MASTER

Systematic approach for requirement engineering applied to machine design

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Project phase

Systematic approach for requirement engineering applied to machine design

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Abstract

The growing complexity of product requirements often results in complex product solutions. Different commercial organizations have embraced collaborative approaches in their workgroups to enable information accumulation, exchange, and storage. The goal of every organization is to design and produce solutions with tailored functionality in a cost-effective way that can satisfy stakeholders' needs. An improved development process, primarily focused on requirement engineering, was proposed to Allseas Engineering B.V. to bring efficiency in equipment development. A model-driven approach was used as a basis to introduce the new methodology into the company. The challenge in the introduction of the new methodology is due to the old-fashioned work culture and absence of dedicated tools in the company. Therefore, the original model-driven approach was simplified and altered to overcome the current limitations and get accepted by inexperienced users. The focus of the proposed methodology was made in achieving an open and simple interface for requirement elicitation, analysis, and system modeling. The methodology uses commonly used tools currently available in the company like MS Excel, MS Word, MS Visio, and Draw IO. As a case study, the proposed methodology was tested on one of the accomplished projects. Several workshops were conducted with different department employees to test and evaluate the proposed methodology. Based on positive feedback from the participants, it was understood that the new methodology can significantly improve the efficiency of the development process in the company. Finally, a user's manual together with tools for the new methodology was formulated.

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Chapter 1

Introduction

This chapter introduces the reader to the subject of this thesis which was performed within the Innovations department at Allseas Engineering B.V. Delft, from now on called Allseas. The section 1.1 starts with a brief overview of Allseas and department of Innovation. In section 1.2, the problem definition is stated. Followed by the goal of the project in section 1.3. In section 1.4, the research questions are formulated. Finally, section 1.5 gives the approach of this thesis and the structure of the report.

1.1 Allseas

Allseas Group S.A. is a Swiss-based offshore company specializing in pipeline installation, subsea construction, and platform installation and decommissioning. The company operates a versatile fleet of specialized heavy lift, pipe-lay and subsea construction vessels which are designed and developed in-house. The company was founded in 1985 and operates worldwide. Pioneering Spirit and Solitaire are one of the largest construction vessels in the World, which are engineered by Allseas Group [1].

The philosophy within Allseas is to develop and operate its equipment, ranging from the small equipment up to the biggest pipelay vessel. From this philosophy, the engineering department of innovations develops state-of-the-art solutions to serve the company's needs in equipment and technologies. The main goal is to design and develop offshore pipelay equipment and subsea tools to fulfill stakeholders' expectations in a given time and budget. To achieve their goals, the Allseas innovations department adheres to sequential work procedures. Every project in Allseas undergoes certain phases from the start until the end of the project is elaborated in section 2.1. The focus of this thesis is on the improvement of the work procedures by optimizing the requirement engineering activities.

1.2 Problem definition

Design requirements are one of the most important factors considered for developing machines. Ineffective requirement practices are an industrial-wide problem. Industry research shows that the root cause of 56% of all errors [2] identified in products and engineering projects are introduced in the requirements phase. Mechanical, electrical, and software design are driven by correct product requirements. Due to the increase in complexity of the product, there is a lack of understanding. Also, poor communication of requirements across all engineering disciplines and to the respective stakeholders is time-consuming. Figure 1.1 depicts the problems in engineering projects which cause the project to fail.

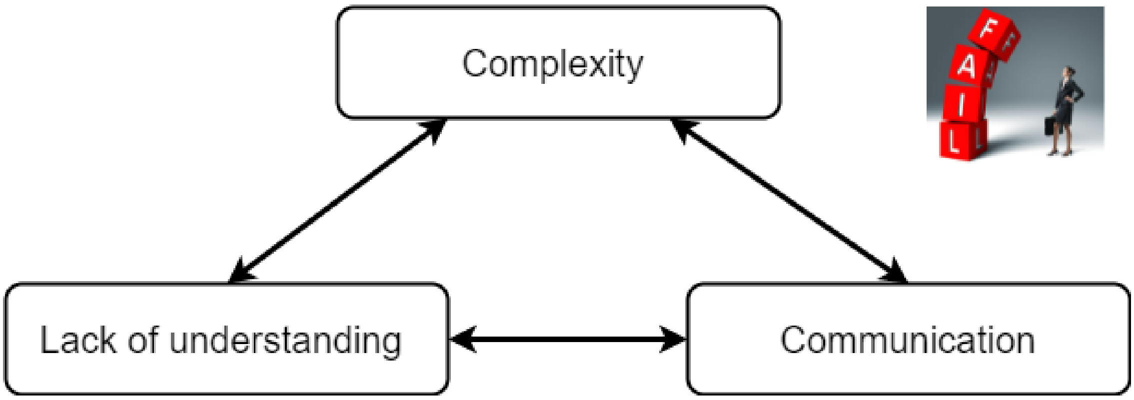

Figure 1.1: Problems in engineering projects [3]

The reason for these challenges is due to the unavailability of dedicated system engineers in Allseas to identify, analyze, and trace the requirements. Currently, according to the design approach used at Allseas, there is a lack of a clear framework or methodology that could perform proper requirement elicitation and analysis during the initial design phase of the project. This results in delay and additional costs because the errors in the design and conceptual phase are discovered only in the testing phase. Therefore, to overcome all the above-stated challenges and design a working solution that satisfies the stakeholders' expectations, a more disciplined approach to requirements engineering is needed to improve project success rates.

1.3 Project goal

The main objective of this project is to develop a systematic methodology for requirements engineering in machine design to improve the current Allseas development process. The methodology focuses on the eliciting of requirements, reducing errors during machine design, improving the current concept development phase, and helping the decision-making process.

The current requirements elicitation ways applied at Allseas are informal interviews and unstructured meetings. Therefore the main focus of this project was provided on the structuring of the requirements elicitation and analysis activity. An approach successfully used in system engineering methodology like "questionnaire – high gain questions" or "a checklist". It assists the engineers to stimulate the proper formulation of project objectives and thinking in a structured way. In the longer run, adding new questions to the questionnaire over time would help the engineers to improve the methodology. The information regarding the available resources is collected to improve the project economics. During requirement analysis, improper and inconsistent requirements are spotted to reduce errors during machine design. The methodology is developed by using the model-driven approach to reduce the complexity of the machine design. Also, detailed and structured guidelines are provided to improve the concept development phase. The fundamentals of a systematic approach are incorporated in the methodology. Further, the requirements database is created which acts as a focal point for upcoming phases of the project and the central purpose to the accounting of the requirements. The guidelines for requirements diagrams and requirements classification are provided to illustrate the relationships between the requirements and categorize the requirements. The methodology is adapted to meet Allseas demands in terms of work procedure. Allseas' old and new projects are considered case studies for the implementation of the proposed methodology. Finally, workshops are conducted with different department employees to test and evaluate the methodology.

1.4 Research question

The research questions are formulated to achieve the project goals as described in the section 1.3. The objective and research questions are as follows:

Obj: *To develop a systematic methodology for requirements engineering that could improve the current Allseas development process of offshore pipelay equipment and subsea tools.*

RQ.1: *How does the requirements methodology contribute to the elicitation of requirements?*

RQ.2: *How does the requirements methodology help to locate and reduce errors in requirements during offshore equipment development?*

RQ.3: *How to improve the concept development process of offshore tools and equipment using the requirements methodology?*

RQ.4: *What is the impact of the requirements methodology on the decision-making of the concept development process?*

1.5 Structure and approach

The thesis report is organized as follows: Chapter 2 discusses the study on the company work procedure, problem analysis, requirement engineering, review of the process model, justification and theoretical background required for the methodology and the tooling. Chapter 3 outlines the sequential methodology for Allseas work procedure and also the various activities involved in the methodology. Then, an example case study is elaborated in Chapter 4 to showcase the implementation of the proposed Allseas research methodology. Further, the evaluation of the methodology is discussed in Chapter 5. Finally, Chapter 6 completes this thesis report by summarizing the key contributions and providing recommendations regarding future research work.

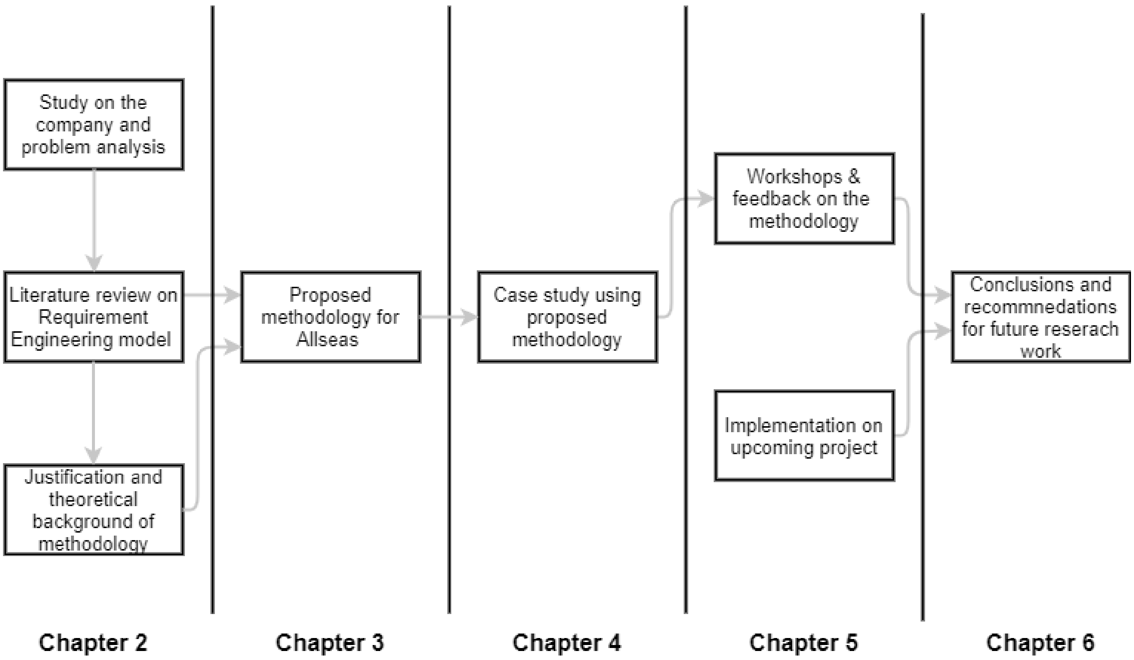

Figure 1.2: Schematic framework of the report

Chapter 2

Project's background

The section 2.1 gives an overview of Allseas project phases, section 2.2 describes the detailed problem analysis performed in Allseas, section 2.3 and section 2.4 gives an overview of requirement engineering and review of process models, section 2.5 and section 2.6 outlines the justification and background of the methodology. Lastly, section 2.7 gives an overview of tooling.

2.1 Allseas project phases

The projects carried out by Allseas innovations department undergo various phases from the start till the end. The various phases of the project and its nomenclature practiced are devoted to Allseas Engineering.

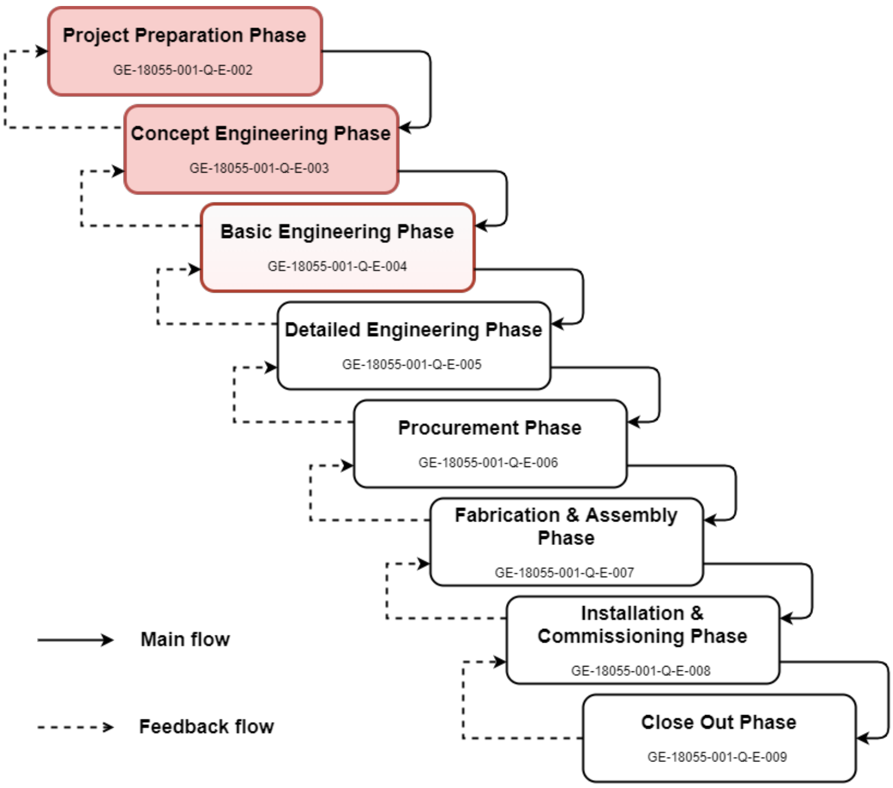

Figure 2.1: Allseas project phases [4]

Allseas adopt the iterative waterfall model where the project phases are constructed into a linear sequential process with feedback from the earlier phase which is presented in Figure 2.1. Every phase depends on the deliverables of the previous step. The first phase is the project preparation where the requirement analysis, feasibility study, budget, and time calculations are executed. Then, the project enters into the concept engineering phase where several methods and techniques in realizing the goals are analyzed. The next phase is basic engineering. Here, the concept is further analyzed. A basic working concept of the system is created, and the model is verified with the requirements. It is important to eliminate any conflicting requirements. The next phase is detailed engineering. The basic working concept is further developed. At the end of this phase, the stakeholder must verify all the requirements which were defined earlier. The required materials for the fabrication are purchased in the procurement phase according to the defined budget calculation. The designed system is fabricated in the fabrication phase. In the installation and commissioning phase, the finished product is installed and commissioned on site. The final phase is the project close-out [4].

The projects carried out by the innovations department could be of different nature, but primarily they are related to the design of equipment to be installed on a vessel and RD. In vessel equipment related projects, the developed product is installed and commissioned on the vessel. The vessel team acts as a client to the development team at innovations. In RD type of projects, the products are thought of and developed to optimize certain processes. In such projects, the development team develops solutions for the Unit head at the innovations department, who plays the role of the project owner. The scope of this master thesis project is considered to be the project preparation phase, the concept engineering phase, and partially contributing to the basic engineering phase as highlighted (in red) in Figure 2.1.

2.2 Problem analysis

Requirements development plays an important in the success of a project. However, miscommunication, lack of understanding, and time losses are because of a lack of emphasis on requirements analysis.

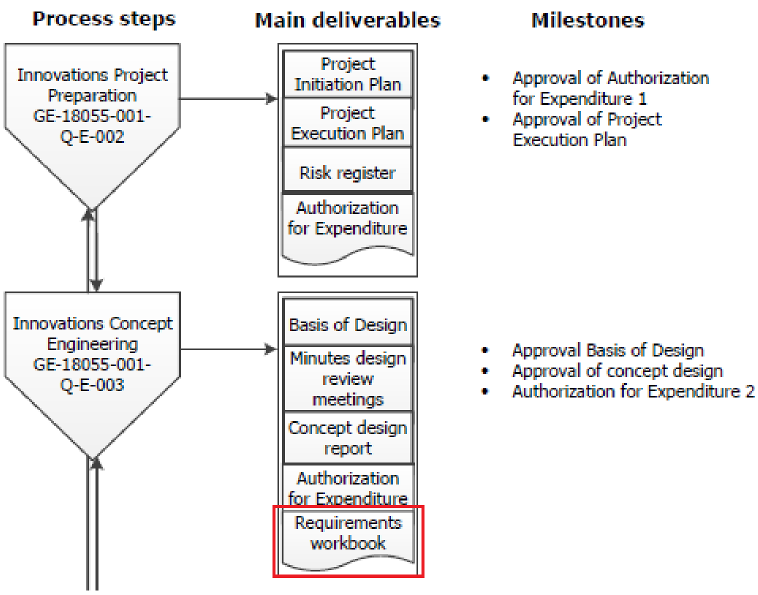

Figure 2.2: Snippet of Allseas project initiation and concept engineering phase [4]

Allseas does not have a dedicated requirement engineer or a methodology to perform or assist requirement analysis during the initial phase of the project. Figure 2.2 describes the process steps, main deliverables, and milestones of the project preparation and concept engineering phase.

The main deliverables in the project initiation phase are the project initiation plan, project execution plan, risk register, and authorization for expenditure. There is a lack of emphasis on requirement development in the first phase of the project. Additionally, in the concept engineering phase, the main deliverables are the basis of design, concept design report, and the requirements workbook. As highlighted (in red box) from Figure 2.2, it is evident that documenting of requirements is introduced in terms of the requirement workbook at the later stage of the development life-cycle. Furthermore, based on the feedback of Allseas employees, the responsibility hierarchies in terms of machine development are not clearly defined during the initial phases of the project.

On further analysis of various sub-activities in the concept engineering phase, there are insufficient requirement guidelines and not defined tools for requirement analysis activity. Allseas does not have any dedicated tooling for requirement activity. In practice, the requirement workbook is created in MS excel and serves for the documenting of requirements. This requirements workbook acts as a focal point for the upcoming phases of the project. The explanation sheet of the requirements workbook is shown in Figure 2.3.

1	WARNING - LISTS HERE ARE ALSO USED IN DROP DOWN LISTS REQUIREMENTS SHEET	
2	**Type of requirement**	
3	CR	control requirement
4	DR	design requirement
5	ER	environmental requirement
6	FR	functional requirement
7	IR	interface requirement (E&I and data / hydraulics)
8	OR	operational requirement
9	PR	physical (geometrical) requirement
10	SR	safety requirement (related to potential hazards, maintenance, redundancy)
11	TR	test and commissioning requirement
12		
13		
14	**Requirement states**	
15	new	
16	for review	
17	approved	
18	rejected	
19	removed	
20		
21	**Testing states**	
22	not tested	
23	failed	
24	passed	
25		
26		
27	**Sub Systems**	
28	Sub1	
29	Sub2	
30	Sub3	
31	Sub4	
32	Sub5	
33	Sub6	
34	Sub7	
35	Sub8	
36	Sub9	
37	Sub10	
38	Sub11	
39	Sub12	
40	Sub13	
41		
42		
43		
44		

Type	Description	Example
CR	Relates to performance characteristics of the systems' actuators.	All hydraulic systems of the x-drive shall be directly controlled by the ABC via the LBC.
DR	Relates to the imposed design and construction standards, as well as to the design capacity information of (sub-) systems.	Regenerated power by the X-drive shall not be fed back into the vessel's network.
ER	Relates to the general and/or system environment during its life cycle.	Topside lifting and lowering shall be possible in design sea states of Hs = 2.5 m, Tz = 3-6 s.
FR	Defines what the system shall do, in order to meet the needs of the user.	IBS shall allow movement of the TLS beam in Xv and Yv directions.
IR	Relates to the interconnection characteristics between the product and other items.	OBS assembly shall provide a mechanical interface with the lower x-drive assembly.
OR	Relates to the system operability.	Each individual TLS beam shall be able to be operated manually, where the operator determines the position and speed of the beam in either Xv, Yv or Zv direction.

Type	Description	Example
PR	Relates to the geometrical boundary conditions to ensure physical compatibility.	The retracted pin to pin distance of the AHC system shall be 4910 mm with a tolerance of -2 to +2.1 mm.
SR	Relates to the overall safety of a system.	Failure of a system within the OBS shall not lead to a system failure of the OBS or other systems within the TLS.
TR	Relates to the specific requirements that are necessary to do the tests.	Testing of the TLS beams on the *Pioneering Spirit* shall only be done in case a signed test procedure document is in place.

- "shall": a provision is a requirement
- "should": a provision is a recommendation
- "may": a provision is a permission
- "can": indicate a possibility or capability

Figure 2.3: Snippet of requirements workbook

It is evident from the Figure 2.3 that the explanation sheet does not focus on the major activities of requirement engineering such as requirement elicitation and requirement analysis rather it focus on requirement classification. Due to insufficient explanation in the requirement workbook, most of the project members tend to skip the workbook or rather use normal MS word documents for noting the requirements in their respective fashion. This may lead to incoherent logging of requirements and misinterpretation of requirements which in turn affects the development process. Additionally, after Allseas intranet database analysis, there are many incomplete requirement documentation for various projects.

In the current Allseas development process among designers, solution-based thinking is more predominant rather than functional-based thinking which shortens the development space. Also, for the vessel projects, available resources are not properly documented before the concept engineering phase which decreases the project economics. Furthermore, there are no standard procedures followed by the designers of various teams in concept engineering which makes the concept development process unstructured during the initial phases of the project.

Based on the analysis of some executed projects and several one-to-one meetings with the various project members, there is a lack of requirement engineering activity in project phases which explains the incomplete requirement documentation of the executed projects and large deviations from execution time and budget. This problem validates the reason for the chosen research questions, focuses on building requirement methodology which contributes to the elicitation of the requirements, reduces errors, improves the concept development process, and helps the decision-making process. The improvement in the engineering process eventually would result in a product that suits all stakeholders.

2.3 Overview of requirement engineering

Requirements engineering involves life-cycle activities devoted to the identification of requirements, analysis of the requirements to derive additional requirements, documentation of the requirements as a specification, and validation of documented requirements against stakeholder needs, as well as processes that support these activities. Requirement engineering is considered a domain-neutral discipline and is used for software, hardware, and electro-mechanical systems [5].

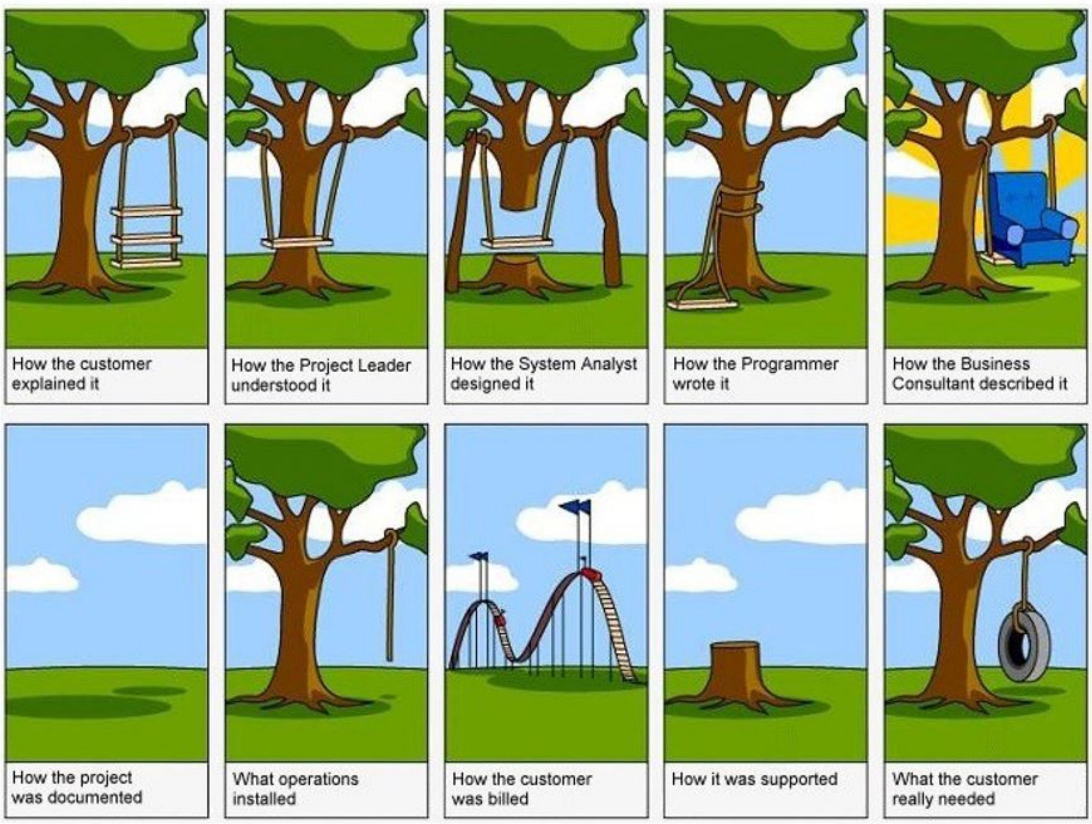

Figure 2.4: An example of miss-communication in requirement engineering [6]

Requirements are a specification of what should be implemented. It is the descriptions of how the system should behave, or of a system property or attribute. It may be a constraint on the development process of the system. This definition acknowledges the diverse types of information that collectively are referred to as "the requirements". Requirements cover both the developer's view of some internal characteristics of the system and the stakeholder's view of the external system behavior. It includes both the behavior of the system under specific conditions and those properties that makes the system functional for its intended use [7].

The Figure 2.4 gives the overview of different views and processes involved during the project life-cycle. It depicts the importance of the requirements engineering process in an organization and how misinterpretation of requirements impacts the final result of the project. It consists of different stakeholders such as customer, project leader, system analyst, programmer, business consultant and their views on the project or the upcoming product. Each stakeholder in an organization has their view of the product. Also, the different product development processes such as project documentation, product operations, product support, etc are not executed as expected. The takeaway from the Figure 2.4 is that the miscommunication between different stakeholders and not following the requirement engineering process leads to the wrong design of the product and frustration of all stakeholders. This assignment aims to define a clear and consistent requirement process to avoid misconceptions during the early stages of product development.

2.3.1 Challenges in requirement engineering

Requirement Engineering is a core process for any product development. Poor requirements not only lead to modifications in requirement specifications but also needs re-designing, re-implementing, and re-testing of the entire system. Therefore, requirement engineers have to strive and conquer uncountable numbers of challenges in eliciting effective and proper requirements. The requirement engineering methodology aims to overcome these challenges. Some of the typical challenges in requirement engineering are listed: [8]

- *Incomplete/hidden requirements* - Set of requirements that are focused on functional requirements without adequate consideration of business and non-functional requirements.
- *Inconsistent requirements* – Set of requirements that contradicts with another one which makes difficult it to provide solutions.
- *Terminology* – Set of requirements are written in different terminology which leads to different understandings of requirements.
- *Unclear responsibilities* – During the development cycle, the stakeholder's priority is not clear. This creates confusion (whom to talk with) during clarifying certain requirements.
- *Communication* - This is one of the key factors in all organizations which involves short emails, different departments, different cultures, different languages, etc.
- *Moving targets* - This refers to changing of requirements over time. This will affect the cost and development time.
- *Technically unfeasible requirements* – Set of requirements that are technically not possible to implement during the product development which has to be spotted in the conceptual phase.
- *Stakeholders* – The project team has to give adequate inputs to the stakeholders to obtain clear and consistent requirements as the stakeholders are not technical experts.
- *Under-specified requirements* – The system under development can be able to perform more things but specifying only some may lead to uncertainty.

2.4 Review of requirement engineering models

Requirement Engineering (RE) is a set of different processes that work at different levels, which are incorporated at individual and organizational level projects [9]. The engineers must have a proper understanding of the requirement engineering process to adapt the activities. A detailed study of different requirement engineering process models is presented from the existing literature review [10]. However, each process model has its advantages and disadvantages. In this review, out of many RE models, four different types of widely accepted requirement engineering process models are analyzed. To summarize, the detailed view of requirement engineering process models along with their strengths and weakness helps in the technical selection of an appropriate model for Allseas.

2.4.1 Macaulay linear model

This is a pure linear requirement engineering process model suggested by Macaulay as shown in Figure 2.5. It does not support overlapping of activities. The stages of the process model are sequential and comprise concept, problem analysis, feasibility study analysis and modeling, and requirement documentation. As suggested by Macaulay, the RE process is dependent on the situation as well as customer-supplier relationships [11]. It is the most simple RE model which is used for small and less complex projects. It does not suit well for large projects.

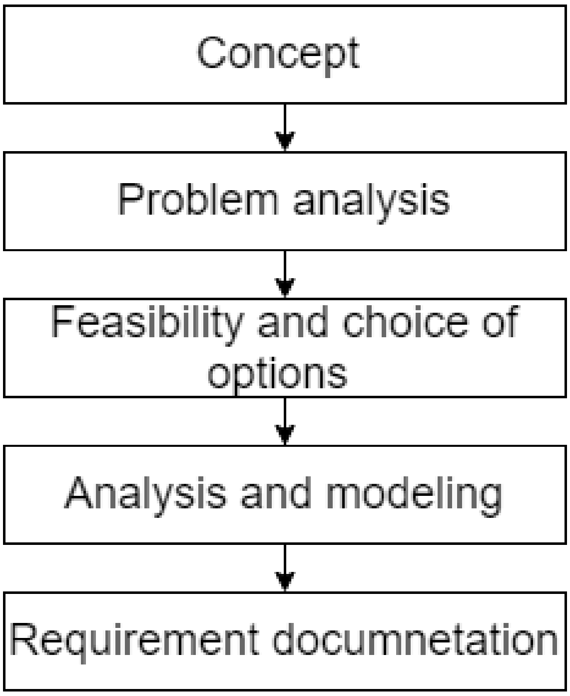

Figure 2.5: Linear model from Macaulay [11]

In Allseas, the industrial equipment team handles the project with 4 to 5 members whereas the JLS team handles the project with 50+ members. For instance, industrial equipment projects are considered small projects, and JLS projects are considered large projects. This model does not have overlapping activities which makes the RE process simple and understandable.

The strength and weakness of the linear requirements engineering process model are tabulated in Table 2.1.

Strength	Weakness
• It provides support to analyze the feasibility of the system. • It provides the facility of validating customer requirements. • Pure linear model and does not involve any overlapping of activities.	• It does not support the reverse engineering process. • It lacks the policies for performing risk management. • It lacks the activities of requirement preprocesses. • It lacks the facility of changing requirements. • It lacks the feedback activity.

Table 2.1: Strength and weakness of linear model [10]

2.4.2 Kotonya and Sommerville spiral model

The spiral model is proposed by Kotonya and Sommerville as presented in Figure 2.6. The key feature of this model is spiral. Each spiral has four major sections as requirements elicitation, requirements analysis and negotiation, requirements documentation, and requirements validation. Each phase begins with a goal and ends with the developer or client validates the progress. The benefit of the spiral model is that it allows step-by-step releases and refinement of products through each loop of the spiral model. It supports building prototypes at each loop. In Allseas, the machine's digital design is considered as release at each loop. All the activities of RE engineering are covered in the machine design during each release. Also, the model's objective is to overcome the consequences that affect the quality and cost of the project which arise in various stages of product development.

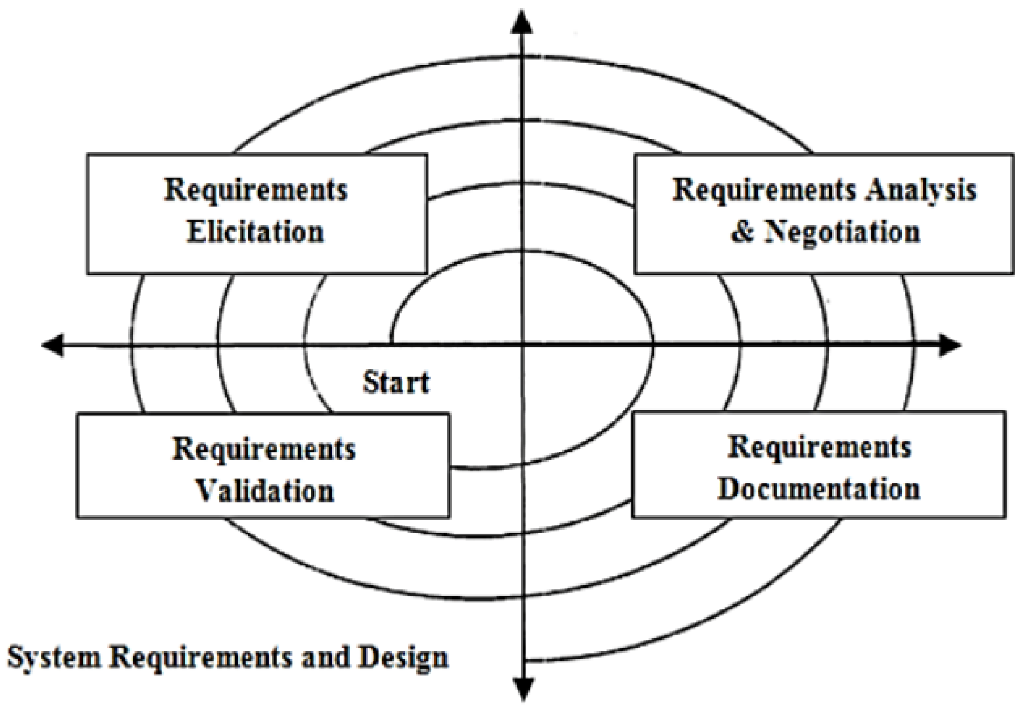

Figure 2.6: Spiral model from Kotonya and Sommerville [12]

The strength and weakness of the spiral requirements engineering process model are tabulated in Table 2.2.

Strength	Weakness
• It supports the policies for performing risk management. • It supports changing of requirements at later phases. • It is well suited for large and complex projects. • It supports prototyping and more suitable for agile work procedure. • It provides the means of client's feedback.	• It is not suitable for small projects as it is expensive. • The process is more complex than other models. • Number of intermediate stages in the process require excessive documentation. • It lacks the process of requirement prioritization.

