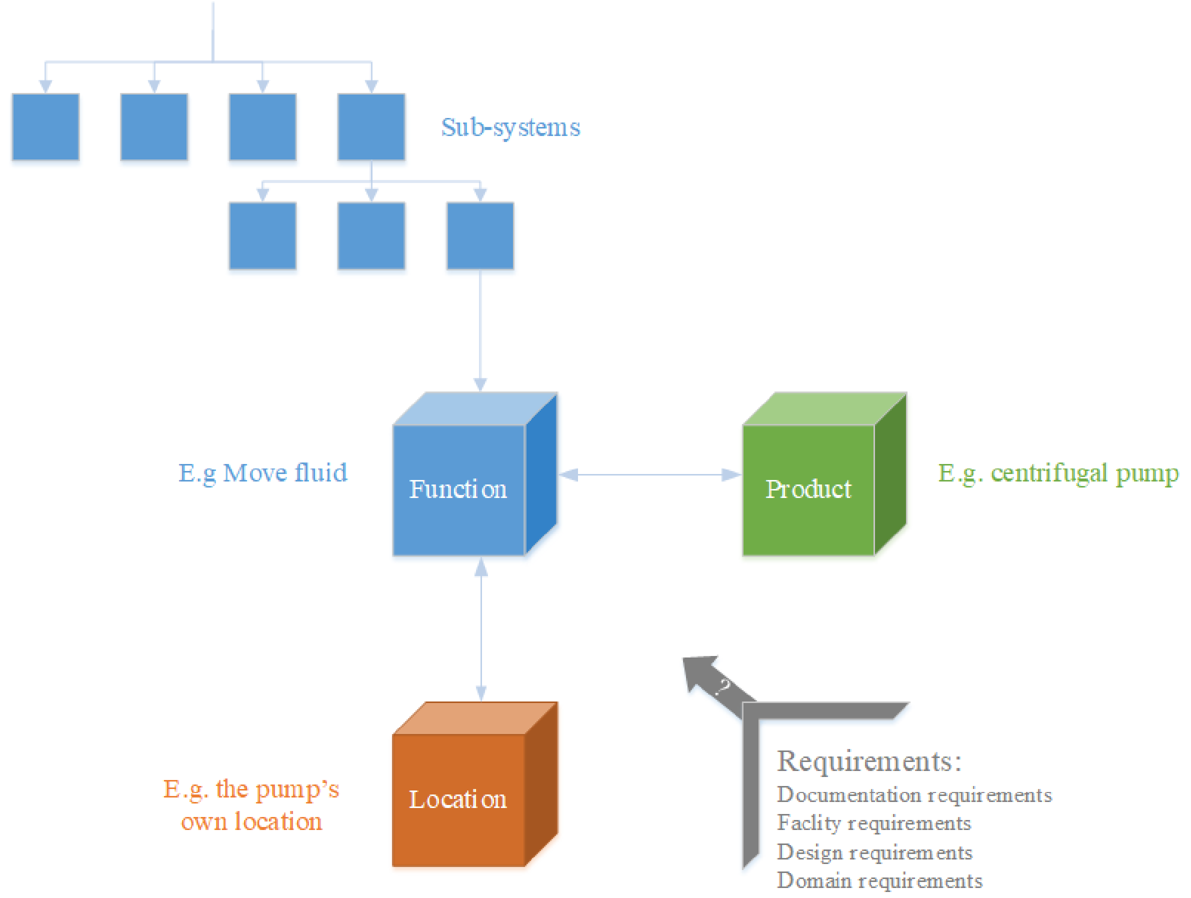

Fig. 1. A visualization of the asset information model

changes, and deviations, in addition to considering the relevant underlying human factors, such as events, project coordination, competence etc. The study also aims to provide an insight into requirement management methods that are efficient and constructive for industrial applications.

The study adopted a qualitative systems approach in the research, gathering and analyzing significant amounts of data in addition to conducting interviews to map out the requirement management practice in practice. The preliminary results have also been presented in seminars to test the acceptance of findings. Almefelt et al.[6] conclude by saying the requirement management process is an intricate and complex process, where the priority is given to the different requirements in the practical work situation often mirrors the resources of the corresponding requirement specialist discipline.

