Systems modeling in the naval domain

Relating stakeholders with requirements in the early stages of naval ship design

E.R. Kooij

Thesis for the degree of MSc in Marine Technology in the specialization of Ship Design

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Relating stakeholders with requirements in the early stages of naval ship design

By

E.R. Kooij

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Company supervisors

Responsible Supervisor:	ir. J. van Leeuwen J.
Daily Supervisor:	ir. K. Droste

Thesis exam committee

Chair/Responsible Professor:	Dr. A.A. Kana
Staff Member:	ir. J.J. le Poole
Staff Member:	Dr.ir. P. de Vos
Company Member:	ir. K. Droste

Author Details

Studynumber: 4315154

Preface

I hereby present the final deliverable as part of the graduation assignment belonging to the masters program of Marine Technology at the TU Delft. The result is a report with the main objective of relating stakeholders with requirements during the early stages of naval ship design. At first, efforts were taken to explore the areas of Model Based Systems Engineering, early stages of naval ship design, stakeholder analysis and information modelling. Understanding the specific system modeling tool 'Capella', as used at DAMEN Naval, proved to be a time consuming process. As time progressed, the elements contributing to the problem became clear and hence an iterative process began of constructing a method in order to deal with this abstract subject. The abstractness of the problem in combination with a confidential environment was the main cause for experiencing challenges in grasping the direction of the preferred research.

The research is conducted in collaboration with DAMEN Naval, a Dutch company specialized in the design and construction of naval vessel. Figuring out the needs and understanding the problem they face during the transition towards Model Based Systems Engineering was a daunting task, but in the end, I feel confident of presenting the results as given in this thesis. This report, being the final version of a long journey, is the concluding part of the research and marks a milestone in completing my 'never-ending' efforts of studying at the Delft University of Technology.

Words of gratitude are in place for the supervisors in guiding me during my academic endeavours of this thesis. Support from the Delft University of Technology was given by ir. J.J. le Poole in the form of inspirational weekly meetings, pointing me in the right direction, pushing me back on track and above all insisting on moving forward. Besides support from the TUD, I had the honor of receiving guidance from DAMEN Naval by ir. K. Droste, an expert in the field of systems modeling. The weekly meetings helped me in contextualising the problem and above all awoken enthusiasm about the harder-to-grasp topics. Besides Koen, I would like to thank all members of the system modeling team at DAMEN Naval, in special ir. Jaap Janssen, for helping me out with Capella problems, providing the diagrams for the case study and giving pragmatic feedback at the end of presentations. A word of gratitude is also given, in advance, towards the external committee member dr.ir. P. de Vos for evaluating me and this thesis during the defence. And last but certainly not least, I would like to thank dr. A.A. Kana for his valuable feedback and meetings which were shaping the research into an academic perspective, I appreciate the time and effort he took in his busy schedule to help me out at certain stages during the process.

Besides the academic support, I am grateful for receiving best wishes, tips and advice from my friends in Delft and those further away in Heiloo and Arnhem. Motivational talks are key in conducting individual research. As this thesis marks the end of my studies in Delft, I feel like this is the right place to thank my parents for their ongoing interests and financial support; it was an unexplored world for all of us but we managed to survive!

Enjoy reading!

E.R. Kooij
Rotterdam, November 2022

Abstract

The need for relating stakeholders with requirements and the need for systems modeling are the main drivers for this thesis. Relating stakeholders with requirements is beneficial in order to balance the interests of all stakeholders associated with complex design projects. The variability in types of stakeholders and information abundance in current projects are the main causes of the difficulty in establishing this relationship. The need for system modeling is part of the transition towards Model Based Systems Engineering (MBSE), realizing a single source of truth and improving efficiency by better communication between all involved stakeholders.

At first, a breakdown of requirements management processes is presented, followed by an exploration of stakeholders within the naval domain. Requirement management processes are extensive, elaboration of requirements is the more important step during this thesis. Structuring the requirements as part of the elaboration is based on an OFP-decomposition, where ‘O’ stands for Operational, ‘F’ for functional and ‘P’ for physical. The complexity of stakeholders is tackled by an analysis which consists of the main steps: identification, differentiating & categorizing, investigating relationships and prioritization. Prioritization of stakeholder is based on four attributes: power, interest, urgency and legitimacy. Applying MBSE by incorporating systems modeling demands a selection of the main pillars, being a method, tool and a language. The method during this thesis is ARCADIA, preferred by DAMEN due to the compatibility with the software ‘Capella’. The language is chosen to be the NATO Architectural Framework (NAF). System modeling is currently in a state of implementation at DAMEN Naval, therefore, this research aids in the continued development of their processes. As mentioned, the NAF is used as a language to model the stakeholder‘s concerns in a systematic way. The NAF consists out of 47 independent viewpoints, each specifying a different concerns on a specific level of detail. The representations of these viewpoints are not strict, therefore, translating these concerns into Capella was one of the first major tasks.

A method is designed to establish the relationship between stakeholders and requirements by using the NAF as a backbone. The method consists of 12 steps and inhibits an iterative character, as is common in naval ship design processes. The inputs of the method are a stakeholder analysis and a set of OFP-classified requirements, resulting in a systems architecture relating requirements with stakeholders. Creating additional non-NAF existing concerns is one of the pitfalls of the method and the presented guidelines are still creating room for error, therefore more research into this part of the method is advised.

The method has been assessed by using a Proof of Concept (PoC), a limited case study based on 2 selected stakeholders and a limited set of requirements. The requirements for the PoC were found in the Maritime Interdiction Force Operations (MIFO), displaying demands for conducting boarding and deterrence missions at sea. Concerns per stakeholder have been analysed and viewpoints were selected from the NAF. The Capella project model was used to construct the diagrams from. The result was an agglomeration of diagrams representing all viewpoints, contributing to the construction of the ‘best suited’ systems architecture and fulfilling most of the success criteria. Relating all requirements to the diagrams has proven to be hard during the PoC and it is recommended to improve these efforts in a next iteration, as well as the use of other representation-forms instead of the diagrams common to Capella.

The subsequent step was to address the method by a case study, including more stakeholders from within the naval domain. The analysis comprised 12 stakeholders, internal and external with respect to DAMEN Naval. The concerns per stakeholder have been analysed, viewpoints selected and the diagrams were constructed by the system modelers team. This resulted in more detailed diagrams w.r.t. the PoC. The final systems architecture is capable of relating the requirements from the operational layers to the physical layers by the structured representation according to the NAF. Classification of requirements is done according to the OFP-decomposition, however further research into other classifications could prevent increasing complexity.

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Glossary

Architecture: Fundamental organization of a system embodied in its components, relationships, environment and principles guiding its design and evolution.

Architectural Framework (AF): Skeletal structure that defines suggested architectural artifacts, describes how these artifacts are related to eachother and provides generic definitions for what those artifacts might look like.

Component: The smallest decomposition used in systems engineering, similar to an element.

Model Based Systems Engineering (MBSE): Extension of the traditional SE by implementing the use of a central model, composed by individual department-specific models, throughout the process, hereby increasing requirements traceability and early validation during the design phase. The constituents of a functioning MBSE include an universal language between models, synchronous access by all stakeholders and a continuously up-to-date source of information.

System: A collection of parts that interact with each other to function as a whole (Kauffman, 1980). A system is also a set of integrated end products and their enabling products (Martin, 1997).

Systems Architecture (SA): Composition of diagrams to reveal the structure of the solution through the eyes of a specific stakeholder, underlying structure of a system

Systems engineering (SE): Interdisciplinary approach in which the design solution constitutes of multiple dependent or independent systems. The division in systems or even subsystems is mainly based on functional requirements in order to accomplish a certain behaviour of the design solution.

Functional analysis (FA): Analysis of the actions, operations or services performed by the system or the components of the system in order to fulfill requirements demanded by the client. The end goal of the FA is to obtain a functional architecture which traces all requirements of the system to functions of the system.

Operational analysis (OA): The OA is a means of capturing what the users of the system must achieve as part of their work or mission. The conditions in which the system will take part are a significant part of this analysis.

System Needs Analysis (SyA): Procedure to define the contribution of the system to the demands of stakeholders, which are the result after the operational analysis or by the requirement documents provided by the client,

Logical architecture (LA): Implements the primary decisions of the solution, hereby maintaining abstract decisions from where the physical architecture can create concrete solutions constituting of physical components. The LA has to fulfill the expectations from the stakeholders, an abstract decomposition of the LA leads to the principles of behaviour and the interaction between the stakeholders (Roques, 2018b).

Physical architecture (PA): Commonly known as the finalized architecture, is a definition of the solution at a sufficient level of detail. The PA has to ensure a specification of the developments and acquisitions of all subsystems part of the solution. After constructing the PA, a clear definition and orientation of the systems integration, verification and validation procedures is known and part of this architecture (Roques, 2018b).

Information mapping: Procedure to organize the required information in a design process to a corresponding phase of the design. Care should be taken to determine when which kind of information is needed during the process, this decomposition is detailed until clarity is guaranteed.

Acronyms

- ADM: Architecture Development Methodology
- AF: Architecture Framework
- ARCADIA: Architecture Analysis Design Integrated Approach
- COI: Contact of Interest
- ConOps: Concept of Operations
- DBSE: Document Based Systems Engineering
- DMO: Defense Material Organization
- DoDAF: Department of Defense Architecture Framework
- ESSD: Early Stage of Ship Design
- INCOSE: International Council on Systems Engineering
- MBSE: Model Based Systems Engineering
- MIFO: Maritime Interdiction Force Operations
- NAF: NATO Architectural Framework
- NATO: North Atlantic Treaty Organization
- OCD: Operational Concept Design
- OFP: Operational, functional and physical
- RAM: Reliability, availability and maintenance
- SA: Systems Architecture
- SE: Systems Engineering
- SM: System Modeling
- SWBS: Ship Work Breakdown Structure
- SysML: System Modeling language
- UAF: Unified Architecture Framework
- UML: Universal Modeling Language

The next list gives an overview of the abbreviations used in Capella and of relevance to this thesis. With respect to the diagrams related to each layer, the first letter indicates the specific layer being operational, system, logical or physical. Due to the similarities of naming over the four layers, only the names of diagrams corresponding to the operational layer are presented, with exemptions made on diagrams non-existing in the operational layer. Besides the abbreviations of the achievable diagrams in Capella, some other working principles are used which are abbreviated.

- OCB: Operational Capabilites Blank
- OABD: Operational Activity Breakdown

- OAIB: Operational Activity Interaction Blank
- OAS: Operational Activity Scenario
- OAB: Operational Architecture Blank
- ORB: Operational Role Blank
- OES: Operational Entity Scenario
- OEDB: Operational Entity Breakdown
- LDFB: Logical Data Flow Blank
- LFBD: Logical Functional Breakdown
- HMI: Human-Machine Interaction
- FC: Functional Chain
- LES: Logical Exchange Scenario

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1 Introduction

This thesis will illustrate, explore, and address the problem during the early stages of naval ship design in relating stakeholders with requirements which is currently hard to establish due to the complexity of projects and the evolving character of information. The problem has been around for decades (Okesola et al., 2019, Loughlin and Ryan, 2007), and with the current transition towards Model Based Systems Engineering (MBSE), available tools to address this problem are being developed. The practical implication of MBSE involves system modeling, which is essentially the interdisciplinary study to conceptualize and construct systems in any specific development program or project. Furthermore, the maritime industry has accepted a shift towards MBSE, given the successful application in e.g. the aerospace industry, and is eager to introduce working protocols in order to ease the implementation of these new processes. Therefore, this thesis aims to provide an MBSE-based solution in the naval domain for the problem of relating stakeholders with requirements by applying an architecture framework based approach.

First, the research partner, DAMEN Naval, is introduced. Secondly, the importance of relating stakeholders with requirements is elaborated and the reasons for pursuing systems modeling are presented. Finally, the research objective is formulated and the research questions are presented.

1.1. DAMEN Naval

DAMEN Naval, part of the DAMEN Shipyards Group since 2000, is the dedicated division specialized as full service provider of naval vessels throughout the lifecycle. The portfolio of designs consists of custom naval combatants, standardized naval combatants, naval logistic support vessels, patrol vessels and auxiliary vessels such as landing vessels and rigid hull inflatable boats (RHIB). Over these past 147 years, more than 400 vessels have been delivered to customers all over the world, with examples such as the Shabab Oman II, a training vessel for the Royal Navy of Oman, or the HNLMS Karel Doorman, the newest joint support vessel ordered by the Royal Netherlands Navy and commissioned in 2015. These products are established by the collaboration of over 500 professionals based at the headquarters in Vlissingen, The Netherlands. The construction of vessels often takes place in Romania, or on request by the client at another preferred location. Hence, DAMEN has to deal with many national and international stakeholders throughout the process of designing and constructing a vessel.

The interest of DAMEN Naval in systems modeling has increased by the awarding of the multi-billion dollar contract for the design and construction of new innovative frigates for Germany. The technological requirements and coherent complexity of the design resulted in innovative ways to deal with the overload of information and seeking for a constructive method to relate stakeholders with requirements. Therefore, systems modeling has been demanded by the client as a way to deal with this information and merit the advantages of the model-based approaches such as de-risking the design process and maintain traceability of requirements. Besides the specific demands of the client, DAMEN Naval recognizes the benefits of innovating at design processes to preserve the delivery of outstanding naval vessels and is therefore eager to support this research.

1.2. The need for relating stakeholders with requirements

The idea of relating stakeholders with requirements is not new and is incorporated in conventional design processes by e.g. System Requirements Documents (SRD) (Michael Edwards and Howell, 1991). However emphasizing this relation while transitioning towards an MBSE-approach is a new and useful addition when concentrating on the advantages of MBSE. Besides, the relationship between requirements, or in special requirements engineering, and stakeholders are hardly discussed (Pedrini and Ferri, 2019, Maalej et al., 2014), making it difficult to balance the interests of stakeholders in complex design projects (Okesola et al., 2019).