Table 2.2: Strength and weakness of spiral model [13, 10]

2.4.3 Pandey and Suman generic model

The generic process model proposed by Dhirendra Pandey and U. Suman relates the requirements engineering process to the development process which is depicted in Figure 2.7. The noteworthy aspect of this model is that it introduces important and unseen viewpoints of requirements engineering process such as constraints, security requirements, business requirements, customer requirements, information requirements, user requirements, standards, etc. for producing quality products. The projects handled by Allseas consists of mechanical, electrical, and software aspects and this model supports the software and hardware requirements in eliciting and the development phase. Also, it provides broader scope for documentation of requirements and includes validation and verification of requirements. Furthermore, it covers the requirements management and planning phase to support changing of requirements [14].

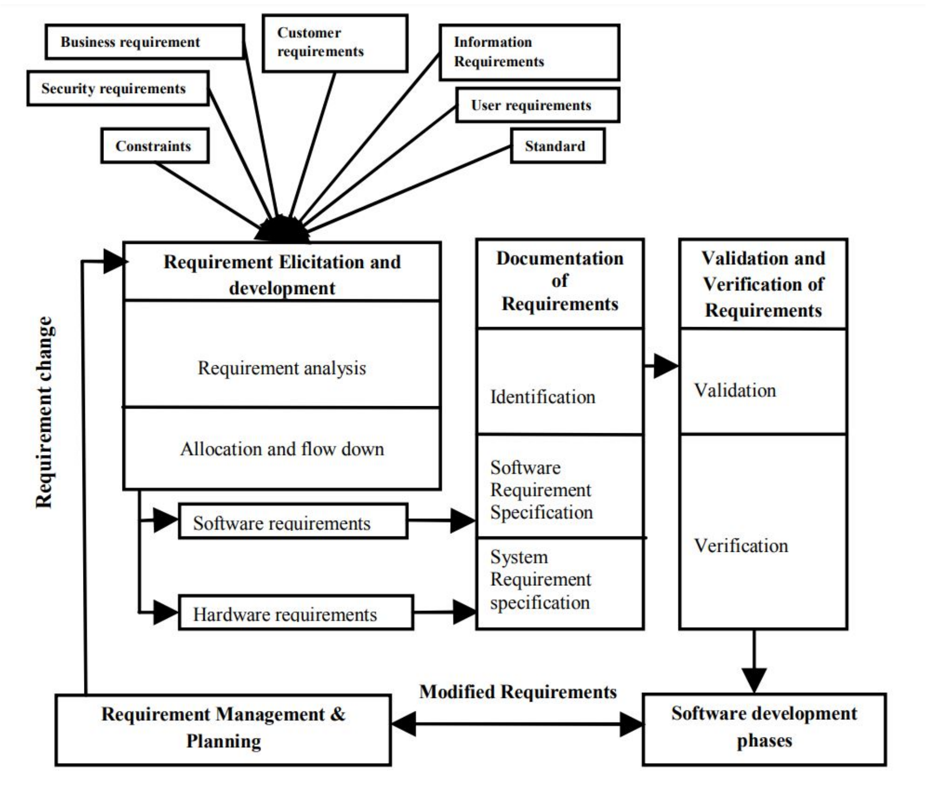

Figure 2.7: Effective requirement engineering process model from Pandey and Suman [14]

The strength and weakness of the generic requirements engineering process model are tabulated in Table 2.3.

Strength	Weakness
• It supports requirement management and planning for product development. • It provides the facility of changing requirements. • It supports different viewpoints during requirement elicitation. • It provides the means of client's feedback.	• It lacks the facility of selecting an appropriate selection of elicitation technique. • It lacks the activities of requirements preprocesses. • It gives focus on requirements classification rather than requirements analysis. • It is more inclined towards software development.

Table 2.3: Strength and weakness of generic model [14, 10]

2.4.4 Sommerville requirement model

The requirement engineering process model proposed by Ian Sommerville is shown in Figure 2.8. The first phase of the project is the feasibility study which delivers the feasibility report. The study majorly focuses on budgetary planning from a business point of view. Then, the requirements elicitation and analysis, requirements specification, and requirements validation phases are iterative. The outputs of the requirement elicitation and analysis phase are system models which is a key aspect of this requirement engineering process. It involves the development of one or more system models for a better understanding of the system to be specified. In the context of Allseas, the system models refer to machine design. The requirement specification is the activity of translating the information gathered during the analysis activity into a document that defines a set of requirements. The user and system requirements are considered in this process. Requirement validation checks the requirements for realism, consistency, and completeness. Finally, all the outputs of requirement phases contribute to the requirements document [15].

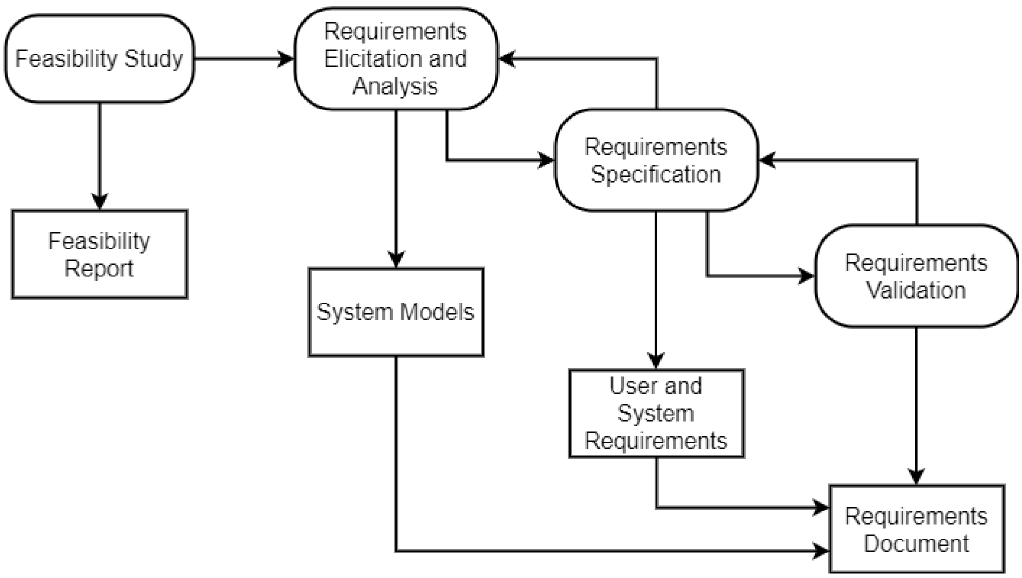

Figure 2.8: Requirement engineering process model from Sommerville [15]

The strength and weakness of the iterative requirements engineering process model are tabulated in Table 2.4.

Strength	Weakness
• It supports feasibility study which involves budgetary analysis. • It provides the facility of changing requirements. • It supports higher-level system modeling for requirement analysis. • It supports to identify errors in the early stage of process. • It provides excellent support towards documentation.	• It lacks the process of detailed requirement prioritization. • It lacks the policies for performing risk management. • It needs more project management activities. • It does not support different viewpoints.

Table 2.4: Strength and weakness of Sommerville requirement model [15, 10]

2.5 Justification of methodology

This section discusses the proposed requirement engineering model, fundamentals of the systematic approach, Model-driven System approach, and analysis of RE techniques to support the proposed RE model. The results from this subsection establish the foundation for chapter 3. The results are achieved through literature review, interviews in a technical environment, feedback sessions from internal meetings and during presentations, and observations of working patterns in the Allseas industrial equipment team.

2.5.1 Proposed requirement engineering model

Based on the review of requirement engineering models from section 2.4, a suitable requirement model is selected. The RE model is selected based on specific criteria. The broad lists of selection criteria are narrowed down by prioritizing the needs of the RE model. The selection criteria are based on the feedback of the Unit meeting presentation in Allseas which was presented on 24^{th} February 2021. The feedback is given from unit heads of different teams, project leads, and project members within the innovations department. The most common feedback is to adapt the generic model to Allseas standard, reduce the bureaucracy, create a pragmatic methodology, support for different departments, and support re-definition of requirements. The collected feedback is rephrased and added as selection criteria for the assessment. An overview of the criteria is described:

- *Suitability for project phases*: The model is compatible with Allseas' iterative waterfall model for the project phases.
- *Support simple process*: The model supports a simple process that infers discrete outcomes after every stage. There should not be overlapping of stages.
- *Support changing requirements*: The model supports changing requirements. If there are conflicting requirements, feedback from designers to stakeholders is accepted.
- *Support varied-size projects*: The model supports different departments of varied-sized projects in Allseas.
- *Support concept development*: The model supports and gives guidelines in the Allseas concept engineering phase.
- *Support project economics*: The model supports the economic value of a project.

A detailed analysis of former requirement engineering process models is carried out and tabulated in Table 2.5. The comparison is conducted using the aforementioned selection criteria. '✓' means the model suit the criteria whereas '✕' means the model does not suit the criteria.

Criteria for selection	Linear Model (2.4.1)	Spiral Model (2.4.2)	Pandey Model (2.4.3)	Sommerville Model (2.4.4)
Suitability for project phases	✓	✕	✓	✓
Support simple process	✓	✕	✕	✕
Support changing requirements	✕	✓	✓	✓
Support varied-size projects	✕	✕	✓	✓
Support concept development	✓	✓	✕	✓
Support project economics	✓	✕	✕	✕

Table 2.5: Comparison of requirements engineering model

Detailed argumentation

A detailed argumentation is discussed based on Table 2.5. The argumentation is split into subdivisions namely assessment of RE models, selection of RE main activities, and proposed RE model incorporated in project phases at Allseas.

First, the assessment of various RE models is solely based on the selection criteria. From the Table 2.5, Macaulay and Sommerville's model has a large number of '✓' marks. The Macaulay linear model is a simple process and supports project phases, concept development, project economics whereas it is only suitable for small-sized projects and does not support changing requirements which are the critical reasons to eliminate this model. Then, the spiral model is one of the prominent models in the software development organization. This model was not considered due to its complexity and requires heavy documentation. It also requires expertise in system engineering knowledge and an agile way of working which are not attainable in Allseas. Following is the Pandey model which majorly focuses on unseen viewpoints of requirements and requirements management and planning phase. This model was rejected due to its lack of support for concept development. Finally, the Sommerville model showed promising coherence towards the selected criteria. It is well suited for project phases, varied-sized projects, and changing requirements. One of the primary reasons for selection is that it supports concept development by system models. The system models promote better communication between stakeholders and promote functional thinking. The downside of this model is that it is not a simple process and does not support project economics. Therefore, it requires few adaptations in the model to reduce the pitfalls of the model. To conclude, Allseas requires improvement in requirement elicitation and analysis along with concept development which is emphasized in the Sommerville model. Also, major selection criteria are supported which strengthens the argument and validates the reason for choosing the Sommerville model.

Second, the main activities of Sommerville's model are feasibility study, requirements elicitation and analysis, specification, and validation. The main activities have discrete outputs such as feasibility reports, system models, user and system requirements, and requirements documents. The model is reduced down to make the process abstract and simple. As the requirement elicitation and analysis need more focus, it is separated into two main activities. The feasibility study is included as the sub-activity of the requirements analysis to reduce down the feasibility report. Allseas's clients are vessel team and unit head depending upon the project type which gives the reason for not choosing user requirements step in the model. The major focus is given to requirement elicitation and analysis rather than the classification of requirements. The step of improving the project economics is included in the RE sub-activity to reduce the pitfall of the model. The system models from the Sommerville model are transformed as the main activity termed 'System Modeling' in the proposed model. The system models are not only considered as outcomes but it requires actions and guidelines to develop the system models. The requirement validation is primary in the methodology as every requirement needs to be validated in the later phase of the project. The following RE main activities are selected in the proposed model:

- Requirements elicitation
- Requirements analysis
- System modeling
- Requirements validation

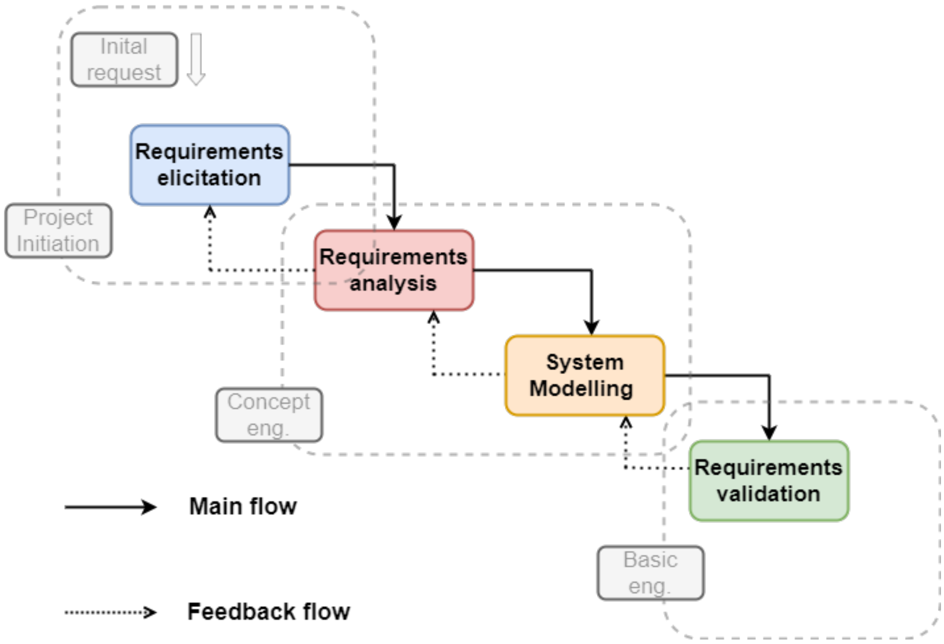

Figure 2.9: Proposed sommerville requirement engineering process incorporated in Allseas work procedure

Finally, the RE main activities are proposed according to project phases at Allseas. Figure 2.9 depicts the RE activities incorporated in Allseas' work procedure. As discussed earlier in section 2.1, about the project phases at Allseas which are constructed into the linear sequential process with feedback from Figure 2.1 which are represented in the dotted grey box in Figure 2.9. The initial request from the product owner or vessel team is processed in the requirement elicitation activity and so on. Importantly, the RE activities inside the project phases at Allseas also follow the sequential process with feedback which strengthens the argument for choosing this model. The color-coding of the RE activities is maintained in the chapter 3 which gains an understanding of RE activities in stages of the methodology. Also, higher-level system modeling is compatible with the Allseas concept engineering phase. The requirements are documented during each activity which partially contributes to the Allseas basic engineering phase. The requirements validation is performed later in the project phases which is not in the scope of the thesis.

2.5.2 Fundamentals of systematic approach

The fundamentals of the systematic approach can be classified into two categories namely cognitive psychological relationships and general methodical principles. The scope of the thesis is restricted to general methodical principles. It helps to structure the proposed procedures and individual methods which are applied to machine design. A general working methodology should be widely applicable, independent of discipline (mechanical, electrical, software), and adaptive. Moreover, it should require minimum technical knowledge to use the methodology and support a structured and effective thinking process.

There are numerous general methodical principles involved in the systematic approach. Some of the important principles relevant to this thesis are analysis, abstraction, synthesis, method of persistent questions, and method of systematic variation [16] which are explained:

- *Analysis* is the resolution of anything complex into its components and study of components and their interrelationships.
- *Abstraction* is to find a higher level interrelationship, that is more generic and comprehensive. It reduces complexity.
- *Synthesis* is the putting together of parts or elements to produce new effects and to demonstrate effects to create an overall order.
- *Method of persistent questions* evokes fresh thought and intuition.
- *Method of systematic variation* involves dividing the overall problem into sub-problems; finding individual solutions; combining solutions into an overall solution.

The following aspects are full-filed using a systematic approach [16]:

- *Definition of goals* - It is achieved by formulation of the overall goal and individual sub-goals. It ensures understanding of the problem and solving the task.
- *Clarification of boundary condition* - This is performed by defining constraints that help to focus on the defined goals.
- *Elimination of prejudice* - This is to avoid assumptions or preconceptions in a technical environment or project and to avoid logical errors.
- *Search for variants* - This is to ensure the wide range of possible solutions from which the best can be selected.
- *Decision making* - This is attained through structured evaluation of variants.

2.5.3 Model-Driven System approach

The proposed RE model gives a higher-level abstracted view of the process. After the selection of the proposed RE model, a proper methodology that supports the RE activities are selected. The requirements of the methodology should improve understanding of tasks, stakeholders' communication, and the development of conceptual models. Additionally, the methodology should support modification according to specific purposes. Based on the aforementioned needs, SYSMOD methodology is selected.

SYSMOD is a general-purpose methodology that works well with the modeling language SysML. Based on a specific purpose, the SYSMOD-based methodology (purpose-driven methodology) can be derived. SysML model elements are derived from the proposed methodology (query-driven modeling) [17].

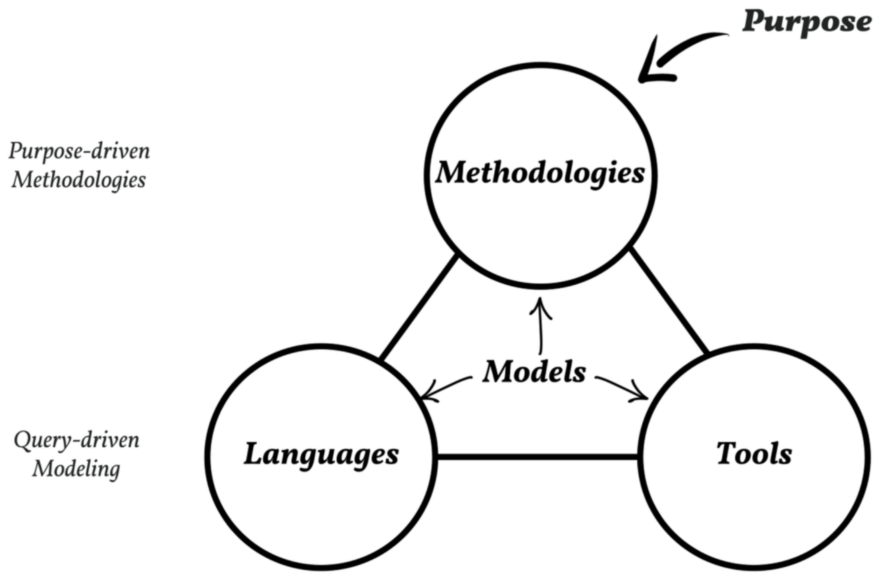

Figure 2.10: SYSMOD along with languages and tools [17]

Figure 2.10 shows the integration of the methodology along with the language and tools. The important characteristic of SYSMOD is that it can be modified according to the specific purpose. In Allseas, the requirement elicitation and analysis are extended according to a specific purpose which is explained in detail in the upcoming section 2.6. The SYSMOD approach corresponds to a widely used pattern: identify an element, describe some context (external view) and then immerge (internal view) [18]. Adding to it, the SYSMOD approach focuses on system modeling through language such as UML, SysML, AutoStar, etc. Out of all available languages, the SysML language appropriately fits requirement modeling as it provides specific notation and diagrams for requirements. The various SysML diagrams help and structures the higher-level system modeling. Moreover, the changing project management scheme in Allseas towards stage gating, an additional benefit of the SYSMOD approach is that it is independent of the 'waterfall with feedback' or 'stage gating' approach. This is an orthogonal aspect and both are possible with SYSMOD [19]. To conclude, the aforementioned points validate the reason for choosing the SYSMOD methodology.

2.5.4 Analysis of requirement engineering techniques

The proposed model includes several RE activities. There are many techniques available to perform the requirement engineering activities. To choose suitable techniques for Allseas, certain criteria are formulated. This is collected from interviews in the technical environment and feedback sections from internal meetings presentations. The techniques are selected based on certain criteria which are listed:

- Simple and inexpensive technique.
- Adhere to principles of systematic approach.
- Fits with available tools in Allseas.
- Provides a better overview of the system.

Requirement elicitation is the practice of researching and discovering the requirements of a system from stakeholders [20]. This can be achieved in a lot of ways. There are many requirement elicitation techniques such as interviewing, prototyping, questionnaires, role-playing, user observation, etc. are followed in many organizations [8]. The current technique used in Allseas is informal interviews, brainstorming, and unstructured meetings. Based on the demanded criteria, an inexpensive and practical technique of elicitation called a questionnaire is selected. This satisfies one of the principles of a systematic approach called *method of persistent questions* which evokes fresh thoughts and intuition among stakeholders. The questionnaire also does not need additional resources or tooling, unlike prototyping and role-playing. To strengthen, the questionnaire technique, the Zachman framework is introduced along with a questionnaire that stimulates the maximum possible questions. Furthermore, the Zachman framework along with the questionnaire aims to solve potential miscommunication, lack of understanding in specific technical domains, and problems related to responsibility hierarchies in terms of machine development. Detailed theoretical background about the Zachman framework is discussed in subsection 2.6.1.

The requirement analysis focuses on tasks that determine the needs of the project. Such analysis helps eliminate the unidentified and conflicting requirements [12]. The analysis focuses on identifying the available resources on the vessel, studies the state-of-art technology, and analyses the set of already collected requirements. Similar to the requirement elicitation, the analysis can be done through various techniques such as gap analysis, TRIZ solution matrix, etc. These above-mentioned techniques require high technical expertise and resources. The technique should be simple for engineers to adapt and can be implemented in the Allseas available tooling. The checklist is one of the easiest and affordable ways to gather resources and analyze requirements. A detailed explanation of the usage of a checklist in the population of the resources available on vessels is explained in chapter 3. The study on the available resources helps to generate new ideas for brainstorming during concept development. A technique named "requirement formalization" is used for analyzing the requirements. The primary goal of this technique is to correlate the collected requirements with the pre-populated checklist to attain formulated requirements in the form of the design specification. It helps to spot the unidentified and conflicting requirements. Importantly, it follows the principles of systematic approach - *analysis*. Also, Requirement formalization is simple and fits with the available Allseas tools. Detailed theoretical background about requirement formalization is discussed in subsection 2.6.2.

The term "system modeling" has multiple meanings. In this context, it relates to the use of the models to conceptualize and construct systems with the help of formulated requirements from the previous step. The constructed higher-level model helps engineers to analyze and validate the requirements. Referring to the problem analysis in section 2.2, one of the important pitfalls currently dominating at Allseas is is solution thinking rather than functional thinking. This problem could be overcome by using functional decomposition, which could be performed during the concept development phase. The detailed steps to perform the functional decomposition are explained in chapter 3. The concept of functional decomposition is implemented using various SysML diagrams. The sequential steps involved in system modeling are elaborated in subsection 2.6.3. The concept selection and evaluation are performed as suggested in [16] which helps to increase the solution space of the product and avoid impractical solutions. Also, the system modeling adheres to principles of systematic approach namely *abstraction*, *synthesis* and *method of systematic variation*. The concept of system modeling is further elaborated in chapter 4 using a case study.

Finally, requirement validation is checking requirements defined for development, and required documentation is accounting for all the requirements. There are various techniques and templates to accomplish it. The requirements validation is not in the scope of this thesis. Requirements validation is the main source for the requirements document. However, other RE activities also contribute to the requirements document as shown in Figure 2.9. Diagrammatic representation of requirements and relationships between requirements are taken from the SysML requirement diagram. Documentation is one of the critical problems at Allseas. To improve the classification of requirements during documentation, a template is suggested from ISO: systems and software engineering - Requirements engineering [21]. This concludes the analysis of RE techniques.

2.6 Background of the methodology

The theoretical background provides support to the selected concepts relevant to the topic of the study. Before moving into the methodology for Allseas work procedure, theoretical prerequisites regarding Zachman framework, Requirement formalization, and extended SYSMOD approach are to be known beforehand to gain a clear understanding of the following chapters.

2.6.1 Zachman framework

The Zachman framework is an ontology that provides a formal and structured way of viewing and defining an organization or a system. The ontology is the intersection between two historical classifications. The first is primitive interrogatives: What, How, When, Who, Where, and Why. The second is derived from reification transformations which are: identification, definition, representation, specification, configuration, and instantiation. The Zachman framework provides a structure with different views of the stakeholder. The usage of framework is due to increase in complexity and changing nature of industrial products [22].

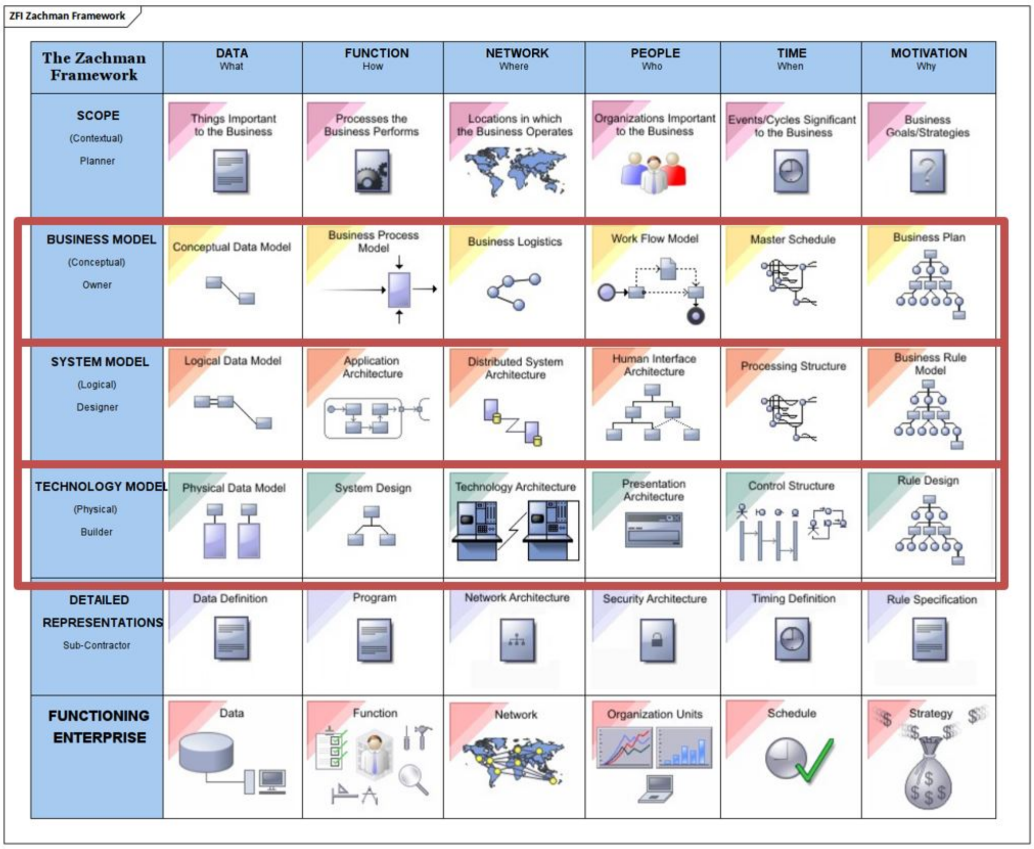

Figure 2.11: Zachman framework - Overview [22]

The framework is a generic classification scheme for design artifacts, (i.e.) descriptive representations of any complex system. The use of such a classification scheme is to enable focused concentration on selected aspects of the system. Each cell in the framework (intersection of a column and a row) provides a unique representation or view of the system as depicted in Figure 2.11. The columns of the template outline the fundamentals of the system depending upon the context in the question (what, how, where, and so on), while the rows represent the perspectives of each stakeholder involved in the project. The 6 X 6 matrix is filled with processes, essential materials, important roles, relevant locations, and goals or rules associated with the project, based on the fundamental question and perspective represented in each cell [23].

Adapted Zachman framework

Zachman's framework in Allseas methodology is primarily used to elicit requirements. The questions were modified to reflect the company's context and typical project stakeholders. The roles, responsibility and the relation between the stakeholders within a typical project are defined during the initial phase of a project. Thus an input from several departments and different projects is analyzed to find commonalities. Since the current project mainly focuses on the RE related to industrial equipment development, which does not have a big impact on the executive model (scope) of the company and the building of the equipment is done in-house, it was decided to reduce the number of stakeholders. As a result, it was proposed to select 3 major perspectives (owner, designer, and builder) as highlighted from Figure 2.11. The three selected perspectives are sufficient to gather information about the project and represent the responsibility and product relationship within the company. Owner's questions are used in the initial phase of the project, whereas the designer's and builder's questions are used in the concept development phase. The original matrix has been adapted from 6 X 6 to 3 X 6 during the application of the Zachman framework in the RE methodology for simplification. The different questions formulated from the perspective of different stakeholders result in better mutual understanding between the stakeholders and open broader possibilities for engagement in discussions. It enables structured thinking during machine development. The versatility of the questions from various interdisciplinary teams based on the proposed Zachman framework improves the requirement elicitation procedure.

Zachman framework - Responsibilities

The Zachman framework is used to depict the roles and responsibilities of the employees in an orderly fashion. From the Figure 2.12, it is clear that only three perspectives are focused in this methodology. The owner's responsibility is to define the scope of the project and the purpose of the product, which includes setting milestones for the project team, anticipating the vessel team's (client) needs, criteria of product evaluation, and the progress of the project. The designer's responsibility is to design a fully functional product which consists of engineering the product, creating manual or digital drawings, and defining the product specifications. The builder's responsibility is to deliver the physical product involves material handling, fabrication of the product, assembly, handling of the product like transportation, product testing, and product commissioning.

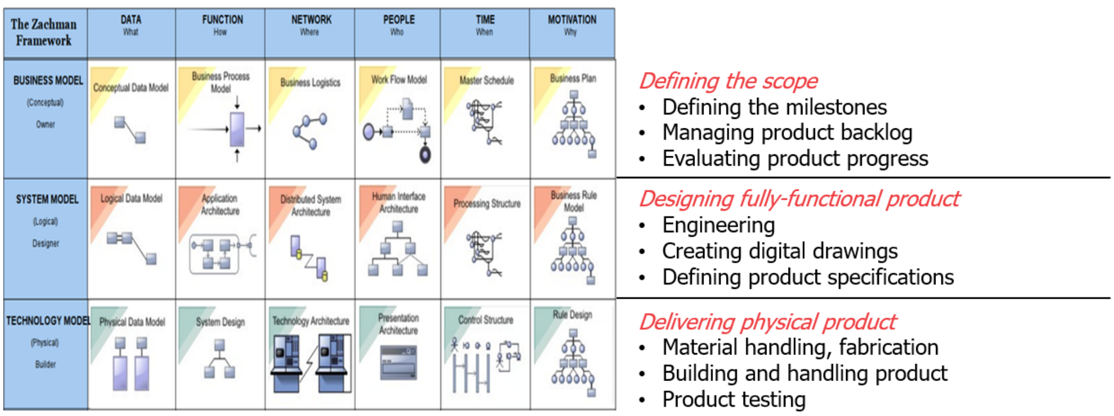

Figure 2.12: Zachman framework - Responsibilities

Zachman framework - Product

Each stakeholder has a set of tasks and ownership of the product during the development. Zachman's framework can be used to depict the aspects of the product in correlation with the stakeholders. In the Figure 2.13, the first row focuses on the conceptual view of the end product, as the owner can think about its real-life application. The descriptive representations reflect the usage characteristics of the end product. In other words, it describes what does the owner(s) are going to do with the end product, or how they will use it. The second row works on the translation of the concepts into requirements representations from the designer's perspective. The designer determines the data elements, logical process, use cases, and system functionalities. The third row represents the builder's perspective, with sufficient detail to understand the constraints of tools, technology, the programming languages, input/output (I/O) devices, or other required supporting technology and material knowledge related to the product manufacturing. The upshot of the Figure 2.13 is that the owner focuses on problem identification, the designer focuses on solution identification, and the builder focuses on solution implementation.

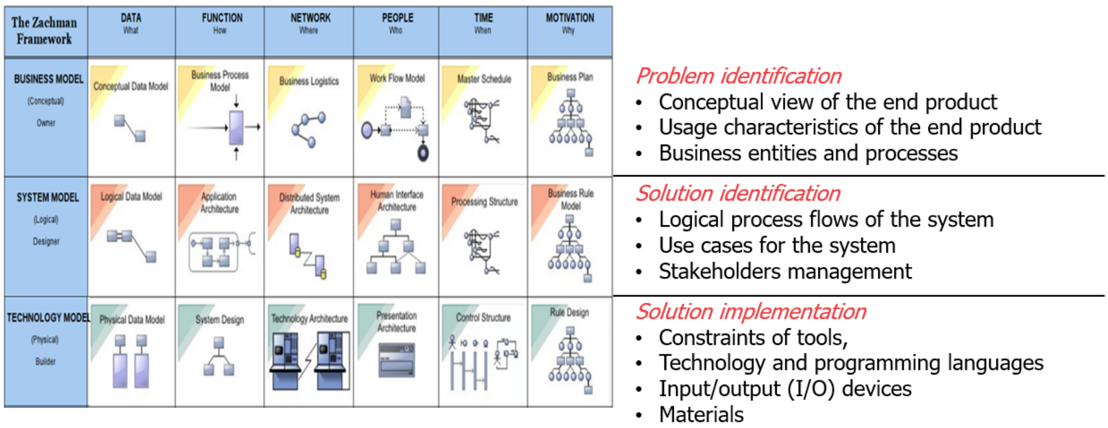

Figure 2.13: Zachman framework - Product

2.6.2 Requirement formalization

System development activities such as requirements elicitation, the population of design specifications, solutions generation, and implementation are well defined in software engineering. In software engineering, the term "design specification" is used to refer to the various models that are produced during the design process. A well-established model-driven process in software engineering might result in the automatic synthesis of the executable code [24]. This type of formalization process has not yet been achieved in engineering design. The process of formalizing the requirements is more complex because the knowledge in engineering design is more diverse and the hardware concepts are not precisely defined as in the software engineering domain. Furthermore, due to increasing systems complexity, and more demanding requirements, the role of knowledge in engineering disciplines in the conceptual phase has to be improved.