To identify early phase needs and reduce late-phase design changes, Engen and Falk[7] applied formal systems engineering methods in early phase concept studies in the oil and gas industry. A study was conducted to investigate the development process in the company through both analysis and interviews. The key findings from the analysis were that the client is the only stakeholder considered, the client asks for a solution as opposed to a concept and there was no standard for documentation. From the interviews the key findings were that clients ask for a concept, the contracts are integrated, covering both subsea umbilical's, risers, flowlines, and subsea systems and the projects had a shorter time span. Engen and Falk[7] found that the current process is dependent on the client identifying early phase needs before requesting a study, but that it did not seem to be the case for most clients.

Furthermore, Engen and Falk[7] suggest a solution by using a system engineering framework in the early phases of the project that facilitates for the company to take responsibility to understand the initial need and identify the stakeholders. For increased information flow to people working in later phases of the project, Engel and Falk[7] suggest using informal models to document each stage of the process such as graphical illustrations of the system and ConOps.

Daneva and Wieringa[8] describe how a modern enterprise resource system is used to ensure coordination support to stay connected with other companies and customers when orchestrating cross-organizational change through openness and collaboration.

The study found that there were a small number of coordination technologies in use in the enterprise systems layer: shared databases, data warehouse, enterprise resource planning (ERP) functional application modules, workflow management systems, electronic marketplaces, and knowledge management systems. At the business level, they found these coordination mechanisms: utility-oriented mechanisms referring to goals and benefits of coordination, process-oriented mechanisms to establish an end-to-end inter-organizational process, semantics-oriented mechanisms concerned with the partners' agreements about definitions and key information and communication-oriented mechanisms including the transmission and interpretation of information in the organization[8].

Daneva and Wieringa[8] describe a system for coordination in the enterprise between different organizations and customers when going through a change process. The proposed solution is to use coordination theory to identify the coordination mechanisms supported by the ERP system. By specifying the mechanisms in a cross-organizational setting, the requirements engineer could match the coordination mechanisms required by other companies and the coordination support offered by the ERP system in use.

Kannenberg and Saiedian[9] investigate the reasons why software requirements traceability remains a challenge in the industry, looking into why neither manual traceability methods nor existing commercial off-the-shelf (COTS) traceability tools are good enough for the current need. Inadequate traceability is an important contributing factor to budget overruns and project failures. The challenges with traceability are well known in the industry, but research suggests that many organizations still struggle with the implementation of traceability practices because of a lack of understanding of the principles of traceability[9].

Kannenberg and Saiedian[9] highlight some of the most important benefits traceability can bring to the organization, pointing at improvements within project management, process visibility, verification and validation and maintenance for software projects. Further on they describe the challenges the practice of traceability faces, such as cost, managing change, different stakeholder viewpoints, organizational support, poor tool support, challenges with manual traceability methods and problems with COTS traceability tools.

To conclude, Kannenberg and Saiedian[9] state that traceability needs to be hardcoded into a process to be replicated iteratively on every project. The challenges are so comprehensive that the organizations often end up with only implementing as much traceability as is required by their customers. The proposed solution is to create cost-effective traceability tools to improve the existing tools.

Robinson[10] explores the need of a requirements monitoring framework for enterprise systems stating that requirement compliant software is becoming a necessity. Both businesses and partnership agreements push less mature organizations to improve their systems. The study states that technology for monitoring requirements compliance for transactions has lagged.

Robinson[10] addresses the need for realigning the systems with their policies, implementing systematic design methodologies for requirement monitoring systems and increasing the support for real-time requirements monitoring. As a solution, Robinson[10] has defined a requirements monitoring framework called ReqMon that seeks to define a methodology for defining requirements, identify potential challenges tied to requirements, analyze feedback, and define a language for requirements and monitor definitions.

Maro et al.[11] stress the importance of a well-defined and goal-oriented traceability information model to be able to implement a successful traceability strategy in an organization. By using a traceability information model, the organization can keep track of relationships between diverse artifacts created during system development and provide information about organizational structures, workflow, the interaction between platforms and products and the collaboration between different parts of the organization[11].