First of all, the types of stakeholders and their information needs are varied in naval ship design processes. For example, subcontractors are often more interested in the interfaces of the design, whereas the client is eager to buy a product with all the desired requirements. The expectations demanded by each of the stakeholders is eccentric and specifies their respective views of the system (Piaszczyk, 2011). Secondly, the information abundance relating to requirements has increased since information technology-intensive projects have emerged (Piaszczyk, 2011). Clients have become more aware of the possibilities for tracking design progress, updates can be given more frequently and the demands of these clients have therefore increased. Creating structure in the vast amount of requirements is essential for projects to deliver on time, within budget and with minimal risk. Therefore, demarcation of requirements is necessary. The combination of a vast amount of stakeholders and demarcated requirements results in challenges for system modeling. Therefore, the challenge of this thesis is to relate these two increasingly complex domains.

The reason for relating stakeholders with requirements is found related to the Early Stages of Ship Design, where requirements elicitation is one of most important tasks (Andrews, 2011). During the elicitation of requirements, which is a major part of the investigation into concept alternatives, identification of stakeholders and understanding their concerns vital for obtaining an understanding of the actual design objective. An extensive dialogue between stakeholders about their interests is necessary in order to develop a fulfilling set of requirements able to capture the wishes of, ideally, all stakeholders. Relating stakeholders with their requirements is therefore essential (Wang et al., 2012). Furthermore, as will be explained in section 1.3, the advantages concerning traceability of requirements and improved communication are reasons for constructing these relationships.

The advantages of relating stakeholders with requirements during the system modeling process are numerous and include better communication between stakeholders, mitigation of risks, and prevention of delays in schedule (INCOSE, 2014). The dialogue during the elicitation process is refined when understanding the origin of requirements and contacting the corresponding stakeholder in order to resolve individual issues. Furthermore, conflicting requirements between stakeholders can be resolved by discussing the matter and proposing a solution by the accountable person.

1.3. The need for systems modeling

In an effort to deal with the increasing complexity of current projects, a transition towards MBSE is desired by DAMEN Naval. The traditional systems engineering processes are replaced by systems modeling processes. System modeling consists of the derivation and elicitation of requirements, system design, integration, verification and validation, all taking place within the digital environment (Crawley et al., 2004). The role of a single source of truth belongs to the system model, but the practical implementation is far from convenient. Over time, other industries have dealt with these challenges and their successes and flaws are a good basis to start. This initial endeavor of system modeling occurs by selecting three pillars, commonly known as the pillars of MBSE (Tepper, 2010), consisting of a *tool, method and language* as depicted in figure 1.1. The *tool* represents software able to cope with the generation of system models such as Enterprise Architect or Capella (Whitehouse, 2021, Roques, 2018a, Roques, 2018b). The *method* is followed in order to structure the process, e.g. the ARCADIA method (Roques, 2018a). A *language* is used to translate the practical demands into manageable slots of unified information convenient to digest for the software, e.g. SysML, or more abstract conceptions such as a specific architectural framework (Friedenthal et al., 2007, Alai, 2019). The Venn-diagram, presented in figure 1.1, illustrates the coherence of the pillars by the overlapped sections. The principles of MBSE are only valid in the cross section of all three pillars.

As indicated in figure 1.2, the selected *tool* for this thesis is Capella with the accompanied *method* ARCADIA. This choice has been made by the systems modeling team at DAMEN Naval and is also

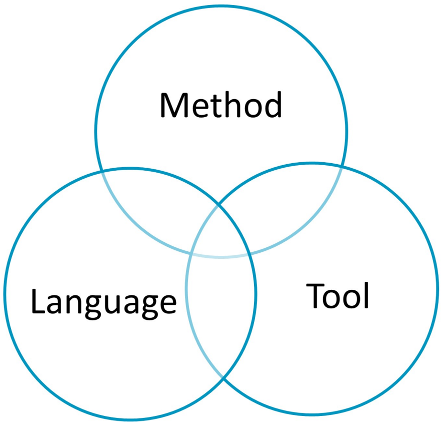


Figure 1.1: General pillars of MBSE (Tepper, 2010)

the standard combination being pursued in the Netherlands, therefore it is continued throughout the thesis. The selection of a *language* was left to the author, after examining various variants and possibilities such as the Department of Defense Architectural Framework (DoDAF) and Unified Architecture Framework (UAF), the NATO Architectural Framework (NAF) has been chosen. The reason for selecting the NAF as language is, primarily, because the NAF claims to "provide a way to organize and present architectures to stakeholders", hence organizing the information in such a way advantageous to stakeholders and satisfying their needs (Architecture Capability Team, 2020). Secondarily, the applicability on military and business enterprises is essential for the affiliation with the research partner DAMEN Naval.

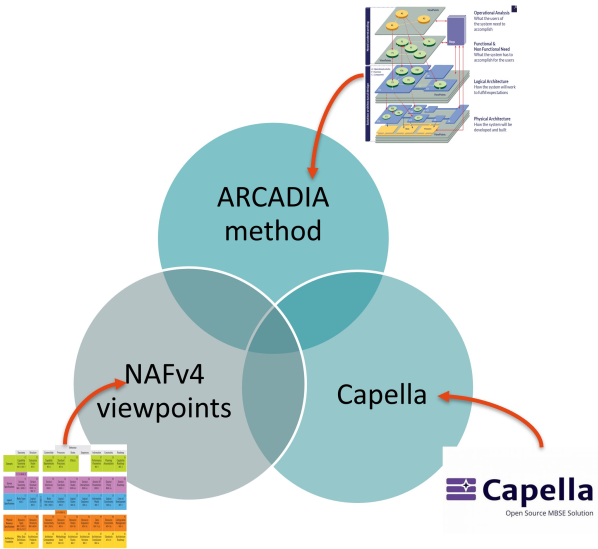


Figure 1.2: Selected pillars of MBSE

1.4. Research objective and questions

In order to tackle the challenge of relating stakeholders with requirements while using systems modeling, the following research objective has been established:

"To develop and demonstrate a methodology to relate stakeholders with requirements using systems modeling in the early stages of naval ship design"

To achieve this research objective, the following research questions will be addressed in this thesis.

First of all, the problem is elaborated in Chapter 2 with the aim of understanding all involved aspects. Therefore, this section will answer the sub-question:

"What is the problem when relating stakeholders with requirements in the early stages of naval ship design?" See Chapter 2.

The subsequent section will present details regarding a possible solution to this problem. The NATO Architectural Framework is introduced and explained by answering the sub-question:

"How is the NATO Architectural Framework able to relate stakeholders with requirements?" See Chapter 3.

Chapter 4 introduces the method and specifies the steps to be executed. Before establishing a method, the following sub-question has to be solved.

"What are the criteria for the development of a method suitable of relating stakeholders with requirements?" See Chapter 4.

Once a method has been constructed capable of responding to the research objective, a demonstration is necessary to strengthen this claim. Therefore, two demonstrations have been carried out. The process of executing these demonstrations corresponds to answering the following sub-question.

"How to demonstrate if the method is capable of establishing the required relationship?" See Chapters 5 and 6.

By answering these sub-questions in order, the research is guided from a broad problem description towards a solution in relating stakeholders with requirements using systems modeling.

2 Background

This chapter will elaborate on the subjects introduced in Chapter 1 and further explain their meaning in order to provide information necessary to grasp the development and demonstration of the method. First of all, the early stages of ship naval ship will be addressed and the relation with regards to DAMEN Naval will be emphasized. Next, information regarding requirements engineering and specifically requirements classification will be presented. The goal of this part is to illustrate conventional methods of dealing with complex requirements. Subsequently, an explanation of stakeholder analysis is given as a fundamental approach to deal with a set of stakeholders and thereby understand the complicated web of stakeholders en their interests. At last, information about the practicalities of MBSE with a focus on systems modeling and architectural frameworks are presented.

2.1. Early stages of naval ship design

A design process consists of multiple phases with each distinct properties (Andrews, 2018). Design methods have developed ever since, with one of the more familiar methods in naval architecture being the iterative design spiral from Evans (Gaspar et al., 2012). The development of methods has ultimately led to systems engineering practices (Laverghetta and Brown, n.d.), symbolised by the familiar V-model, as incorporated at DAMEN Naval. During the application of systems engineering practices, distinguishable states can be identified. One of the initial states is addressed as the early stages of ship design (ESSD). Capturing the requirements of a customer and translating this set of information into a feasible concept design is the main task during the ESSD. The amount of available information and the prompt increase during this stage is substantial, causing the development of new design methods, see figure 2.1. Therefore numerous decisions have to be taken based on an overload of conflicting information, hence it is estimated as the phase containing the highest uncertainty. Therefore, synthesising the requirements is one of the primary goals (Doerry, 2006), accomplished by elucidation (Andrews, 2011).

In order to understand the ESSD at DAMEN Naval, an explanation of the specific industry should be given. DAMEN Naval is operating in the naval domain by constructing naval vessels for governments all around the world. Naval vessels and their corresponding design processes are typified by the following characteristics.

- Multi-mission capable vessel (Duchateau, 2016)
- High degree of autonomy (Andrews, 2018)
- Man-made and mobile environment for large numbers of people (Andrews, 2018)
- High development costs; multi-billion dollar projects
- Politically concerned vessels; orders from national multi-year policies
- Prolonged execution times of projects spanning 5 - 15 years
- Not obliged to sail under class, but is classified easier to sell second-handed (Droste, 2022)

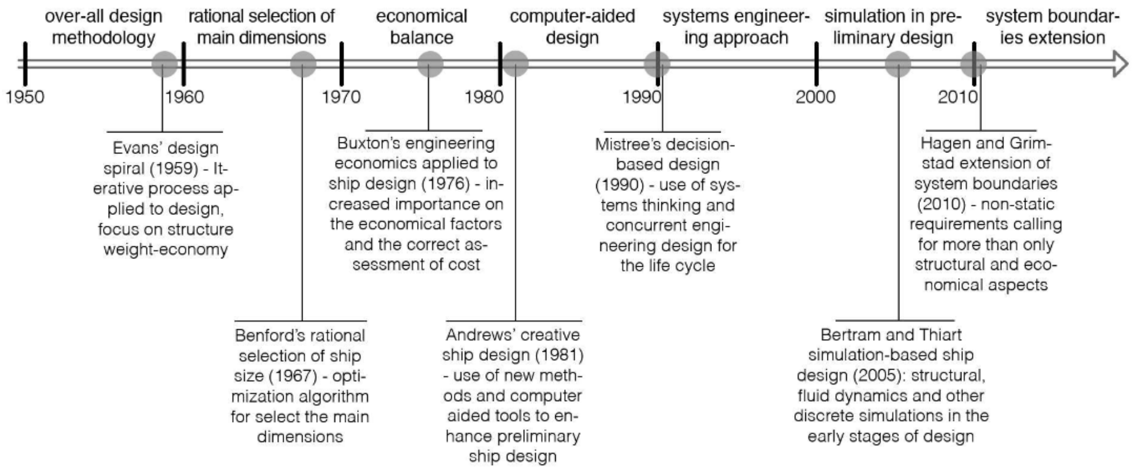


Figure 2.1: Development of design methods for a ship design process (Gaspar et al., 2012)

- Rapidly adaptable set of requirements (Shields et al., 2016)
- Design process identified as wicked problem (Andrews, 2012)

Most of the characteristics are self-explanatory, but the last one needs more emphasis for this thesis. The volatility of a set of requirements is due to two principles: the elicitation process between customer and shipyard and the technological innovation during the lifespan of a project (Dick et al., 2019). The former is caused by the iterative process of defining the needs of a customer versus the affordability of these needs, and could even be supplemented by the constraints in possibilities at a shipyard. The later is due to vast increasing technological developments in combination with the immense lifespan of a naval design project creating an evolving availability of new technical equipment (Kerns et al., 2011). In order for a naval vessel to be competitive with regards to the adversaries, equipping vessels with the latest technological innovation is a must.

The requirements are contractually awarded to the winning company bidding for a tender, abiding to the requirements is therefore important for a company such as DAMEN Naval. Not complying to contractual requirements will cause financial consequences for the company. This again stipulates the importance of this research in relating requirements with stakeholders and avoiding, or at least decreasing, the risks and financial burdens.

2.2. Dealing with the complexity of requirements

The first part of the problem is concerned with handling complex requirements. Before introducing the systems modeling environment, it is best to concentrate on the current ways of dealing with requirements in systems engineering practices. These current ways of handling requirements could potentially lead to a partial solution of relating stakeholders with requirements during systems modeling (Shukla and Auriol, 2013,Sharp et al., 2008). At first, all sequential stages of a requirements engineering process will be given, followed by a specification of two of these stages: the elicitation and elaboration of requirements.

2.2.1. Requirements engineering processes

This section will elaborate on the different processes followed in order to systematically deal with requirements. The requirement engineering processes consists of the following key phases:

1. **Inception:** During inception of the requirements, a formal start of the project is given by identifying the necessities and performing a feasibility study. The goal of this phase is for the requirements engineer to have an overview of the stakeholders objectives and plan (Fernandes and Machado, 2015). Pitfalls during this phase are the verbal communication between client and project executives. Obtaining a clear view of what is expected and what is understood to be expected is of major importance.

2. **Elucidation:** The elicitation phase demands an extensive dialogue between the various stakeholders and the project executives. The techniques available for performing this dialogue and constructing sharp requirements are numerous, consisting of e.g. interviews, surveys, domain analysis and prototyping (Fernandes and Machado, 2015).

3. **Elaboration:** Through elaboration of the requirements, an analysis is conducted and the respective requirements are classified based on the specific classification-scheme, as will be discussed in the next section. Ambiguity of requirements is a usual problem (Katina et al., 2014, Malan et al., 1999), meaning multiple requirements cover the same subset of functions, hence conflicting the architecture. Besides ambiguity, requirements could be described vaguely or incomplete. At the end of this phase, a first system architecture is developed in which the requirements are cohesively grouped. In order to address the problem when including requirements in the process, elucidation of requirements has been chosen as the most essential phase of the process. By elucidating requirements, parties involved try to resolve conflicting issues between requirements and establish a common understanding. The elucidation process is carried out to constrain the solution space of the wicked problem and allow creativity when defining the initial set of requirements (Andrews, 2011). The importance of this step is stipulated as being the only time designers can truly be divergent and radical in their work, since downstream processes depend on the lock-in of a set of requirements (Andrews, 2011).