Raw requirements,(i.e. requirements that have not been analysed), are usually expressed in narrative format. The raw requirements are termed narrative requirements (NR). Conventionally, any development process starts with the NR. Similarly in Allseas, the NR from the vessel's team comes in the form of Action request form (ARF). These NR provide the foundation for the design efforts. But it does not certainly provide the complete knowledge required for the subsequent design process. Therefore it is important to analyze and formulate the NR to become abstract, unambiguous, and traceable, in other words well-formed.

There are different approaches for the formalization of the NR into a formalized design specification. Most of the proposals are document-centric and laborious. The most suitable approach for requirement engineering is knowledge-oriented and information-driven. During the early project development stage at Allseas, the designers barely account for the required information and knowledge needed for the project. This happens mainly due to the absence of formal communication lines between different departments, easiness of making assumptions based on own work experience, and absence of information verification with the stakeholders. Proper collection of information from the various sources plays a vital role not only in the development phase but throughout the whole project as well.

The approach presented in the proposed methodology aims to formalize NR, usually the vessel's team (client) requirement. It is a model-centric approach on refining and extending NR which is based on an interaction matrix operations described in [25]. First, modeling the single requirements checklist database (C) with the combination of available requirements checklist (RC) and knowledge/information sources. Second, formalizing the narrative requirements using the requirements checklist database. In the Allseas methodology, more emphasis was given to the formalization of NR. The whole approach is considered as an extension of the requirements capturing with the help of SysML diagrams. The SysML diagrams provide more insights about the purpose and functioning of the future system, which help in gathering a more detailed and accurate set of system requirements. To summarize, the existing knowledge in the machine engineering domain (such as mechanical, electrical, control, etc.) integrated with the SysML formalism to provide a consistent set of requirements which are used in the machine development phases [26].

Engineering design is a process that primarily involves knowledge of physics, logical thinking, and creativity. Many systematic engineering methods and tools are developed to aid engineers to analyse the project goals and stimulate the creative process of problem-solving. There are various checklists available in books with different nomenclature. For this approach, the requirement checklist was adapted from [16], where it is proposed to shift from a document-centric approach to a model-centric approach. The checklist is one of the most important aspects in the requirement engineering process to formalize the process. The main benefit of using checklists is in its systematic nature, which helps the stakeholders in taking well-grounded and objective design decisions. Also, it helps to record the information in a hierarchic way, which helps to prioritise the tasks generation, allocation, and execution [27].

Logical approach to requirement formalization

From the Figure 2.14, it is clear that the available requirement checklist (RC) from the literature [16] and existing Allseas knowledge/information source in the machine engineering domain was used to create the requirement checklist database (C). It was created in achieving an open and simple interface, which can be modified and expanded in the future together with a glowing user experience. Then, the action request form (ARF) from Allseas vessel's team known as NR and the information collected from the Zachman framework questionnaire are analysed with the help of the created requirement checklist database (C). The logical/matrix operations mean finding a correlation between the requirements and checklist. This helps to develop the higher-level design specification (DS) table with the available information. The DS table is updated accordingly as the project progress. The requirement checklists are tabulated in a specific tool to help engineers during the development process. An example of an interaction matrix between the narrative requirements (NR) and the requirement checklist database (C) for a particular case study is shown in the chapter 4. Subsequently, the functional and behavior models are modeled with the help of the created (DS) using the SYSMOD approach [26].

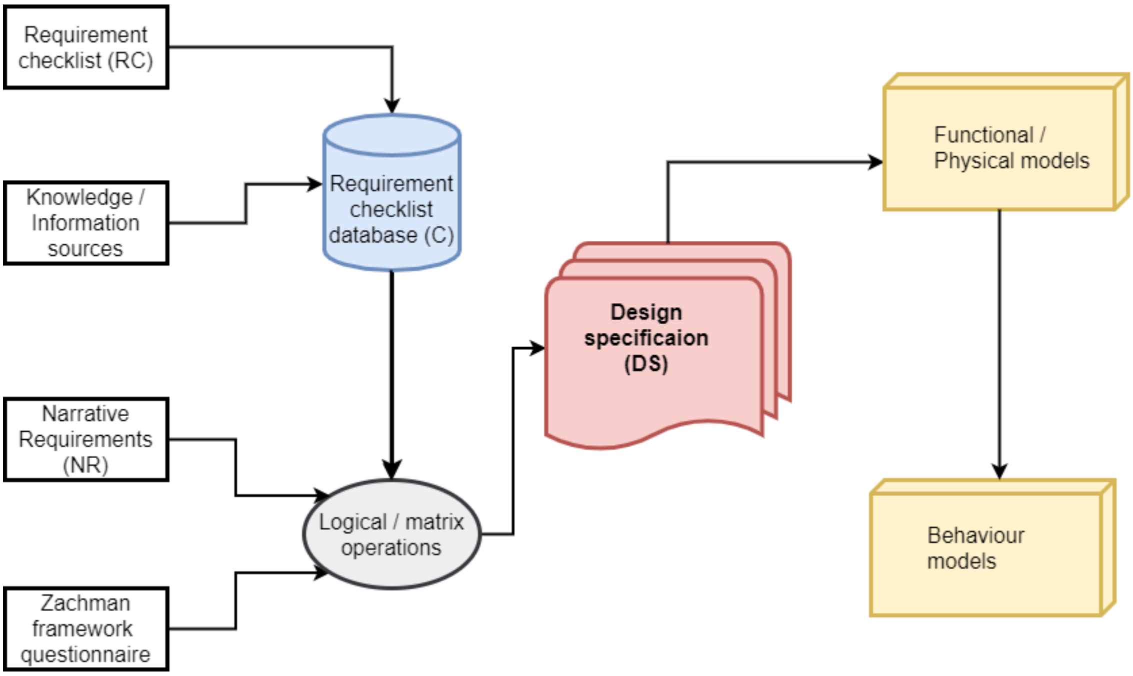

Figure 2.14: Logical approach to requirement formalization

2.6.3 Extended SYSMOD methodology

The Systems Modeling methodology (SYSMOD) is a pragmatic approach to model requirements and system architecture. It provides a toolbox of tasks with input and output work products, guidelines, and best practices. SYSMOD uses the Object Management Group (OMG) Systems Modeling Language (OMG SysML) [19]. Figure 2.15 depicts different steps of extended SYSMOD methodology. The theoretical background of the Zachman framework to elicit requirements and Requirement formalization to analyse requirements are described in subsection 2.6.1 and subsection 2.6.2 respectively which are included as an extension to the SYSMOD methodology. The same color-coding from Figure 2.9 is used to gain an understanding of steps related to RE activities. The other steps regarding implementation, validation, and requirements document are not in the scope of this thesis which is differentiated with less opacity in Figure 2.15. The various steps involved in SYSMOD methodology are elaborated in the following subsection:

Steps in extended SYSMOD methodology

- **Requirements elicitation and analysis** - As already discussed in the previous section, requirements elicitation is achieved by Zachman framework with the questionnaire, and requirements analysis is performed by Resource identification sheet and Requirements formalization technique.

- **Project context** - This step is to define the project context for the system. It represents the common objective towards which the individual or the whole team will work. The project context contains the mission paragraph, project boundaries, and priorities from the previous steps. The definition of project context is primary in determining the following steps.

- **System context** - The next step is the system context. It represents all external entities that may interact with the system. The external entities include the environment, actors, other systems, etc. The objective of the system context diagram is to focus attention on external factors and events that should be considered in developing the system.

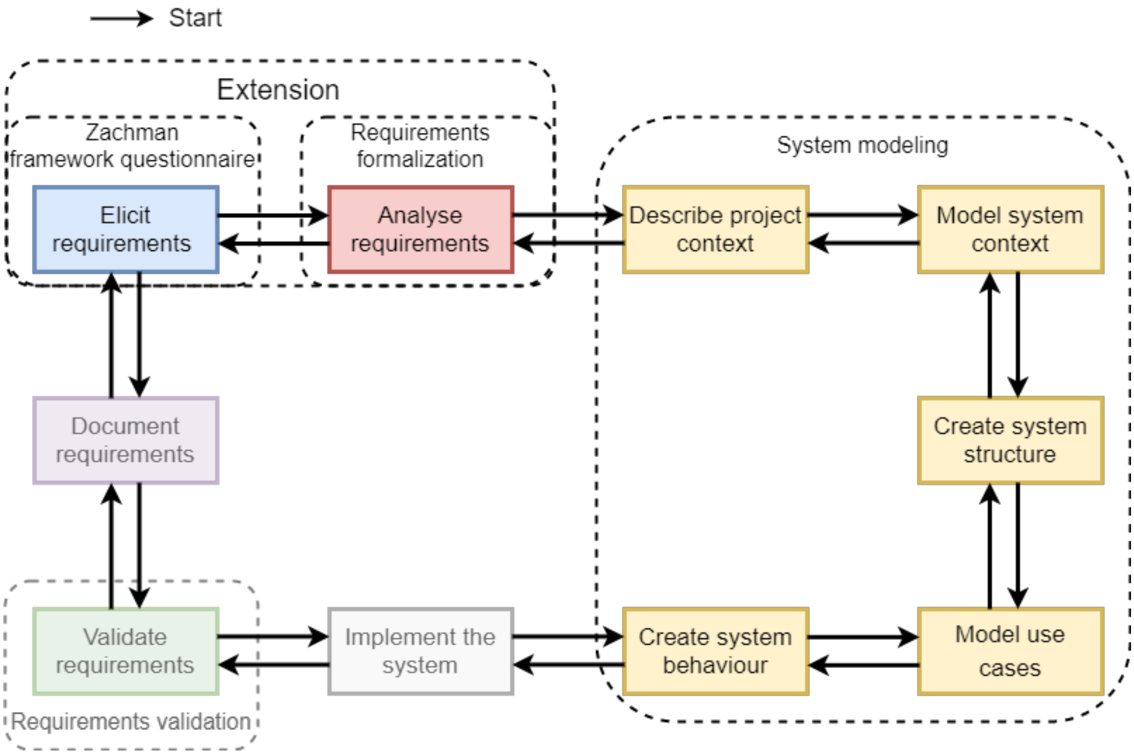

Figure 2.15: Extended SYSMOD methodology

- **System structure** - This step is to define the structure of the system. The structure of the system is shown as a block definition diagram. This diagram represents the classification of systems and their hierarchies. It shows the system components, their contents (properties, behaviors, constraints), interfaces, and relationships. The interaction between the sub-systems can also be represented by an internal block definition diagram.

- **Use case** - The next important step is defining the use case of the system. A use case is a description of the behavior of the system. It can be represented as a sequence of simple steps. Use case diagram involves the interaction with the use case and the actors and also the interaction between the use cases with different relationships. It provides a simplified and graphical representation of a higher-level view of the system.

- **System behavior** - This step is to define the dynamic behavior of the system. System behavior is represented by various diagrams such as activity, sequence, state machine, etc which are used to visualize the dynamic aspects and behavior of a system or process.

- **Implementation** - This step is to implement the developed concepts and make the system a workable model. The implementation is subjective according to the system definition which is not in the scope of this thesis.

- **Requirements validation and documentation** - Finally, requirements validation is performed in the later phase of the project which is not in the scope of this thesis, and classification of requirements for the requirements document is adapted from ISO template [21].

2.7 Tooling

Communication and exchange of information between various engineers and stakeholders in a project play a vital role to guarantee efficient progress in the project and proper functionality of the engineered solution. Every project team member must be aware of requirements and design specifications within their domain and preferably other domains [28]. Additionally, it is essential to store the relevant information in a structured way right from the start of the project. Doing such enhances accountability of requirements while designing the system and trace-ability of requirements when a design change is required.

After several interviews and analysis of the project documentation at Allseas, it became evident that the aforementioned points are performed in an unstructured way. There is a lack of standard tools/methodology that could be used by project team members. Every project team decides on their way of accounting and communicating requirements which usually leads to misinterpretation of the project requirements. Therefore, standardisation of the information collection, distribution, and storage in projects are proposed in the requirement engineering methodology by using standard tools.

There are a lot of tools available in the public domain and commercially to account for and manage the requirements. During the initial search for proper tools, some of the tools which fit the methodology were selected as suitable. IBM Engineering Systems Design Rhapsody (Rational Rhapsody) offers a proven solution for modeling and systems design activities that are optimised for complex projects and systems. It enables collaborative work in the project teams and offers a test environment for systems. Next to that, it has the requirements modeling and trace-ability features accompanied with integration with leading requirements management tools [29]. The other requirements management tools such as IBM Doors, Helix ALM, Visure requirements, and Modern requirements were found to be useful for the proposed methodology. Unfortunately, none of the above-mentioned tools could be applied by Allseas due to high license costs and the expensive learning curve of the employees. Therefore, a different approach was proposed for implementation shown in chapter 3 which makes use of already available tools at Allseas.

2.8 Conclusion

Based on several analyses and literature reviews, the methodology was selected which theoretically suits the project phase at Allseas. Moreover, the primary focus of the proposed methodology was made to the requirement engineering activities such as requirement elicitation, analysis, and system modeling, as these activities play the most important role in any project. During the implementation of the proposed methodology in Allseas, various activities which are appropriate for the company were adopted and the guidelines for the activities are described. Due to the unavailability of dedicated system engineers in Allseas, it was developed in a way that engineers without system engineering knowledge can use it. Chapter 3 elaborates the methodology for Allseas work procedure.

Chapter 3

Methodology for Allseas work procedure

In this chapter, the methodology for Allseas work procedure is formulated and the guidelines are discussed. The section 3.1 gives an overview of the methodology. Then section 3.2, section 3.3, section 3.4 and section 3.5 explains the steps involved in the methodology along with the associated activities. Finally, the database implementation using available tools in Allseas is discussed in section 3.6.

3.1 Methodology overview

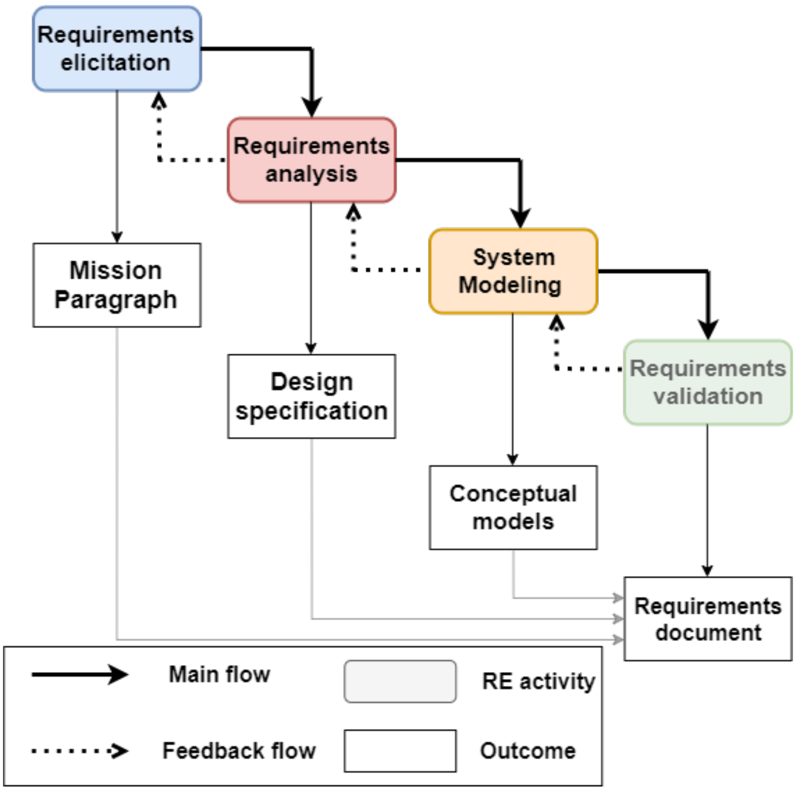

Figure 3.1: RE activities and its outcomes

Based on the review of requirement engineering models, the proposed Sommerville model was selected as depicted in Figure 2.9 in the previous chapter. The Figure 3.1 shows an abstracted view about the associations and outcomes of the selected RE activities. The RE activities such as elicitation, analysis, and system modeling are performed by selected techniques from the previous chapter to attain mission paragraph, design specification, and conceptual models. The terminologies are selected based on consultation with the engineers in the company. The requirements validation is not in the scope of the thesis which is depicted in Figure 3.1 with less opacity.

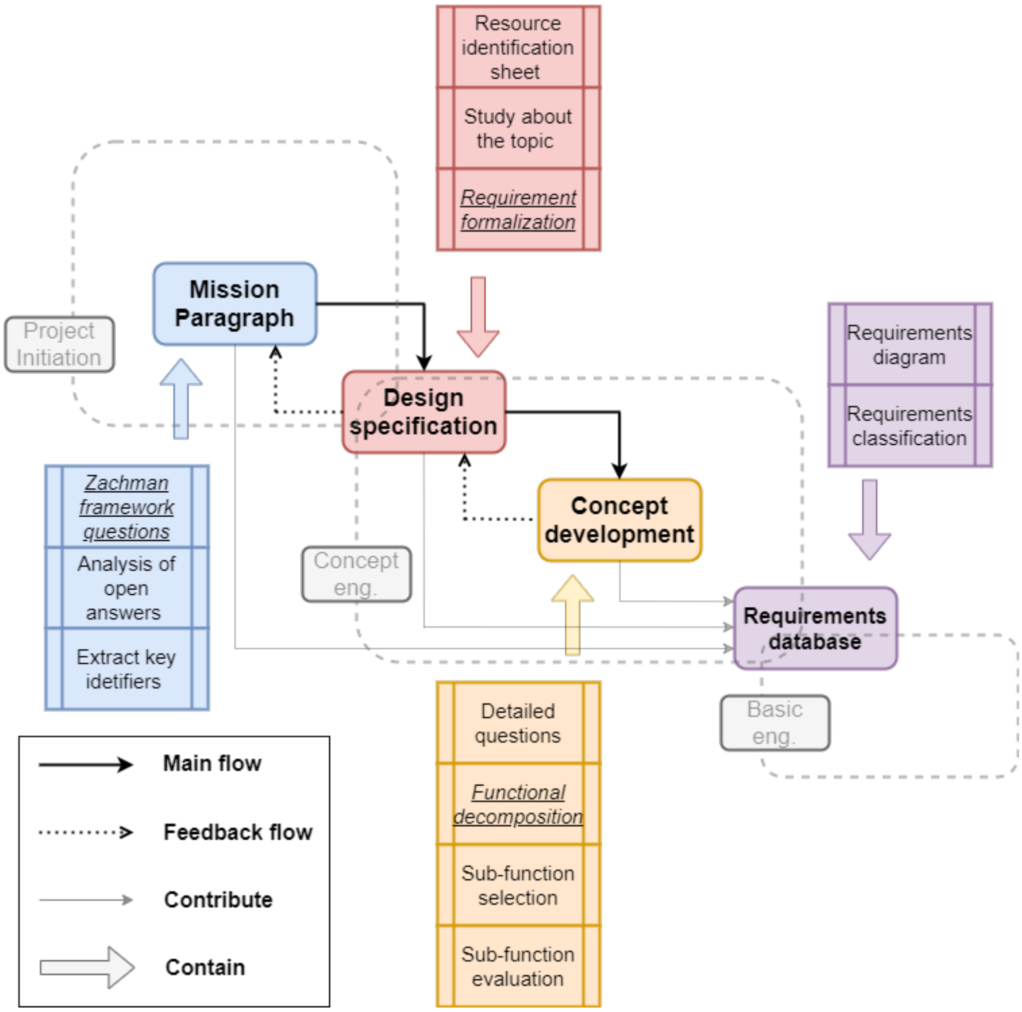

Figure 3.2: Proposed methodology with associated activities incorporated in Allseas work procedure

The Figure 3.2 gives an overview of various activities involved in each step of the methodology which is incorporated in the Allseas work procedure. The output terminologies with slight modification are used as nomenclature for different steps of the methodology to make it suitable and convenient for engineers in the company. The color-coding from the Figure 3.1 is maintained to gain an understanding of RE main activities. The sequential steps in the methodology fit into the project initiation and concept engineering phase of the Allseas. The information from each step of the methodology contributes to the requirements database which supports the basic engineering phase. The methodology contains a review cycle to its previous step that allows changes or modifications. For instance, if there are contradicting requirements in the design specification step, the designer goes back to the previous step and modifies the requirements after discussing them with the necessary stakeholders. As discussed earlier, the methodology is performed using an extended SYSMOD approach. The activities involved in each step are explained in detail in their respective sub-chapters.

3.2 Mission paragraph

The mission paragraph is the first step in the methodology. The main aim of this step is to understand the problem context. It is attained through proper questions asked to appropriate stakeholders in the company, analysis of open answers, and extract key identifiers which are explained in the following subsections.

3.2.1 Questionnaire - Owner

The questionnaire is one of the inexpensive and quick ways to get information from the stakeholders. It is also a practical way to gather data. Also, the questionnaire allows easy analysis of data. Incorporating the right questions depending upon the project yields positive results. Moreover, the Zachman framework is combined with the questionnaire ensures that the information regarding the design process is considered holistically. As discussed in the previous chapter, the Zachman framework itself acts as a tool to elicit requirements. The vertical columns contain the interrogatives, that is useful to apply on any level [30]. The interrogatives are shown in the order of decreasing importance in Figure 3.3. However, the interrogatives are arranged in the original order during implementation.

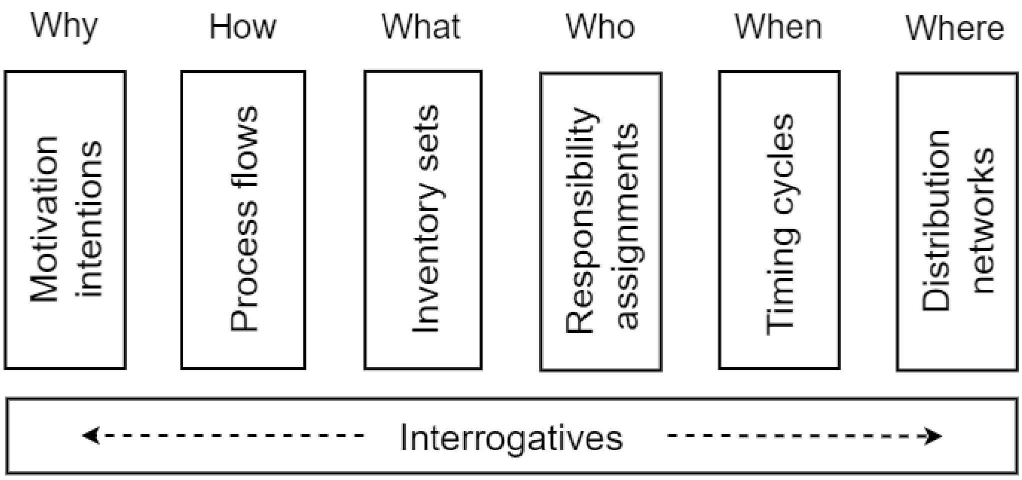

Figure 3.3: Interrogatives dimension of the Zachman framework [30]

As discussed earlier, the horizontal row of the framework was deduced down to three. In simplistic terms, the horizontal row is the employee's hierarchy. It starts from the owner's perspective to the builder's perspective. The designer and the builder questions are filled in the later step of the methodology. The sample lists of questions in terms of owner perspective are shown in the Table 3.1. The category of questions is answered by the respective stakeholders. The primary aim of these questions from this perspective is to find the problem identification rather than solution identification. In terms of product, these questions answer the following aspects:

- Conceptual view of the end product.
- Usage characteristics of the end product.
- Real time application of the product.

Zachman Framework	What (Inventory Sets)	How (Process flows)	Where (Distribution Networks)	Who (Responsibility Assignments)	When (Timing Cycles)	Why (Motivation intentions)
Owner	What are you trying to solve with this project? – Root cause What are the clients planning to achieve? What prerequisites are already there for this project? What do you consider as the biggest risks for this project? Are there any relevant deliverables or artifacts available for review? What is the cost allocated for the project? What type of material are we working (to remove, to clean, to join)? What investments in infrastructure, tools, and training will be made?	How do you prefer to communicate? How often you prefer to communicate with vessels team? How are the clients solving the problem currently? How do you evaluate previous product? - History of the project If suppose it is older project, how have the previous solutions failed? How will the project performance be measured?	Where and how much are the working area for our product? Do you see any dependencies or similarities between this project and other projects? In which technical area does the project mainly focus on? In which business area does the project mainly focus on? What is efficient working area? What is area of disposal, if any?	Who are you solving this problem for? What are the different roles of the people involved in the project? Does the client have proper knowledge to use the product? Who else do we plan to collaborate with outside of our team?	When does our project starts? When does conceptual design phase ends? When does the project ends?	Why do we need this project? What value does it bring to the client?

Table 3.1: Owner - Questions

3.2.2 Analysis and identifiers

The questions are answered by the owner and different stakeholders. First, understanding the interrogatives categories and analyzing the answers are the key aspects. This makes it easy to find out unanswerable questions. However, all the questions cannot be answered descriptively at the start of the project. Second, some of the unanswerable questions are clarified with the vessel's team (client) which makes the communication clear and accountable. The answers are written coherently according to the order of priority. The analysis is done with the help of identifiers.

The key identifiers are derived to obtain essential information about the project. The aspect of the analysis is to link the identifiers with the acquired answers from the questionnaire. The sample list of identifiers are listed out below:

- Purpose/Goal of this project
- Root cause of the problem.
- Benefits of the new product
- Previous solution used to solve the problem.
- Disadvantages of the solutions
- Commonalities which can be used in the new product, if any
- Meeting details
- Schedule
- Responsibility

3.2.3 Derivation of mission paragraph

The mission paragraph is the outcome of this step. The mission paragraph is derived by combining the answers after the analysis. The mission paragraph answers the list of identifiers as shown earlier. An example of a mission paragraph was demonstrated in the chapter 4. A clear and rational product mission paragraph has the potential to improve the product development process. The mission paragraph acts as a focal point during the design process and helps in the following aspects of the machine design:

- Simplicity in the product design.
- Paving the way for compelling products.
- Clear communication between stakeholders.
- Improves team's understanding of the product.
- Streamlines and simplifies internal processes.

3.3 Design specification

In this section, the primary focus is to attain the higher-level design specification (DS) table. The design specification is a document providing a list of points regarding the product. There is a step of activities that are performed to reach higher-level DS of the product. As discussed earlier, requirement formalization helps formalize the raw and narrative requirements to a proper DS table. There are also other activities such as resource identification and study about the topic that helps the engineers to design an economical product. Finally, insights about requirements structuring and using the right terminology while accounting requirements are also covered.

3.3.1 Resource identification

The primary objective is to know the available resource in the vessel. The vessel is designed for various purposes such as single-lift installation, removal of large oil and gas platforms, pipe-laying, etc. The industrial equipment team from the innovations department develops in-house machines for the vessel's team to satisfy stakeholders' demands. The vessel is the final destination where the machines are deployed and commissioned. It is necessary to acquire the knowledge regarding the vessel that helps to build a suitable machine. The following aspects of resources are covered in this stage:

- Equipment and tools
- Facilities
- Labor
- Consumables and materials

A resource identification survey sheet was created to get essential resources from the vessel team. Specifically, this survey sheet was designed customized to Allseas. The resource survey sheet covers a wide range of aspects in terms of resources. Based on several iterative discussions and meetings with the engineers, the survey sheet was created. Also, by filling in the survey sheet from the vessel's team, the communication between the design and the vessel's team is promoted. During the concept development, the machine is designed with the knowledge of available resources in the vessels, which reduces many practical implementation problems during the commissioning of the machine in the vessel.

A detailed list of survey sheets was formulated. Some of the topics in the sheet are listed:

- Local utility
  - Electrical energy
  - Mechanical energy
- Space requirements for vessel
- Strength requirements for vessel
- Vessel in-house condition
- Miscellaneous needs

In local utility, the subtopics such as machine and equipment, units, methods, and explanations are covered. As the name suggests, '*machine and equipment*' lists the available or unused machines, equipment, and tools in the vessel. It has to be filled by the vessel's team. There are lots of predefined tools and equipment that are listed in the resource sheet to help the vessel team to pick one of them. The '*units*' refer to the specification of the tools and equipment such as power, size, weight, etc. Then, the '*methods*' covers the underlying facts behind the machine or the equipment. For instance, if there is a motor available, the underlying principle behind the motor can be electric, centrifugal, etc. This is determined by the designer in communication with the vessel's team to get a deeper understanding of the resource available. The '*explanation*' is the notes from the vessel's team filled in to provide more information about the respective topics. Also, there are various other topics in resources covered in this resource identification survey sheet. Finally, there are some essential benefits to analyse the resource available in the vessel. The following benefits for an effective project resource identification strategy:

- Reduce project cost and promote sustainability.
- Increase project economics and maximize profitable utilization.
- Competent resource allocation.

3.3.2 Study about topic

Research is an integral part of product development. The results of research for design solutions give the project a competitive advantage as well as a more developed understanding of long-term design strategy significantly increased the chance to create a successful product [31]. The study can be done through various ways such as real-time data (prospective studies) and past data (retrospective studies). It can be achieved in numerous ways as depicted in Figure 3.4.

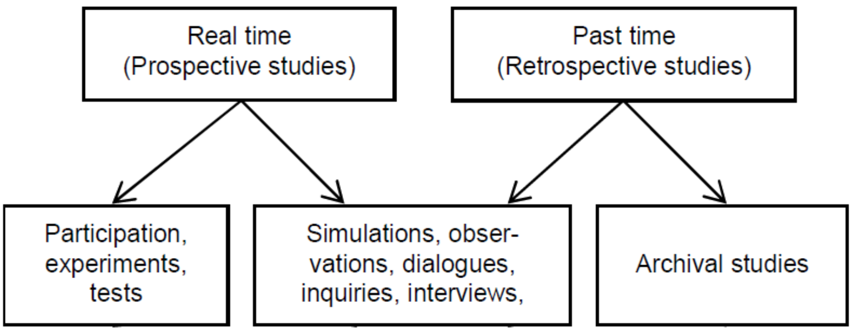

Figure 3.4: Different study patterns [31]

First, check for the root cause of the problem as derived from the mission paragraph helps to understand the purpose of the machine. The information from the resource identification is considered during the study. A list of key terms can be derived depending upon the project which can be researched in a scholarly article database. The new state of art solutions and technology can be extracted through patents and publications altered depending upon the project and can be re-used. Second, the most common way is to perform a background study through the Allseas intranet database where a list of machines, equipment, tools, and different department's project information can be retrieved. This information can be adapted effectively and re-used to the current project. Finally, discuss with Allseas specialist. Allseas have technical experts in their respective domains. The higher-level conceptual ideas can be discussed with a relevant specialist to channel the development process in the right direction.

3.3.3 Requirement formalization

Requirement formalization is a technique to convert a Narrative requirement (NR) to a Design Specification (DS) table with the help of a requirement checklist database (C). The theoretical background of the requirement formalization and the logical approach to requirements formalization are outlined in the subsection 2.6.2. The whole technique is performed sequentially by the following steps:

- Initial requirement setup
- Mapping entity concepts onto the abstract concepts
- Creating interaction matrix
- Creating design specification table

In the procedure, first, the Narrative requirement (NR) is collected. In Allseas, the NR is received from the vessel's team in the form of a document. The document is termed as '*Action request form*'. The document contains vessel name, date of request report, project number, description of the requested action, etc. The description of the requested action has the necessary information about the NR. The action request form answers some of the questions from the Table 3.1. The additional information from the mission paragraph is added to the NR. After the collection of NR, the initial requirement setup table (R) is formed. The initial requirement table consists of requirement number, description of the requirement, and functions & parameters. Second, the NR is categorized by requirement numbers. The individual requirement is distinguished by verbs & adverbs (f_i - function concept) and nouns & adjectives (p_i - parameter concept). The parts of the requirement checklist are shown in Table 3.2.

In this thesis, the main design criteria are termed as 'Axioms', and the sub-division of those criteria is termed as 'Entities'. The Table 3.2 shows the sample lists of Axioms and list of entity concepts. Entities e_i from C are utilized to derive abstract concepts (f_i, p_i in R). It is termed the mapping of entity concepts onto abstract concepts. Third, the interaction matrix is created. The X-axis of the matrix is the requirements and the Y-axis is the pre-defined checklist (Axioms). These are correlated to form the matrix (i.e.) the interaction between R and C is modeled with the interaction matrix. Finally, the higher-level design specification (DS) table is created for the identified requirements (R) under the various pre-defined categories (Axioms). There are various benefits of creating a higher-level design specification table. The major benefits of the DS table are listed:

- Assign responsibility by design criteria.
- Spot the incomplete information about the requirements.
- Detect the contradicting requirements.

Axioms	abbr.	Entity concepts	abbr.
Function	C_1	Branch	e_1
		Channel	
		Convert	
		......	
Geometry	C_2	Size	e_2
		Number	
		Breadth	
		......	
Signals	C_7	Inputs	e_7
		Outputs	
		Display	
		......	
Maintenance	C_{15}	Inspection	e_{15}
		Servicing intervals	
		Exchange and repair	
		......	
.....	.....	.....	.....

Table 3.2: Parts of requirement checklist

This process is iterative and the procedure described above is applied to make the higher level DS information well-formed without any ambiguity and incompleteness. The DS table should have adequate information to proceed to the conceptual development step. The contradicting requirements are discussed with stakeholders and resolved. As the project progress, the DS table is updated accordingly.