To understand the challenges in different companies regarding their current traceability information models and their management, Maro et al.[11] conducted a workshop. The findings revealed that every company participating in the workshop manages their models in radically different ways but faces similar challenges. Some of the challenges they faced were due to the complexity of the developed products, being large and distributed companies with challenges regarding collaboration and coordination within the organization and the maintenance of the model links over an extended period. Maro et al.[11] state that there are existing guidelines that form a good starting point for practitioners within established systems engineering methods but conclude with the need for further research to understand and provide a viable solution to the challenges.

Broy[12] describes how key tasks such as capturing, analyzing, and documenting system-level requirements, functional system specifications and the decomposition of systems into subsystems produces artifacts for verification, documentation, and impact analysis of change requests. He states that traceability has the goal of related artifacts. The study investigates techniques and concepts to specify the relationships between different development artifacts and the content within them by looking into artifacts derived from system-level requirements, functional system specification and logical architecture.

The proposed solution provides a logical model of systems where each artifact's content is represented by a set of logical assertions. The assertions contain several logical relationships such as implication, logical independence and inconsistency that can provide the relevant relations between different assertions by logical relations and provide the basis for forming sets of assertions. The result is an approach that allows for a description of semantic linking and tracing within and between artifacts[12].

Sánchez et al.[13] investigate the need for a framework for developing traceability solutions in small manufacturing companies. They state that companies, government institutions, researchers and traders all have stressed the importance of monitoring systems for manufacturing processes, mentioning multiple solutions adapted by companies to facilitate traceability in manufacturing processes. However, these solutions apply to large-sized companies with the financial and technological resources to manage this radio frequency identification (RFID) based traceability systems. To facilitate traceability in smaller companies, Sánchez et al.[13] a framework strongly based on Cyber-Physical Systems to be a successful path forward. The study revolves around the development of a framework called Traceability Framework for Small Manufacturers and aims to explore if the time response to inefficiencies would improve and if the number of inefficiencies in productive processes could be reduced by implementing the said framework. Sánchez et al.[13] conclude with their framework sufficiently filling the gap by allowing real-time traceability and process monitoring through a flexible and open architecture.

Winkler and von Pilgrim[14] investigate traceability research in software and model-driven engineering. By looking into model drive development (MDD) the study covers an area of software engineering where the way of working seems to be able to leverage traceability by automatically generating the documentation needed as MDD is an area where parts of the software development process are executed using model transformations. Implementing traceability practices in software engineering is still seen as pretty much uncharted terrain though, as the researchers often are part of larger communities looking into requirements engineering, modeling etc.

Winkler and von Pilgrim[14] describes basic principles of traceability, identifying its value in validation and verification in software engineering, mentioning knowledge engineering and project process management as it goes along. They talk about different traceability schemes and metamodels, building on earlier surveys conducted by other researchers. When investigating the schemes, the study goes through the questions of what, who, where, how, when, and why to identify how much traceability could be achieved. Furthermore, they investigate the schemes in further detail, defining eight categories of links between artifacts (dependency, refinement, evolution, satisfiability, overlap, conflict, rationalization, and contribution[14].)

A summary from the literature studies with categorization for comparison of relevant findings is presented in Table 1. The table offers a brief description of the purpose of the studies, source types, target industry and the major themes discussed in the studies.

Table 1. Summary from literature studies

Authors	Purpose	Type of Source	Target Industry	Major Themes
Almefelt et al. [6]	Provide insight into requirement management methods for industrial application	Case study	Automotive industry	Requirement management, Social system, change, human factors
Engen and Falk[7]	To identify early phase needs and reduce late phace design changes	Research	Oil and gas	Systems engineering framework, stakeholder identification, cross-organizational change
Daneva and Wieringa[8]	Provide a system for coordination between organization and customers in a change process	Research	All industries	Requirements engineering, oordination, change, enterprice resource planning
Kannenberg and Saiedian[9]	Investigate why software requirements traceability in is a challenge in the industry	Research	Software industry	Traceability, requirements, implementation, traceability tools and methods