4. **Negotiation:** The next step in the requirement management process is to negotiate about the arising conflicts of requirements from various stakeholders. The role of the requirement engineer is to promote these negotiation mechanisms. Negotiations will not solely take place after the elaboration, but are consistent throughout all earlier mentioned phases. During the next phase however, negotiations are preferably to be avoided at all costs since changes later on will have significant influence on project cost and schedule.

5. **Documentation:** Documenting of requirements is crucial in setting a principal reference framework for further design processes. MBSE is of main importance in this phase, since it will enhance the traceability of requirements. The requirements document, especially useful in document driven hierarchies, is structured in a way to accompany quality and verifiability (Fernandes and Machado, 2015). In engineering a software system, the requirements document is structured by user requirements and system requirements (Fernandes and Machado, 2015).

6. **Validation:** Subsequently, validation of the documented requirements is pursued in order to ensure compatibility of the requirements for the desired system. Validation occurs by inspections or technical reviews of the system.

7. **Management:** Lastly, management of the requirements resides among the tasks performed by the requirements engineer. This is in fact not a phase, but an activity performed throughout the systems lifecycle. Managing the requirements includes identification, control and tracing of the requirements and the subsequent changes.

The details regarding the elucidation and elaboration of requirements will be addressed in more detail below, with regards to the proposed method by Andrews of solving this wicked problem (Andrews, 2011).

2.2.2. Requirements elaboration

Structuring the elucidated requirements requires a classification scheme, a suitable decomposition of requirements fit for the project. The approach of the ARCADIA (Architecture Analysis Design Integrated Approach)-method is structured according to four sequential layers: operational, functional, logical and physical. Requirements are incorporated within each layer, hence classifying the requirements in similar sets makes sense. Therefore, throughout this thesis, the classification according to operational, functional and physical requirements is used, hereinafter referred to as OFP. The use of logical requirements, describing how the system should work to fulfill expectations, is unnecessary since these are derived from the functional and non-functional requirements.

Operational requirements

The operational requirements have to be established in order to perform the desired missions, frequently established during an operational analysis (van Oers and Logtmeijer, 2014). This section discusses the operational analysis as described in literature for naval shipbuilding processes with the goal of identifying the boundaries of operational requirements.

Gathering of operational information starts with the definition of the operational requirements during elaboration. Depending on the research executed by the customer, the process of investigating the operational profile for a specific vessel is diverse. In the earlier ages of naval ship design in the Netherlands, the Defense Material Organization initiated with investigations into the future missions to be executed, resolved into a package of operational requirements and handed over to the shipyard, which is DAMEN Naval in this case. The operational requirements, as explained by (Randi et al., 2013), cover all the requirements related to the operational tasks. These operational tasks range from carrying a certain amount of payload on deck to launching a helicopter for offensive missions. Besides these mission-related operational tasks, maintaining a certain speed in a given environmental condition is also seen as an operational requirement. The branching of missions to tasks to operational requirements seems logical, and it is in the field between missions and tasks where misinterpretations occur frequently in practice, hence resulting in erroneous operational requirements.

The US Department of Defense (DoD) is an initiator at investigating systems architectures in the naval domain which helps to relate the operational requirements. The distinction used in the DoD Architecture Framework (DoDAF) is based on a ship system architecture, which consists of three domains: Operational Architecture, Ship System Architecture and Program/Engineering Management Domains (Kerns et al., 2011). Attention is raised by expediting the Operational Architecture in this section, which is capturing the operational requirements, guidance, mission and required capabilities. The research specialized on obtaining a quantitative analysis with an Overall Measure of Effectiveness (OMOE), essential for the trade-offs in ESSD (Kerns et al., 2011). Previous research revealed the use of Design Reference Missions (DRM) to be implemented in Operational Effectiveness Models and causing a greater confidence in the results obtained by performing a measure of effectiveness on the operational requirements. The operational effectiveness is the fundamental reason for establishing the operational requirements and validating their existence (Tepper, 2010).

Functional requirements

Functional requirements define the desired function of a vessel and are given by functional verbs such as ‘fighting‘ or ‘sailing‘. These functional verbs are closely related to behavioral aspects, hence it is fair to conclude that behavior of a system is captured by functional requirements (Malan et al., 1999).

As Andrews suggested, organizing the decomposition of a ship design into smaller parts by allocating functions is a common method (Andrews, 1998). Andrews describes a building block approach dividing the ship into the generic functions ‘float‘, ‘move‘, ‘fight‘ and ‘infrastructure‘, hereby emphasizing on the required functionalities of a design. A similar functional distinction has been used by the US Navy at the Expanded Ship Work Breakdown Structure (ESWBS), in which the structure was organized based on functional allocation (Chalfant, 2015). The categories included were hull structure, propulsion plant, electric plant, command and surveillance, auxiliary systems, outfit and furnishings and armament.

The functional description is stated by various sources as being the tool for transforming the input to outputs in terms of systems theory, with a focus on the interaction between the elements which accomplish this conversion (Whitcomb and Szatkowski, 2000). In a situation of multiple desired functions of a system, the individual behaviour of a element should constitute to the collective interaction of all elements which ultimately are able to perform the desired function. The desired functions can be mathematically decomposed into sub-functions by linear superposition. This means summation of the sub-functions will represent the actual system (Whitcomb and Szatkowski, 2000). In the same paper it is discussed that different interpretations of a function for naval architects and combat system engineers exist, in which the former identifies a function as ‘a use to which a form is put’ and the latter as ‘define the use of an element, module or subsystem in terms of a transform of input to output’ (Whitcomb and Szatkowski, 2000). The latter corresponds more to the frequently used definition in systems engineering practices.

In System Based Ship Design greater emphasis is given to the functional analysis and thereby reducing the number of loop to find the best concept (Sugita et al., 2020). The increase in attention to the functional analysis indicates the major importance on the overall design.

Functional information is decomposed from a top level function into lower level functions (Tepper, 2010). The lower level functions are uniquely defined but questions arise when to stop in decreasing this level. The solution to this, presumably indefinite decomposition, is found in the unique allocation of a function to a single component. Each allocated function of a component should be linked with associated performance requirements (Tepper, 2010).

Physical requirements

Physical information during ESSD encompasses mostly detailed requirements or components of subsystems allocated to functions and able to form a physically connected structure (Whitcomb and Szatkowski, 2000). The former usage is a client-specific desire to implement a type of physical component in the design for modularity or maintainability reasons. The latter is based on the decomposition of requirements during systems engineering.

The SWBS is a firm-independent total-lifecyle method to decompose the ship based on the functions in specific weightgroups (Koenig and Christensen, 1999), as proposed by the US Navy in the early seventies (Ze et al., 2005). The SWBS decomposes until a detailed level is achieved at which traceability of all physical objects is established to be traced back to desired functions originating from the functional requirements. The main problem of using an SWBS is the lack of reflection of the shipbuilding processes in the decomposition. For instance concerning the labour hours, which are not taken into account when composing an SWBS. Decisions for alternative designs or processes could be based in the efficiency of labour (Koenig and Christensen, 1999). Besides the aforementioned problem, modern day shipbuilding encompasses modular building with zone outfitting, which can not be captured by the system boundaries of an SWBS.

2.3. Dealing with the complexity of stakeholders

The second part of the problem is dealing with the complex needs of stakeholders throughout the process. In a less complex design environment, such as during the design of a drinking carton, stakeholder needs are easier to map when compared to a dynamic iterative design process such as the naval ship design (Missonier and Loufrani-Fedida, 2014). Therefore, the definition of the needs of interested parties is developed by conducting a stakeholder analysis allowing the project to identify, categorize and prioritize the interested parties (Bendtsen et al., 2021). In this section, an explanation of a generic stakeholder analysis method is elaborated, followed by a scope of the problem in the naval domain including an identification of naval related stakeholders. These stakeholders will be invoked during the case study in chapter 6.

2.3.1. Stakeholder analysis

In order to conduct a stakeholder analysis, the following sequential steps have been determined due to their overall recurrence in literature (Wang et al., 2012, Wood et al., 2013, Heidrich et al., 2009, Mitchell et al., 1997). The following enumeration will elaborate on the different methods applicable in each step, addressing the advantages and disadvantages per step. Depending on the environment for conducting the stakeholder analysis, an appropriate method will be selected.

1. Identifying the stakeholders

    - **Semi-structured interviews** are conducted by using open-ended questions, depending on the reaction of the interviewee. The interviewer does not use a formalized set of questions but efficiently asks by responding to the reactions of the interviewee, therefore providing a space for discussion between the interviewee and interviewer. The interviewer should be well experienced in order to guide an open discussion and obtain the answers requested for the objective. Within the scope of the identification of stakeholders, semi-structured interviews shall commence at the top-level positions, e.g. a customer/client of shipyard, and from thereon starting to identify the lower-level stakeholders.
    - **Expert opinion** is a way of exploring the identification of stakeholders by assessing the knowledge of one or multiple experts in the domain. It is preferred to assess multiple experts in order to provoke the biased view and start to identify important stakeholders, which will

be nominated numerous times by different experts. Based on the availability of experts, gathering the opinions could be time-consuming and comprehensive.

- **Focus groups** are in fact a conglomeration of experts which are able to discuss and therefore providing each other with new insights concerning stakeholders. Despite being with a group of experts, the reality of focus groups is subjected to less structure for obtaining the right results (Reed et al., 2009), mitigation by effective facilitation of the focus group in the form a neutral discussion leader and an location away from the conventional offices.
- **Snow-ball sampling** is a practical approach by letting stakeholders identify other stakeholders, hence the circle of involved stakeholders will increase exponentially. The success of this method is determined by a deliberate choice of the first tier of stakeholders, otherwise bias could corrupt the sampling. Since snow-ball sampling could either invoke the identification of higher or lower- tier stakeholders, it is best to choose for a mid-tier stakeholder which acts as chain in between. In the specific case of the shipbuilding process, it is preferred to initiate with subcontractors.

2. Differentiating and categorizing the stakeholders

   Classification of stakeholders can be accomplished in two manners, either by a top-down or a bottom-up approach. The top-down approach uses interest influence matrices and radical trans-activeness, whereas the bottom-up approach uses stakeholder-led stakeholder categorization and Q-methodology (Wang et al., 2012). In practice, the bottom-up approach consists of gathering more detailed information with regards to the top-down approach. The choice between a top-down or bottom-up approach is based on the available time for research, manning of the research station and the importance of invoking the biases of the researchers. When time is not a limiting factor, preference is given to the top-down approach, whereas a more complete profile can be generated at the bottom-up approach.

   - **Interest-influence matrices** are part of the top-down approach by mapping stakeholders on a basis if the attributes interest and influence, or similarly power and interest (Varvasovszky and Brugha, 2000). The objective of this mapping is to obtain a prioritization of stakeholders for inclusion. The resulting mapping is divided into four quadrants, of which each quadrant has a specific way of dealing with the stakeholders included. Overall, management of the four quadrants is summarized by the following key words in decreased order of importance: engage closely, keep satisfied, keep informed and monitor.
   - **Radical trans-activeness** is an approach where two-way dialogue between stakeholders is actively promoted, particularly concerned with stakeholders of which their power is estimated to be of marginal influence, isolated, non-legitimate or fringe. The advantages of this method, according to Hart and Sharma, 2004, are for businesses to stimulate disruptive change which may lead to the generation of new business ideas. However, this method is time-consuming and hence has a high demand on resources.
   - **Stakeholder-led stakeholder categorization** is in the liberated process similar to semi-structured interviews (Wang et al., 2012); stakeholders will categorize all stakeholders themselves in handcrafted categories while no strict rules have been set, hence not limiting the creativeness of them. This method is the first to be specified as part of the bottom-up approaches.
   - **Q-methodology** is analogous to stakeholder-led stakeholder categorization in terms of flexibility of the categories (Cuppen et al., 2010), only this bottom-up approach is governed with the grouping of stakeholders based on shared discourses, which constitutes shared perceptions and commonalities. The prevalent feature of both bottom-up approaches is the empirical analysis of perceptions, instead of grounding the analysis by theoretical perspectives.

3. Investigation of the relationships between stakeholders

   The relationships between stakeholders becomes important when considering for example an intricate web of information needs. An overview of these relationships, or in practice dependencies, will establish certain links in a systems architecture which should be maintained. There are three ways of revealing these relationships: by an social network analysis, knowledge mapping or actor-linkage matrices.

- **Actor-linkage matrices** are grid representations of stakeholders, where the type of relationships between two stakeholders becomes evident in the crossing cell by means of a keyword. These keywords are free to be defined and could be in the range of 'conflict', 'collaboration' or 'nonexistent' to indicate the relationship. This method is assumed to be easy applicable and information can be subtracted from stakeholders by focus groups or individual interviews. On the contrary, the linguistic definitions in a matrix can become overwhelming by this complex overview.
- **Social Network Analysis** is almost similar to the actor-linkage matrices but differs in the way relationships are defined, instead of linguistic terms, this approach uses numerical quantifiers to indicate the relationships. These numerical values could be based on a Likert-scale of which the extreme terms could be 'conflict' and 'collaboration', but these terms can vary based on the specific need. Multiple matrices can be obtained in this way scoping in on the individual terms of interest. Since the numerical interpretation of the relation can be tedious, this approach is more stagnant when compared to the actor-linkage matrices. However, while being more stagnant, the social network analysis provides a comprehensive overview of the relations including the different types and strengths.
- **Knowledge Mapping** is the last approach to be specified as an approach to identify the relationships between stakeholders. This method is used in conjunction with the social network analysis and further specifies the interactions between the stakeholder, detailed on the knowledge available and missing. Capturing the knowledge across time, people and locations is essential to identify the bottlenecks, dominant flows, latent knowledge and knowledge seepage. Linkages in the mapping of knowledge assist to identify information exchanges between stakeholders.