3.3.4 Requirements structuring and terminology

A requirement is a statement that translates or expresses a need and its associated constraints and conditions. The requirement is a description of a system to be developed. The description is always written in natural language and should comprise a subject, a verb, and an object. The syntax for defining the semi-formal requirements is adapted from – ISO29148 [21] which are described below:

[**Condition**] [**Subject**] [**Action**] [**Object**] [**Constraint**]

- [**Condition**] - when is the requirement applicable e.g., receive signal.
- [**Subject**] - actor, e.g., “the application”, “the system”, “the software”.
- [**Action**] - action or verb of requirement, e.g. “shall perform”, “shall send”.
- [**Object**] - of the action, e.g., “message”, “book”, a particular state.
- [**Constraint of Action**] - restriction on the action, e.g., time limit.

Condition or constraints can be omitted from the syntax if it is not necessary for the requirements. This syntax gives a general overview but not any strict adaptation rules. However, natural language is susceptible to mistakes. Vague and general terms are avoided while writing requirements. They result in requirements that are often difficult or even impossible to verify. Also, it creates a problem for multiple interpretations. The following are types of unbounded or ambiguous terms [21]:

- Superlatives (such as 'best', 'most')
- Subjective language (such as 'user friendly', 'easy to use', 'cost effective')
- Vague pronouns (such as 'it', 'this', 'that')
- Ambiguous adverbs and adjectives (such as 'almost always', 'significant', 'minimal')
- Open-ended, non-verifiable terms (such as 'provide support', 'but not limited to', 'as a minimum')
- Comparative phrases (such as 'better than', 'higher quality')
- Loopholes (such as 'if possible', 'as appropriate', 'as applicable')
- Incomplete references (not specifying the reference with its date and requirement number)
- Negative statements (such as statements of system capability not to be provided)

The importance of requirement structuring and terminology is indispensable for a large organization like Allseas. As the project undergoes various preliminary checks with many interdisciplinary teams (mechanical, electrical, control, etc.), it is primary to use standard syntax and terms to maintain coherence across the organization.

3.4 Concept development

This step in the methodology is one of the crucial steps. It involves creating a conceptual model of the product with the help of functional analysis. The designer and builder questions are formulated to help the concept development step which is attached in Appendix B. The guidelines for functional decomposition of the product are discussed using the SYSMOD approach. Then, the concept selection chart is proposed. Finally, the procedures for concept evaluation are discussed with the help of a systematic evaluation chart. The output of this step is a fully defined conceptual model that is finalized by various iterations by the design team and related stakeholders through reviews.

3.4.1 Functional decomposition

The functions of the system and the input and output relationship are derived from the requirements. The overall function is depicted by block diagrams based on inputs and outputs of the system. First, the system is viewed in terms of its inputs and outputs without any knowledge of its internal workings. This is termed a black-box concept and it is derived from the SYSMOD approach. Then, the system structure is created in terms of the functionality of the system.

Depending upon the complexity, the complex overall function is broken into sub-functions of lower complexity. The number of sub-function levels is determined based on the relative complexity of the problem. The combination of individual sub-functions results in a function structure representing the overall function of the system. The benefits of breaking down the complex functions are:

- Determination of sub-functions, and helps subsequent search for sub-function solutions.
- Scalable design approach.
- Combination of sub-functions into simple and unambiguous function structure.

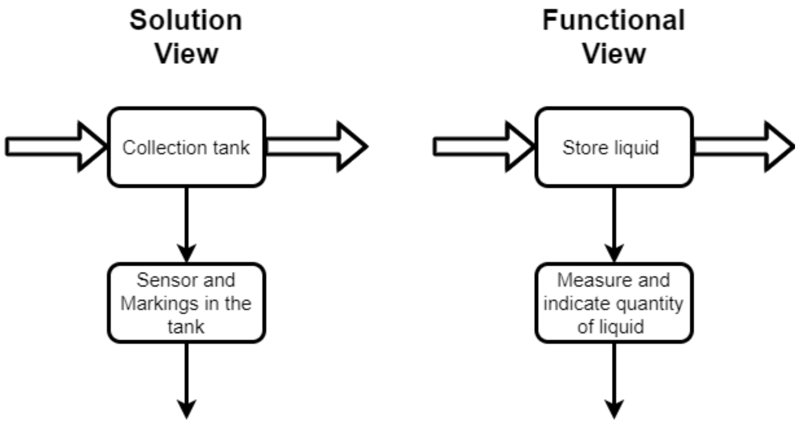

Figure 3.5: Example of solution and functional view [16]

The concepts of solution and functional view are depicted in Figure 3.5. In Allseas, solution thinking is more predominant rather than functional thinking. To effectively implement the functional decomposition concept in Allseas during the machine design, the detailed instructions for establishing a function structure is adapted from [16] and listed:

1. First derivation of an abstracted function structure (black box concept) as per the higher-level design specification table (step-2), and then break this structure down, step by step, by forming various sub-functions. Rather than starting with complex structures, this may be helpful to substitute any idea or concept for the abstracted function structure and then derive other important sub-functions. In this way, the determination of inputs and outputs for the neighboring functional block is feasible.

2. If no clear relationship between the sub-functions can be identified, list down important sub-functions without logical or physical relationships, but if possible, arrange according to the extent to which it can be realized.

3. Logical relationships may lead to function structures through which the logical elements of various working principles (mechanical, electrical, etc.) can be anticipated.

4. Function structures are specified with the existing or expected flow of energy, material, and signals. However, it is recommended to start with the main flow because it determines the design and is easily derived from the requirements. The auxiliary flows help in the further elaboration of the design.

5. From a rough structure, or a function structure obtained by the analysis of known systems, it is possible to derive further variants and hence to optimize the solution, by:
   - Breaking down or combining individual sub-functions.
   - Changing the arrangement of individual sub-functions.
   - Shifting in the system boundary.

6. Function structures should be kept simple, to lead to simple and economical solutions. It is also advisable to aim at the combination of certain functions.

7. In the search for a solution, promising functions structures should be introduced, for which purpose a selection procedure should be employed, even at this early stage (systematic selection chart).

8. For the representation of function structures, it is best to use simple and standard symbols as shown in Figure 3.6.

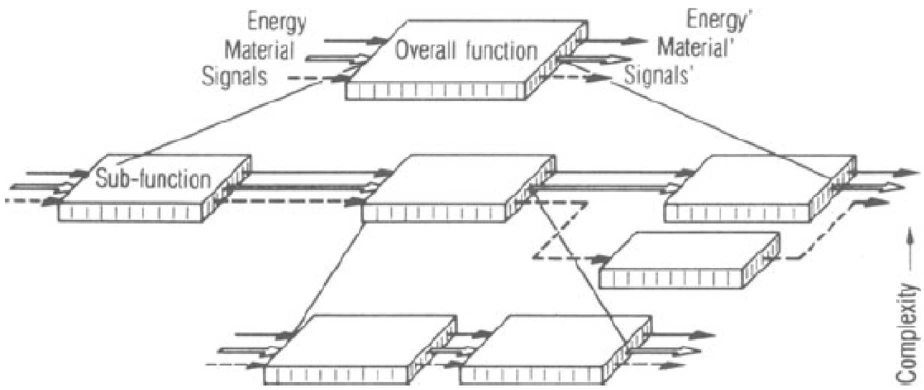

Figure 3.6: Functional decomposition overview [16]

Additionally, along with the function structure block diagrams, the use case diagram can be implemented to depict the functionality. Behavioral diagrams such as state machines, activity diagrams are used to illustrate the flow of the system. To summarize, SysML diagrams are used to create the structure and demonstrate the behavior of the conceptual model of the system.

3.4.2 Sub-function selection

After the functional decomposition, the sub-function table is generated. Commonly, a function of a system can be achieved by 'n' number of ways. Likewise, each sub-function has numerous solutions. In this table, the sub-functions and their respective solutions are shown in Figure 3.7 which was adapted from [16]. The Figure 3.7 also symbolizes the possible combinations of principles that can be a potential solution variant for the product. The solution variants are evaluated in the next step.

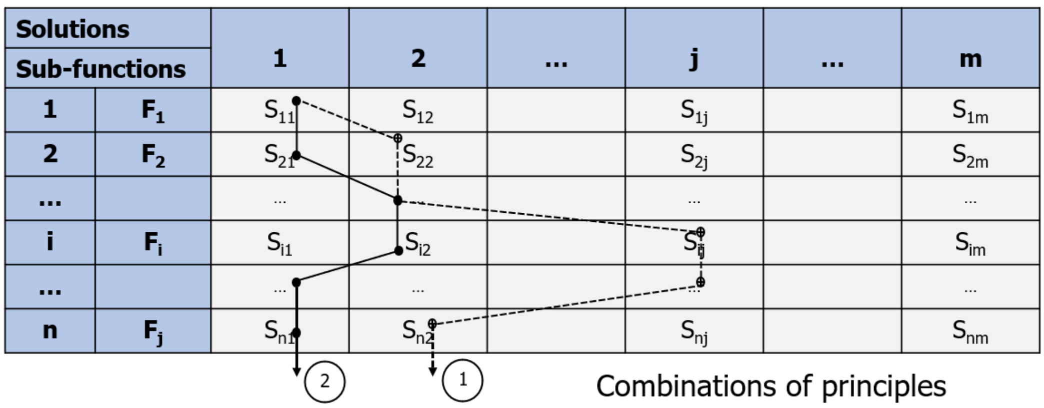

Figure 3.7: Sub function selection chart

The main problem in combining sub-function principles is that ensuring the physical and geometrical compatibility of the solution. It should also avoid geometrical interference in the mechanical systems. The combination of sub-functions can also be established by a compatibility matrix. (i.e.) two sub-function solutions are co-related in a matrix to check the feasibility. To summarize, combine only compatible sub-functions, pursue a solution that meets the demands of the requirements list, and concentrate on promising combinations.

3.4.3 Sub-function evaluation

The use of a systematic selection procedure facilitates the choice of promising solutions. The selection of sub-function is done by two steps, namely elimination and preference. First, all inappropriate proposals are eliminated. If too many possible solutions remain, those that are patently better than the rest are given preference. Only feasible solutions are elaborated and evaluated. Systematic selection chart is displayed in Figure 3.8 which is adapted from [16], where 1, 2, 3, etc. are solution variants of the proposals and the columns are the selection criteria. Also, symbols are used to mark the solution variants in the selection chart.

Allseas evaluation chart						
Solution variants	Selection criteria: (++) Excellent (+) Good (?) Lack of information (-) Bad (--) Worst				Decision: (+) Pursue solution (+) Eliminate solution (?) Re-evaluate solution	
	Selection criteria					
	Demand of Design specification	**Realisable in principle**	**Within cost allocated**	**Resource and expertise availability**	**Remarks**	**Decision**
1						
2						
3						
4						

Figure 3.8: Sub function evaluation chart

The selection criteria are set based on yes/no decisions, quantitative consideration, safety, etc. Some of the essential criteria such as compatibility, full-filling demands, realizable in principle, and within permissible cost are added in the selection chart. The criteria are selected based on an assessment of technical, safety, environmental and economic values. Based upon the project, the criteria, and their ordering changes. The size and complexity of the project vary in Allseas and it plays a role in determining the criteria. The selection procedure is systematized for easier implementation. Also, the reasons for eliminating any solution proposal are accounted to give clarity during the machine design. The selection procedure described can be applied quickly and gives the reasons for selection. Additionally, a high degree of redundancy is built in the selection process as all the possible solution proposals are accounted in the selection chart.

3.5 Requirements database

The requirement database acts as a collection of information throughout the steps of the methodology. The requirements document is finalised after the requirements validation which is not performed in the thesis. Instead, the requirement database is developed in such a way that it helps the documentation. In this section, the guidelines for requirements diagram and classification of requirements are discussed. The outcome of this step effectively contributes to the requirements documentation.

3.5.1 Requirement diagram

A Requirement diagram is a static structure diagram that shows the hierarchy of requirements of a system. The SysML has a dedicated requirement diagram that is used to represent requirements and their relationships. The predefined notations in the requirement diagram provide an essential and central part of the traceability views are the fundamental aspect of a model-based approach (SYSMOD) towards requirement engineering. The significance is that the model is created in the conceptual phase could be validated with the requirements. It makes the conceptual model rational and testable.

The notation used in SysML requirement diagrams is condensed in a single diagram and shown in Figure 3.9. Each requirement in SysML is shown in a rectangle box with the stereotype << *requirement* >>. It consists of two properties *id#* and *txt* properties. The *id#* is unique for every requirement and *txt* contains the description of the requirement. The SysML requirement diagram supports various types of relationships which are shown in Figure 3.9 that are used in the following ways [32]:

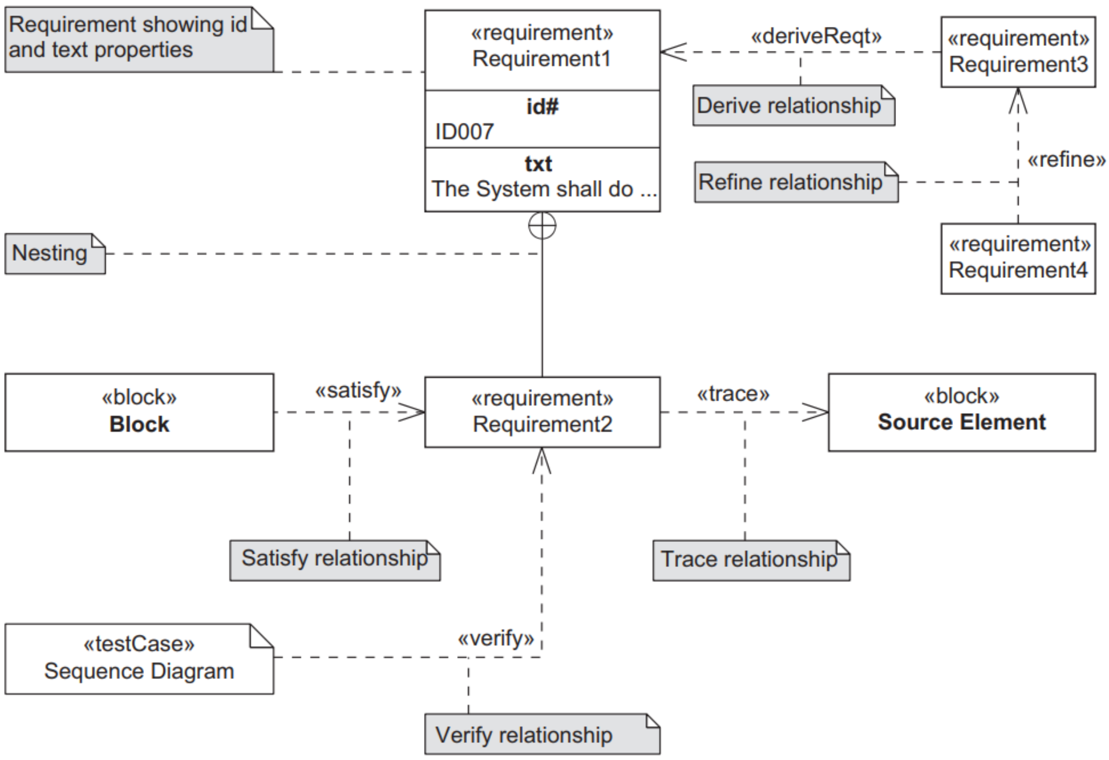

Figure 3.9: Summary of requirement diagram notation [32]

- *Nesting relationship* - Requirements are decomposed into one or more sub-Requirements. In SysML, this decomposition is known as nesting indicated with a nesting relationship such as that shown between ‘Requirement1’ and ‘Requirement2’ in Figure 3.9. It is one of the most common requirement relationships used in the diagram.
- *Derive relationship* - A derived requirement is not explicitly stated by the stakeholder. The

relationship is found by the designer during the modeling. An example showing that 'Requirement3' is derived from 'Requirement1' in Figure 3.9.

- *Satisfy relationship* - It is used to relate the conceptual model to the requirements that those elements are intended to satisfy. Figure 3.9 shows satisfy relationship between a block and a requirement.
- *Trace relationship* - This provides a general-purpose relationship that allows model elements and requirements to be related to each other. An example is shown by the trace relationship between 'Requirement2' and 'Source Element' in Figure 3.9.
- *Refine relationship* - This is used to show how model elements and/or requirements can be used to further refine other model elements and/or requirements. 'Requirement4' refines 'Requirement3' in Figure 3.9.
- *Verify relationship.* - This is used to show that a particular test case verifies a given requirement. This is shown in Figure 3.9 by the verify relationship between the test case called 'Sequence Diagram' (behavior diagram) and 'Requirement2'.

To conclude, SysML requirement diagrams offers several advantages as:

- Standardize the way of specifying requirements through a defined semantics.
- Better organizing of requirements and shows various relationships between different requirements.
- Easy to create and understand.
- Improves the communication between the interdisciplinary team.

3.5.2 Requirement classification

The requirement document serves as a central purpose to the accountability of the requirements in a project. Defined and documented requirements are the key aspect of the development process. During the creation of a requirement document, requirements classification plays a vital role in a comprehensive document. The classification of requirements can vary depending upon the company. The classification schema suggested for Allseas was adapted from ISO: Systems and software engineering - Requirements engineering [21]. Example categories for requirement classification are shown below:

- System requirements specification
- System purpose
- System scope
- System overview
- Functional requirements
- Usability requirements
- Performance requirements
- System interfaces
- System modes and states
- Physical characteristics
- Environmental conditions
- System security
- Information management
- Policies and regulations
- System life cycle sustainment
- Packaging, handling, shipping and transportation
- Assumptions and dependencies

3.6 Database implementation in alternative tools

As there are no dedicated systems engineering tools available at Allseas, a coherent methodology integrated with the generic documenting tools can help to overcome the absence of dedicated systems engineering tools. The primary requirements for the tools in the company are: cost-effective, readily available, should not require expertise to use, and user-friendly. Based on the requirements of the company, the list of applicable tools currently available in Allseas are:

- Microsoft Office suite
- Azure DevOps (basic version)
- Microsoft Visio
- Microsoft Share-point
- Draw IO

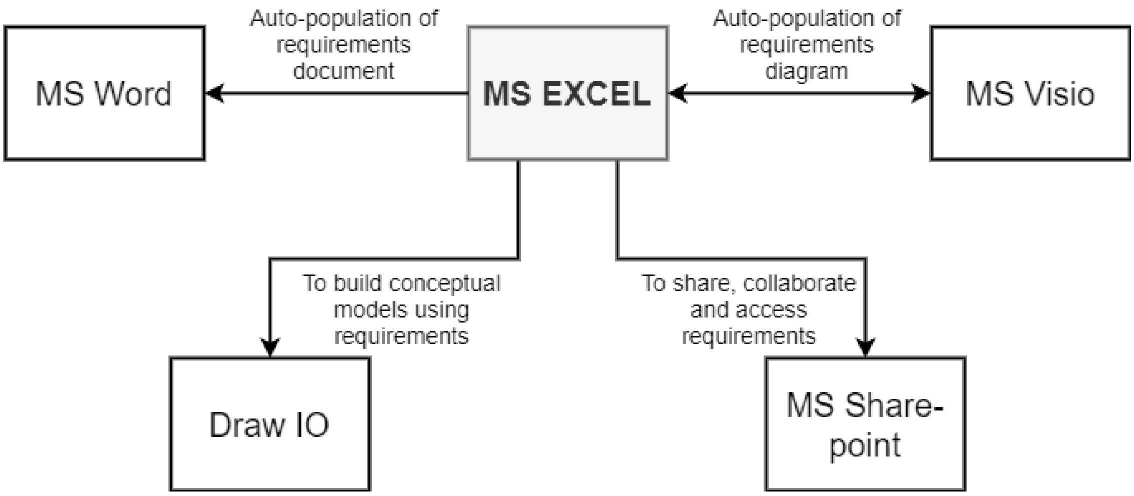

Figure 3.10: Schematic diagram for integration of tools in Allseas

Figure 3.10 shows the schematic diagram for integration of Allseas' tools. MS Excel is selected as a primary tool for implementing the methodology. The different sheets of MS Excel are treated as sequential steps in the methodology. The MS Excel is configured in a way to assist the engineering team to follow the proposed methodology in a structured way while developing the system similar to the approach used in IBM Rhapsody. MS Excel is considered a "living document" while working on the project. Thus, each team member should use this document while generating input or changing information and inform stakeholders and teammates about the changes instead of creating a separate document and distribute it. Such a work style secures the collection of the project information in one document preventing loss of information.MS Word is a popular word-processing program used mainly for creating documents. An integration between MS Word and MS Excel is created using Visual Basic macros to auto-populate the requirements document. A more detailed explanation of VB code is elaborated in Appendix A.1.

MS Visio is diagramming and vector graphics application. The main aim of introducing MS Visio in this project is to create a requirements diagram and depict the conceptual models. The integration between MS Excel and MS Visio is performed in such a way that any requirement changes in MS Excel are automatically updated in MS Visio. A detailed explanation about the integration is included in Appendix A.2. Due to the sudden reduction of the MS Visio license in Allseas, Draw IO is promoted in replacement of MS Visio. In this case, the conceptual models are created in Draw IO but the automatic update of requirements is not possible as MS Visio. An example of building conceptual models in Draw IO is shown in Appendix D. For the case study shown in chapter 4, the system modeling was carried out in IBM Rhapsody for demonstrative purpose in this thesis.

Finally, Allseas share-point is used to share, collaborate and access the living document (MS Excel) periodically to communicate with all the project team members effectively. Azure DevOps suits task separation and allocation which can be extended with modern requirements plug-in for requirements management which is considered as future work.

3.7 Conclusion

In this chapter, the guidelines for the methodology and its various activities for Allseas are explained. The methodology was developed based on the literature review and theoretical background considered in chapter 2. The implementation of the methodology is performed using a case study. The De-icing machine is considered as the case study. Chapter 4 describes the detailed implementation of the methodology in the De-icing project.

Chapter 4

Case study – De-icing machine

A De-icing machine is a mechanical tool, which is used to de-ice the surface of the pipe. This chapter describes the steps in implementing the methodology which was stated in the chapter 3 for the De-icing project as a case study. First, an overview of the De-icing project is given in section 4.1 After that, the mission paragraph and design specification are outlined in section 4.2 and section 4.3. Then, the conceptual model of the system is explained in section 4.4 which includes the SYSMOD steps. Finally, the requirements diagram and requirements classification are described in section 4.5.

4.1 De-icing project overview

This section starts with the introduction of the De-icing project. Then, the problem description is explained. Next, the project justification and objectives are described. Finally, the risk estimation of the project is discussed.

4.1.1 Introduction

The Nord Stream II project (project name) involves laying two 48-inch pipelines through the Baltic Sea from Russia to Germany. The Pioneering Spirit and Solitaire (pipe vessels) are involved in this project. During Nord stream I (older project), winter conditions slowed down the pipe laying process. This project is initiated to reduce delays and focus on ice removal from pipe joints before being handled in the Double Joint Factory (DJF) on both vessels involved. During Nord Stream I, personnel has been equipped with hammers and propane burners to remove ice from pipe joints to complete this task. It was a hazardous task due to falling ice and the low temperatures. The hard work of the crew could not prevent significant delays. Additionally, the vessel wants to step away from this risky activity which was flagged as a QHSE (Quality, Health, Safety, and Environmental) issue.

4.1.2 Problem description

Due to expected cold weather and winter conditions, ice/snow accumulation is expected on the pipe joints during transport on the Pipe Supply Vessels (PSV). Also, experience from the past (Nord stream I) shows that the accumulation can still be significant due to sea spray and precipitation during transport, depicted in Figure 4.1. Ice accumulation can be distributed due to sea spray and precipitation on the pipe supply vessel. However, mostly it is not uniformly distributed. Ice can be present on the cutback area and over the whole surface of the concrete coating. Such accumulation of ice creates the following issues:

- A pipe with ice on the pipe ends cannot be beveled.

- Alignment issues for the bead pass in the double joint factory.
- Welding can only be done under clean and dry circumstances.
- A reduction of the holding capacity of the tensioners due to uneven pipe surface.

Another reason to remove the ice before the joints enter the DJF is to prevent water from entering the vessel. For instance, a 20 mm thick layer of ice on the whole outer surface of the 48" pipe leads to approximately one cubic meter of water per pipe, once melted. This much water is dangerous for the equipment inside the DJF and Firing Line (FL).

Figure 4.1: Ice accumulation on pipe joints [33]

4.1.3 Project justification and objectives

The main goal of this project is to perform pipe laying in severe winter conditions without delays. It decreases the downtime on the vessel leads to significant cost savings as the day rates of Pioneering Spirit and Solitaire are high. Other benefit includes reduction of the maintenance costs for the equipment inside the double joint factory and FL. Moreover, the operator's safety in the vessel can be assured rather than risky activities. A final justification is the reduction of the required man-power for de-icing operations leads to cost reduction.

Therefore, the objective of this project is to create a system, tool, or method that ensures that normal pipe laying operation can be continued at $-15°C$ with pipe covered in ice. This temperature is chosen as most equipment on deck is designed to continue operation to $-15°C$. The maximum ice thickness with this temperature and without delays in the pipe laying process is taken at 20 mm. This thickness is based on pictures taking from pipe joints during the Nord Stream I project, presented in Figure 4.2.

4.1.4 Risk estimation

Risk analysis is a technique used to identify and assess factors that prevent the success of a project. Some of the potential risks for this project are listed:

- Limited time and budget for the project.
- Power requirement in the vessel based on the process.
- Additional corrosion due to extra saltwater on the deck.
- System complies with marine regulations.

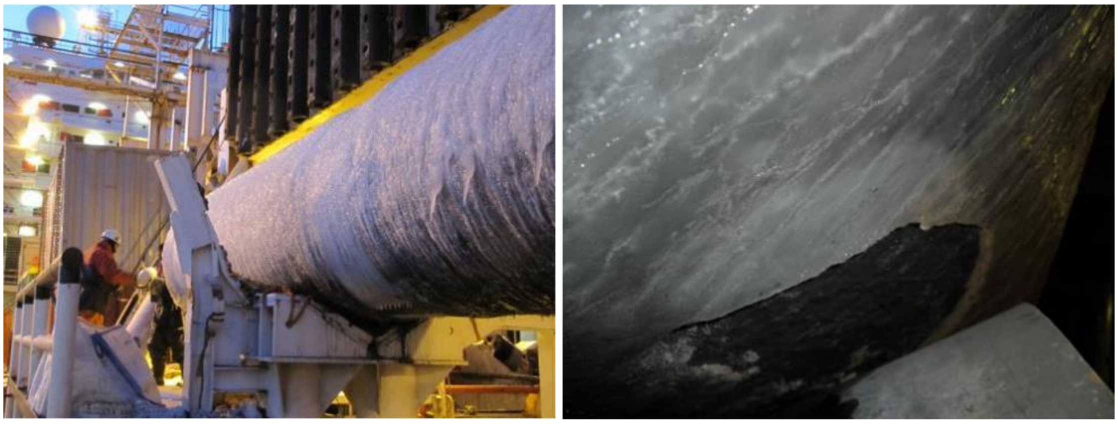

Figure 4.2: Pipe joints in Nord Stream I project [33]

4.2 Mission paragraph

The mission paragraph is the initial step of the methodology. The major aim of this step is to understand the context of the problem in the De-icing project. This is achieved through checking the questionnaire and answering the questions by the owner of the project. The context of the owner changes according to the system considered. In Allseas, the project sponsor, project manager, and engineering sponsor are considered as an owner in Heavy lift department. In another hand, the unit head and project lead are considered as the owner of the industrial equipment department. To summarize, the owner changes depending upon the size of the department and the system. Identification of the owner, designer and builder and knowing their responsibilities for the project are mandatory.

Based on the Zachman framework, the questionnaire is designed. An example list of questions and answers for the de-icing case study is presented in Table 4.1. It is categorized by What, How, When, Who, Where, and Why. The questions and answers in the Table 4.1 are differentiated with black and red color respectively. The owner of the project answers the questions with the help of the following:

- Action request form from the vessel team.
- Stakeholder communication.
- Project description.

In Allseas, during the population of answers for the mission paragraph, the Action Request Form (ARF) takes place a major role in answering the predefined questionnaire. The analysis of ARF is discussed in detail in the upcoming sub-section. Also, left out answers are gathered by meetings, discussions, interviews, etc by various eliciting techniques depending upon the owner of the project. After populating the answers, the analysis is performed. The key identifiers are extracted to obtain important details about the project. The purpose of the project and root cause of the problem is the most significant identifiers which need to be answered by the questions. Alongside, the old product and the disadvantages of the old product are recorded. Meeting details, schedules, and responsibilities are also decided and recorded beforehand to avoid confusion in the later phase of the project. The identifiers can vary depending upon different types of projects. Finally, the essential aspect of the analysis is to link the identifiers with the acquired answers from the questionnaire.

Zachman Framework	What (Inventory Sets)	How (Process flows)	Where (Distribution Networks)	Who(Responsibility Assignments)	When (Timing Cycles)	Why (Motivation intentions)
Owner	What are you trying to solve with this project? – Root cause of the problem To remove ice from the pipe before entering the DJF or RBS What are the clients planning to achieve? Proper welding of the pipes without delay in time during winter condition What prerequisites are already there for this project? Not known What do you consider as the biggest risks for this project? Proper techniques and design should be finalized with the domain expert before developing the machine Are there any relevant deliverables or artifacts available for review? Not known What is the cost allocated for the project? Not known What type of material are we working (to remove, to clean, to join)? Ice (thickness of ice not known)	How do you prefer to communicate? Teams meeting How often you prefer to communicate with vessels team? Bi-weekly communication is preferable How are the clients solving the problem currently? By, using hammers or mechanical tool to break the ice How do you evaluate previous product? - History of the project No automation is involved in the previous product only mechanical and labour efforts; Cost of the man hour and reduction in operation time should be accounted If suppose it is older project, how have the previous solutions failed? Not known	Where and how much are the working area for our product? PS and xxxx m2; 3 favourable location in the vessels Do you see any dependencies or similarities between this project and other projects? Alignment mechanism can be used from Internal pipe cleaning or Grit blasting machine operation In which technical area does the project mainly focus on? Automation; Conduction; Heated coil. In which business area does the project mainly focus on? Increase the pipelaying speed, reducing the operation time What is efficient working area? Not decided (full pipe or ends of pipe), must choose in-terms of principle and cost analysis What is area of disposal, if any? Collection of water	Who are you solving this problem for? Vessel team (winter condition) What are the different roles of the people involved in the project? Kirill – Owner, Niek & Hendrik – Designer, xxxxx – Builder Does the client have proper knowledge to use the product? Demonstrate the digital design of the conceptual model Who else do we plan to collaborate with outside of our team? Domain experts from another team for cross checking its correctness	When does our project starts? Jan 2018 When does conceptual design phase ends? May 2018 When does the project ends? November 2018	Why do we need this project? - outcomes To remove ice from the pipes, extra measure for pipe handling and safe workability for the operators What value does it bring to the client? Reduction in vessel manpower, decrease labour efforts, safe working condition and minimize the downtime

Table 4.1: Owner - Questions and Answers

Identifiers	De-icing example
Purpose	The purpose of the project is to remove ice/snow from the ends of the pipe.
Root cause	To achieve proper welding quality by removing the water deposition on the ends of the pipe.
Benefits	By implementing it properly, there will be a reduction in vessel manpower, decrease labour efforts, and increased speed of welding.
Old products	Hammers and mechanical tools are used to break the ice.
Disadvantages	The old product leads to increase in the cost of man-hour and operation time.
Meeting details	Client meetings will be on Teams and a Bi-weekly meeting is preferable.
Commonalities	To reuse some aspects from the previous project, vague commonality can be picked from the Grit blasting machine.
Responsibility	Vessel team – Owner, engineer 1 & engineer 2 – Designer, engineer 3 & engineer 4 – Builder.
Schedule	Project start date – Jan 2018, Project end date – Nov 2018.

Table 4.2: Answers co-related with identifiers

After the analysis, the sample list of identifiers and co-related answers are tabulated in 4.2. Moreover, an example of a mission paragraph for the De-icing case study is presented below:

`Mission paragraph`

The purpose of the project is to remove the ice/snow from the pipe before entering the DJF to achieve safe workability for operators and extra measures for pipe handling. By implementing it properly, there will be a reduction in vessel manpower, decrease labor efforts, safe working conditions, and minimize downtime. Hammers and mechanical tools are used to break the ice leads to an increase in the cost of man-hour and operation time. Client meetings will be on Teams and Bi-weekly meeting is preferable. To reuse some aspects from the previous project for the alignment system, vague commonalities can be picked from the Grit Blasting machine. Vessel team – Owner, engineer 1 & engineer 2 – Designer, engineer 3 & engineer 4 – Builder. Project start date – Jan 2018, Project end date – Nov 2018.

The mission paragraph act as the focal point during the design process. Also, the process is iterative can involve review cycles when the requirements are not consistent which depends on the project. The derivation of the mission paragraph is the outcome of this step.

4.3 Design specification

This step consists of three activities resource identification, study about the topic, and requirement formalization. Also, multiple sequential steps are elaborated in requirement formalization. The requirements structuring and terminology are known to account the requirements consistently.

4.3.1 Resource identification

Resource identification is one of the essential activities. As discussed earlier, most of the projects in the Allseas are deployed in the vessel. The resource identification sheet is created to help engineers to know about the various resources such as equipment, tools, facilities, labor, consumables, etc. in the vessel.