Robinson[10]	Define a requirement monitoring framework that seeks to define a methodology for defining requirements and identify challenges.	Research	All industries	Requirement monitoring framework, Requirement complient software
Maro et al.[11]	To identify challenges implementation of a traceability strategy in an organization and the importance of a well defined traceability information model	Research	All industries	Traceability, information model, multiple companies, implementation, collaboration and coordination, systems engineering methods
Broy[12]	Provide insight into techniques and concepts to specify the relationships between different development artifacts and the content within them	Research	All industries	Traceability, requirements, system and subsystem breakdown, artifacts and their logical assertions
Sánchez et al.[13]	To investigate the need for a framework for developing traceability solutions in small manufacturing companies	Research	Small companies	Traceability systems, inefficiencies, open architecture, framework
Winkler and von Pilgrim[14]	To investigate traceability research in software and model-driven engineering.	Discussion	Software industry	Model drive development, traceability practices and principles, artifacts

2.1. Methodologies

Previously researchers have developed a custom tool that integrates with other tools in the respective organization, which provides support for evaluating traceability methodologies. In addition, a methodology from Hubka's theories[15] was used to develop the concept of advanced engineering[5], where several concept proposals were generated and evaluated. However, for the traceability tool, some researchers suggest that the feature only works if the project methodology is based around the tool itself[9].

Several articles also suggest that there are no systematic design methodologies for requirements monitoring systems, but that there is observed limited support for real-time requirements monitoring[10]. Robinson[10] indicates that monitor descriptions can be derived from a requirements hierarchy, which implies that an analyst can select requirements in an *and*-refinement or in an *or*-requirement to derive obstacles. Therefore, the ReqMon approach has been developed to monitor different activities, where it analyses the requirement satisfaction as fulfilled by run-time software objects[10].

2.2. Principle questions being asked

The previous literature on traceability captures a wide diversity of challenges. Despite the general research among scholars, there are still unanswered principles questions concerning the topic:

- What could be a standard of traceability links which can be created as part of this transformation tool?[14]
- How can we avoid automatically producing overwhelming amounts of irrelevant traceability links?[14]
- Even if a project's artifacts are traceable, what are the benefits?[14]
- In what ways can an ERP system be arranged differently while achieving the same goals?[8]
- Would the time response to inefficiencies improve by deploying a system based on TF4SM in companies?[13]
- Is it possible to reduce the number of inefficiencies in productive processes using a TF4SM-based system?[13]
- Why do so many challenges exist in traceability practices today?[9]
- Is the system satisfying my requirements?[10]
- Does the system - as represented by the run-time model - satisfy the design-time model?[10]

These are questions researchers still aim to study in relation to traceability techniques in systems engineering practices. The reviewed research has tried to express requirements as models, or a model-oriented context[14].

2.3. Proposal for future research

The literature in the review identifies a gap in the literature. Daneva and Wieringa[8], propose that additional research needs to build in more analytic capabilities for the framework to be useful and applicable. In addition, they suggest that one must apply the transaction cost theory to analyze the costs and benefits of several coordination mechanisms and to derive requirements engineering guidelines from the conducted analysis[8].

Maro et. al[11] identify a strong need for further research into areas such as management of traceability information models, the creation of guidelines for designing models that support product-line platform-related activities, the evolution of such models and how organizations can design models that support multiple processes and workflows.

Winkler and von Pilgrim[14] also emphasizes the challenge to provide easy and appropriate access to traces to benefit from the effectiveness of using them. The researchers also suggest that future research should try to broaden the benefit to the recorders of traces to improve motivation and positively influence the human factor in traceability[14].

3. Research Design

For this study, we have chosen a case study research design to have a detailed and intensive analysis of a single case within an organization[16]. This approach allows us to focus on a system and examine a setting. Stake[17] observed that case study research is concerned with the complexity and particular nature of the case in question. However, the case study approach is relatively popular and widely used within research[16]. The Aibel-case falls under the category of an instrumental case study as it focuses on the understanding of a broader issue or allowing generalizations to be challenged[16].