4. Prioritization of stakeholders with regards to system architectures

   The identified stakeholders have to be prioritized in order to decide on the applicable systems architecture when diagrams have been generated. The manner to handle this process is to rate the stakeholders based on four attributes. The attributes will be given a weighting based on their importance during the ESSD. The weighed score of each category is added and a score is retrieved to, quantitatively, conclude on the prioritization of stakeholders.

   Depending on the timescale of the process, the attributes are weighted differently. Given the fact that this thesis is concerned with the ESSD, the weighing of the attributes is addressed to the processes contained in the ESSD: acquisition- and contract phase. Stakeholders could attain a different score when processes during the detailed design phase or testing phase are considered. Before defining the score of each stakeholder, an explanation of the attributes is given (Wood et al., 2013).

   - **Power** is defined as the ability of a stakeholder to attain their desires on another entity
   - **Interest** is the amount of intrinsic motivation, driven by potential earnings or objectives, enclosed within a stakeholder
   - **Urgency** as an attribute is the call for immediate action demanded by a stakeholder
   - **Legitimacy** is the valuation of a certain set of actions performed by the stakeholder which are deemed justifiable by common norms, rules, standards or beliefs

   In order to apply these attributes to the stakeholders, each attribute has to be given a score. Table 2.1 reveals these factors, which have been determined given the definitions above. Each stakeholder is scored on a Likert-scale of 1 to 10, these scores are weighted and after summation the prioritized score belonging to each stakeholder is obtained.

Attribute	Weighting factor
Power	1
Interest	0.5
Urgency	0.7
Legitimacy	0.8

Table 2.1: Assigned weighting factors to provide prioritization

2.3.2. Stakeholder involvements in naval domain

In this section, an explanation of the stakeholders involved during the early stages of ship design in the naval domain is given. The goal of this section is to identify the major stakeholders and gain an overview of their role in the design process. This will aid the latter section when the stakeholders are assessed at their needs of OFP-requirements.

Dutch Naval Shipbuilding Industry

The identification begins by summarizing the stakeholders involved in the Dutch naval shipbuilding industry, but at first an exploration of the stakeholders specifically allied to the DAMEN Naval shipbuilding activities is given. Another way of describing this division is by external or internal stakeholders, from a DAMEN Naval viewpoint.

- **Legislative parties**: The legislative parties exercise an authoritative power on the design of all vessels, but naval vessels tend to be more closely regarded by the law since these have to comply to rules set by the NATO. The classification societies are strict in classifying the design according to the current regulations, however, a dialogue between designer and classification society is always possible in order to convince one or both. Besides classification societies, the NATO has a specified set of rules and regulations for new-build warships, membership of the NATO comprises of an obligation to behave according to these rules and regulations.

- **Customer/client and user**: The Defence Force in the Netherlands is divided into an executable party (user) and an administrative organization (customer/client). The executable party in the maritime domain, involved in operating assets in order to protect and serve the constitution, is called the Royal Netherlands Navy, or abbreviated CZSK. The CZSK is responsible for the operational requirements during the ESSD of a new naval asset. The administrative organization, occupied with managing the material assets, is split up in the DMO and DMI. The Defence Material Organization (DMO) is responsible for the procurement of material and setting a baseline of functional requirements during the ESSD. The Naval Maintenance and Sustainment Agency (DMI) is responsible for the maintenance of current assets, which involves specialisms of current systems and their integration (van der Weg, 2020).

- **Shipyard**: The shipyard is the constructing partner during the procurement of a naval vessel. Due to the governmental character of these projects, a public tender procedure is started in order to give shipyards a fair change of gaining a military contract. The specialization in the naval domain is fairly restricted within the Netherlands, it is therefore common to offer the tender to shipyards abroad, hence the shipyard of preference in this thesis is DAMEN Naval.

- **Enemies/commercial competitors**: The enemies or commercial competitors influence the design by, essentially, presenting the needs to innovate. Without enemies or commercial competitors, there is no need to build a naval vessel. The strategic relevance of enemies shall be considered during the concept design phases. The goal is to conquer an enemy, or in design-terminology: supersede the competitor by emphasizing on superior requirements in the design of a naval vessel.

- **Taxpayers**: Due to the politically concerned characteristics of naval vessels, as prescribed in section 2.1, the statement ‘who pays owns’ should establish ownership of the naval vessel in the hands of the taxpayers. The influence of these taxpayers is however minimal and can only be presented in two ways: by elections or demonstrations.

- **External suppliers and external subcontractors**: The external suppliers and contractors play a major part in the construction of a naval asset. In contrary to naval shipyards, external suppliers and contractors are more frequently Dutch-based companies with specialities in e.g. armament, communications or electrical outfitting. The provided information towards the external suppliers is depending on the stage in which they are included during ESSD. In general it is stated that the earlier the involvement is, the more information is expected from the external suppliers as input to the design. External contractors on the contrary have a larger involvement during the process and are assigned design activities for systems, subsystems or components tailored for their purpose.

DAMEN Naval

The DAMEN Naval specific internal stakeholders are categorised in the following four categories. The scope has been established within a project-team, other specialities such as marketing, communications, office management and research & development have been left out of this summation.

- **System integrators**: The system integrators are at the core of system modeling and define the architecture, in collaboration with the system modellers. RAM (reliability, availability and maintenance)-specialists are parallel structured to each system integrator, since a RAM-specialist is concerned about every system separate. The engineering specialist disciplines concerned in the naval domain are ambiguous to the specialists in any normal shipbuilding design with addition of some -ilities that are characteristic for a warship. These peculiarities are the effect of the hostile environment the vessel should be capable of dealing with, as described in section 2.1.

- **Engineering specialists**: Given the sheer size and complexity of naval projects, specialized engineers are involved. The specializations include e.g. hull, stability, structure, electronics, propulsion, machinery and armament.

- **Plan & Proposal**: The Plan & Proposal department is one of the first points of contact when a customer desires to invest in a vessel, approached during the tendering procedure and at the start of an obtained contract. The requirements extracted from a client are evaluated and elucidated within this primary effort.

- **System modelers**: The system modelers define the architecture of the design and allocate OFP-requirements to the corresponding architectures.

2.4. System modeling in MBSE

In order to combine complex requirements with the complex needs of stakeholders, efforts have been made to concentrate on the generation of models capable of handling multi-dimensional problems. The evolution towards Model Based Systems Engineering is a promising solution for improving the link between complex requirements and stakeholders, and as the method indicates, modeling of systems is involved.

In the subsequent sections, an explanation of an architectural framework is given to guide the process of systems modeling. Therefore, to prevent confusion about the terms systems modeling and systems architecting, an explanation of the differences is given. Systems modeling is concerned with the conceptualization of a collection of elements interconnected in some way and creating a model with a predefined purpose, whereas systems architecting is a process of defining the organisation of a model and operates at the boundaries of a system model (Crawley et al., 2004, Alai, 2019). System architectures can be used to model the organization of enterprises and projects within the enterprise, whereas system modeling is purely concerned with the modeling of specific projects. Both processes have the advantage of revealing emergent behavior and are therefore able to mitigate the associated risks such as non-compatibility of requirements and undesired effects.

This section will elaborate on the overarching term Model Based Systems Engineering by explaining the advantages and introducing it's main pillars. Followed is a justification of the selection of pillars used during this thesis and the current state of systems modeling at DAMEN Naval. At last, an introduction of architectural frameworks is given.

2.4.1. Model Based Systems Engineering

A logical step in the development of systems engineering, based on the technological influence of the computer in modern society, is to accommodate a transition from Document Based Systems Engineering (DBSE) towards Model Based Systems Engineering (MBSE). MBSE differentiates from DBSE by emphasizing the use of computer-based models to support System Engineering (SE) processes (Do et al., 2014). The combination of SE-processes and computer-based models results in defining the ship design process as a detailed system architecture, in which dependencies are modelled. This architecture is the base of knowledge and forms a 'single source if truth', or in practice a repository that includes all elements contributing to the architecture (Kerns et al., 2011). Managing the complexity encountered in the design process of, for instance naval vessels, becomes less difficult. The mentioned repository, or database, will be used to capture the derived requirements, design standards and system attributes during the process (Tepper, 2010). Desired reports can be generated and retrieved from this central repository instantly, hence guaranteeing accurate and up-to-date documented information (Madni and Sievers, 2018).

Besides the applicability of MBSE as part of SE, it is proposed in this thesis to support the concurrent design efforts by focusing on the design domains and activities, hence aiming for process consistency. MBSE will, in this case, assist in performing the deterministic design exploration and improve communication among the internal stakeholders within an organisation (Maimun et al., 2019).

In the wake of concurrent design, MBSE will complement set-based design methods by clearly presenting the stable design parameters. A representation of the stable parameters assists the set-based design in conducting trade-offs based on the stable design parameters (Tepper, 2010). The volatility of requirements, which is unavoidable in reality, causes projects to overrun in cost and schedule when using a traditional design method (Tepper, 2010). The MBSE process has the potential to prevent the overruns in cost and schedule by volatile requirements since traceability is warranted, hence changes and their consequences are visible and therefore guiding the designer in pursuing the change or not. Adding to the requirements traceability is a comparable effort of including validation and verification of systems early on in the design process, which ultimately become a dynamic process within the system model.

Besides stating the advantages of an MBSE implementation, the disadvantages have to be investigate in order to conclude on the applicability. The complexity of connecting models and adaptation resistance within the project or company are stated as the most important disadvantages (Jenkins, 2021). Furthermore, current modeling tools are pushed to their limits, hence slow tool development is a deal-breaker for the implementation of MBSE.

Unfolding MBSE within a company starts with a selection of the pillars of MBSE, being a method, tool and language (Tepper, 2010); elaborated in the list below.

- **Method**: First of all, the applicable method provides order while switching to MBSE and guides the tasks at hand by universalizing the processes. Different methods are available such as the Object-Oriented System Engineering Method (OOSEM), Object-Process Method (OPM), Vitech, Relational Orientation for Systems Engineering (ROSE) and Architecture Analysis Design Integrated Approach (ARCADIA). The latter is of interest during this thesis because it is tightly coupled to Capella.

- **Tool**: Secondly, a tool has to be selected in order to achieve MBSE modeling. The tool is merely software-based and acts as a way to transfer the information from the documents into the digital modeling environment. Over time, various enterprises have established certain tool-packages to deliver the capabilities demanded from an implementation tool, such as MagicDraw, Sparx Enterprise Architect, CORE or Capella.

- **Language**: MBSE has developed over the past fifteen years into multiple different programs with each a specific language. The choice between a developed method depends on multiple aspects such as the background of the company, associated stakeholders in the process and their preferences for software systems. The Object Management Group created the Universal modeling Language (UML) standard as a base for interoperable enterprise applications. INCOSE thereafter created an addition at the UML-language by focusing more on the SE part, hence the System Modeling Language (SysML) was created. The features of SysML are more aimed at modeling complex systems which include hardware, software, data, personnel and procedures (Tepper, 2010). The main advantage of SysML is the independence on tool and methodology, hence the language is categorized as a generic language, capable of transforming the system architectures in an unambiguous way. Furthermore, SysML adds the possibility of representing requirements, non-software elements, physical equations, continuous flows and allocations (Roques, 2018a). In contrast, the interpretation of language during this thesis is in the form of an architectural framework, which is essentially a means of transferring knowledge, hence a language.

2.4.2. ARCADIA - Capella

The use of a MBSE-capable software package has been employed for the first time at DAMEN Naval during the design of vessels for a current project. The client insisted on the implementation of systems modeling during the design of their new vessels in order to e.g. assure the traceability of requirements. The choice for the software package Capella has been made based on the open-source availability of the software and the supported instructions handed by Obeo, the software-developer. An explanation of the workings of the ARCADIA method, as used in the Capella-software is given in this section. Since the aim of the research is to design an information model applicable to the already used modeling methods, the relevance of understanding the ARCADIA method can not be disregarded.

As mentioned previously, ARCADIA is the methodology used by Capella and originates around 2007 during the introduction of a new variant of the UML-language, SysML. Thales Group, a multi-industry French company specialized in designing high-tech systems, identified the need for a new methodology to cope with the SysML-language and hence constructed ARCADIA. The reason for constructing a new methodology was due to the fact that engineers were struggling with the shift from UML to SysML, as the latter is a more programming language easily used by computer scientists (Roques, 2018a). The aim of ARCADIA is to define and validate the architecture of complex systems, with a strong link towards collaborative efforts between all stakeholders. The list below shows some of the innovative characteristics of ARCADIA (Roques, 2018b)

- Covers all systems engineering activities
- Integrates all levels of engineering, from total systems to subsystems and components
- Joint elaboration of models making collaborative engineering possible
- Engineering stakeholders share the same methodology and the same information

ARCADIA is dependent on the software to be used, Capella has been designed to comply with the ARCADIA methodology and gain full advantage of the innovative characteristics of ARCADIA. The decomposition is shown in figure 2.2 with a description of the layers. This methodology is a pure top-down approach, starting at the needs and ending at the solution. The consequence with respect to iterative ship design clarifies the need for more feedback during the execution of these four layers, hence the top-down approach will practically be less sequential as depicted. As can be noted in figure 2.2, the requirements are integrated throughout the whole methodology, accomplishing a major advantage of MBSE: requirements traceability.

2.4.3. Systems modeling at DAMEN Naval

The objective of this research originates from the System Modeling team at DAMEN Naval, recently founded as a reaction to the awarding of a new project for the design and construction of frigates. In order to understand the work executed and efforts in aligning the results with current practices, a brief description of the DAMEN Naval Systems Modeling approach is presented.