The requirement identification ought to be filled by the vessel's team in guidance with the designer. In this case study, an example resource sheet is filled alongside with the designer based on the previous problems faced in the project. Some of the examples of resource identification for the De-icing project are listed:

- **Local utility requirements**
  - *Electrical energy*: Electric switchboards - 230V and 3 phase current. It may be useful for some modes during the operation which can reduce the generator cost.
  - *Hydraulic energy*: Hot water blow guns – During the waiting period, the hot water blowgun can be clamped in a fixed spot and can be sprayed on the ice-coated pipe to reduce the thickness of the ice.
  - *Mechanical energy*: Motor - It can be used to move some parts of a machine which building reduce the cost of the product.
- **Global utility requirements**
  - *Electrical energy*: Transformers – High amount of current can be generated from x location. If there is a way for transferring to the current location, it would be efficient.
- **Space requirement**
  - *Machine location*:

    The system is placed in the pipe yard. Ice removal operation is done after loading the pipe joints. Moreover, the ice should be removed before entering the DJF. The schematic diagram of machine location in the vessel is shown in Figure 4.3.

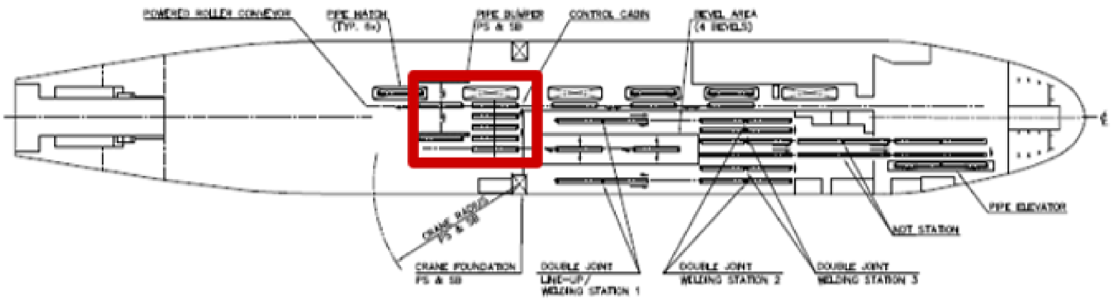

Figure 4.3: Vessel top view with possible location marked [34]

  - *Operation space*:

    Figure 4.4 shows a more detailed drawing of the pipe yard. The De-ice machine locations are highlighted with a yellow box.

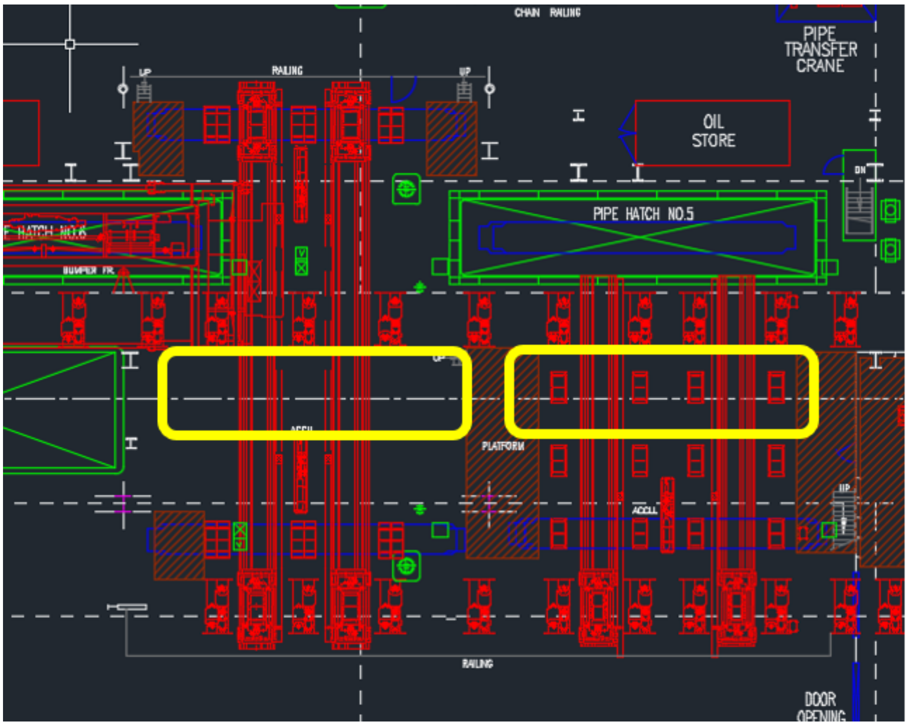

Figure 4.4: Detailed drawing of De-ice location [34]

- **Vessel's in-house condition**
  - *Roofing*: Proper roofing is present in the vessel to cover the machine from water or dust.
  - *Walls and barriers*: This is present to separate from another process like DJF.
  - *Fire/Sprinkler system*: This fire alarm system is present in the working location acts as an emergency unit.
- **Miscellaneous needs**
  - *Storage containers*: If there is a big storage container that can be used to store the disposed water but depends on the shape and size of the container.
  - *Lifting machine*: It can be used to lift the product during commissioning. The lifting machine can lift 250 kilos.
  - *Electrical cable rails*: This can be used when the system is designed to have an electrical cable rail system.

An example of a resource identification activity is performed with Allseas engineers to get acquainted with the activity. The sheet is generalized and it can be used for the other product development project. The resource sheet is developed with some pre-listed resources which makes it easy for the vessel's team to pick one or multiple resources among them. This activity promotes sustainability in the product and also reduces the project cost.

4.3.2 Study about topic

This step is undertaken to know about any information which could ease the design process. First, the root cause of the problem is to achieve welding quality by removing the ice from the pipe.

The information from the previous step (resource identification) such as the availability of motor, water blowguns, the electric switchboard is considered while designing to reduce project cost. Importantly, a list of key terms related to this case study is derived which can be researched in a scholarly article database. Some of the key terms used for research are Deice, Melting, Conduction, and Heat transfer. This is conducted to find state-of-the-art solutions and technology which can be incorporated into the project. Also, through Allseas intranet database where a list of machines, equipment, tools, and different department's project information are investigated and gathered information about this specific project. Finally, the collected information is pitched to the project team along with the domain expert to check the correctness of the information.

4.3.3 Requirement formalization

The requirement formalization technique helps to formulate a well-defined design specification table. For instance, the design specification could include required geometry, environmental factors, operation, transportation, maintenance, ergonomic factors, etc. In this step, a list of predefined checklists for engineering design is referred to create the higher-level design specification table.

IN-010-03-T-005
INNOVATIONS ACTION REQUEST FORM

Allseas

Description of requested action:

Winterization of PS pipe handling equipment for Nordstream II.

Investigate:

- if current PS design temperature of -15 degrees Celsius is sufficient
- possible condition of pipes supplied by PSV prior to lifting (covered with snow / ice?)
- how to remove snow / ice from pipes to safely lift pipe on board (if covered)
- what extra measures are required for pipe handling equipment to function (wipers for snow on tracks, snow built-up that might freeze, etc.)?
- if pipes in the pipe stacks can be protected against snow and ice to prevent them from freezing up
- how to de-snow / de-ice pipes that are in the stack; how to inspect this and what to do with the melting water?
- requirements to clear pipes covered with snow before entering the DJF and/or RBS
- how to safely work on slippery decks and platforms, replace tear plate with grating will resolve some issues (i.e. bumper frames platforms)

'Standard' preventive measures like winter clothing, winter (hydraulic) oil, draining of certain piping and covering of certain equipment is not considered part of this action request. This is to be double-checked with TD / operations to make sure nothing is forgotten.

Expected schedule	Expected responsible persons/departments
Depending on vessel schedule: to be installed o/b from April 2018 onwards. Engineering, fabrication, and transport should therefore be completed before that. Larger structures most likely to be installed in Rotterdam.	TD (TBC)

Table 4.3: Action request form [35]

To understand the approach and formalism presented in the subsection 2.6.2, the Action Request Form (ARF) from the De-icing project is considered. Table 4.3 represents the shortened version of the ARF from the vessel's team to the Industrial equipment department which consists of a description of the requested action, expected schedule, and expected responsible persons/departments. During the implementation of the methodology in a new project, it is important to include information obtained from the mission paragraph and perform the approach of formalization. In this case study, only the ARF is considered to formalize to simplify the understanding of the concept of requirement formalization. The sequence of steps is as followed:

Step 1: Initial requirement setup

The textual description in the ARF is considered as the narrative requirement. From the narrative requirement, an initial requirement is formulated as shown in Table 4.4. The first step is to abstract the level of details of the requirements. Then, each requirement is specified with the requirement number and written in the standard ISO format. Finally, each requirement is segregated in terms of functions and parameters. Functions (F_i) deals with the functionality of the system and the parameters (P_i) refer to inputs, outputs and other aspects of the system.

Rq. no	**Requirements**	**Functions & Parameters**
R1	The current PS design temperature is $-15°C$.	P1
R2	The pipe is covered by ice before lifting.	P2
R3	The system shall remove ice from the pipe to safely lift the pipe on board.	F1, P3
R4	The system shall perform extra measure for pipe handling equipment.	F2, P4
R5	The system shall protect ice from the pipe in the stack.	F3, P5
R6	The system shall remove ice from the pipe in the stack.	F4, P5
R7	The system shall inspect the condition in the stack.	F5, P5
R8	The system shall remove the meting water.	F6
R9	The pipe should be clear before entering DJF.	P5
R10	The working condition should be safe (safety).	P3
R11	The system should provide collection and draining of water.	F6, F7, P6
R12	The project deadline is April 2018.	P7
R13	The structures of the system will be installed in Rotterdam.	P8

Table 4.4: Formulated initial requirements

Step 2: Mapping entity concepts onto the abstract concepts

Before the performing the mapping, the terms used are explained: *"Axioms"* are design summary checklist such as functions, geometry, kinematics, energy, etc. *"Entities"* are the sub division of Axioms shown in Table 3.2. Both Axioms and Entities together forming the *"Requirement checklist database"* (C) shown in Figure 2.14. *"Abstract concepts"* are from the formulated initial requirements shown in Table 4.4.

Entity concepts are mapped onto the abstract concepts defined in step 1. For instance, considering the initial requirement R_3 to explain the mapping of entity concepts onto the abstract concepts. The following mapping $\{e_1 \rightarrow F_1, e_8 \rightarrow P_3\}$ = (function → remove, safety → safely lift) according to Table 4.4 and Table 4.5. Likewise, all the requirements are mapped into their entity concepts.

Step 3: Creating interaction matrix

An interaction matrix is constructed to identify the interactions between Requirements (R) - X-axis and Requirement checklist database (C) - Y-axis as shown in Table 4.5. Each requirement can have various entity concepts. Also, the function C_1 has entity concepts such as $e_{1.1}$, $e_{1.2}$, etc. which represents the functional categories and it changes depending upon the case study.

Requirement checklist database		Formulated initial requirements												
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
Function	C1			e1.1	e1.2	e1.3	e1.3	e1.3	e1.1			e1.1		
Geometry	C2				e2	e2	e2	e2						
Kinematics	C3													
Forces	C4													
Energy	C5											e5		
Material	C6		e6							e6				
Signals	C7													
Safety	C8			e8							e8			
Ergonomics	C9													
Production	C10													e10
QC	C11													
Assembly	C12													e12
Transport	C13													e13
Operation	C14	e14												
Maintenance	C15													
Recycling	C16											e16		
Costs	C17													
Schedules	C18												e18	

Table 4.5: Interaction matrix

Step 4: Creating design specification table

The higher level DS-table is then created for the identified requirements with the help requirement checklist database (C). Due to space limitations not all identified requirements in the case study are shown in Table 4.6. For a bigger project, the responsibility is allocated according to the design specification categories.

Design Specification Sheet **Project: De-icing project**	**Responsible**
Functional performance: 1) Remove ice from pipe Collection of water Disposal of water 2) Perform extra measure for handling equipment 3) Protect from pipe on stack Remove from pipe on stack Inspect from pipe on stack *Geometry* *(Product)* No information *(Pipe)* Pipe in stack *Kinematics* --- *Force* --- *Energy* Storage Disposal *Material* Ice covered before the process Clear pipe after the process *Safety* Be safe for operators *Production* Large structures in Rotterdam *Transport* Large structures in Rotterdam *Operation* PS design temperature - 15°C *Maintenance* ----	

Table 4.6: Design specification table

The higher-level design specification table is the outcome of this activity. Importantly, this DS-table displays the requirements which makes the designer easy to spot the uncertainties and abnormalities in the requirements. It prevents a lot of unnecessary development time and solutions for non-existing issues. Moreover, this answers one of the essential aspects of the research question: spot errors in requirements during offshore equipment development. For instance, analyses are made in the DS-table. The following problems are noted:

- <u>Functional performance</u> - Contradicting requirements
  The functionality of the system is not clear. Remove ice from both locations? During the pipe in the stack and also in the waiting time?
- <u>Geometry</u> – Effective area of working
  The ice has to be removed from the whole pipe or the ends of the pipe?
- <u>Energy</u> - No constraints
  No available and defined force/energy is proposed?

The following problems from the DS-table are traced back to the requirements. The problems are discussed with the respective stakeholders and the owners of the project. Based on discussions, the inconsistencies of the requirements are solved. This activity establishes a synergy between team members and stakeholders. Thus, helping to improve the development process of offshore pipelay equipment and subsea tools.

4.4 Concept development

Concept development is one of the vital steps in the methodology. This section involves creating conceptual models of the product by functional decomposition using the SYSMOD approach. The SYSMOD approach is requirements-driven which means that from the previous steps, its goals and main objectives are derived. In the next steps, all logical and physical system components and their relations are inferred [36]. After creating the conceptual model, selection and evaluation of the model are performed. Adding to it, the designer and builder questions help to design the conceptual model which is attached in Appendix C. The different steps of the concept development are presented.

4.4.1 Project context

The first step is defining the project context for the system. A project context represents the common goal towards which the team will work. Such goals are the key in determining the subsequent steps. Before designing the system, the project boundaries have to be defined clearly. The main project boundaries are described in Figure 4.5. The project boundaries are indicated by a dashed black line. The project boundary gives an idea about the before and after process of operation which helps the engineer during the concept development process. Additionally, it also gives the location knowledge of the machine where it has to be commissioned.

The De-icing machine is operated in the ships of Allseas engineering B.V for pipeline production. Therefore, the working environment of the machine is not steady. These factors are considered during the designing process. From Figure 4.5, the De-icing machine highlighted in colour is the *system* to be developed. Also, the collection and disposal system falls under the scope of the project. The arrows depict the sequential process of loading pipes, waiting for the Double Joint Factory (DJF), De-icing machine, Pipe into the DJF, and welding pipe sections.

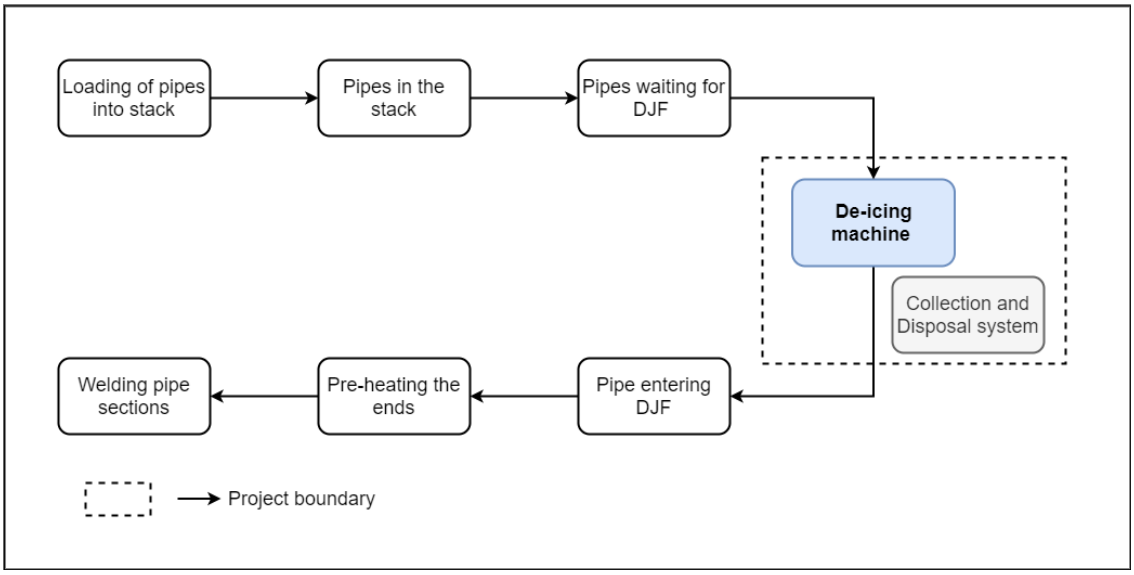

Figure 4.5: Project context - De-icing machine

4.4.2 System context

System context describes the interaction of a system with its environment. For a system to be developed, it is important to consider the system context. By defining the system and its boundaries as well as the relevant information about the system environment, aspects regarding system development are extracted. At this stage, the system is considered a black box. A black box is a system that can be viewed in terms of its inputs and outputs, without knowledge of its internal workings. In this case study, the de-icing machine is considered to be the system.

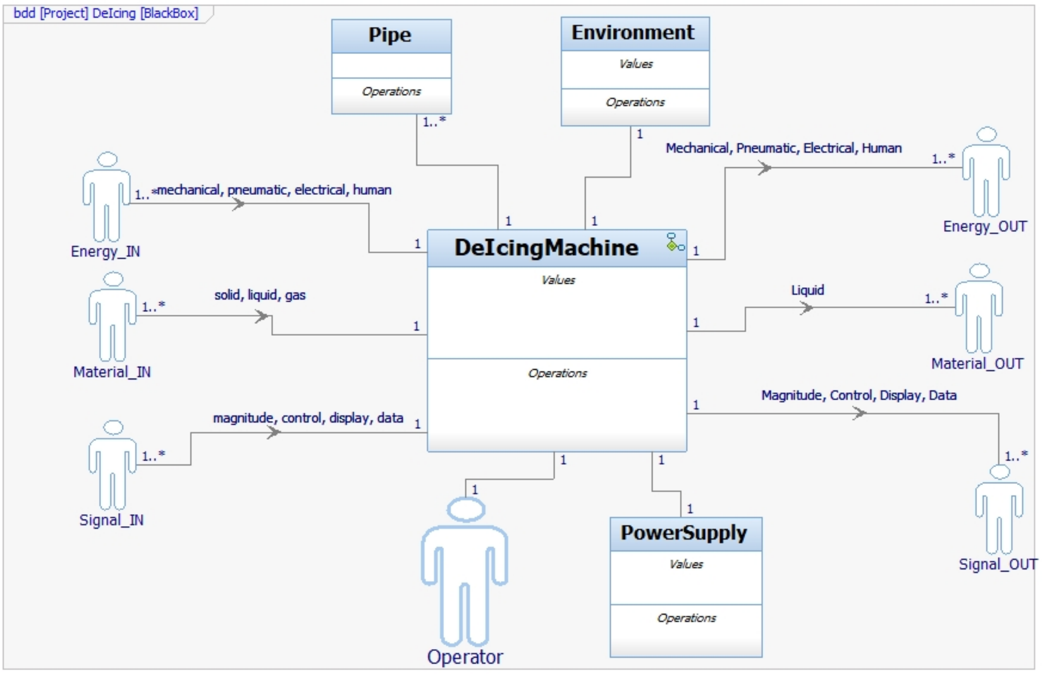

Figure 4.6: System context - De-icing machine

A system context diagram is a diagram that defines the boundary between the system or part of a system, and its environment, showing the entities that interact with it. This diagram is a high-level view of a system [37]. In this case study, the concept of system context is represented using a block definition diagram. The relation between the system and the actors is shown in Figure 4.6. The actors in this example are the inputs and outputs of the system and the operator. Also, the pipe and the power supply are considered. In Allseas, the Energy, Material, and Signal form the basis for all technical systems. For instance, the energy_in can be mechanical, electrical, human, etc. The flow (arrows) represents the direction of flow and the multiplicity in the Figure 4.6 represents the number of actors interacting with the system (i.e.) an allowable number of instances of the element. 1..* near the actors represents that one or many of the same actors can interact with the system. To conclude, this diagram helps the engineer to view the system by inputs and outputs without the information about the internal working of the system. The system context creates the basis for the conceptual design.

4.4.3 System structure

This subsection describes the structure of the De-icing machine. The block definition diagram (BDD) is used to describe the structure of the system. During the development of conceptual models, the level of abstraction plays an important role. First, the system level decomposition is performed. Second, the sub-system level decomposition is presented. Finally, the sub-system's internal interaction and also interaction with other subsystems are created.

System decomposition

Figure 4.7 describes the overall structure of the system. Based on the information from the previous steps of the methodology, the De-icing machine is divided into Alignment system, Melting system, and Collection and Disposal System. The sub-system is connected to the De-icing machine with the directed composition which means the sub-system lies inside the system. The color-coding to distinguish the various sub-system for better visualization and the dedicated color for each subsystem is used throughout the modeling to achieve coherence.

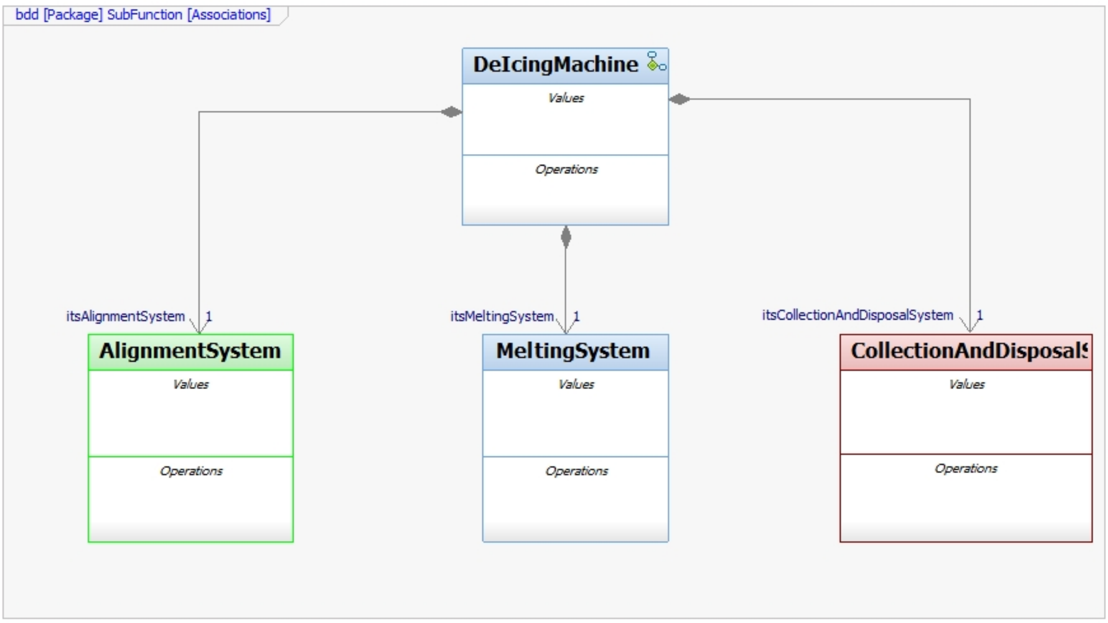

Figure 4.7: System level decomposition

Figure 4.8 depicts sub-system interaction to the external actors and also the interaction between the subsystems. A bi-directional flow is created between the alignment system and the melting system based on their expected operation. Similar to the system context, the flow and multiplicity represent the direction of flow and the number of instances of the element respectively.

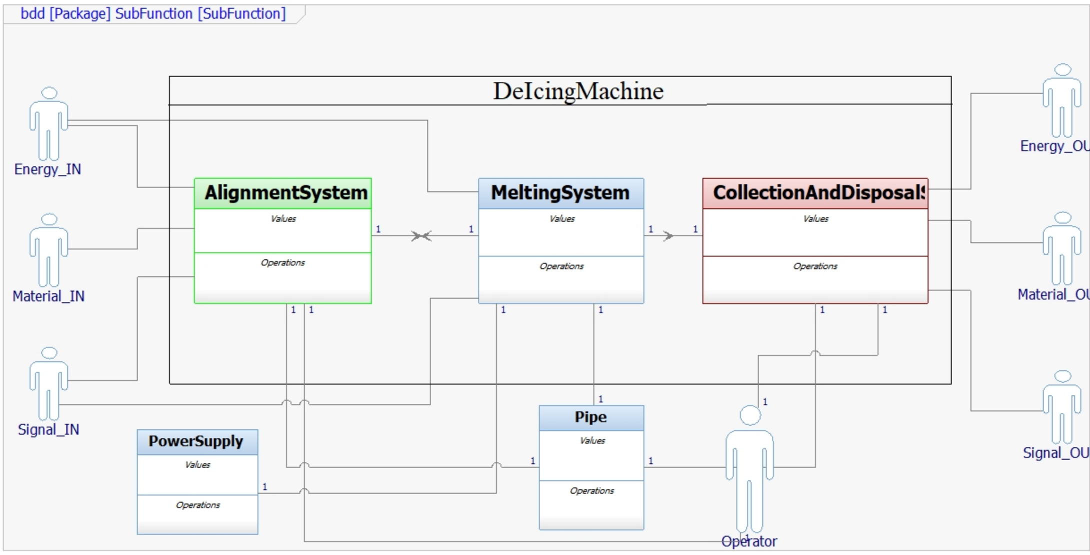

Figure 4.8: Sub-system interaction

Sub-system decomposition

Each sub-system is decomposed into its respective functionality blocks (components). Components are then decomposed into cohesive, well-defined sub-components. Although, the sub-components hierarchy is not covered in this case study. The subsystem decomposition is explained as follows:

Alignment system

The alignment system is segmented into five functionality blocks: X translation system, Y translation system, Z translation system, Pipe measuring system, and Locking and Unlocking system as shown in the Figure 4.9. Every functionality block is connected to that alignment system through directed composition relation.

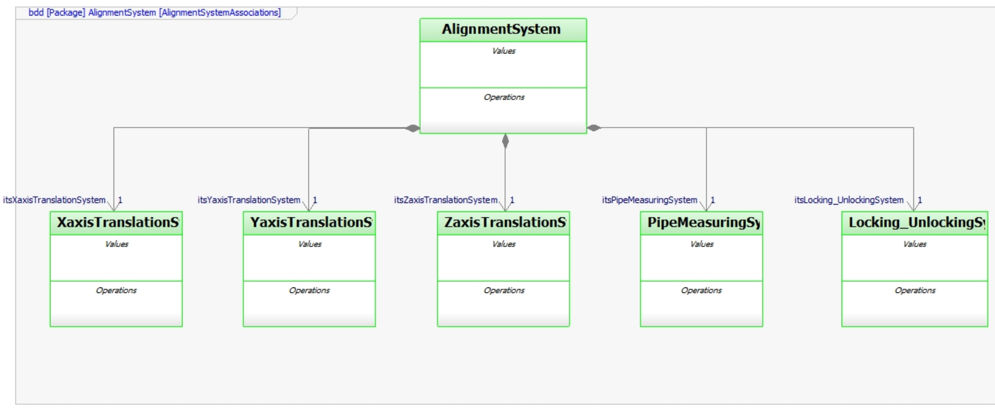

Figure 4.9: Alignment system decomposition

Figure 4.10 represents the interaction between the subsystems and with the actors. The actor energy interacts with X, Y, and Z translation in turn links to the locking and unlocking system. Likewise, the actor signal interacts with the pipe measuring system. In addition to that, the locking and unlocking system interacts with the pipe, operator, and melting force system.

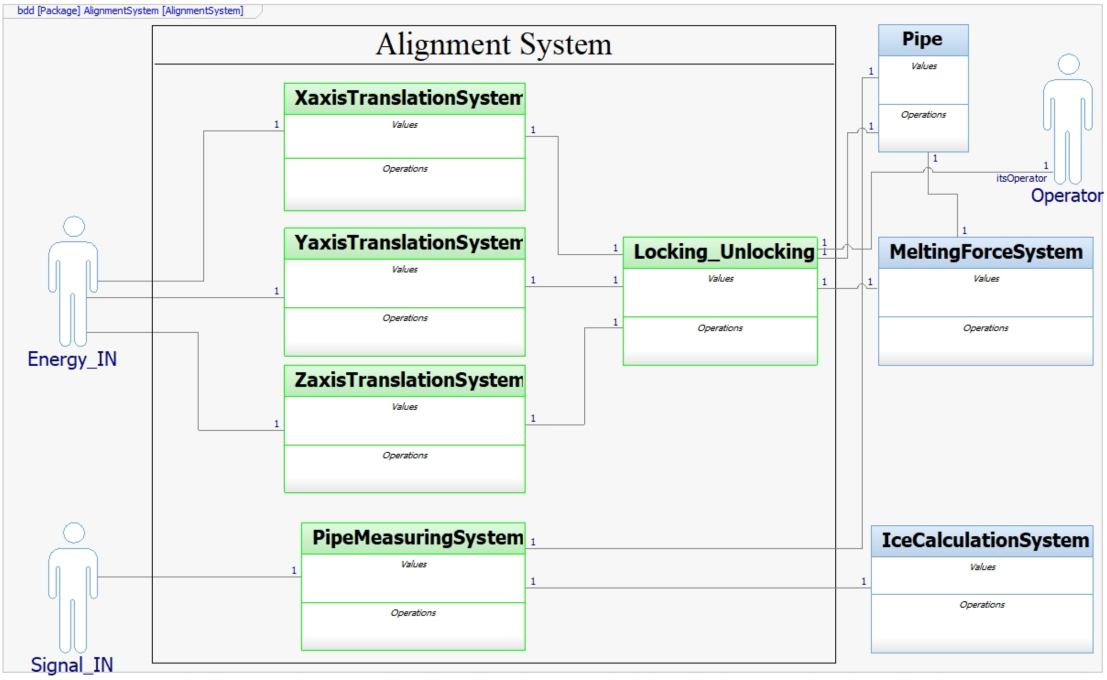

Figure 4.10: Alignment system interaction

Melting system

The melting system is divided into two functionality blocks: The melting force system and the ice calculation system as shown in the Figure 4.11.

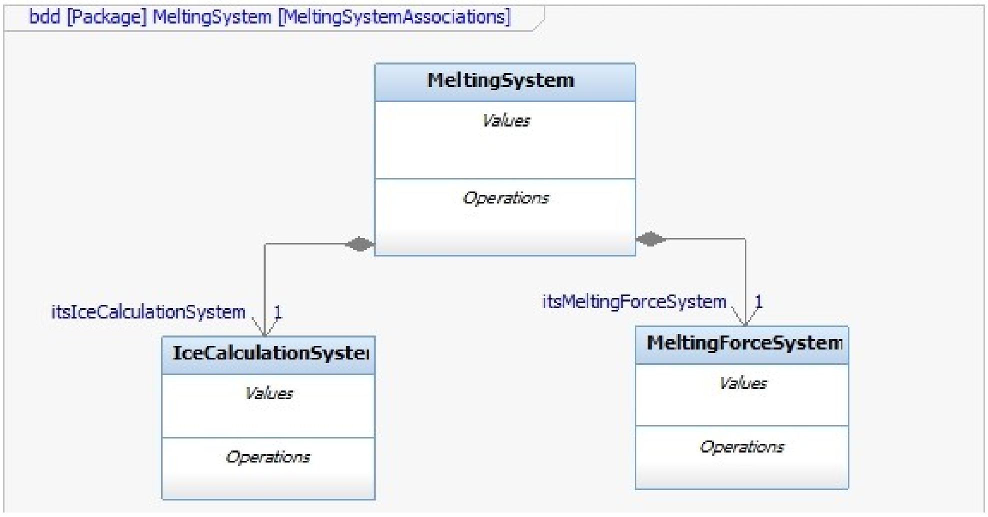

Figure 4.11: Melting system decomposition

Figure 4.12 represents the interaction between the components of Alignment and Collection and Disposal system. The actor energy is connected to the power supply in turn links to the melting force system. Likewise, the measuring system is connected to the ice calculation system. Also, the melting force system interacts with the pipe, locking and unlocking system, and collection system. The locking system is used to lock the pipe before the melting process. Later, the pipe is unlocked after the melting process. It explains the interaction between locking and unlocking and the melting force system.

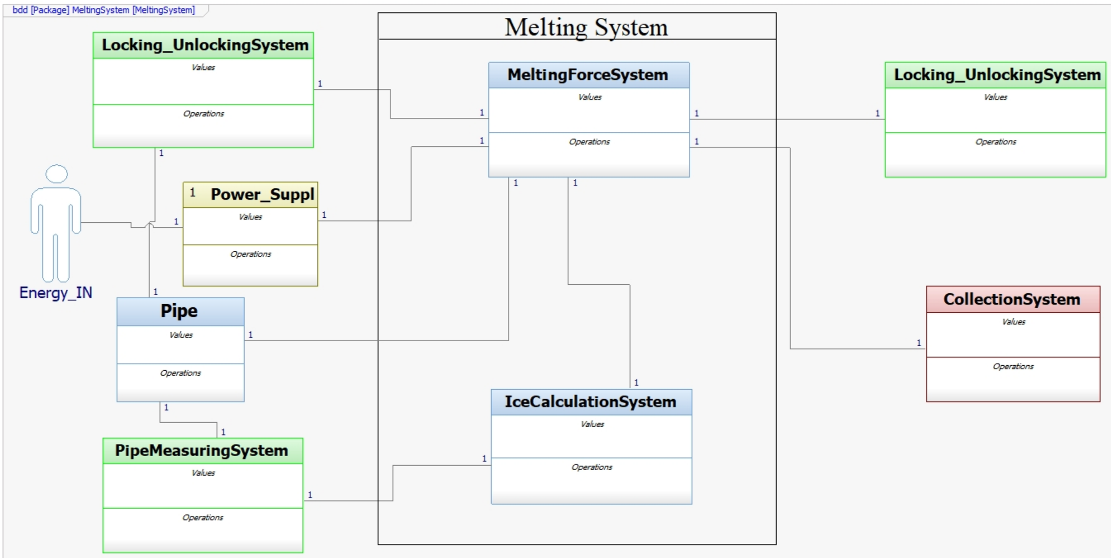

Figure 4.12: Melting system interaction

Collection and Disposal system

Similar to the previous sub-system, the collection and disposal system is classified into two systems such as collection system and disposal system is depicted in Figure 4.13.