However, there are some concerns regarding single case studies regarding external validity. Researchers propose the question of how a single case study can be representative enough so it might yield findings that can be applied more generally to other cases[16]. Therefore, to handle the issue of external validity, Yin[18], emphasizes distinguishing between different types of cases. This case seeks to explore whether it can exemplify an everyday situation or form of organization[16].

The chosen case study is an offshore wind converter station, a complex system to be based in the British sector. To conduct the research, we will develop an AIM specially adapted to the complex system in question. This part can be divided into 5 steps:

1. Identifying relevant client requirements and industry standards.
2. Evaluation and analysis of gathered material to form initial asset model structure.
3. Conduct semi-structured interviews to gather data about the functional structure and importance of requirements in development decisions from relevant experts.
4. Analyze the data gathered from the interviews and complete the AIM based on findings.
5. Verification. To verify if the AIM model is successful, the project delivery shall be analyzed and compared to similar projects using different methods. Important parameters to investigate in the verification is the number of deviations, the employee satisfaction, and perception of knowledge transfer and the time spent analyzing gaps.

Step 1-4 should be revisited in a second and third iteration after finishing the steps initially, to make sure no important aspects are missed in the light of the first iterations' findings, see Fig. 2.

This research aims to identify the potential improvements a system engineering and traceability approach can have in early phase projects. A thorough understanding of the situation as it is now and the stakeholders are needed to develop a solution that might improve important aspects such as increased information flow, understanding and traceability of requirements within the projects. The research also focuses on literature relevant to these challenges. The AIM development and verification will be performed during the research execution phase from January to May 2022.