At DAMEN Naval, the current status of shifting from a DBSE approach towards a MBSE approach is well underway. At the moment, system modeling has been executed based on functional chains, whereas the physical elements are not yet modelled in the systems architecture (Droste and Hage, 2022). There are however still challenges to conquer during the transition towards system modeling as a step in the direction of MBSE. As an example given during a team-meeting of System Modelers, the scope of systems modeling is currently not clear. The demarcation and division of tasks between the engineering specialists and system modelers have to be well defined and communicated. The risk of creating a responsibility-gap between these disciplines is identified as an hazardous area. In figure 2.3, a representation is shown of the systems modeling process within the context of the needs analysis

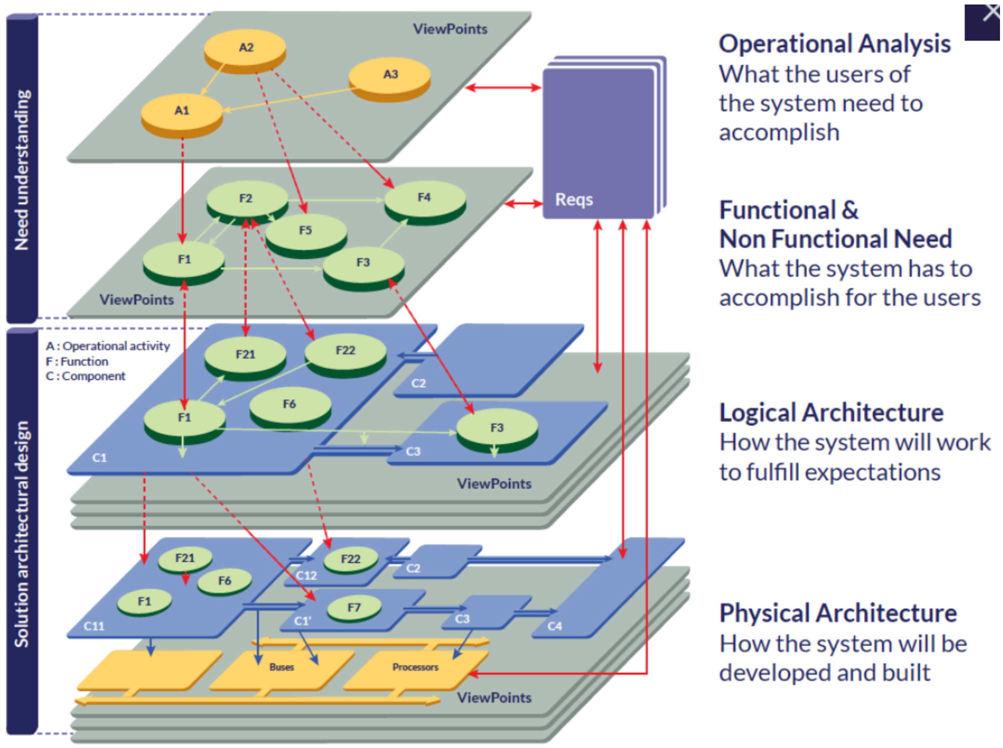


Figure 2.2: ARCADIA methodology as implemented at Capella (Roques, 2018b)

from the client and the desired final system model. The green-boxed area indicates the current status of system modeling at DAMEN Naval. A more refined description of the different elements in 2.3 is explained below.

The start of system modeling is at the Operational Concept Design (OCD), in which the desired capabilities of the design are evaluated and a clear understanding is obtained about the operational needs. A client, such as the DMO, will have a defined Concept of Operation (ConOps) for in-house goals, this document will not be shared among industry due to strategic purposes. The OCD is established mainly by reverse-engineering and will result in the similar operational capabilities, without knowing the exact missions and strategic relevance the design has to fulfill. Once the operational description is clear, system capabilities are decomposed by functional chains. Relationships are formed due to these functional chains. Currently, one of the problems during system modeling is to obtain a full overview of the functional chains, since these are divided over multiple layers in the decomposition. It is therefore desired to define who needs what information at what time, hence the objective of this thesis.

The description of functions appears when the functional chains are established. Functional chains are paths within the system modeling process to highlight the actions taken to perform a certain function. For example, in order to comply to the function 'fire-fighting', the functional chain could start at 'pumping water aboard', followed by 'distribute water onboard' and finalized at 'discharging water'.

The functional requirements are decomposed over distinguishable functions and the functions are allocated to the respective systems. During this phase, while constituting the functions to systems but not yet obtaining a permanent set of systems, a loop is obtained to execute separate aspect analysis over the obtained systems. The aspect analysis covers main naval characteristics such as vulnerability, shock and sound, reliability, availability and maintainability and system security. The output of these aspect analysis is directed towards the systems description with a feedback-loop back to the description of functions. As previously mentioned, the domain of system modeling is currently limited up and to the description of systems. The reasons for not including the last part of the decomposition during system modeling is mainly due to uncertainties about responsibilities between engineering specialists and system modelers and misalignment of top-down and bottom-up approaches being applied simultaneously (Droste, 2022).

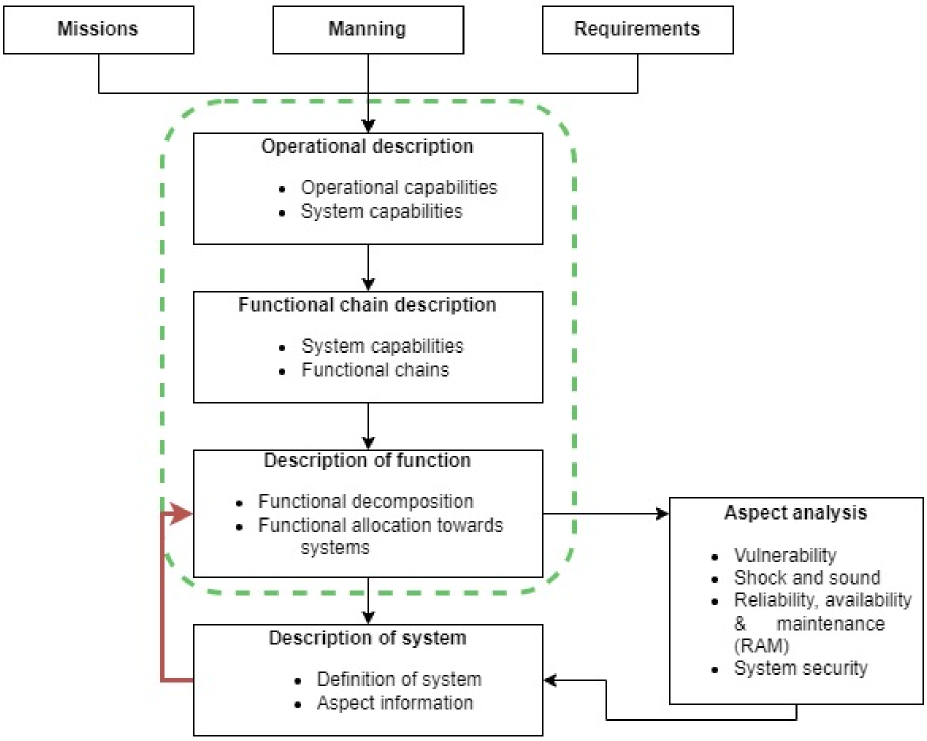


Figure 2.3: Demarcation of current status of system modeling at DAMEN Naval (Droste, 2022)

As mentioned at the introduction of this section, system modeling and systems architectures are related, whereas stating one is the product of the other is not sufficient. Creating systems architectures requires more information and therefore, the need arose for a framework to guide this creation. Architectural frameworks are the logical solution to structure the creation of systems architectures and will be explained in the subsequent section.

2.4.4. Architecture frameworks

To construct system architectures, the use of architectural frameworks (AF) is preferred since these act as a skeleton on which the elements (systems, subsystems) of an enterprise or project can be governed (Thales Learning and Development, 2018). The aim of an AF is to provide a generic basis of guidelines and principles to contribute to an efficient development of a certain target. The AF's have been designed with objectives to minimize development costs, prevent delay and optimize quality of the specific program. Interoperability between projects using the same AF is one of the main advantages.

Architectural frameworks have evolved over time, as indicated in figure 2.4, where the origin of architecture frameworks is presented. The framework defined by Zachman in 1987 has been set as the start of architectural frameworks, defined out of an empirical assessment of different engineering domains. Zachman tackled complexity by identifying the repeated patterns of model types related to the roles, responsibilities and concern of different parties (Emes et al., 2012). The newest addition in line of architectural frameworks is the NATO Architectural Framework Version 4 (NAF). The NAF is specifically tailored for military organizations, but also suitable for business use. In combination with the scope of this thesis it is therefore determined to be the preferred architectural framework and will be further explained in chapter 3. Advantages of using a standard architectural framework include improved interoperability and reuse of architectures, driven by a common language and a cognitive framework.

2.5. Conclusion

This chapter has started with an explanation of the early stages of naval ship design in order to illustrate the context of the problem, followed by an elaboration of the two factors which make this problem

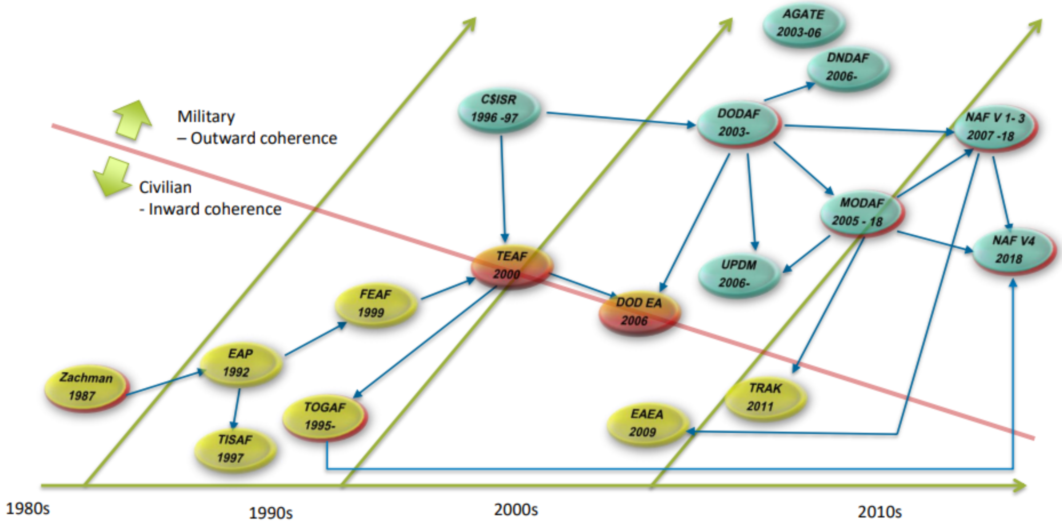


Figure 2.4: History of architectural frameworks (INCOSE, 2018)

challenging: the complexity of requirements and the complexity of stakeholders. A classification of requirements has been given based on the OFP-principle and different elements of stakeholder analysis have been given. The relation with stakeholders and the naval domain has been worked out in section 2.3.2. MBSE and system modeling have been described by elaborating on the three pillars and selecting the right element for this thesis. At last, an introduction about architectural frameworks has been given which will be elaborated in the subsequent chapter 3.

3

NATO Architectural Framework

The NAF version 4 (NAFv4) complements the ISO/IES 42010 conceptual model in order to include enterprises and the respective phases during strategy implementation (Architecture Capability Team, 2020). The methodology of the NAF is applicable across a wide variety of processes such as operational analysis, planning or capability management. The methodology describes firstly how to develop architectures and secondly how to execute an architecture project (Architecture Capability Team, 2020). A remark about the NAF methodology should be made, since it is still necessary to tailor the method based on the subjects of interests. The high degree of liberty constitutes to a universal framework.

3.1. Architecting stages

The list below presents the eight architecture stages belonging to the Architecture Development Methodology (ADM) as used as foundation of a method in the NAF. The first three stages of the architecting effort are concerned about the construction of architectures and therefore elaborated. The five subsequent steps are mainly involved with evaluation and managements processes which is out of scope for this thesis. The Architecture Landscape defines the organization of the architecture and determines a tailored, fit for purpose, process suitable for the specific organization (Architecture Capability Team, 2020). The Architecture Vision validates the high level stakeholder requirements and estimates the impact of the architecture in terms of cost, risk, value and opportunities for the organization. The Architecture Description is the stage for collecting viewpoints as will be elaborated at section 3.2 and proposing various architectures to represent these viewpoints.

- Architecture Landscape (AL)
- Architecture Vision (AV)
- Architecture Description (AD)
- Architecture Evaluation (AE)
- Plan Migration (PM)
- Architecture Governance (AG)
- Architecture Changes (AC)
- Motivation & Dashboard (MD)

The dependencies between these eight stages is presented in figure 3.1. The stages are executed by iteration to support decision making in architecting a baseline. Artefacts are created at each stage and the corresponding objectives of each stage are defined. The moment a next iteration will start depends on agreement concerning the scope, timeline, milestones, stop criteria or acceptance criteria. The primary step in architecting a methodology is to understand the overall objectives of the considered organization, enterprise or project. A content and structure of systems can be derived from these objectives, in which rules, constraints, and guidelines form a central element for architects.

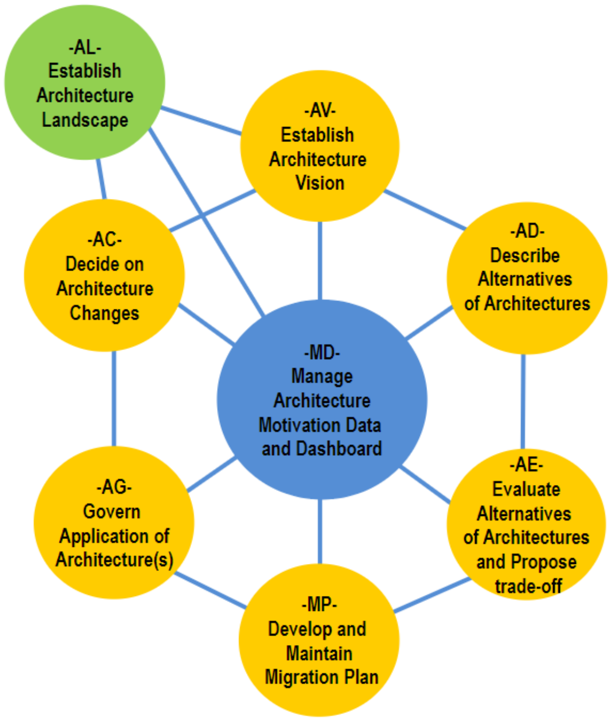


Figure 3.1: Architecting stages as used by NAF (Architecture Capability Team, 2020)

3.2. Viewpoints

In this section, a summarized explanation is given about the viewpoints as used in the NAF. A distinction should be made between 'views' and 'viewpoints', where the former is a mechanism to purposefully convey information about a specific concern and the latter prescribes the concepts and models to visualize the view (Architecture Capability Team, 2020). As dictated by the NAF, the viewpoints do not satisfy every stakeholder case and additional non-NAF viewpoints could be added to complete the analysis. To obtain an overview of all NAF viewpoints, a summary of each viewpoint will be given supplemented with an expectation of the use in this study. The reason for elaborating on all viewpoints is because a selection should be made during the Proof of Concept and Case Study from these viewpoints.