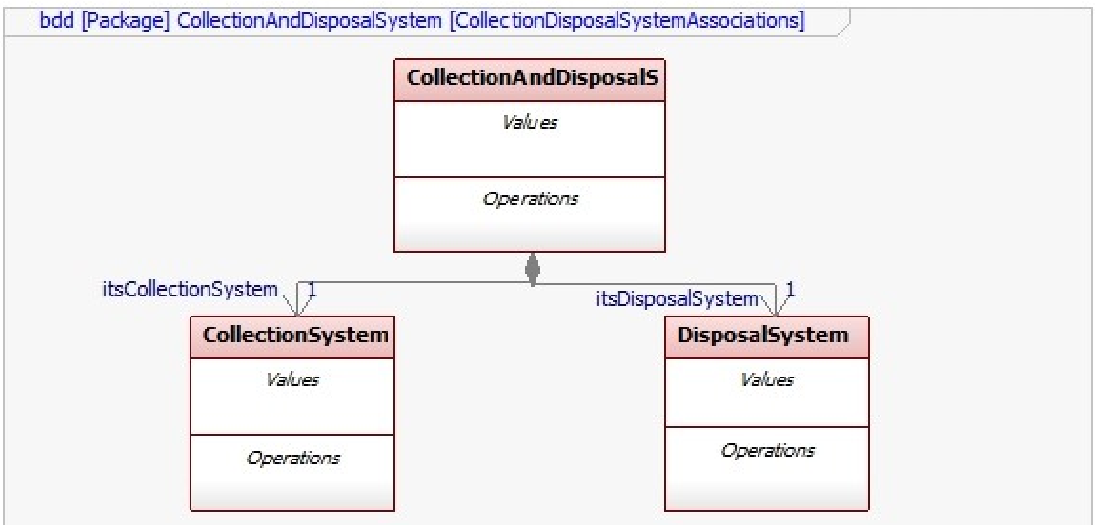

Figure 4.13: Collection and Disposal system decomposition

Figure 4.14 also depicts the interaction between the subsystems and with the actors. The melting force system interacts with the collection system. For instance, after the operation, water from the pipe is collected and disposed by the operator which explains the link between the collection and disposal system and the interaction between the energy_out, material_out, and the operator.

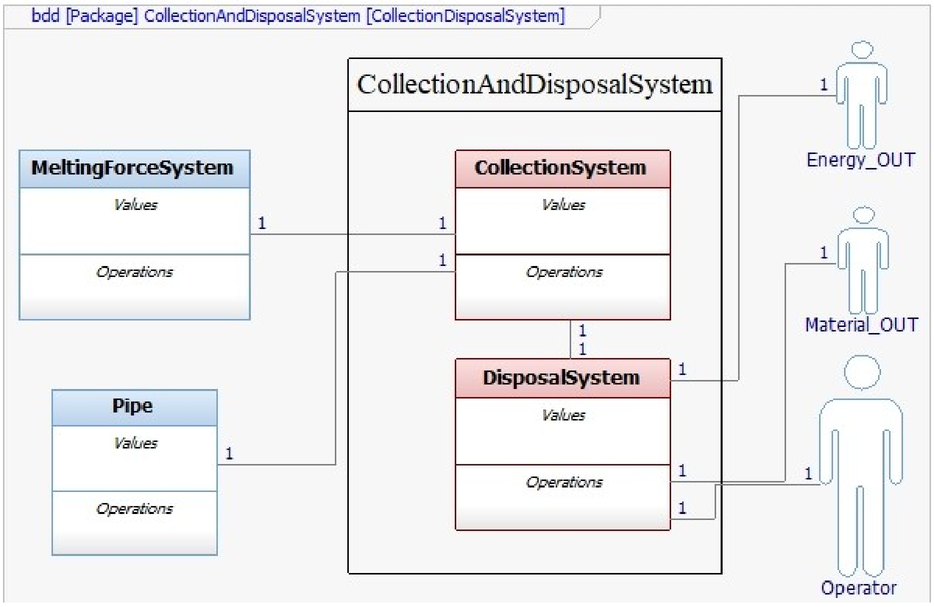

Figure 4.14: Collection and Disposal system interaction

4.4.4 Use cases

Use case (UC) is a service provided by the system to achieve a goal. A use case diagram is a simple representation of a user's interaction with the system that shows the relationship between the user and the different use cases in which the user is involved. During the conceptual phase, the use case diagram does not show the user's interaction (not yet known) instead it shows the actor's interaction (energy, material, and signal). After the conceptual model is finalized, the user interaction can be represented in the use case diagram. Also, with more additional information, the same use case can be expanded with the template for the use case description taken from [38] as shown below:

- Use case name
- Use case ID
- Short description
- Pre-condition
- Post-condition
- Error situations
- Actors involved with UC
- Trigger
- Standard process
- Alternative process

Figure 4.15 provides an overview of the use cases and the interaction with the actors. This use case diagram depicts the functionalities of the created subsystems namely the Alignment system, Melting system, and Collection and disposal system. It is created following the system structure. The same color coding is maintained for better understanding. The relations between the use cases are denoted with the help of *include* relationships. The use cases of the subsystem are presented:

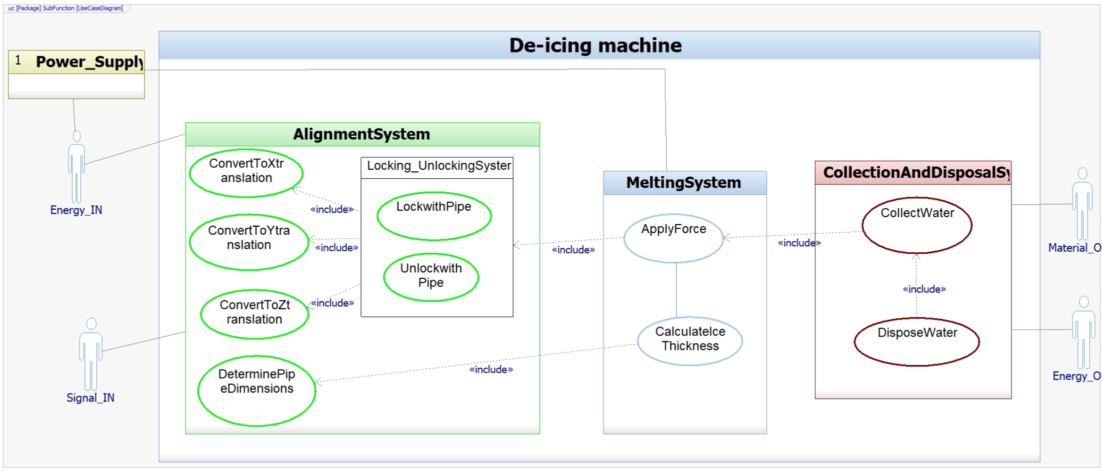

Figure 4.15: Use case diagram

- Convert X translation
- Convert Y translation
- Convert Z translation
- Determine pipe dimensions
- Lock with pipe
- Unlock with pipe
- Apply force
- Calculate ice thickness
- Collect water
- Dispose water

4.4.5 System behaviour

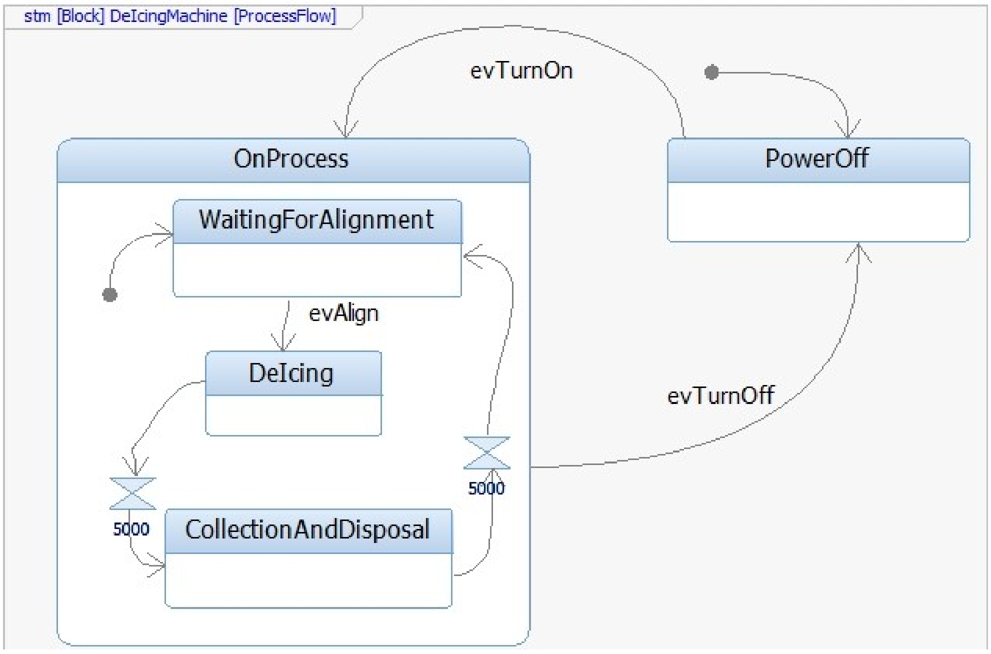

Figure 4.16: Expected operation of the system

In this case study, the behavior of the system is anticipated and represented through the state machine diagram. The main purpose of the diagram is to depict in a pictorial representation which helps the designer to understand the process beforehand. The flow diagram acts like an abstracted digital prototype of the system that explains the operation. From Figure 4.16, the expected operation of the system is modeled. First, the De-icing machine is supplied power which is represented as *evTurnOn*. Then, it goes from *PowerOff* state to *OnProcess* process. After that, it goes to the *WaitingForAlignment* state where it waits for alignment with the pipe. *evAlign* exemplify that the machine is aligned with the pipe and the Deicing occurs in *DeIcing* state for a specific time and then it goes into the *CollectionAndDisposal* state. Finally, after the disposal is done, it again waits for alignment for the next operation. Additionally, *evTurnOff* represents if power is not supplied to the system, it goes to *PowerOff* state.

The whole process is controlled and operated in panel diagram is outlined in Appendix C.3 and depicted in Figure C.1. The purpose of creating the panel diagram is to gain an impression of the expected operator HMI of the system. Additionally, an activity diagram is created for heat calculation of the system is explained in Appendix C.4 and depicted in Figure C.2.

4.4.6 Sub-function selection

After a complete analysis of the system using the SYSMOD approach, the various solutions for the sub-functions are listed in a table. The functionality of the system is taken from the use case of the system. Table 4.7 shows, the sub-functions of the De-icing subsystem are shown in the column and the solutions for achieving the sub-functions are shown in the row. For instance, the converting X-axis translation of the machine to the pipe can be done by conveyors, human (operators), rack and pinon, mesh gear, etc. Likewise, all the solutions are tabulated.

Solutions / **Sub functions**	**1**	**2**	**3**	**4**
Convert X axis translation	Conveyor	Human	Rack and pinon	Mesh gear
Convert Y axis translation	Human	Motor	Gear train	X
Determine pipe dimension	Optical sensor	Proximity senor	Human	Laser reading
Apply force to pipe	Hot air	Hot water	Heating coil	Mechanical
Water collection	Tub	Large container	Tank	Barrel
Water disposal	Pipe	Human	Filter and reuse	x

Solution variant - 4   Solution variant -1   Solution variant - 3   Solution variant - 2

Table 4.7: Sub-function selection

The compatible and optimal sub-function solutions are mapped forming different solution variants. There are four solution variants presented in varied colored dashed lines. For instance, combining the solutions 1-2-3-3-3-2 in a chronological order forming solution variant 1 represented in yellow dashed lines. The basis and the template for creating the table are taken from [16].

4.4.7 Sub-function evaluation

For the systematic approach, the solution field should be as wide as possible. The major purpose of the evaluation chart is to assess the solution variants which are attained from the previous step. The criteria for evaluation differs based on different departments in Allseas. Table 4.8 outlines the assessment of the various solution variants for the De-icing case study. The remarks are written for every solution variant gives clarity during the machine design. The decision is based on stakeholder meetings, various digital designs, etc are not discussed in this case study. The fundamental concept of the evaluation chart is taken from [16]. After the evaluation of the concept model, the DS table is updated. An updated design specification table is attached in Appendix C.5.

Allseas evaluation chart						
Solution variants	Selection criteria: (++) Excellent (+) Good (?) Lack of information (-) Bad (--) Worst				Decision: (+) Pursue solution (+) Eliminate solution (?) Re-evaluate solution	
	Selection criteria					
	Demand of Design specificatio n	Realisable in principle	Within cost allocated	Resource and expertise availability	Remarks	Decision
1	++	+	+	+	Promising solution, approval needed.	+
2	-	+	--		Not meeting the demands and cost	-
3	+	?	+	?	Proximity sensor expertise lacking	?
4	?	+	++	?	Operator availability and demands to be checked	?

Table 4.8: Sub-function evaluation

4.5 Requirements diagram and classification

In this section, the requirements diagram and requirements classification are presented for the De-icing case study. The main aim is to contribute to the requirement database which helps the formulation of a final requirements document. The detailed list of collected requirements for the De-icing machine is represented as a table in Appendix C.7 which consists of unique ID, name of the requirement, and requirements specification.

The functional requirements diagram is depicted in Figure 4.18. The main functional requirement is divided into sub-requirements which are shown by the 'nesting relationship'. The sub-requirements have a 'derive relationship' with other requirements. Also, SysML blocks such as melting system, alignment system, and collection and disposal system are used to illustrate the 'satisfy relationship'. There is also another SysML requirement diagram notation that can be used to show the relationship between the requirements. A detailed diagram that demonstrates the relationship of requirements to the use cases of the machine is shown in Figure C.3 which is attached in Appendix C.6. Finally, all the other requirements diagrams such as environmental requirements, operational requirements, etc are illustrated in Appendix C.6.

Figure 4.17 gives an overview of the classification of requirement packages which was created in the IBM Rhapsody environment. The classification schema is adapted from [21]. However, it is not necessary to follow the same classification pattern. The classification schema can be modified depending upon the project.

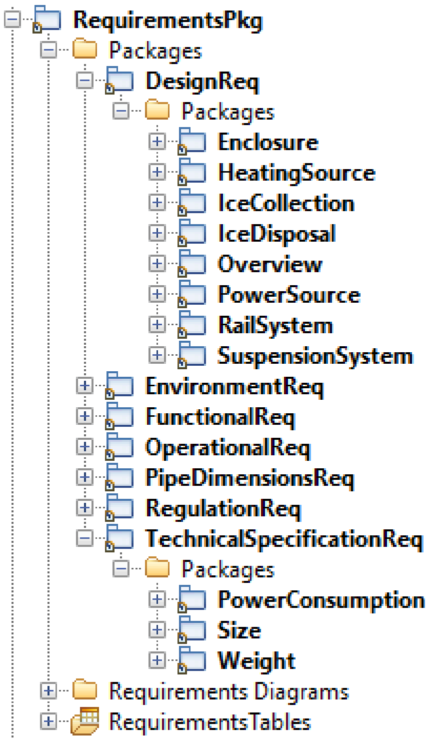

Figure 4.17: Requirements packages

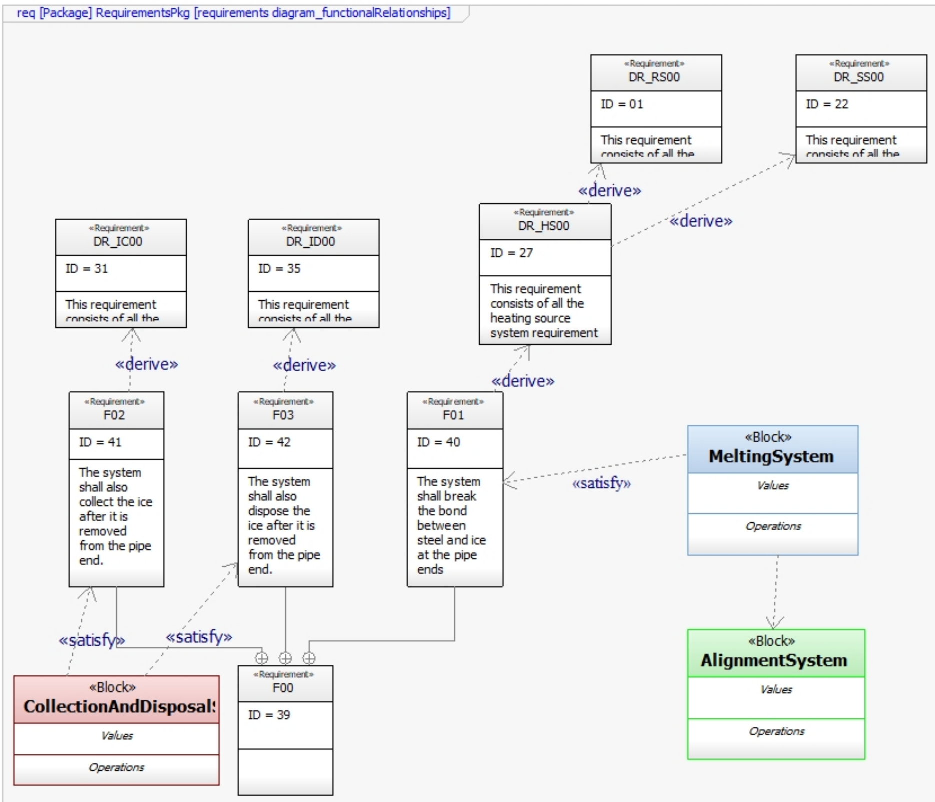

Figure 4.18: Functional requirements diagram

4.6 Conclusion

The development of De-icing machine was elaborated based on the extended SYSMOD approach. There are several issues and impacts during the development of De-icing project by the industrial equipment team that is tabulated in Table 4.9.

Description of issue	**Impact on project**
Unclear requirements and expectations from vessel management	For a long time, the specifics of the problem were unclear, resulting in a lot of unnecessary development time spent. Solutions were developed and engineered for non-existing issues.
Insufficient methodology	Parts of the project were not done according to the procedure. For example, drawings were made by Innovation instead of drawing office.
Lack of understanding and communication	Solution was being developed/researched in a wrong or impossible direction.
Inadequate guidelines for concept development	Solution space getting smaller and smaller and design getting more complicated.

Table 4.9: De-icing project - issues and impact [39]

These are the important reasons for choosing this case study to implement in the methodology. Most of the issues that occurred during the real-time development of the project can be solved using the Allseas methodology and the unspecified issues in the later phases of the project are considered to be solved in future work. Chapter 5 describes the testing of the methodology by using Allseas experts.

Chapter 5

Evaluation of the methodology

In this chapter, the proposed methodology is evaluated. The main aim is to check the suitability of methodology for Allseas. This is achieved by conducting workshops with the engineers from different departments in the company. There were participants from the industrial equipment department, heavy lift department, and jacket lift system project team. During the workshops, the methodology was presented and the participants were asked to evaluate the methodology. The proposed methodology was initiated at the industrial equipment department and therefore tailored for use to develop automated equipment. This is shown in the case study described in this thesis. The workshops with the engineers from the other departments were used to check the applicability of the methodology to the other projects. The primary evaluation technique used is 'workshops and feedback' which is elaborated in section 5.1. The possible implementation of the methodology to the upcoming project served as a secondary evaluation which is discussed in section 5.2. The assessment of the methodology based on 'wish list' is enclosed in Appendix E.2.

5.1 Workshops and feedback

This section elaborates on the conducted workshops and collected feedback. The workshop was conducted to upscale and promote the methodology to bigger projects in comparison with equipment development and to other departments rather than limiting it to the Innovations department. Thus, a steering group was formed voluntarily. There were participants with different backgrounds and work experience. Some of the participants had an affinity with systems engineering methodology whereas some did not. However, all the participants had a feeling that their current way of running the projects is not systematic. The whole methodology was divided into three workshops to explain the methodology in an understandable way to the participants:

- *Workshop 1* - Zachman framework with questionnaire.
- *Workshop 2* - Requirement formalization.
- *Workshop 3* - Functional decomposition, concept selection and evaluation.

During the workshops, the theoretical aspect of the methodology was explained. Then, an instruction manual on how to apply the methodology practically to the projects with a case study was presented. At the end of each workshop, the steering group was asked to evaluate the proposed methodology and try to apply it in their projects. At this moment, the participants could not able to apply the methodology to their projects due to time constraints. The important discussions during workshops are elaborated.

During the first workshop, the practical difficulty of responsibilities of the stakeholders in a large project using the Zachman framework was discussed and resolved. The follow-up work regarding this subject is presented in Appendix E.3. The analysis and refinement of additional questions for the "project owner" depending on the particular department or project were suggested. The tools and their functionalities proposed to be used together with the methodology were discussed. The differences between the participants in terms of tools were big. It appears that in some departments the engineers do not use any tools, some have already thought of introducing certain tools, but the others have already a well-established set of tools to apply the proposed methodology.

The requirement formalization technique and its implementation to different projects were explained during the second workshop. The checklist used in the requirement formalization was introduced to the group and discussed. The checklist which initially was developed for equipment engineering had to be slightly modified to suit heavy lift projects and some other departments. Also, the development and contribution of the requirements database were discussed.

During the third workshop, the methodology according to the SYSMOD for conceptual development was presented in the IBM Rhapsody environment. It appears that the majority of the inexperienced participants in the steering group had difficulties in distinguishing the difference between functional analysis, concept generation, and solution generation. The difference between the above-mentioned project phases was explained and the importance of focusing on functional concept generation rather than solutions generation was emphasised. Finally, the concept selection and evaluation were discussed and analysed.

Steering group

The steering group consists of seven Allseas employees. The diversity of the group is an important aspect of the workshops. The composition of the group is presented in Table 5.1.

Position	Department	Location
Unit Head	Innovation - Industrial equipment	Delft
Unit Head	Innovation - Jacket lift system	Delft
R&D Engineer	Innovation - Deep sea mining	Enschede
Senior Structural Engineer	Innovation - Heavy lift	Delft
Senior Software Engineer	Innovation	Eindhoven
R&D Engineer	Innovation - Industrial equipment	Delft
Functional Safety Engineer	Innovation - Naval	Delft

Table 5.1: Steering group

Summary of feedback

The feedback after the discussions during various workshops regarding the implementation of the proposed methodology was elaborated earlier in this section. To evaluate the workshops and contents of methodology, a workshop assessment survey was developed and distributed to the steering group. The responses from the participants were collected. Among multiple responses, the workshop assessment questionnaire along with a response is attached in Appendix E.1. To summarize the responses, the Zachman framework is considered by the participants as a powerful part of the proposed methodology. It appears that engineers often tend to assume the information instead of clarifying it by stating the right questions to the stakeholders. It appears that having a structure in questioning the stakeholders provides structure to the design phase and a better overview of the problem space. Requirement formalization and functional decomposition are also considered to be valuable but need expertise. The proposed tooling was evaluated, but no common view on the particular tools has been formed yet. Further research on tooling and its application by engineers at Allseas is required.

5.2 Implementation on upcoming project

Chapter 4 describes the implementation of a methodology on an old project. However, a new project as a case study would be a better option to try out the proposed methodology. Also, a recently initiated project called "Internal pipe cleaning tool" is selected to test the methodology on a new project. Therefore, an action request form for the project provided by the vessels' team was analysed. The diagrams for system concept generation were created using the tools mentioned in this thesis. The major aspects regarding the implementation of methodology to "Internal pipe cleaning tool" are outlined in Appendix D.

Initially, the methodology was considered to be evaluated by comparing the results using the conventional Allseas way of implementation and the proposed methodology. Unfortunately, due to delays with the start of the project, the use of the proposed methodology was evaluated by my supervisor and not by the project team. Therefore, the analysis and discussion about the new project are presented in Appendix D.

Chapter 6

Conclusions and Recommendations

This thesis aimed to develop a systematic methodology for requirements engineering, applicable to the design of equipment at Allseas, and serve as an improvement to the company's development process. The detailed guidelines on the systematic methodology applicable to Allseas work procedure were elaborated in chapter 3. The implementation of the proposed methodology, using the "case study - De-icing machine", to the initial phases of the project are shown in chapter 4. Based on the evaluation of the proposed methodology performed by several engineers from different departments as described in chapter 5, it shows clear improvements in the RE activities in comparison to the current Allseas development process. This proves that the project goals mentioned in chapter 1 have been fulfilled. The major contribution of the proposed methodology towards the improvement of the equipment development process at Allseas is summarized which answers the following research questions:

RQ.1: How does the requirements methodology contribute to the elicitation of the requirements?

The introduction of the Zachman framework based on a clear questionnaire provided a better overview of the problem space in machine design. The formulation of appropriate questions from the perspective of different stakeholders has resulted in a better understanding of the expectation of the stakeholders, opened broader possibilities for engagement in discussions, has helped to solve potential miscommunication, evoked fresh thoughts and intuition among stakeholders, and enabled structured thinking during the equipment development. Thus, the proposed methodology has effectively contributed to the elicitation of the requirements at Allseas.

RQ.2: How does the requirements methodology help to locate and reduce errors in requirements during offshore equipment development?

The requirement formalization technique has expanded the scope of the requirement analysis. Initially, the classification of preliminary requirements in terms of functions and parameters, which has improved the understanding of requirements. The introduction of structure and strict terminology in the requirement has reduced the misinterpretation of requirements. The usage of predefined requirements checklist to formulate a well-defined design specification table has helped to identify incomplete and inconsistent requirements. Subsequently, the errors in the requirements are greatly reduced, by accounting and communicating the inconsistent requirements with the respective stakeholders, prior to the basic engineering phase. Doing so can potentially save costs and time of rework at the latter project phases. Hence, the proposed methodology has helped to locate and reduce errors in requirements during offshore equipment development.

RQ.3: How to improve the concept development process of offshore tools and equipment using the requirements methodology?

The implementation of the SYSMOD approach in the concept development phase to perform functional decomposition of the system has given more structure and understanding to the development team about the system in the concept development phase. The pre-defined guidelines from SYSMOD about the modeling of system context, use cases, and system structure enhanced abstract thinking during the concept development process. The appropriate usage of SysML diagrams and their relationships to depict the conceptual models could greatly improve the communication between the stakeholders. Thus, the SYSMOD approach improved the concept development process of offshore tools and equipment.

RQ.4: What is the impact of the requirements methodology on decision making of the concept development process?

The improved accounting of requirements in a single database throughout the proposed methodology has eliminated assumptions taken by engineers based on their personal work experience and miscommunication. Additionally, an objective and transparent concepts selection and evaluation method that takes all variants in form of a chart was proposed. The application of selection and evaluation charts has broadened the solution design space. The introduction of the resource identification step has improved the project economics and design decisions. Finally, the use of pre-defined checklists has helped the stakeholders in taking well-grounded and objective decisions during the engineering design of the system. The mentioned contributions of the proposed methodology have resulted in a positive impact on the decision-making process during the conceptual phase.

Additionally, a few improvements could be mentioned to further improve the proposed methodology. The recommendations are listed as follows:

- Only the most obvious questions are considered in the current Zachman questionnaire. Adding more questions based on the domain of particular departments and disciplines can make the questionnaire more efficient and less abstract. Likewise, adding more domain knowledge to the predefined checklist can make the requirement checklist database more complete.
- The proposed methodology introduces the systematic approach mainly in the initial phases of the project. Hence the methodology can be extended to other project phases to systematise the work during the other project phases too.
- Currently, the methodology is implemented in Microsoft office applications as tools. Implementing the methodology in more dedicated tools such as Helix ALM, Modern requirements for Microsoft DevOps could simplify the workflow for requirement management and project tasks generation.

Appendix A

Integration

A.1 Integration of MS Excel and MS Word

The integration is performed to directly transfer requirements from specific MS excel cells into a word document with a click of a button. This is done through Visual basic macros. The following steps are performed with developer settings in MS excel.

1. In developer tab of MS excel, select Visual basic
2. Create a module with the code attached below (document name and path can be changed in the code)
3. In the develop tab, Click Macros and link the module to macros

```
Sub ActivateWordTransferData()
Worksheets("FinalDocument").Range("A1:C87").Copy
Dim wdapp As Object, wddoc As Object
Dim strdocname As String
On Error Resume Next
Set wdapp = GetObject(, "Word.Application")
If Err.Number = 429 Then
Err.Clear
Set wdapp = CreateObject("Word.Application")
End If
wdapp.Visible = True
strdocname = "C:\Users\gowth\Desktop\Thesis\Document.docx"
If Dir(strdocname) = \" Then
MsgBox "The file" & strdocname & vbCrLf & "was not found"&
vbCrLf & "C:\Users\gowth\Desktop\Thesis\.", vbExclamation,
"The document does not exist."
Exit Sub
End If

wdapp.Activate
Set wddoc = wdapp.Documents(strdocname)
If wddoc Is Nothing Then Set wddoc = wdapp.Documents.Open(strdocname)
wddoc.Activate
wddoc.Range.Paste
wddoc.Save
wdapp.Quit
Set wddoc = Nothing
```

```
Set wdapp = Nothing
Application.CutCopyCode = False
End Sub
```

A.2 Integration of MS Excel and MS Visio

For the integration of MS Excel and MS Visio, the following steps are to be performed.

- The Excel sheet which has the requirements are imported to MS Visio.
- Data Graphics are created. The data graphics should be based on the requirements classification.
- After the data graphics are created, drag the required shape after selecting the data row which is to be integrated. Then, select the required data graphic from the Data tab.

Importing Excel sheet

Following steps are to be performed in-order to import the Excel sheet into MS Visio

1. Select **Data** –> **Custom Import**
2. A Data Selector dialog box appears
3. From the dialog box, select **Microsoft Excel workbook** and click on **Next**. This can be seen in Figure A.1

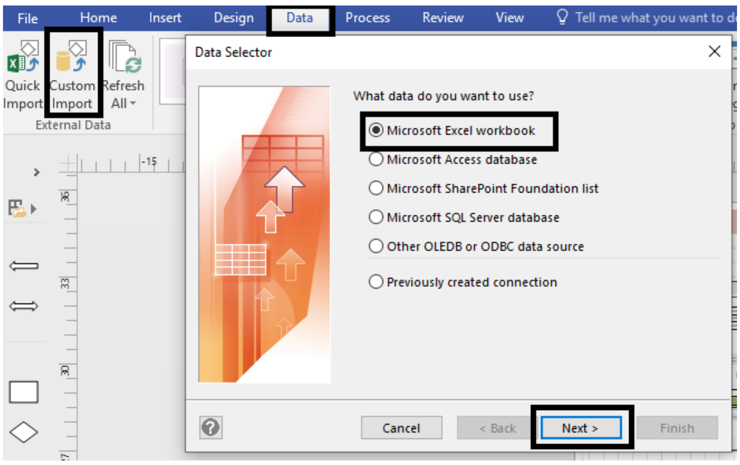

Figure A.1

4. Click on **Browse** button and select the Excel sheet in which the calculations have been performed. Then click on **Next**. This step is shown in Figure A.2

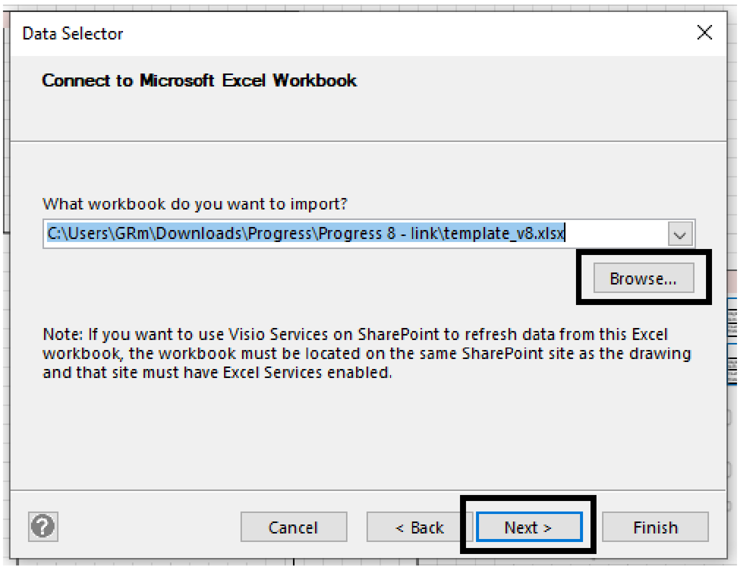

Figure A.2

5. In the next window, click on Select **Custom Range** as shown in Figure A.3. This will open the excel sheet. Select the range of the data and click on **Next**.