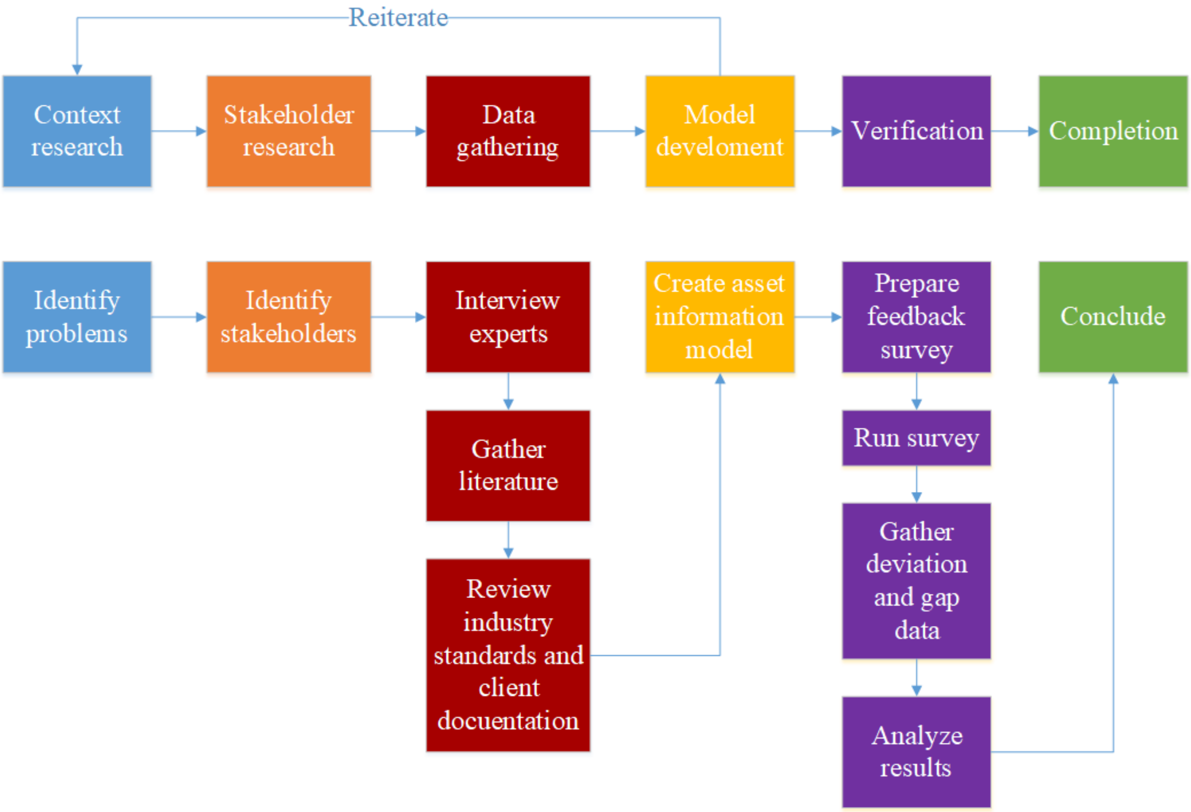

Fig. 2. Research design

4. Results

The results of this study will be presented in a future paper after the research execution phase ends in May 2022. Expected results are to see an increased understanding of the system and the requirements that drives the design which can contribute to consistency and more comprehensive consideration of multiple aspects when making changes to the design. Another expected result is for the involved engineers to spend less time organizing documentation and relevant information.

5. Discussion

Implementation of an AIM will hopefully facilitate further development into traceability techniques and knowledge transfer between both different phases within a project and between similar projects. It should also make it easier for engineers to follow the history of changes throughout development providing a visualized relationship between location, function, and product tracing back to the triggering requirement.

The different requirement inputs can however be a challenge to implement as they might be presented in different formats for the client. Customer requirements in this sector can be presented as extensive reports with unprecise formulations and a significant number of references to other documents. There is no automatic way to extract requirements from these types of documents, so a manual interpretation by the engineers is still necessary and a risk when it comes to implementing all relevant requirements in the AIM. In addition to this, some requirements are more important than others. The AIM must have a requirement rating categorization that aims to offer the engineers an understanding of the prioritized order of requirements critical to success. There will be situations where different stakeholders impose different or contradicting requirements which imposes a need of a prioritization.

A significant risk to consider, however, is the strict time constraint and the challenges related to the cost of these early-phase projects. The complexity of the system and the time required to provide a comprehensible and full-fledged traceability solution might be too costly and again lead to internal organizational issues. The organization might only consider doing the minimal amount of effort required to be able to provide what the industry standard and the client requirements ask of the delivery. This might lead to a superficial solution that does not offer the traceability we want in the projects. And vice versa full traceability may exceed available time manifold. To find a solution that offers the required amount of traceability but still doesn't require too many recourses and time we would need to look for the sweet spot.

Another risk is the difficulty associated with managing change. The AIM may need to be designed in a tool that can facilitate the use of machine learning or other relevant smart data analysis technologies to keep the relationships and connections updated. The complex system that is an offshore converter station may be too complex to be updated manually. A challenge related to this is proper balancing of human and machine strengths and tasks.

Providing Aibel with a functional method to facilitate traceability through project developments is expected to lead to many benefits for the organization. The forecasted future of energy-related projects seems to be characterized by a higher number of simultaneous projects with smaller scopes. That opens a need for more employees willing to take on management responsibilities. Traceability will make the project management easier by simplifying project estimates[9] which in turn might contribute to an easier transition for inexperienced employees taking the step up to become project managers.

By developing and implementing the AIM at Aibel, we expect increased traceability in projects through improved knowledge transfer across project phases and similar consecutive projects, a structured and clear requirement management process that contributes to higher quality in project deliveries and quicker design decisions. The AIM is expected to provide an overview of relevant and important requirements in a way that can help the company determine the requirements critical for success faster than previously used methods. The stakeholder requirements form the basis of the project, and without them, there would be no need to develop anything. If they are not sufficiently taken into consideration when making development decisions the organization is in dire need of methodology changes to ensure their future projects are answering the client need and stakeholder requirements.

6. Conclusion

Reaching a level of traceability that provides a competitive advantage is a major challenge in industries that develop complex systems. The amounts of data required to keep updated and maintained are massive. However, a visualized AIM might help organizations such as Aibel to start defining their systems engineering methodologies and start to develop a structure that can provide traceability in the future. The information that can be derived from a successfully maintained AIM can help engineers make quick and well-designed development decisions and solutions that can increase the quality of early-phase project deliveries. It can also contribute to an increased information flow which frees up resources and saves money by decreasing the amount of duplicated research processes into what has been done in earlier phases or projects.

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