The grid is given in figure 3.2, where the rows represent levels of abstraction and the columns correspond to the different types of diagram categories. These nine categories have a close relation to the original Zachman framework (Zachman, 2003), the first architectural framework, but are more abstract written, the list below gives an explanation of these categories.

- Taxonomy: Categorization and classification of concepts such as capabilities and services
- Structure: The description of how the elements are assembled
- Connectivity: Relations between elements, from high level capability dependencies to detailed system connectivity
- Processes: Process flows and decompositions
- States: Transitions of elements
- Sequences: The interaction between elements and the order of interaction
- Information: Description of the sort of data used
- Constraints: Rules applicable to the enterprise, nodes or resources
- Roadmap: Planning and milestones affecting the elements

Figure 3.2: Grid composition of the NAFv4 (Architecture Capability Team, 2020)

3.2.1. Concepts

The viewpoints in the row of Concept Viewpoints aim to support the delivery of capabilities according to the vision of the enterprise.

C1 - Capability Taxonomy

The first viewpoint of the Concepts-family is aimed at providing a representation of all capabilities included within the project. Stakeholders of interest are concerned with the planning and management of capabilities. All stakeholders involved with the translation of operational to physical design objectives are expected to benefit from this viewpoint.

C2 - Enterprise Vision

In this viewpoint, the relation between the capabilities and the enterprises long term vision and goals is constituted. The focus is on the long term and enduring tasks performed by the enterprise. Stakeholders addressed by this viewpoint are concerned with the strategy of the enterprise and the planning of capabilities. In other words, stakeholders not solely interested in the project but looking for long-term relationships with the subject.

C3 - Capability Dependencies

As the name suggest, this viewpoint structures the dependencies between capabilities and identifies capability clusters. Stakeholders subjected to interconnected systems are the reason for implementing this viewpoint.

C4 - Standard Processes

This viewpoint specifies the doctrinal processes in combination with the capabilities expressed by the C1 viewpoint. Stakeholders concerned with frequently repeating tasks and activities are involved in this viewpoint. Examples during a shipbuilding project are the suppliers of standardized components such as electrical cables.

C5 - Effects
The capabilities as identified at C1 are followed by desired and achieved effects. This viewpoint captures these effects and treats them as scenarios with states and modes. All stakeholders concerned with the C1 viewpoint will have an interest in the effects of the capabilities.

C7 - Performance Parameters
Measuring the capabilities based upon a certain set of requirements is displayed in this viewpoint. The identification of measure categories and linking to capabilities is the objective. This viewpoint assists in evaluating the contributions from stakeholders to the respective capability.

C8 - Planning Assumptions
Assumptions can be made during the implementation of the capabilities in the form of constraints such as a specific quantitative operational constraint in the form of an required availability. The capability owner may inflict constraints on the capability for other stakeholder to comply with, an example is the shipyard insisting on the use of an FiFi-pump to work independently from other systems and being available 24/7.

Cr - Capability Roadmap
The last viewpoint as part of the family 'concepts' is concerned with mapping of capabilities over time resulting in a roadmap. Interested stakeholders are concerned with the planning of capabilities and management of acquisitions.

3.2.2. Service Specifications

The viewpoints in the purple colored row specify the description of services without covering the implementation of these services in the architecture. The goal of these viewpoints is to construct a library of standard services in order to support the design of architectures.

S1 - Service Taxonomy
In the first viewpoint of this row, an overview is given of the services included by means of multiple taxonomies. It is obliged to contain all relevant service specifications. The services indicated here are exclusively IT-services. Stakeholders activated by this viewpoint are the sender or receiver of IT-services, or concerned with the effect these services may have on their daily businesses.

S2 - Service Structure
The S2-viewpoint determines the structuring of services with respect to dependencies, nodes, resources, interfaces and functions. Aggregated services will be clarified by using this viewpoint. One of the benefits for using this viewpoint is the specification of the interoperability of services.

S3 - Service Interfaces
As mentioned in the S2-viewpoint, interfaces consist between services to account for the interoperability between services. The interfaces can either originate from other services by means of specifying the service. Stakeholders interested in the implementation of a service will be aided by using this viewpoint.

S4 - Service Functions
The expected functions a service will perform are treated at this viewpoint and may constitute in a decomposition of multiple functions.

S5 - Service States
Besides functions, services could obtain certain states which indicate the behaviour. Services have the ability to transition between different states, these transitions are captured in this viewpoint as well. The change of a state depends on specified conditions.

S6 - Service Interactions
The interactions between service consumers and services are described in this viewpoint, including the sequence of interaction when multiple consumers are present and the dependencies between these interactions.

S7 - Service Interface Parameters
During service operations, relevant parameters of the service are displayed at this viewpoint.

S8 - Service Policy
The constraints to which a service is influenced by constitute mainly from rules applicable to the specific service. These rules could be either specified by regulatory bodies or by the customer requirements.

S9 - Service Roadmap
The last viewpoint of the services-row prescribes life-cycle information to account for planning and acquisition management.

C1 - S1 - Capability to Service
This viewpoint serves as a linkage between the capabilities and services. It therefore identifies en describes services that enable capabilities.

3.2.3. Logical Specifications

The blue-colored row in the NAFv4 represents the logical specification viewpoints, which supports the solution-independent description of logical nodes, activities and resource/information exchanges in order to accomplish missions.

L1 - Node Types
Logical entities are the nodes used in NAFv4, which are independent of their implementation and are able to perform a certain behaviour. In this first viewpoint, the identification of the nodes occurs and the dependencies in the form of hierarchies could be represented. The traceability from nodes to the capabilities necessary and activities performed can as well be represented here.

L2 - Logical Scenario
Nodes can interact with other nodes, hence this viewpoint is needed. The result is a flow of logical information from node to node. This flow of information is the basis of a scenario and defines operational concepts.

L3 - Node Interactions
The logical flows between nodes shall be represented at this viewpoint; the production and utilization of the exchanges shall become clear by using L3. The main advantage of including this viewpoint is the definition of interoperability requirements, stakeholders interested in these interoperability requirements will benefit from this viewpoint.

L4 - Logical Activities
The logical activities viewpoints specifies the identification, grouping and decomposition of logical activities. It helps stakeholders with the construction of a concept of operations and increases effectiveness in the operational planning.

L5 - Logical States
Similar to services, nodes may have several states. Hence, this viewpoint is concerned with the identification and definition of these states and the transitions between them.

L6 - Logical Sequence
The logical flow, as presented in subsection 3.2.3, is normally behaves in a chronological sequence, just as the activities. The L6 viewpoint is concerned with the representation of this chronological sequence.

L7 - Information Model
Besides nodes, information elements can occur in analysing an architecture. This viewpoint is concerned with the identification of these information elements and illustrating their relationships.

L8 - Logical Constraints
Operational or business rules restrict the creativity of performing the logical activities as preferred, hence this viewpoint considers these rules and will apply them as constraints on nodes, activities or logical flows of information.

Lr - Lines of Development
The Lines of Development constitute to the mapping of logical threads over time in order to identify project deliverables and relate these to project milestones.

L2 - L3 - Logical Concept
The linkage between L2 and L3 guarantees an executive level representation and will show the main elements in scope of the Architecture Description. It does so by providing the information in a visually attractive format. The purpose of this viewpoint is to convey the information in a manner easy to grasp and leaves therefore more room to discuss the matter.

3.2.4. Physical Resource Specifications

Delivery of capabilities and services by resources is specified in this viewpoint. Requirements traceability is enhanced by linking the resources back to the logical nodes, as specified in the Logical Specifications Viewpoint.

P1 - Resource Types
The first viewpoint in this row deals with the specification of the different types of resources, these are categorized in: people, organizations, artefacts and software-resources, or may constitute out of a combination from these single resources. Complementary, the required technologies and competences in order to integrate the resources are identified. The identified resource types are furthermore traced back to the preferred capabilities or services. Concerned stakeholders are those of which the interest lies in the interface specification between capabilities and hardware contributions, such as subcontractors and the shipyard.

P2 - Resource Structure
This viewpoint covers the relation between the operational and physical architecture views and thereby realizes the logical architecture as defined in subsection 3.2.3. A decomposition of resources constitutes to a specified structure and thereby enhances the implementation of systems engineering. The decomposition of resources is gathered in specific configurations which are to be linked at a sole capability.

P3 - Resource Connectivity
Resource Connectivity is concerned with the physical implementation of the logical flows, indicating the relationship between communication systems and providing more technical detail to explain these relations. Furthermore, attributes realizing the connection between communication systems are given in order to perform e.g. a capacity analysis.

P4 - Resource Functions
The functionality of resources is specified in this viewpoint, working as the functional counterpart from the viewpoint defined in subsection 6.6.3. The Logical Activities Viewpoint, as defined in subsection 3.2.3, shall be related to this viewpoint by the description of implementation-specific realisations.

P5 - Resource States
Similar to Logical States, Resource Types can change state due to certain events. This viewpoint covers these changes and dictates the triggers that cause the transition between states. Furthermore, it specifies causes of the events related to Resource Types.

P6 - Resource Sequence
Resource Types interact in a chronological order, which is depicted in this viewpoint. The chronological sequences of exchanged data elements are presented between Resource Types or Ports.

P7 - Data Model
Structuring data used by Resource Types is expressed in this Viewpoint, it has a direct link with the Viewpoint discussed in subsection 3.2.3 where an Information Model is presented. However, the implementation occurs in this viewpoint which is the mapping of L7 to a logical or physical layer.

P8 - Resource Constraints
The elements so far used in the Physical Resource Specification row can each possess one or multiple constraints, which are presented by this viewpoint. The constraints can be in the form of rules, just as the constraints presented at subsection 3.2.3.

Pr - Configuration Management
The last specific viewpoint is concerned with the life-cycle transition of a resource in the form of a planning. It shows the planned availability of capability configurations over time, due to maintenance and organisational or human resource deficiencies.

L4 - P4 - Activity to Function Mapping
The link between operational activities and functions is constituted by this viewpoint, as well as the link between the Resource Functions and the Service Functions. Traceability of functional system requirements to user requirements and solution options to requirements is the result when using this viewpoint.

3.2.5. Architecture Foundation

The last row of viewpoints is concerned with the administration of the architecture effort, e.g. a summation of the selected viewpoints and the status of implementation of the Architecture Descriptions, which posses an iterative character.

A1 - Meta-Data Definitions
As the name suggests, this viewpoint covers the meta-data used throughout the architecture, which is essentially all data concerned with describing the main data. Besides the meta-data, this viewpoint shall provide a glossary of the terms used in the architecture.

A2 - Architecture Products
The Architecture Products are the selection of viewpoints used in the architecture from which the stakeholders view from. Besides the viewpoints, it shall furthermore specify the structure of the architecture.

A3 - Architecture Correspondence
In enterprise architecting, various architectures exist of which project architectures are just one form. The dependency and relationship between these various architectures will be explained in this viewpoint by means of a table or diagram.

A4 - Methodology Used
The iterative Architectural Description and methodology used to conform to this AD is not specified and can be tailored to the specific case. This viewpoint shall describe this tailored process by providing the rationale which constitutes the decision made during tailoring.

A5 - Architecture Status
Since architecting is a long process and implementation of the architecture is gradual, this viewpoint shows the current development status or degree of readiness.

A6 - Architecture Versions
The Architecture Versions viewpoint is complementary on the A5-viewpoint by specifying former versions in a catalogue.

A7 - Architecture Compliance
Terminology and used model-semantics vary between Architectural Frameworks, hence this viewpoint specifies the compliance of the architecture with regards to different standards, such as the ISO42010 or a specific enterprise architecture policy. A feedback with regards to the stakeholder requirements will be presented as well.

A8 - Standards
While following the NATO-standards as described in the NATO Architectural Framework, other standards, rules, policies of guidance's may be applicable to certain aspects of the architecture. This viewpoint therefore specifies these standards, their version and the ratification body responsible for the standard. The aim if this viewpoint is to validate the use of certain standards and arrange for future changes by these standards.

Ar - Architecture Roadmap
The roadmap defines the planning of the architecture as an addition to the viewpoint discussed in subsection 3.2.5. It may even provide options for a successor if the current architecture.

3.3. Conclusion

The description of the NAF by elaborating on the architecting stages and explaining all viewpoints will help during the development of the method. As architecting stages imply, iteration is essential for implementing the NAF. All 47 viewpoints have been described and the interests of stakeholders are elaborated. A selection of the viewpoints based on the concerns per stakeholder is therefore enhanced.

4

Method

In this chapter, the designed method will be presented and discussed. The essence of this method is to bridge the gap between stakeholders and requirements, as explained in the sections 1.2 and 1.3. Given the complexity of the naval domain, a simplistic method is beneficial for the development and implementation. Therefore, one of the key aspects for developing the method was to keep it as simple as possible, hence application on various projects ranging in complexity is more probable. Since projects tend to become even more complex over time, the need for a simplistic universal method is even more preferred.

First, a high-level overview of the method will be presented, after which a more detailed representation is given including a chronological specification of the steps to be followed. From stakeholder analysis to selection of the best suited systems architecture, the method is meant to include all steps from A to Z, hence the result after following the method exactly will correspond to the objective of this thesis: relating stakeholders with OFP-information within a systems architecture.