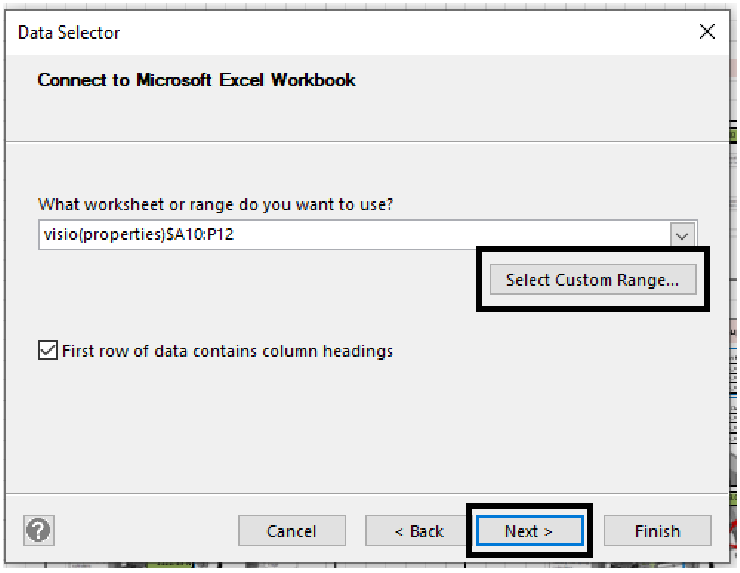

Figure A.3

6. Then, select all the columns and rows that are needed to import into Visio and click on **Finish** button. This can seen in Figure A.4.

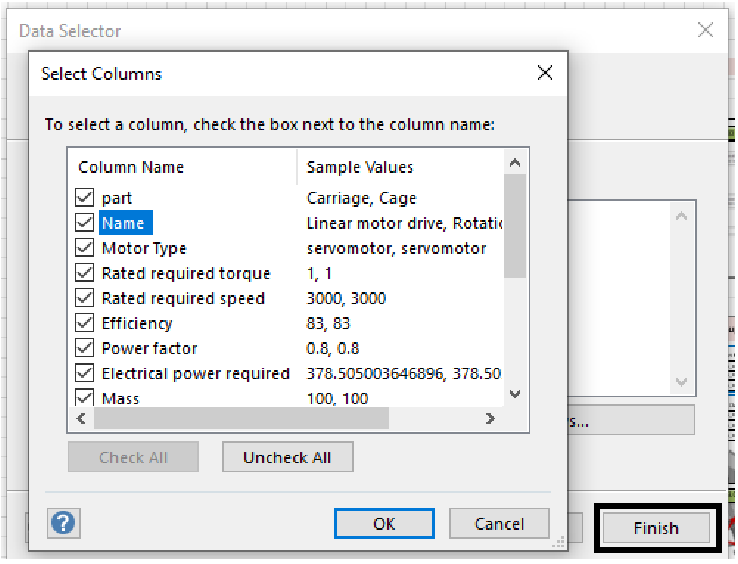

Figure A.4

7. To view the imported data click on **Data** − > **External Data Window**.

Appendix B

Questionnaire

The questionnaire is built to help the designers and builders. The questionnaire technique which was formerly adopted in the mission paragraph is implemented in this stage. Builder's view is also included during the concept development as it explores the tooling constraints, materials, etc. The questionnaire for designer and builder are presented below

B.1 Questionnaire - Designer

The motive is to guide the designers in the right direction and to design a fully functional product. The question majorly focuses on the logical process flows and use cases of the system. It also covers a wide range of questions for different departments in the organization based on their respective disciplines. Sample lists of questions (designer perspective) are shown in the Table B.1.

Zachman Framework	What (Inventory Sets)	How (Process flows)	Where (Distribution Networks)	Who (Responsibility Assignments)	When (Timing Cycles)	Why (Motivation intentions)
Designer	What are the use cases of the product? What are the inputs and outputs of the product? What are the components of the product? What are the resources available? What are the safety aspects in the product?	How is the logical process flow of the product defined? How is the alternative flow of the process defined? How is safety aspect covered? What is the start and end of the process?	Where is the product located? What are the interconnections between the product? Does the product suitable for transportation? What is the working area of the product?	Who are the stakeholders? Who is responsible of digital design of the product? Who is responsible of electrical design of the product? Who is responsible for the software module?	When does the draft design starts? When does the designing phase ends? What is the timing cycles for the operation?	What is the purpose of the sub system of the product in the digital design? What is the purpose that particular component in the product in the digital design?

Table B.1: Designer - Questions

B.2 Questionnaire - Builder

In the same way, the builder questions are constructed to deliver the expected product. For instance, its primary focuses on materials for mechanical discipline and technology, input/output (I/O) devices, and programming languages for software discipline. Sample lists of questions (builder perspective) are displayed in the Table B.2.

Zachman Framework	What (Inventory Sets)	How (Process flows)	Where (Distribution Networks)	Who (Responsibility Assignments)	When (Timing Cycles)	Why (Motivation intentions)
Builder	What are geometry of the product (i.e.) space requirement? What standards and specifications need to be followed? What are the material used in the product? What are the safety regulations in place? What are the aspects of the recycling? What are the commissioning/testing procedures?	How is the assembly of the product? How is the product commissioned? What are the procedure to use the product?	Where is the product fabricated? Where does the testing of the product occurs?	Who is responsible for material handling? Who is responsible of procurement? To whom is (part of) the work subcontracted? Who is responsible for material dispatch and collection? Who is responsible of commissioning the product?	When does the material will be dispatched? Does the testing material been dispatched? What is the timing cycles during testing cycle?	What is the purpose of the sub system of the product? What is the purpose that particular component in the product?

Table B.2: Builder - Questions

Appendix C

De-icing machine auxiliary information

C.1 Questionnaire and answers - Designer

The questionnaire for designer and builder is used in order not to miss key factors during conceptual machine design. During the initial stage of the project, the designer and builder questions cannot be answered. Also, more importance was given to the development of owner questions rather than designer and builder questions. The sample list of questions for the designer is answered. The pattern follows the same as the owner questions in the mission paragraph. The designer questions involve the design aspects such as use case, logical process, etc. Table C.1 shows the sample questions (black) and their respective answers (red) for the de-icing case study.

Zachman Framework	What (Inventory Sets)	How (Process flows)	Where (Distribution Networks)	Who (Responsibility Assignments)	When (Timing Cycles)	Why (Motivation intentions)
Designer	What are the use cases of the product? Align(X direction; Y direction, Pipe diameter) Melt(Apply heat, Melt) Collect(water collection) Dispose(water dispose) What are the inputs and outputs of the product? Energy(Mechanical) Material(Human, Solid heating coil) What are the components of the product? Motor, Heating coil, Conveyor, etc What are the resources available? From step-2(Motor, electricity, air valves) What are the safety aspects in the product? Preventive proximity sensor, Dead switch., etc	How is the logical process flow of the product defined? -Operators turns ON the alignment system - With directional buttons, align with the pipe -Proximity sensor aligns with pipe diameter -Ice melting through coil depends on the thickness of ice -Collection and Disposal of water What is the start and end of the process? Alignment –Melting – Collection – Disposal	Where is the product located? Solitaire What are the interconnections between the product? Separate invertor should be there for the heating coils, The extension of wire should be possible while (dis)alignment. Does the product suitable for transportation? Yes, with the help of the transportation resource available What is the working area of the product? 450 square metre	Who is responsible of digital design of the product? Designer name - Software name – Technique used	When does the draft design starts? 15 Nov 2017 When does the designing phase ends? 25 Feb 2018 What is the timing cycles for the operation? Alignment 60 sec Melting 45 sec Collection 15 sec Disposal 5 sec	What is the purpose that particular component in the product? Motor – translation in Y direction, Conveyor – translation in X direction Heating coil – Meting ice Tank and pipe – Collection and Disposal

Table C.1: Designer - Questions and Answers

C.2 Questionnaire and answers - Builder

As similar to the previous subsection, the sample list of questions for the builder is answered. The builder questions involve the fabrication aspects such as the geometry of the machine, material dispatch, etc. Table C.2 presents the sample questions (black) and their respective answers (red) for the de-icing case study.

Zachman Framework	What (Inventory Sets)	How (Process flows)	Where (Distribution Networks)	Who (Responsibility Assignments)	When (Timing Cycles)	Why (Motivation intentions)
Builder	What are geometry of the product (i.e.) space requirement? Vessel space 250 sqm Operator space 150 sqm What are the material used in the product? SS, Copper, Tungsten What is the commissioning time and cost of the components? 16 hours and Motor – 150$ Heating coil – 900$ What is the maintenance time and cost? 15 mins and repair cost What are the aspects of the recycling? Filtration of water and reusing What are the testing techniques? Alignment testing with various diameter, De-icing coil various range of heat testing	How is the assembly of the product? Assembly manual What are the procedure to use the product? Operating manual	Where is the product fabricated? Rotterdam fabrication yard Where does the testing of the product occurs? Rotterdam Testing yard	Who is responsible for material handling? Material stakeholders Who is responsible for material dispatch and collection? Material collector Who is responsible of commissioning the product? Builder and Designer name	When does the material will be dispatched? 25 March 2018 Does the testing material been dispatched? 10 material testing quantity is ready What is the timing cycles during testing cycle for various range of ice ? 15 cm ice Alignment 60 sec Melting - 50 sec disposal – 10 sec	What is the purpose that particular component in the product? Bolting system in conveyors, sensor calibration in proximity sensor, height adjustment in alignment system, level sensor in collection system

Table C.2: Builder - Questions and Answers

C.3 Panel diagram

In this case, the panel diagram is created to illustrate the possible operator task and process indication. This makes the system clear that the operator performs turning On/Off and alignment of the system which in turn sets the requirements for the operator. Automation of the alignment system without the operator is also possible at this stage. The process indication gives an overview of the operation of the system. Finally, the values for heat calculation are entered to know the approximate amount of heat required to liquefy the ice. The formulas are discussed in the following section. Figure C.1 shows the conceptual view of the panel diagram for De-icing case study.

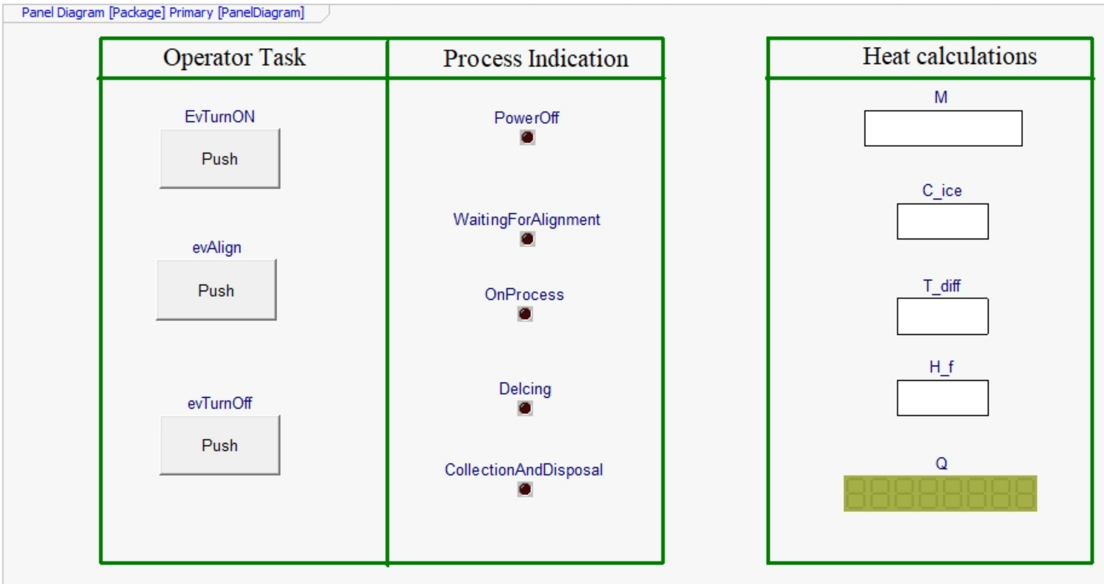

Figure C.1: Panel diagram

C.4 Activity diagram

Heat calculations required to liquefy the ice from the pipe ends are represented in the formula. The formula is modeled as an activity diagram and depicted in Figure C.2.

$$Q = \text{Temperature change} + \text{Phase change}$$
$$Q = m * C_{solid} * \Delta T + m * H_f$$

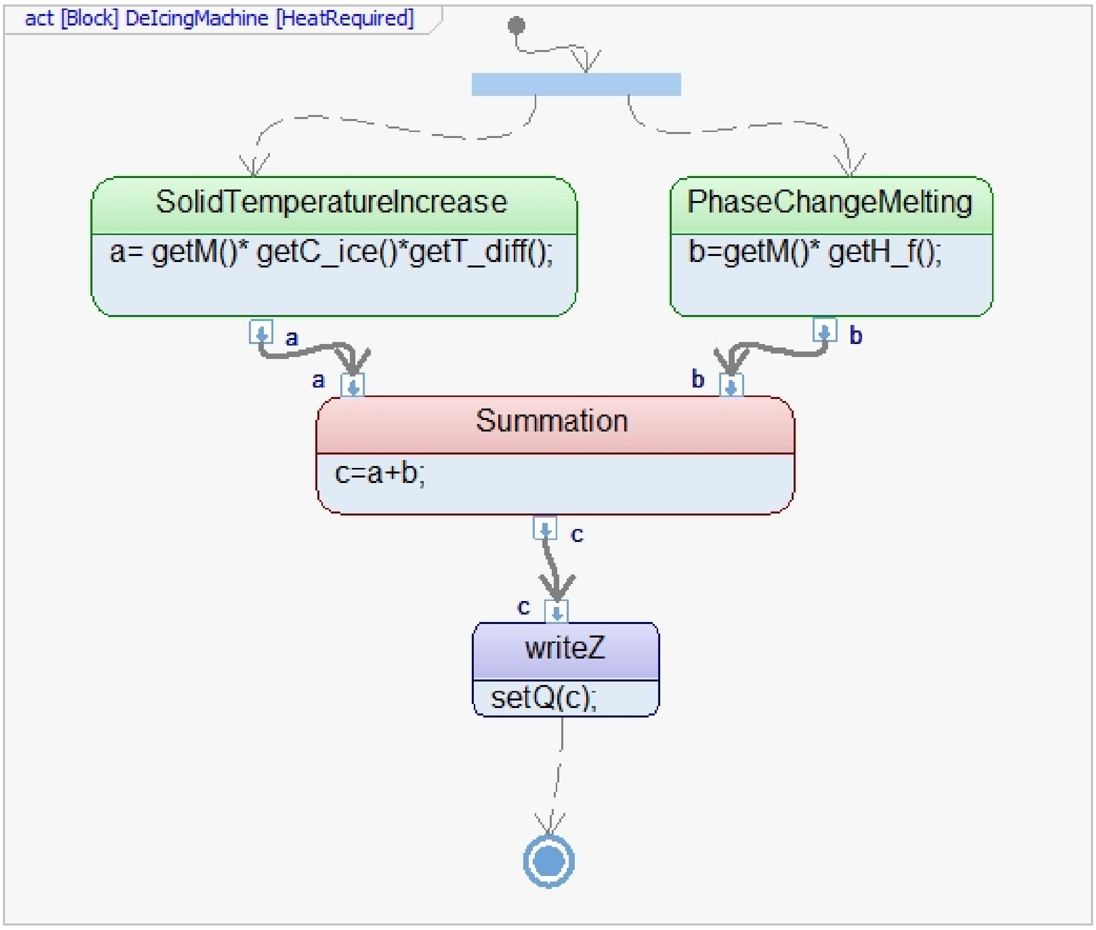

Figure C.2: Heat calculation

C.5 DS table - lower level

The design specification table is extended with additional details covering a wide range of aspects of the machine. Some of this information in the DS table is taken from the finished product. All the information presented in the DS table may not be necessarily available at this stage. The DS table is developed for the whole system or individual sub-system depending upon the complexity of the system. Table C.3 shows parts of the DS table for the whole de-icing machine. Finally, the responsibility is allocated based on the category of the specification table.

Design Specification Sheet Project: De-icing project	Responsible

Functional performance:

- Main functions
  - Remove ice from the ends of the pipe
- Auxiliary functions
  - Collecting water/ice resulting from removal
  - Dispose of water/ice
  - Ensure the pipe will not get stuck, due to added friction, by driving the pipe

Geometry

(Product)

Component	Weight [kg]
Inverter	81
Enclosure	+/- 100
Rail system	+/- 60
Suspension system	+/- 200
Coil	+/- 130
Ice collection	+/- 230 (empty) +/- 630 (full of water/ice)
Ice disposal	+/- 70

(Pipe)

- Current PS design temperature = 15 degree
- Inner diameter is 1153 mm & Maximum outer diameter 1455 mm
- Wall thicknesses: 26.8, 30.9 and 34.6 mm
- Length 12.2 +/- 0.5 m

Force

Heating coil

Energy

Conveyor, Motor and Human

Material

Ice covered

Safety

- System should be fail safe
- Noise and dust levels are to be kept as low as practically possible
- The system shall have guarding and protective coverings
- All moving components that can contact water shall be protected against freezing

Transport

All equipment preferable be transportable in 20ft standard containers (2.24m x 2.23m x 5.86m - width x height x length).

Operation

Maintenance

Table C.3: DS table - lower level

C.6 Requirements diagram

The use diagram of the De-icing machine is Figure 4.15 is selected to demonstrate the traceability of requirements to its use case. Figure C.3 gives an overview of relationships of requirements with use cases. The proper usage of SysML requirement diagrams improves the understanding of requirements. Various requirement diagram notations such as nesting, derive, satisfy, etc are used in this diagram. For instance, the "Collect water" and "Dispose water" use cases are *satisfied* with requirement 31 (ice collection system) and requirement 35 (ice disposal system) which in-turn has *derived* requirements. Likewise, the requirements traceability can be extended to various SysML models.

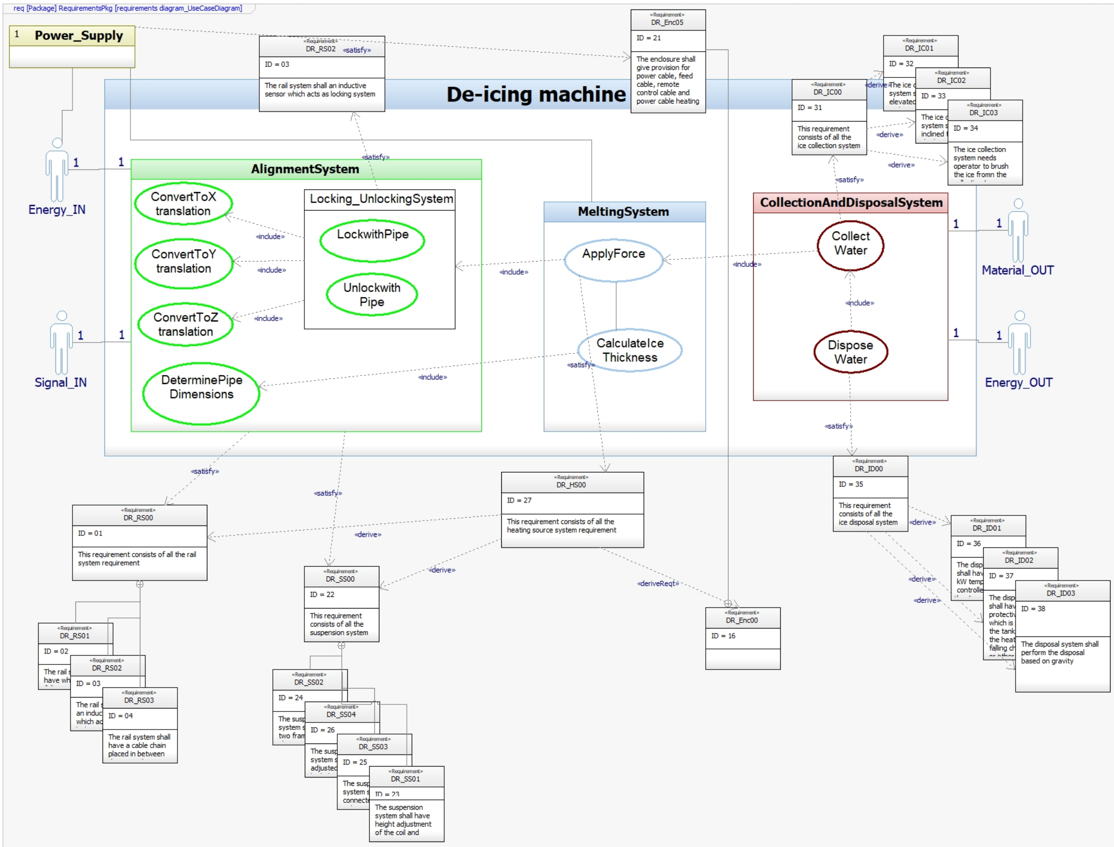

Figure C.3: Requirements validation with use cases

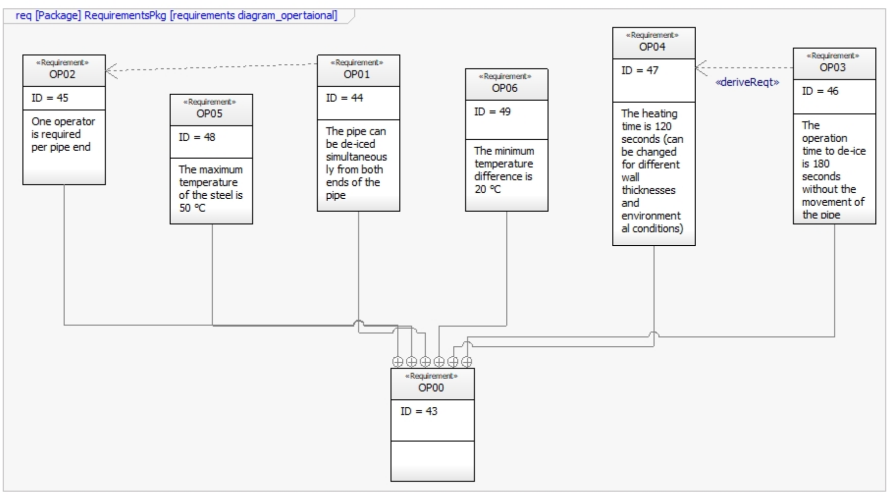

Figure C.4: Operational requirements diagram

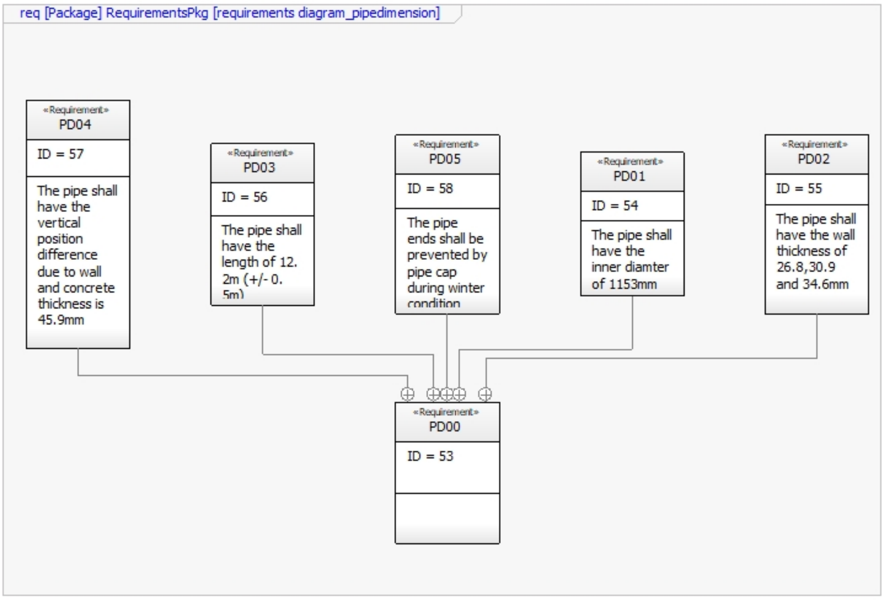

Figure C.5: Pipe dimension requirements diagram

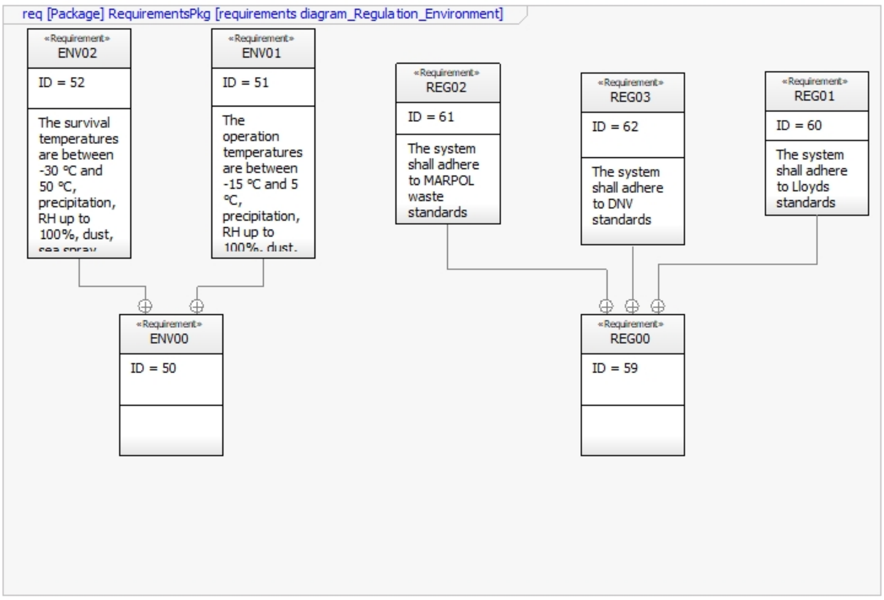

Figure C.6: Regulation and environment requirements diagram

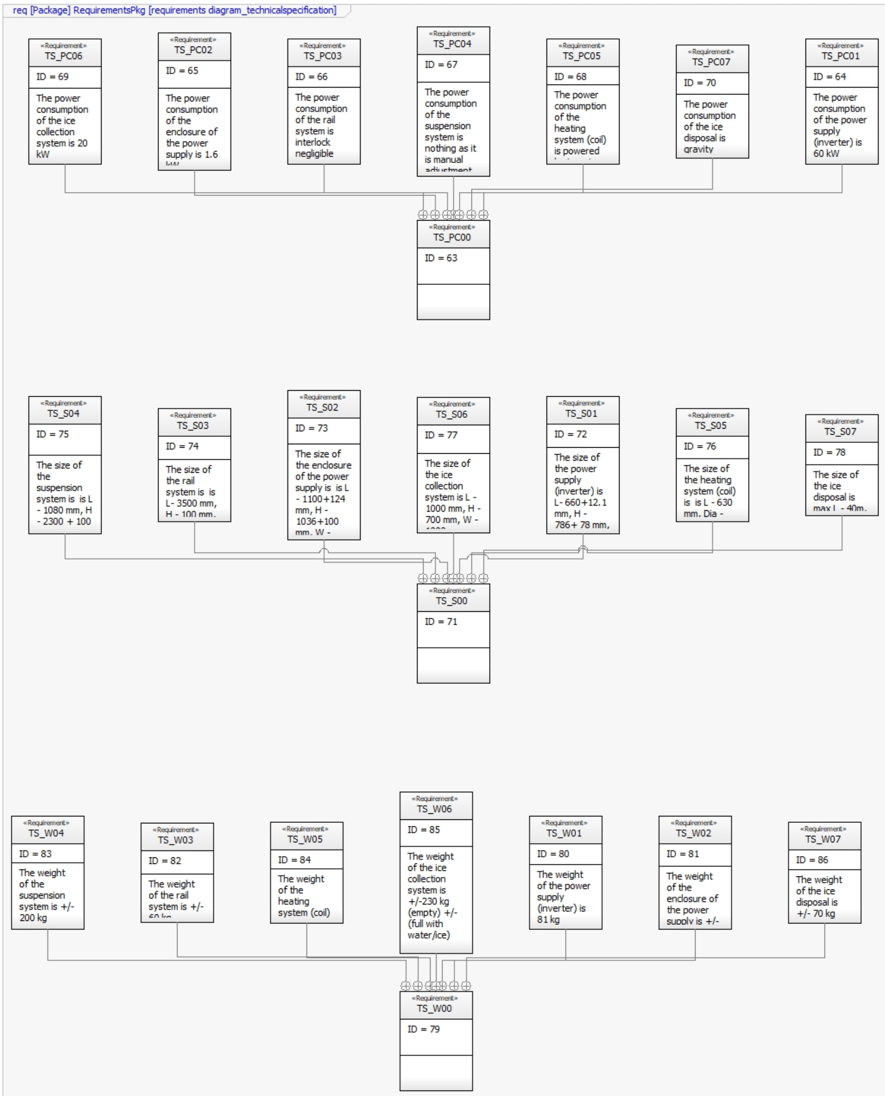

Figure C.7: Technical specification requirements diagram

C.7 Requirements table

The requirements table is generated from IBM Rhapsody. The requirements are taken and modified from the work of the Allseas industrial equipment team. The requirements table is attached to the next page.