Having defined the research gap in Chapter 1 and constructed an objective to address this gap, a methodology has been designed in order to solve the objective. The construction of a methodology, indicated as a creative process, needs to be guided by certain criteria. These criteria help to fulfill the objective, evaluation of these criteria will follow at the end of this section. A list of the criteria established as part of this research is presented below.

- Applicable to the naval domain (Section 2.1)
- Include all stakeholders (Section 2.3.1)
- Include all concerns
- Reveal direct links between stakeholders and requirements (Section 1.2)
- At least one iterative loop (Section 2.1)
- Not complex
- Processes assigned to specific team members

4.1. Description of steps in method

After having defined the criteria for the method, construction of the method begins. The basis of this method originates from the NATO Architectural Framework, which stipulates the relevance of the concerns from stakeholders. However, due to the generality of the NAF, alterations based on this project has to be made. Therefore, additions have been addressed at this method which finally result in the method as presented in figure 4.1. The method consists of 12 processes, including three document-driven inputs numbered as 1, 6 and 11. The sequential steps to be taken in order to succeed in applying this method are given below in chronological order. As mentioned in section 2, the key to success when developing a systems architecture is to iterate constantly. The iteration can occur via two ways, per process element or over an aggregated series of consecutive elements. Iteration per process element could be the alignment of requirements part of the block 'OFP-information', whereas iterations over an aggregated series of consecutive elements include the selection of viewpoints, creation of additional viewpoints and reflection on the purpose of all viewpoints.

1. Conduct a stakeholder analysis
2. Gather stakeholder concerns
3. Select applicable viewpoint from the NATO Architectural Framework
4. Gather OFP-requirements from the client and internal process/design stakeholders
5. Construct the Capella model
6. Match the requested viewpoints with the Capella model
7. Request the respective diagrams from the Capella model
8. Evaluate if all concerns identified during the stakeholder analysis are presented by the selected viewpoints
9. If not, develop additional viewpoints by a tailored sub-method and iterate until all concerns are addressed
10. Review the candidate architectures or alternative representations
11. Define the needs for the systems architecture
12. Select best suited representation for the systems architecture and

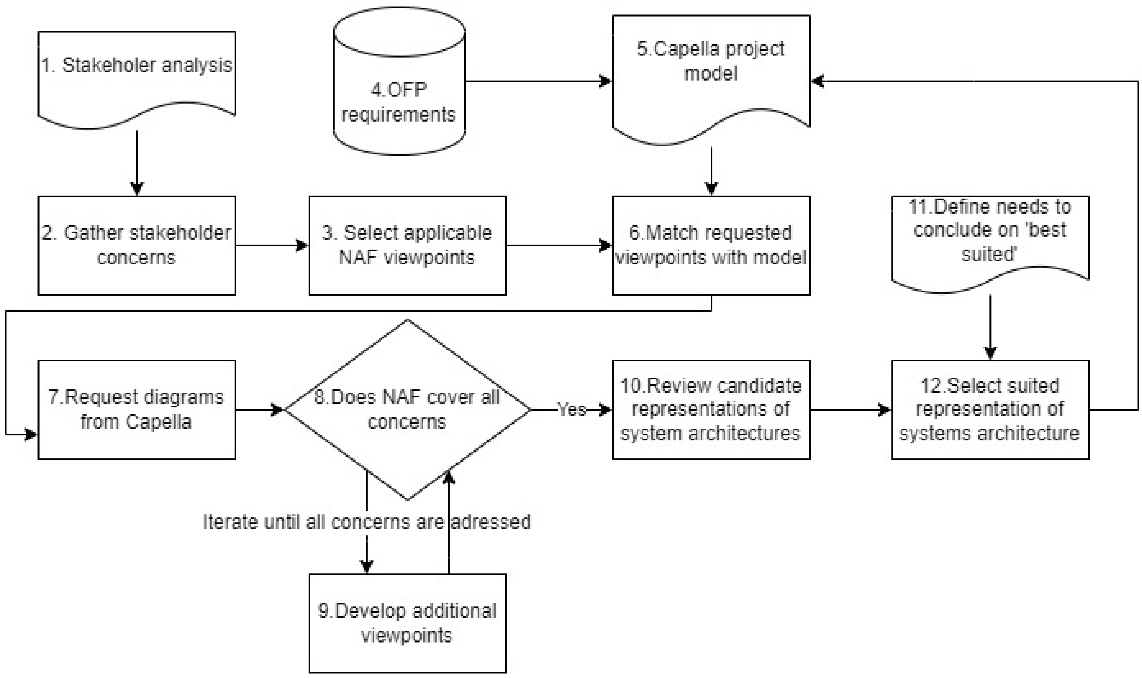


Figure 4.1: Flowchart of the developed method

4.1.1. Step 1: Conduct a stakeholder analysis

The start of this process is concerned with a stakeholder analysis. Stakeholders play a vital role when applying an architectural framework since these specify the concerns raised. These concerns are defined as characteristic interests of stakeholders in e.g. the functionality, feasibility, usage or performance of an object (Architecture Capability Team, 2020). Demarcation of stakeholders is important which is the result after an extensive stakeholder analysis. After identifying all involved stakeholders, relevant stakeholders will be prompted after the differentiating and categorizing stage. The coupling of stakeholders with their respective OFP-information is accomplished by revealing their the mutual relationships between stakeholders and the needs to the different types of information. For more information on the methods and choices to be made during the stakeholder analysis, the reader is redirected to section 2.3.1.

4.1.2. Step 2: Gather stakeholder concerns

After the identification and subsequent steps belonging to the stakeholder analysis, concerns per relevant stakeholder are to be retrieved. These concerns are not yet included in the result of the stakeholder analysis, but based in the identification and categorization, involvements of stakeholders in the ESSD have been clarified. The classification according to their needs of OFP-information discloses some of the concerns, whereas the additional concerns can be derived from the function-specific activities. The key is to keep the stakeholder concerns not too detailed (Wood et al., 2013), e.g. the interest of a stakeholder in the rigging of the vessel is a too detailed concern, a better phrasing would be to specify the interest of the stakeholder with regards to the capability delivery or management, of which docking the vessel is a capability.

4.1.3. Step 3: Select applicable NAF viewpoints

Constructing a system architecture in an unified manner is achieved by consulting an architectural framework. The NATO Architectural Framework has been used as a guidance in this thesis for a foundation of an unified and interoperable architecture, the use of other architectural frameworks is excluded due to the different interpretations of viewpoints. As explained in chapter 3, the NAF consists of selectable viewpoints represented on a grid, each concerned with a set of stakeholder concerns. It is during this phase of the method that identified stakeholder concerns, as explained in section 4.1.2, are matched with viewpoints from the NAF. Stakeholders can be matched with multiple viewpoints, it is therefore recommended to establish an overview of all viewpoints per stakeholder. The frequency of viewpoints is one of the measurable attributes during this stage and will be used during the evaluation phase later on to conclude on the usability of the obtained systems architecture.

4.1.4. Step 4: Gather OFP-requirements

The basis of the Capella model is to have a set of requirements, which ultimately define the goal of the model. As elaborated in Chapter 2, the classification of requirements is according to the OFP-scheme. The requirements originate mainly from clients, but also from internal process- and design stakeholders.

4.1.5. Step 5: Construct Capella model

The construction of the Capella model is the work of system modelers, starting at the operational layer and working their way downwards ending at the physical layer. Many iterations occur inbetween these layers and it is therefore a time-consuming effort. It is however not necessary for the model to be fully complete, as long as all systems and components are included, the construction of diagrams according to the viewpoints is possible.

4.1.6. Step 6: Match requested viewpoints with model

After having obtained a complete list of viewpoints, the implementation of these viewpoints in Capella should be executed. Each NAF-originated viewpoint is labelled with a letter and digit, the identifier, corresponding to the specific column (letter) and row (digit) on the grid representation, see figure 4.2. The identifier in this case is L7. Each viewpoint includes conditions on their usage and representation in order to obtain an uniform architecture. Based on these conditions, the elements in Capella (entities, actors, components, functions) and their exchanges shall be matched with the corresponding identifiers of the viewpoints. Various elements should be related to the same identifiers in order to create the diagram belonging to the viewpoint.

4.1.7. Step 7: Request diagrams from Capella

Up to now, all concerns should be addressed by viewpoints and coupling with the Capella model commences. Construction of the Capella model is out of scope for the method, assuming the project-team responsible for implementing a system architecture is capable of generating a sophisticated Capella model. Therefore, the starting point of this phase is a complete model. The list of viewpoints, specifying particular diagrams, is served as input towards the team responsible for the Capella model. The requirements per viewpoint shall be evaluated and the possible representations in Capella will be the result. If the evaluation does not fulfill the requirement of the concerns, an iteration between the previous step (6) and this one has to be made, whereas a high probability is envisioned to create the additional viewpoints.

4.1.8. Step 8: Evaluate the concerns w.r.t. the NAF

The combination of the previous three steps results in a conclusion on the extensiveness of the viewpoints. The list with concerns per stakeholder should be compared with the selected viewpoints. If, due to specifications of the stakeholders, not all concerns are addressed in viewpoints of the NAF, additional viewpoints should be constructed. For instance at the stakeholder-group ‘taxpayers’, of which their concerns related to the expenditures for a defense-project in relation to the total budget of a government are not included. Primarily, one should consider the relevance of outstanding concerns with regards to the scope of the systems architecture. In this case, the specific concern of the taxpayers is out of scope, hence a new viewpoint is futile. If, however, the unaddressed concern falls within the scope of the systems architecture, a viewpoint should be constructed.

4.1.9. Step 9: Develop additional viewpoints

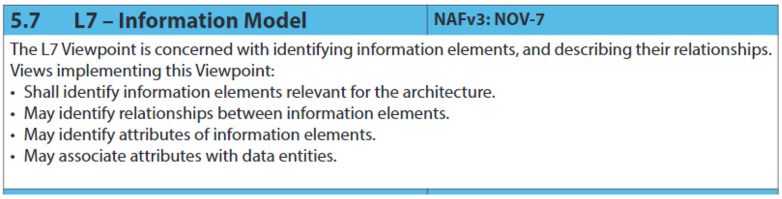
The identified unaddressed concern(s) in section 4.1.8 should be included in the selection of diagrams, hence a manual operation to construct these viewpoints will start. Since the type of viewpoint is very case-specific, there is no way of composing a method suited for this goal. Therefore, to speed-up the process of manually creating viewpoints, a roadmap has been established to guide this process, followed by prevailing conditions to restrict liberty in shaping viewpoints. Finally, an example will be given to illustrate the construction of additional viewpoints, this example has no relevance to the context of this thesis. First, the roadmap for developing additional concerns is constructed and given below, after which the conditions for these newly created viewpoints shall be presented.

1. Identify the unaddressed concern
2. Explain the concern
3. Consult all stakeholders for comparable concern
4. Investigate the properties of the concern
5. Establish the relation with defined viewpoints from the NAF
6. Select a type of diagram from within the possibilities of Capella: Architecture Blank, Role Blank, Entity Scenario, Data Flow Blank, Functional Breakdown or Exchange Scenario
7. Construct the diagram

The conditions for the creation of new viewpoints are presented in the enumeration below.

- Keep it simple
- Do not include concerns or elements of viewpoints already used
- Restrict to the use of similar diagrams over the entire systems architecture

The fictive example to illustrate the creation of additional viewpoints is about a stakeholder interested in the competition between adversaries. In order for the stakeholder to establish capabilities that shall conquer the competition, inventarisation of opponent's capabilities is necessary. The unaddressed concern is the capability delivery of the opponent. Assuming this is the only stakeholder responsible for considering these threats, no comparable concerns have been found at other stakeholders. The properties are in fact similar to the C1-viewpoint from the NAF, however the view and access to information is different, hence speculation will become important. As mentioned, the close relation with the C1-viewpoint will become interesting since the same sort of information is requested by the stakeholders. Therefore, it is advisable to copy the diagram used at C1. Now the structure of the additional viewpoint is defined, a final job lies in obtaining the information from the adversaries.



5.7 L7 – Information Model | NAFv3: NOV-7

The L7 Viewpoint is concerned with identifying information elements, and describing their relationships.
Views implementing this Viewpoint:

- Shall identify information elements relevant for the architecture.
- May identify relationships between information elements.
- May identify attributes of information elements.
- May associate attributes with data entities.

Figure 4.2: Example of the representation of a viewpoint according to the NAF

4.1.10. Step 10: Review candidate representations of system architectures

The sum of requested diagrams form the systems architecture, however multiple ways of ordering the viewpoint-represented diagrams are available. To formalize the review-process, a selection of at least three different representations of systems architectures should be generated. The analysis starts with comparing the inputs and outputs between models, but above all is the traceability of requirements classified as the most important criteria for a systems architecture to be consistent. It is therefore recommended to compose the initial list of requirements and check if the final physical representation of the solution inhibits all requirements. One should take into account the relative difference between requirements; not all requirements are equal in priority and value. For more information about the classification of requirements, the reader is referred to chapter 2. The iterative characteristic of the method is focused around this step. The compatibility of a Capella model with the requested diagrams from the NAF could differ greatly in certain scenarios. Therefore, after having reviewed the candidate architectures, it is advised to analyse the architectures against the concerns once more.

4.1.11. Step 11: Define needs to conclude on 'best suited' characteristic

To define the concept of 'best suited' for a project, the following criteria should be reflected on the systems architecture, awarded a weighted score and leveraged against each other.

- Reflects all viewpoints as addressed at step 3, section 4.1.3
- Contributes qualitatively the most to the objective of the architecture
- Requirements are traceable
- A majority of the viewpoints originates from the NAF

After subjecting the system architectures to the criteria for 'best suited', a final conclusion can be drawn and architecture can be selected about the most appropriate agglomeration of viewpoints composing the systems architecture.