ID	Name	Specification
01	DR_RS00	This requirement consists of all the rail system requirement
02	DR_RS01	The rail system shall have wheel, cam followers and brush
03	DR_RS02	The rail system shall an inductive sensor which acts as locking system
04	DR_RS03	The rail system shall have a cable chain placed in between the two rails
05	DR_OV00	
06	DR_OV01	The power supply system (inverter) is protected by placing inside the enclosure
07	DR_OV02	The inverter shall power the induction coil
08	DR_OV03	The induction coil system hangs in its adjustable suspension system
09	DR_OV04	The induction coil system shall be connected to the deck with a rail system
10	DR_OV05	The collection and disposal system shall collect and dispose the water
11	DR_PS00	
12	DR_PS01	The inverter shall be powered with 460V, 60 Hz
13	DR_PS02	The inverter shall have remote control, which includes a start and stop button as well as an E-stop
14	DR_PS03	The inverter shall have touch screen at the front side
15	DR_PS04	The inverter shall be turned off after 120 seconds of heating cycle via remote control
16	DR_Enc00	
17	DR_Enc01	The enclosure shall have a weather tight cabinet with the wall thickness of 2mm
18	DR_Enc02	The enclosure shall have overhanging lid placed on a rubber profile ensures that no precipitation can enter the cabinet.
19	DR_Enc03	The enclosure shall have cable gland system which allows flexibility during installation
20	DR_Enc04	The enclosure shall have transparent inspection hatch which aligns with the touch screen of the inverter
21	DR_Enc05	The enclosure shall give provision for power cable, feed cable, remote control cable and power cable heating
22	DR_SS00	This requirement consists of all the suspension system requirement
23	DR_SS01	The suspension system shall have height adjustment of the coil and overcoming misalignment between coil and pipe functionality
24	DR_SS02	The suspension system shall have two frames made of aluminium
25	DR_SS03	The suspension system shall be connected to the rail system
26	DR_SS04	The suspension system shall be adjusted manually by bolts and nuts
27	DR_HS00	This requirement consists of all the heating source system requirement
28	DR_HS01	The heating system shall have two rings of six Epratex plates shape the contours of the coil
29	DR_HS02	The heating system shall have 40 meter inductor from Leifert Induction is wound around the base with ten windings
30	DR_HS03	The heating system shall have guidance wheels and sliding blocks
31	DR_IC00	This requirement consists of all the ice collection system requirement
32	DR_IC01	The ice collection system shall have elevated platforms in the pipe
33	DR_IC02	The ice collection system shall have inclined tray under the heating source
34	DR_IC03	The ice collection system needs operator to brush the ice fromn the collection tray
35	DR_ID00	This requirement consists of all the ice disposal system requirement
36	DR_ID01	The disposal system shall have two 10 kW temperature controlled immersion heaters
37	DR_ID02	The disposal system shall have a protective grating which is placed in the tank to protect the heaters from falling chunks of ice or other material
38	DR_ID03	The disposal system shall perform the disposal based on gravity
39	F00	
40	F01	The system shall break the bond between steel and ice at the pipe ends
41	F02	The system shall also collect the ice after it is removed from the pipe end.
42	F03	The system shall also dispose the ice after it is removed from the pipe end.
43	OP00	
44	OP01	The pipe can be de-iced simultaneously from both ends of the pipe
45	OP02	One operator is required per pipe end

ID	Name	Specification
46	OP03	The operation time to de-ice is 180 seconds without the movement of the pipe
47	OP04	The heating time is 120 seconds (can be changed for different wall thicknesses and environmental conditions)
48	OP05	The maximum temperature of the steel is 50 °C
49	OP06	The minimum temperature difference is 20 °C
50	ENV00	
51	ENV01	The operation temperatures are between -15 °C and 5 °C, precipitation, RH up to 100%, dust, sea spray
52	ENV02	The survival temperatures are between -30 °C and 50 °C, precipitation, RH up to 100%, dust, sea spray
53	PD00	
54	PD01	The pipe shall have the inner diamter of 1153mm
55	PD02	The pipe shall have the wall thickness of 26.8,30.9 and 34.6mm
56	PD03	The pipe shall have the length of 12.2m (+/- 0.5m)
57	PD04	The pipe shall have the vertical position difference due to wall and concrete thickness is 45.9mm
58	PD05	The pipe ends shall be prevented by pipe cap during winter condition
59	REG00	
60	REG01	The system shall adhere to Lloyds standards
61	REG02	The system shall adhere to MARPOL waste standards
62	REG03	The system shall adhere to DNV standards
63	TS_PC00	
64	TS_PC01	The power consumption of the power supply (inverter) is 60 kW
65	TS_PC02	The power consumption of the enclosure of the power supply is 1.6 kW
66	TS_PC03	The power consumption of the rail system is interlock negligible
67	TS_PC04	The power consumption of the suspension system is nothing as it is manual adjustment
68	TS_PC05	The power consumption of the heating system (coil) is powered by inverter
69	TS_PC06	The power consumption of the ice collection system is 20 kW
70	TS_PC07	The power consumption of the ice disposal is gravity based
71	TS_S00	
72	TS_S01	The size of the power supply (inverter) is L- 660+12.1 mm, H - 786+ 78 mm, W - 460 mm
73	TS_S02	The size of the enclosure of the power supply is is L - 1100+124 mm, H - 1036+100 mm, W - 600+124 mm
74	TS_S03	The size of the rail system is is L- 3500 mm, H - 100 mm, W - 845 mm
75	TS_S04	The size of the suspension system is is L - 1080 mm, H - 2300 + 100 mm, W - 890 + 610 mm
76	TS_S05	The size of the heating system (coil) is is L - 630 mm, Dia - 1140 mm
77	TS_S06	The size of the ice collection system is L - 1000 mm, H - 700 mm, W - 1000 mm
78	TS_S07	The size of the ice disposal is max L - 40m, Dia - 100 mm
79	TS_W00	
80	TS_W01	The weight of the power supply (inverter) is 81 kg
81	TS_W02	The weight of the enclosure of the power supply is +/- 100 kg
82	TS_W03	The weight of the rail system is +/- 60 kg
83	TS_W04	The weight of the suspension system is +/- 200 kg
84	TS_W05	The weight of the heating system (coil) is +/- 130 kg
85	TS_W06	The weight of the ice collection system is +/-230 kg (empty) +/- (full with water/ice)
86	TS_W07	The weight of the ice disposal is +/- 70 kg

Appendix D

Internal pipe cleaning tool - Case study

Zachman Framework	What (Inventory Sets)	How (Process flows)	Where (Distribution Networks)	Who (Responsibility Assignments)	When (Timing Cycles)	Why (Motivation intentions)
Owner	What are you trying to solve with this project? – Root cause To clean the lower quatre inside surface of the pipe for lower diameters through vacuum extraction What are the clients planning to achieve? Proper cleaning (Nothing or mild dust) of pipe without delay in time What prerequisites are already there for this project? NS2, SOL – 30''- 60'' tool. Karish project 24''-30'' What do you consider as the biggest risks for this project? Proper techniques and design should be finalized with the domain expert before developing the machine. To check the rigidness of tool for 12''and 60'' Are there any relevant deliverables or artifacts available for review? Older project in internal pipe cleaning What type of material are we working (to remove, to clean, to join)? Not known; Dead animals, rag, welding flux (1 kg over 40 cm), etc.	How do you prefer to communicate? Team's meeting How often you prefer to communicate? Bi-weekly communication is preferable How are the clients solving the problem currently? By, using winch, tool(blowing), and cradle system How do you evaluate previous product? - History of the project Older project involves Pneumatic system. Doesn't not support for multi-diameter of pipe ranges. If suppose it is older project, how have the previous solutions failed? Not known	Where and how much are the working area for our product? PS and xxxx m2; 3 favourable location in the vessels Do you see any dependencies or similarities between this project and other projects? Older Pipe cleaning tool can be used at some points based on cost and resource availability In which technical area does the project mainly focus on? Automation; Cleaning. Heated coil In which business area does the project mainly focus on? Increase the pipelaying speed, reducing the operation time What is efficient working area? Lower quatre of the pipe; 4'o clock to 8'o clock What is area of disposal, if any? Vacuum extraction of debris	Who are you solving this problem for? Vessel team for cleaning the pipe What are the different roles of the people involved in the project? Kirill - Owner Gowtham – Designer xxxxx - Builder Does the client have proper knowledge to use the product? Demonstrate to them if there are any settings that needed to be adapted Who else do we plan to collaborate with outside of our team? Some domain experts from another team for cross checking its correctness	When does our project starts? Aug 2021 When does conceptual design phase ends? May 2022 When does the project ends? November 2022	Why do we need this project? To increase the range of diameters of the pipe during the internal cleaning of the pipe. To avoid blowing out of debris to control deterioration of air quality. What value does it bring to the client? Flexible for various diameter of the pipe, reduction of dust in bead stall, decrease labour efforts and increased pipe laying speed

Table D.1: Owner: Questions and Answers - Internal pipe cleaning tool

Mission paragraph

The purpose of the project is to clean the internal side lower quatre of the pipe for various ranges of the diameter of the pipe through vacuum extractions to improve flexibility in the range of diameters and to avoid blowing out of debris to control the deterioration of air quality. By implementing it in a proper way, there will be an increased range of diameters of pipe, reduction of dust in the bead stall, and improving the working condition. Pneumatic tools (blowing out), Winch, and cradle are used to remove the debris. Only a large range of diameters and pneumatic blowers are used. Client meetings will be on Teams and Bi-weekly meeting is preferable. To reuse some aspects from a previous project, commonalities from an older version of internal pipe cleaning. Vessel team – Owner, Engineer 1 – Designer, Engineer 2 – Builder. Project start date – Aug 2021, Project end date – Nov 2022.

Rq no	Requirements	Functions & Parameters
R1	Clean lower quarter of pipe (4 to 8 o'clock)	F1, P1
R2	Vacuum extraction of debris in the pipe	F2, P2
R3	Operation time < 2.30 minutes	P3
R4	Clean quantity >= 1 kg (over 40 cm)	P4
R5	Clean material size < 1 cm3 square	P5
R6	Extract large debris (dead animals, rag)	P6
R7	Space – earlier vessel envelope	P7
R8	Safety	P8
R9	Simple Repair; Maintenance time < 5 min	P9
R10	Withdraw steel cable through DJ = 26m	P10
R11	Accommodate longitudinal pipe end position variation = 1.5m	P11
R12	Pipe Range – 12″- 60″ (12″-20″, 18″-30″, etc)	P12
R13	Pipe length – 24.5m (clean and not fall)	P13
R14	Internal weld cap = 6mm	P14
R15	Weld seam temperature = 200 degree Celsius	P15
R16	Max temperature width = 0.5m	P16

Figure D.1: Formulated initial requirements from action request form - Internal pipe cleaning tool

		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16
Function	C1	e1	e1				e1				e1	e1					
Geometry	C2							e2					e2.1	e2.1	e2.1	e2.1	e2.1
Kinematics	C3	e3															
Forces	C4				e4												
Energy	C5		e5														
Material	C6		e6		e6	e6											
Signals	C7																
Safety	C8								e8								
Ergonomics	C9																
Production	C10							e10									
QC	C11																
Assembly	C12																
Transport	C13							e10									
Operation	C14			e14													
Maintenance	C15									e15							
Recycling	C16																
Costs	C17																
Schedules	C18																

Table D.2: Interaction matrix - Internal pipe cleaning tool

Design Specification Sheet Project: Internal cleaning tool	Responsible
Functional performance: Clean, Extract, Withdraw, Accommodate Constraints *Geometry* *(Product)* Older vessel space *(Pipe)* Pipe Range – 12”- 60’’ (12”-20”, 18”-30”, etc) Pipe length – 24.5m (clean and not fall) Internal weld cap = 6mm Weld seam temperature = 200 degree Celsius Max temperature width = 0.5m *Kinematics* Working area (lower quatre 4 – 8 o clock) *Force* Clean quantity >= 1 kg (over 40 cm) *Energy* Vacuum extraction (Pneumatic) debris in the pipe *Material* Vacuum extraction debris in the pipe Clean material quantity >= 1 kg (over 40 cm) Clean material size < 1 cm3 square *Safety* Be safe for operators *Production* Space – earlier vessel envelope *Transport* Space – earlier vessel envelope *Operation* Operation time < 2.30 minutes *Maintenance* Simple Repair; Maintenance time < 5 min	

Table D.3: DS Table - Internal pipe cleaning tool

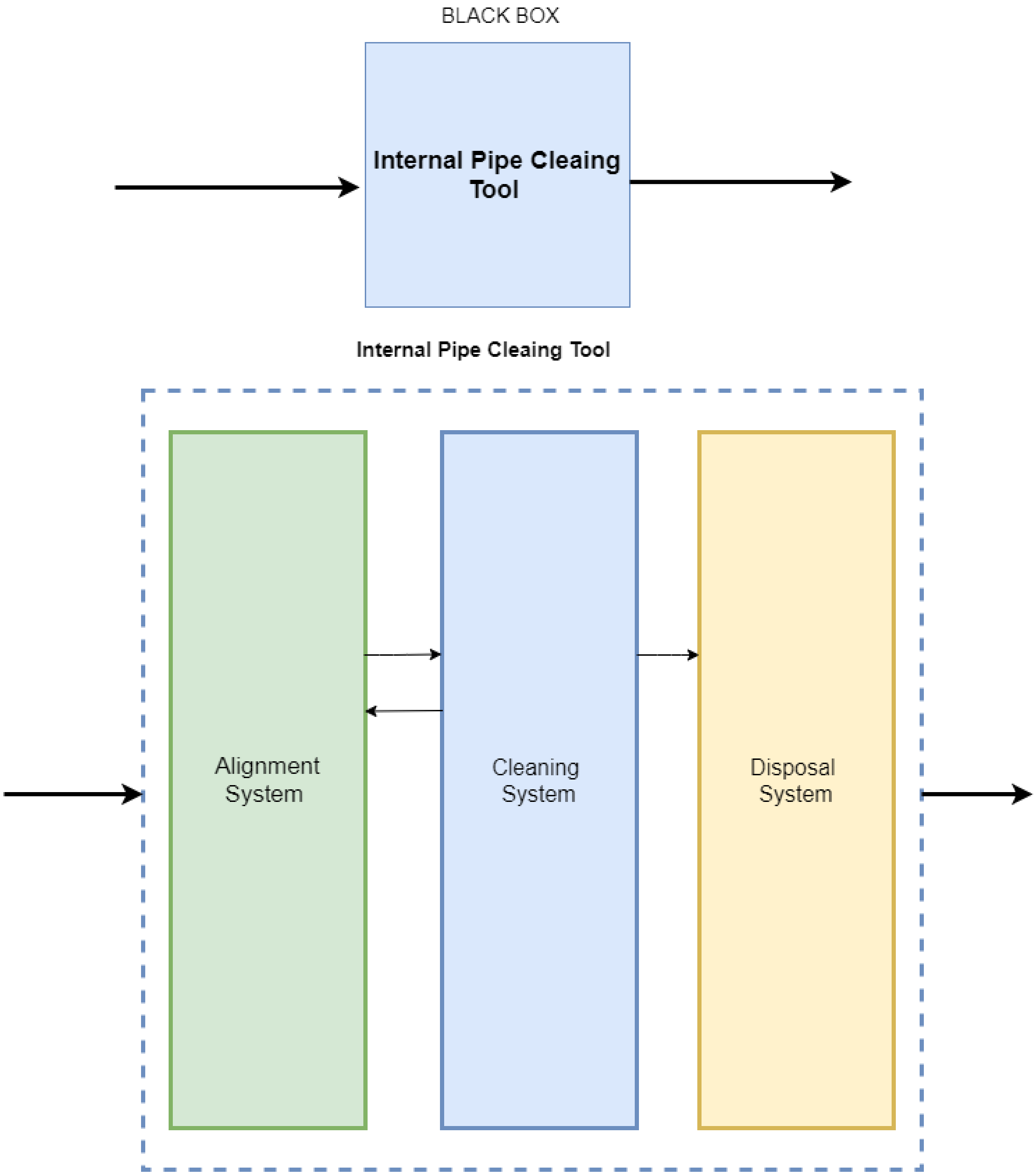

Figure D.2: System context - Internal pipe cleaning tool

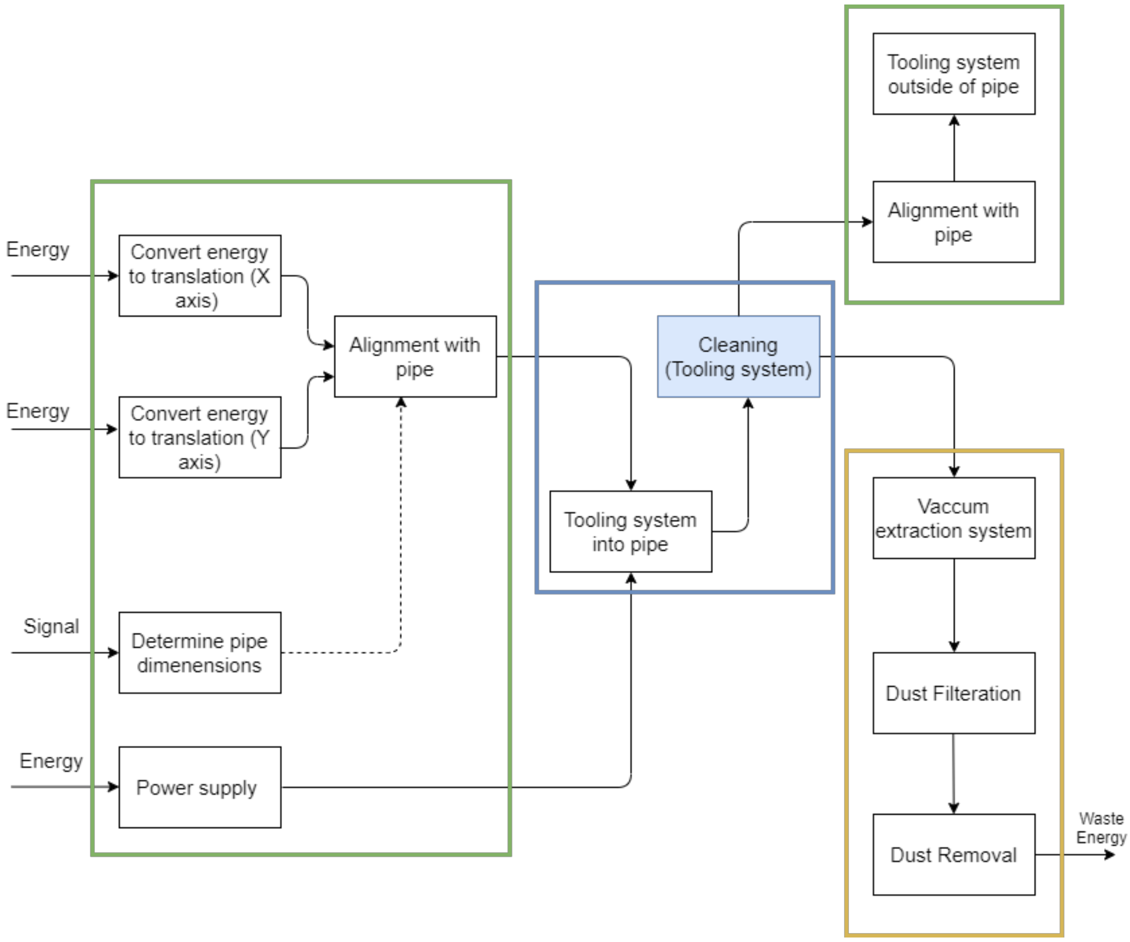

Figure D.3: Sub-function level decomposition - Internal pipe cleaning tool

Solutions / Subfunction	1	2	3	4
Convert X axis translation	Conveyor	Human	Rack and pinon	Mesh gear
Convert Y axis translation	Human	Motor	Gear train	x
Determine pipe dimension	Optical sensor	Proximity senor	Human	Laser reading
Alignment with pipe	Optical sensor	Human	Proximity senor	x
Cleaning	Hot air	Heating + Blow air	Brush	x
Disposal system	Pneumatic	Human	Suction system	x

Table D.4: Sub-function selection - Internal pipe cleaning tool

Analysis and discussion

The request from colleagues at the pipeline production department to develop a new tool was analysed. The project owner is Kirill Kavelin. The implementation was done using the Allseas methodology as described in chapter 3. The analysis was based on the project initiation, degree of completeness, and degree of correctness. The following aspects undermentioned are discussed during the meeting:

- Degree of completeness of the information
  - Interchangeability accepted
  - Cost allocated
  - Project time
  - Resource allocation
  - Debris material
- Degree of correctness
  - R4 (Clean quantity >= 1 kg (over 40 cm))
  - Blower system + Suction system
  - QHSE standard

Appendix E

Evaluation - auxiliary information

E.1 Workshop assessment survey

Workshop assessment

Thank you for participating in the workshop. I hope you gained insights about the following topics:

Topics Covered
Workshop 1 - Zachman framework with questionnaire
Workshop 2 - Requirement formalization
Workshop 3 - Functional decomposition, concept selection and concept evaluation

Disclaimer

I want your feedback to assess my methodology for academic purpose and also helps to improve the methodology for future research in this topic. Your answers will not be posted anywhere in Allseas portal. Please fill this quick survey and let me know your thoughts.

Name *

Elena De Lazzari

Email *

edlz@allseas.com

Job Title

R&D Engineer

Project Responsibilties *

Job resposiblites (Designing, Programming, Safety assessment, etc) and current work manner (A day in your work)

Job responsibilities varying per project; most commonly: computer simulations, hydraulic design, data analysis, test planning and safety assessment, general R&D.
A typical day would also vary per project, some examples:
- Full day of testing in the yard, followed by a day of results analysis and reporting,
- Some analytical tasks in the morning (calculations, simulations), and later review or documentation tasks or communication with the team.

Job location *

Delft

Department *

Innovations

Did you apply systems engineering methodology in your work prior participating in the workshop? *

- ○ Yes
- ◉ No

Beginner

New to the system engineering work procedure

Is this workshop useful to you?

- (●) Yes
- ( ) No
- ( ) Maybe

What did you learn from this workshop?

The collection and management of requirements is a common problem. Timely consideration of all requirements is important but often occurs late in the development phase. There exist frameworks to maintain (changing) requirements and interdependencies, and to formalise requirements for the next design phases.

Experienced

Already have knowledge regarding the system engineering work procedure

If yes, how do you apply in your projects?

What tools were you using for system engineering appraoch and for what purpose?

MS Word, MS Excel, DevOPs, Magic Draw

What were the techniques used for development during concept engineering?

(AGILE, Waterfall, StageGating, etc)

General assessment

How relevant is this methodology to your department?

It can be useful in R&D projects to help identify the client requirements and think about the right questions to ask. It can give more structure to the design phase and a better overview of the problem space, to develop a suitable solution.

Area of development

In which phase/topic of product development will the new methodology help?

Project Initiation, Requirement elicitation, Requirement validation, Requirement management, Concept engineering, etc

Allseas promotion

Would you promote the methodology to your department in future?

- (●) Yes
- ( ) No

Promotion technique

Usage of living doucment, Weekly short meetings, Task boards, etc

What way of promotion would you suggest?

- Updating templates to encourage a more structured approach to formulating requirements.
- Sharing methods that are currently in use that have been successful in the past (the "webinar" from Ingmar can be a good start).
- Involving the Lean team and Inno project management to align objectives and ensure that no conflict in procedures/methodologies occurs.
- Perhaps starting from a "pilot project", as long as the team is actually interested in the method.
- Making an effort to present the methods as less "bureaucratic" would be a good idea. Also, the several methodologies could be introduced separately (based on the project size/need) to better adapt to the preferences of the team.

Technical assessment

What part of the methodology you find the most valuable to be developed in the first place?

- [ ] Zachman framework questionnaire
- [x] Requirements formalisation
- [ ] Functional decomposition
- [ ] Concept selection and evaluation

What part of the methodology would you apply in the first place?

- [ ] Zachman framework questionnaire
- [x] Requirements formalisation
- [ ] Functional decomposition
- [ ] Concept selection and evaluation

What part of the methodology would you be interested to learn more about?

- [ ] Zachman framework questionnaire
- [ ] Requirements formalisation
- [ ] Functional decomposition
- [x] Concept selection and evaluation

Which tools do you like to work this methodology

- [ ] MS Document
- [x] MS Excel
- [x] Azure DevOps
- [ ] MS Visio & DrawIO
- [ ] System Engineering Software (Magic draw, IBM rhapsody)
- [ ] Any recommendation? please specify in additional comments

What tools (from the available at Allseas) you find the most promising to be used in the future?

Azure DevOps and Excel could be good places to start.
I would not introduce system engineering software unless there is an established interest in the teams to use it and knowledge on how to do so.

What is your key take-aways after the workshop? *

There are methodologies that can help the engineers to gather requirements and maintain them during the project. Suitable tools can be used to keep track of them and develop a backlog of actions based on the requirements to be fulfilled.

E.2 Assessment based on 'wish list' of requirement engineering techniques

A theoretical assessment of methodology was performed to understand the area of improvement for future work. It is conducted based on a 'wish list' of RE techniques which is adapted from [40]. The aspects regarding process and communication techniques from the 'wish list' are considered for evaluation. Table E.1 outlines the evaluation in which '✓' supports the wish list whereas '✕' does not supports the wish list.

'Wish list' of RE techniques	Evaluation
Support articulation of the product concept	✓
Support problem analysis	✓
Support feasibility and cost-benefit analyses of options	✕
Support analysis and modelling	✓
Support documentation of requirements	✓
Support a systematic step by step approach	✓
Provide standardised ways of describing work-products	✓
Provide procedures for maintaining work-products	✕
Provide ways of assessing the quality of work-products	✕
Enable identification of measures of the RE process	✕
Supports descriptions of effectiveness in RE terms	✕
Support opportunities for process improvement	✓
Provide automated support for the RE process	✕
Provide guidance on interviewing users	✓
Provide guidance on the design and use of questionnaires	✓
Provide guidance on conducting observations of users	✕
Support the user in reviewing models developed	✓
Support construction of appropriate requirements teams	✕
Support identification of stakeholders	✕
Support the development of a 'shared meaning' of the system being specified	✕
Encourage intuition, imagination and common sense among participants	✓
Support communication between people from diverse backgrounds	✓
Support facilitated meetings with predefined agendas and problem solving strategies	✓
Support the development of listening skills among participants	✕

Table E.1: Assessment based on 'wish list' of requirement engineering techniques

E.3 Workshop - deliverables

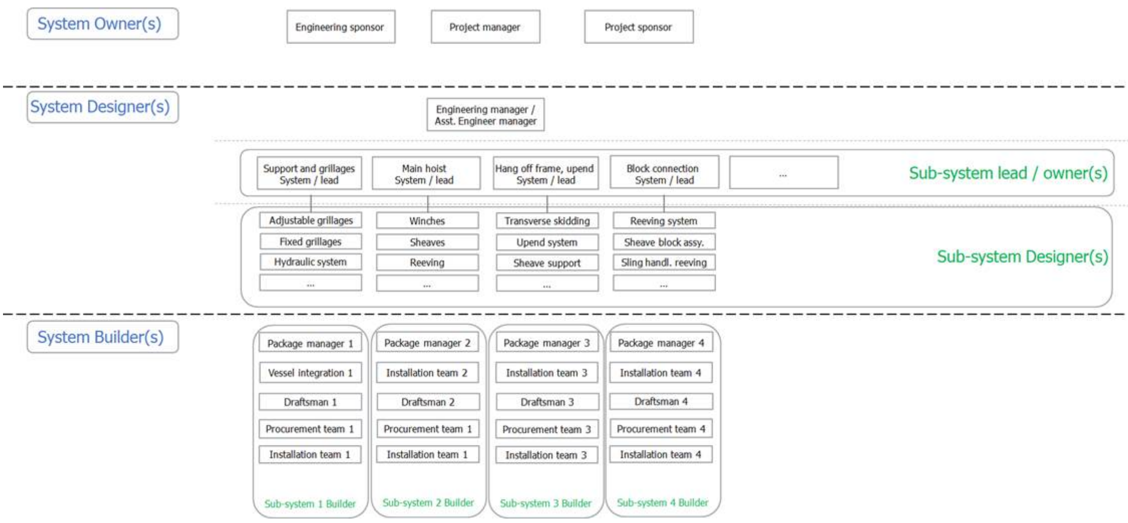

Table E.2: Role in big projects - Jacket lift system (Work by Kirill)

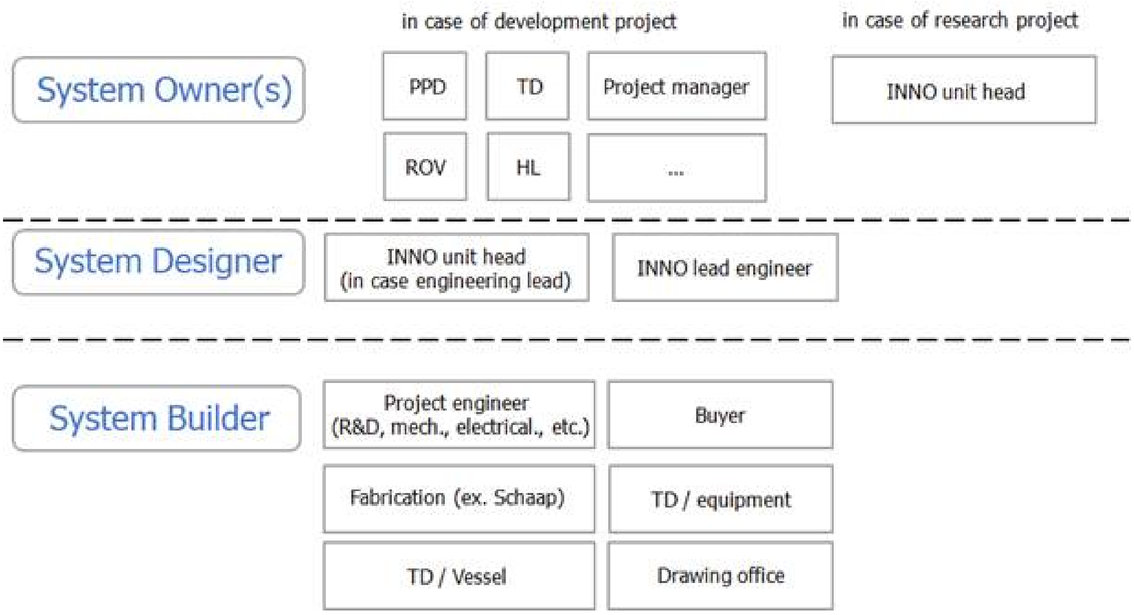

Table E.3: Role in small projects (Work by Kirill)

Abbreviations

RE Requirement Engineering

SYSML System Engineering Modeling Language

SYSMOD System Modelling

V-MODEL Verification and Validation model

UML Unified Modeling Language

TRIZ Theory of Inventive Problem Solving

MBSE Model Based System Engineering

UC Use Case

BDD Block Definition Diagram

FL Firing Line

DJF Double Joint Factory

QHSE Quality Health Safety and Environmental

PSV Pipe Supply Vessels

PS Pioneering Spirit

ARF Action Request Form

R Requirements

C Requirements Checklist Database

DS Design Specification

NR Narrative Requirement

RC Requirement Checklist

UC Use Case

BDD Block Definition Diagram

MS Microsoft

VB Visual Basic

DevOps Development and Operations

ISO International Organization for Standardization

TU/e Technical University Eindhoven

Bibliography

[1] *ALLSEAS Group S.A. company.* https://allseas.com/. [Online; accessed November-2020].

[2] Emma Rudeck. *Concurrent Engineering Blog.* https://www.concurrent-engineering.co.uk/Blog/bid/90476/Why-Requirements-Engineering-should-matter-to-your-company. [Online; accessed January-2021].

[3] Ion Barosan. *SysML lecture slides - Real-time Software Systems Engineering (2IN70).* [Online; accessed December-2019].

[4] Allseas. *Innovations Project Departmental Instructions Overview.* [Document number: GE-18055-001-Q-E-001]. 2017.

[5] U.S. Department of Defense. *Software Technology Strategy.* December 1991.

[6] John A Dotchin and John S Oakland. "Theories and concepts in total quality management". In: *Total Quality Management* 3.2 (1992), pp. 133–146.

[7] I. Sommerville and P. Sawyer. *Requirements Engineering: A Good Practice Guide.* Wiley, 1997. ISBN: 9780471974444. URL: https://books.google.co.in/books?id=5NnP-VODEc8C.

[8] Ralph Rowland Young. *The requirements engineering handbook.* Artech House, 2004.

[9] Dhirendra Pandey, Ugrasen Suman and A.K. Ramani. "An Effective Requirement Engineering Process Model for Software Development and Requirements Management". In: Nov. 2010, pp. 287–291. DOI: 10.1109/ARTCom.2010.24.

[10] Mona Batra and Archana Bhatnagar. "A Comparative Study of Requirements Engineering Process Model." In: *International Journal of Advanced Research in Computer Science* 8.3 (2017).

[11] Linda A. Macaulay. *Requirements Engineering.* Berlin, Heidelberg: Springer-Verlag, 1996. ISBN: 3540760067.

[12] Gerald Kotonya and Ian Sommerville. *Requirements Engineering: Processes and Techniques.* English. John Wiley Sons, Inc., 1998. ISBN: 0471972088.

[13] Rajkumar Upadhyay. *Spiral model.* https://www.geeksforgeeks.org/advantages-and-disadvantages-of-using-spiral-model/. [Online; accessed January-2021].

[14] Dhirendra Pandey, Ugrasen Suman and A Kumar Ramani. "An effective requirement engineering process model for software development and requirements management". In: *2010 International Conference on Advances in Recent Technologies in Communication and Computing.* IEEE. 2010, pp. 287–291.

[15] Ian Sommerville. *Software Engineering.* 9th ed. Harlow, England: Addison-Wesley, 2010. ISBN: 978-0-13-703515-1.

[16] Gerhard Pahl and Wolfgang Beitz. *Engineering design: a systematic approach.* Springer Science & Business Media, 2013. URL: https://www.springer.com/gp/book/9781447135814.

[17] *Model Based Systems Engineering.* https://mbse4u.com/sysmod/. [Online; accessed January-2021].

[18] Tim Weilkiens. *Systems engineering with SysML/UML: modeling, analysis, design*. Elsevier, 2011.

[19] Tim Weilkiens. *SYSMOD-The Systems Modeling Toolbox-Pragmatic MBSE with SysML*. Lulu.com, 2016.

[20] Sommerville Ian and Sawyer Pete. "Requirements Engineering: A good practice guide". In: *China Machine Press, CITIC PUBLISHING HOUSE* (1997), pp. 177–206.

[21] ISO. *IEEE/ISO/IEC 29148-2018 - ISO/IEC/IEEE International Standard - Systems and software engineering - Life cycle processes - Requirements engineering*. https://standards.ieee.org/standard/29148-2018.html. [Online; accessed January-2021].

[22] J.A. Zachman. *John Zachman's Concise Definition of the Zachman Framework*. https://www.zachman.com/16-zachman/the-zachman-framework/35-the-concise-definition. 2008.

[23] J.A. Zachman. *The framework for enterprise architecture: background, description and utility*. https://www.zachman.com/resources/ea-articles-reference/327-the-framework-for-enterprise-architecture-background-description-and-utility-by-john-a-zachman. 2016.

[24] S. Douglas. In: *Model-Driven Engineering*. IEEE Computer, vol. 39, no. 2, pp. 25–31, 2006.

[25] Tetsuo Tomiyama, Masaharu Yoshioka and Akira Tsumaya. "A knowledge operation model of synthesis". In: *Engineering Design Synthesis: Understanding, Approaches and Tools*. Ed. by Amaresh Chakrabarti. London: Springer London, 2002, pp. 67–90. ISBN: 978-1-4471-3717-7. DOI: 10.1007/978-1-4471-3717-7_5. URL: https://doi.org/10.1007/978-1-4471-3717-7_5.

[26] W. Brace and K. Thramboulidis. "FROM REQUIREMENTS TO DESIGN SPECIFICATIONS - A FORMAL APPROACH". In: 2010.

[27] Nigel Cross. *Engineering design methods: strategies for product design*. John Wiley & Sons, 2021.

[28] Ralph Katz. "The effects of group longevity on project communication and performance". In: *Administrative science quarterly* (1982), pp. 81–104.

[29] IBM. *IBM Engineering Systems Design Rhapsody*. https://www.ibm.com/products/systems-design-rhapsody. [Online; accessed July-2021].

[30] Eric Lutters et al. "Tools and techniques for product design". In: *CIRP Annals* 63.2 (2014), pp. 607–630. ISSN: 0007-8506. DOI: https://doi.org/10.1016/j.cirp.2014.05.010. URL: https://www.sciencedirect.com/science/article/pii/S0007850614001929.

[31] Stig Ottosson et al. "Research Approaches on Product Development Processes". In: *9th International Design Conference, DESIGN 2006* (Jan. 2006).

[32] Jon Holt and S. Perry. *SysML for Systems Engineering, 2nd Edition: A Model-Based Approach*. Nov. 2013, pp. 1–935. ISBN: 9781849196512. DOI: 10.1049/PBPC010E.

[33] Ice Removal Nord II - 510164. *Poject Initiation Plan*. Document Number: IN-380-03-R-002, Rev. A.

[34] Ice Removal Nord II - 510164. *Functional Specifications for ice removal*. Document Number: IN-380-03-R-003.

[35] Winterisation for Nordstream. *Action Request Form*. Document Number: 2018-01-18 PI-11000.

[36] Matthias Güdemann et al. "SysML in digital engineering". In: Jan. 2010, pp. 1–8. DOI: 10.1145/1837154.1837155.

[37] Manoj Kumar Choubey. "IT Infrastructure and Management (For the GBTU and MMTU)". In: (2012), p. 53.

[38] Cockburn, Alistair. *Writing effective use cases*. Pearson Education India, 2001.

[39] Winterisation for Nordstream. *Lessons learnt De-icing*. Close-Out document GE-18055-001-Q-E-009.

[40] Linda Macaulay. “Requirements for requirements engineering techniques”. In: *Proceedings of the Second International Conference on Requirements Engineering*. IEEE. 1996, pp. 157–164.