4.1.12. Step 12: Select best suited representation of system architecture

To define the best suited systems architecture, a definition of 'best suited' should be established. The appropriateness of a systems architecture depends on the objective and the level of detail demanded by the complexity of a project. A more complex project requires extensive architectures, containing a multitude of exchanges between functions, systems and actors. Whereas a less sophisticated project attracts more attention on the quality of defined functions. The selection of the best suited architecture depends on compliance with the definition of best suited at section 4.1.11. After having executed this final step, the result should be compared to the Capella project model, as it should enhance the insights of relations between stakeholders and requirements. These enhanced insights will add value to the final project model by increasing the knowledge, further iterations of the project model will benefit from the results of relating the stakeholders with the requirements.

4.2. Uncertainties of the method

The method, as indicated in figure 4.1, is subjected to a variety of uncertainties related to external factors guiding the methodological process. These include the influence of the stakeholder analysis, the correctness of the Capella model and the applicability of the NAF. All scenarios will be discussed in this section including a mitigation to prevent or minimize the consequences.

4.2.1. Scenario A: Stakeholder concerns not universally phrased

One key factor for realizing this method are well defined stakeholder concerns. Similar to requirements engineering, the phrasing of concerns can make a difference and should therefore be restricted within certain set categories and kept on a global level, e.g. the concern of a stakeholder interested in the specification of the connection between a pipe and pump can be rewritten as 'systems specification'.

4.2.2. Scenario B: Capella model not inclusive

A project team dealing with this method for the first time is in the ability of developing an incompatible Capella model which has no ease of handling when delivering the diagrams requested from the viewpoints. Although the difficulty of the requirements for the Capella model is not vast, it should be modelled in such a way to accelerate the generation of viewpoints. A mitigation for this risk is to equip each project team with an experienced member, or develop the Capella model simultaneously with the arrangements of viewpoints.

4.2.3. Scenario C: NAF insufficient to address the project

In the extraordinary case that the identified concerns do not have any relationship with the NAF, this method is not valid anymore since it is based on a majority of the NAF-viewpoints. Although systems architecting is a process with many undefined boundaries, the freedom of concerns not relating to the NAF is too hazardous for the method. The only mitigation to resolve this risk should occur at the stakeholder's domain, the concerns should be identified differently. However as mentioned, this risk is unlikely to happen due to the broad description of concerns addressed in the NAF and the applicability of the NAF to military and business domains. Furthermore, each architectural framework is designed in a way to cope with universal defined inputs and to fit most of the enterprise or project goals.

4.3. Conclusion

The method as presented in this chapter aids to relate requirements with stakeholders via a systematic process. The steps should be followed in their respective order, however this will become challenging when projects increase in complexity due to the increase of iterations during the construction of the Capella model, hence available information and requested diagrams will change. A mitigation of this problem is to divide a complex project and request certain architectures at certain stages, instead of expecting a final architecture. The predetermined criteria, as presented in section 4, should be evaluated in order to conclude if the method is suitable. The inclusion of all stakeholders and all relevant concerns have been addressed, steps 1 and 2 take care of the stakeholders, whereas steps 3 and 4 involve the corresponding concerns. The NAF makes sure the method is applicable to the naval domain. The systematic method and low degree of complexity fulfills another criteria, and the existence of at least 1 iterative loop is satisfied. However, assigning processes to specific team members is not fulfilled because it has proven to be of minor influence to the workings of the method. In the following chapter, the method is tested by means a Proof of Concept.

5

Proof of Concept

By conducting this Proof of Concept (PoC), the realisation of structured elements originating from the NAF and implemented in the Capella-environment by means of the ARCADIA method is shown, based on the method as explained in chapter 4. The PoC is conducted on a modest set of stakeholders to minimise the complexity of modeling and scope on the combination of NAF-elements with Capella. The story behind this PoC is extracted from procedures defined in an public document designed to guide procedures for Maritime Interdiction Operations. First, the goal of this PoC shall be highlighted, whereas the success criteria are established in order to measure the performance of this proof. The stakeholders involved are consequently addressed, after which it is possible to determine their concerns and select viewpoints from the NAF. After the Capella model has been described, the diagrams generated from this model are explained. Once the diagrams are constructed, comments regarding the selection of the best suited architecture are given. At last, an elaboration of the feedback from the success criteria is presented.

5.1. Goal

The goal of this proof of concept is to apply the newly developed method to a small group of stakeholders. The magnitude of the group is chosen to be small in order to emphasize on the workings of the method in stead of the ordering of diagrams. The expected result is to obtain a small subset of diagrams providing the stakeholders with adequate information necessary for a specified phase during the ESSD. Success criteria have been defined to decompose the major goal of the proof of concept and enhance the validation of the results.

5.2. Success criteria

As mentioned previously, success criteria are defined to grasp the qualitative evaluation of the diagrams. Given the flexibility and creativity involved when constructing the viewpoints, it was deemed necessary to keep the criteria as general as possible. The following success criteria have been defined.

- Present majority of requested NAF diagrams: 90% is sufficient
- Easily obtainable diagrams: effortless procedures to acquire the diagrams to represent the NAF-structure
- Upscaling is taken into account; amount of effort required for larger models is minimal
- Show added value with regards to conventional system modeling
- Traceability of requirements is improved
- The agglomerated viewpoints establish a systems architecture suitable to the required phase of the project
- The agglomerated viewpoints should together establish a systems architecture to address the needs of the stakeholder

5.3. Stakeholders involved

As part of this proof of concept, two stakeholders are involved being the operational analyst and the layout specialist. Both stakeholders being specific to the naval domain and the combination of these two, as is expected, shall deliver two different views on the requirements established from the unclassified source.

5.3.1. Description of actors

The goal of this description is to obtain an overview of their respective concerns, from which a selection of the viewpoints is obtained. The concerns are, at first, identified based on the respective tasks of the stakeholder, whereas the selection of concerns is later executed by looking at the concerns used in the NAF. In this manner, an accurate coupling between practical concerns and NAF concerns is established.

Operational Analyst

The operational analyst is concerned with defining and analyzing the operational capabilities as predefined during the RQS phase. In the context of a shipyard, the operational analyst converts the capabilities defined by the customer into a set of requirements. Ideally, the client delivers a Concept of Operations as input for the operational analyst, however, due to confidentiality and strategic importance, these ConOps are not transferred to commercial parties. The interest of an operational analyst is therefore scoped, during the ESSD, at creating, elucidating and managing a set of requirements. During later stages, the analyst is concerned with the justification of operational capabilities within the design.

Given the general description of the tasks and responsibilities of an operational analyst, concerns can be derived which fulfill the needs, these are listed below.

- Operational analysis
- Capability Management
- Operational planning
- Concept of operations
- Capability delivery
- Requirements definition

The six concerns are all part of processes occurring during the ESSD and of special relevance to the operational analyst. One can imagine that the concern ‘operational analysis’ is obvious, but e.g. the ‘requirements definition’ is less obvious since one could assume these requirements to be defined before the operational analyst is involved. However, given the naval domain and the collaboration between DMO and DAMEN Naval it is of best practice to include the operational analyst during the phase of requirements definition.

Layout Specialist

The layout specialist during ESSD is concerned with the generation of general arrangements by means of specific contemporary tools such as FIDES (Takken, 2012) or WARGEAR (le Poole et al., 2022). Multiple variations of general arrangements are created in order to show the alternatives possible and provide the naval architect with a foundation to base the rationale on. As input of information, this specialist relies on functional arrangements and space lists. Whereas the former is a volume block based arrangement and the latter is a detailed list of criteria for each space such as the minimum required area and aspect ratio. The input for a layout specialist concerns a list of rooms/spaces to be implemented in the design, specific mission attributes such as the RHIB or helicopter originating from the Maritime Interdiction Force Operations (MIFO) and requirements concerning speed, range and manning. As mentioned, the output of information from a layout specialist are alternatives of general arrangements. The relevant concerns for the layout specialist are given in the following list.

- Capability Management
- User requirement specification

- Interface specification

- Systems integration

5.3.2. Prioritization of stakeholders

Using the same attributes and corresponding weighting of attributes as defined in table 2.1, a distinction in priority between the two stakeholder is obtained. The scores in table 5.1 have been obtained by analysing the tasks of both stakeholders and indicating their relative influence, hence the power of the operational analyst is more significant than the layout specialist due to the fact that operations (missions) lead to a certain layout. Given the result, the operational analyst is marginally more important, however the small difference in the score is deemed inconclusive, but will still be used when constructing a systems architecture.

	Power	Interest	Urgency	Legitimacy	Total
Operational analyst	5	1.5	2.1	4	12.6
Layout specialist	3	1.5	3.5	3.2	11.2

Table 5.1: Weighted score of stakeholders related to the PoC

5.4. Selection of viewpoints

Based on the concerns given by the stakeholders, applicable viewpoints are selected from the NAF. The selected viewpoints correspond to a representation of the concerns of both stakeholders during the ESSD. The selected viewpoints belonging to the operational analyst are given in the table 5.2. These viewpoints have been selected based on the prescribed usage according to the NAF. For example, the C1-viewpoint addresses the taxonomy of capabilities. An operational analyst is interested in the capabilities of the design solution to support demanded missions, therefore it is only inevitable to illustrate the dependencies between capabilities in order to ensure mission effectiveness. Another example is the P1-viewpoint, the physical representation of the resources and identification of resource types in the final solution. The operational analyst is interested in the resources because these are the last step in the line for the delivery of capabilities, hence the operational analysts will use P1 as a verification stage to check if required capabilities are assured.

Concern	Corresponding viewpoint(s)
Operational analysis	C4, C7
Capability Management	C1, C3, C7
Operational planning	C2, C8, L1, L2, L6
Concept of operations	L4
Capability delivery	P1

Table 5.2: Selection of viewpoints for the operational analyst

The layout specialist has, when compared to the operational analyst, different concerns as indicated in table 5.3. More focus is on the Physical Resource Specifications row in the NAF grid due to the integration of systems within arrangements and rooms. A unique view for this stakeholder is defined in the L5-viewpoint; the description and identification of the logical states. The reason is due to the chronological order of processes, a layout specialist will be involved after the operational analyst has determined the capabilities of the system. The L5-viewpoint covers the behavior of solution-bounded systems, hence the last step before committing to technical allocation of systems. Another distinctive viewpoint is P2; determining the structure of resources. As the layout specialist is concerned with the integration of systems and therefore is required to deal with the interfaces between resources. By presenting the structure of resources, a layout specialist will be aided in decision-making about certain conflicting physical resources.

Concern	Corresponding viewpoint(s)
Capability Management	C1, C3, C7
User requirement specification	L1, L2, L6
Interface specification	P1, P3
Systems integration	P2

Table 5.3: Selection of viewpoints for the layout specialist

5.5. Implementation in Capella

All diagrams relevant for the purpose of explaining the choices made during modeling can be found in the subsequent text, explaining the meaning of all diagrams. The ARCADIA-method is followed during the execution of the modeling of the MIFO-based proof of concept. The inputs for modeling are the requirements generated from the MIFO-documents. The further decomposition from requirements is based on subject-specific knowledge and logical thinking.

5.5.1. Maritime Interdiction Force Procedures

The simulation of a real-life concept starts with an imaginary customer, hence the task at hand was to find a non-DAMEN unclassified set of design particulars or prescribed required procedures. The information has been found in the unclassified EXTAC 1012 document **MIFO**, Maritime Interdiction Force Procedures. The document defines procedures to be carried out during interdiction missions between NATO and non-NATO navies. The goal of the interdiction missions is to deny access at specific ports for countries not complying to the imposed import or export restrictions by applying distinctive levels of non-violent or violent force upon the Contact of Interest (COI). The document is set up in a hierarchical order of describing the procedures from the detection of a COI up and to the boarding and ultimately division.

5.5.2. Extracting requirements

The Maritime Interdiction Force Operations (MIFO) document is assigned to be the provider of the requirements on which this proof of concept is build. As mentioned in section 5.5.1, a description of procedures is provided, hence logically these give an abstract version of the requirements in the form of vague expressions. To mitigate these expressions into contextual solid requirements fit for the modeling process, therefore, certain guidelines for establishing uni-modal requirements have been followed. The result is the following set of requirements, presented in chronological order.

- Shall detect all surface tracks in an area of interest
- Shall identify all surface tracks in an area of interest
- Shall identify a specific and defined COI in an area of interest
- Shall track an COI in an area of interest
- Shall vector a platform to identify an COI
- Shall vector a platform to intercept an COI
- Shall have means to attract attention
- Shall have means to establish initial contact
- Shall obtain required information to board
- Shall communicate boarding procedure to COI
- Shall sail close to COI
- Shall obtain and keep a clear visual of COI during boarding procedure
- Shall identify illegal cargo

- Shall communicate diversion decision
- Shall communicate stopping procedure to COI
- Shall intimidate violently
- Shall intimidate non-violently
- Shall board a COI with 10 crew

5.5.3. Operational analysis

According to the ARCADIA-method, the first step is to address the needs of the solution in the operational layer. The requirements, as presented above, are aligned in a first Operational Capability Blank. Based on the distinction of chapters in the MIFO-document, seven general high-level capabilities have been derived to relate the requirements to, represented in the list below.

- Detect surface tracks
- Identify surface tracks
- Track a COI
- Communicate with COI
- Approach COI
- Intimidate COI
- Board COI

The first task is to relate the requirements with these capabilities, with the sole condition that each requirement should have at least one link with an capability. It is not excluded that multiple links exist between a requirement and capabilities, e.g. at the requirement ‘shall have means to attract attention’ related to the three capabilities ‘communicate with COI’, ‘approach COI’ and ‘intimidate COI’. The next task is to include the interactions with the entities and actors of the system. Basically at this stage, the most important entities are the COI, the shipyard and the environment. The assist vessel, as prescribed in certain actions in the MIFO-document, could be included as well if dual operations are taken into account.

5.5.4. System analysis

The power of Capella is the use of automatic transition between layers, it is at the system analysis where the first use of this function could happen, however nothing is mandatory and it is up to the systems architect to develop a own method. Due to the lack of experience in modeling with Capella, this model was created by using transitions. The transitions do not fulfill the system analysis completely, but take care of the operational activities and capabilities defined in the operational analysis. The next step was to construct System Functional Dataflow Blank diagrams (SFDB) for each capability to define the external functional analysis. Within these SFDB’s, functional chains have been established to present scenario-based processes and connect the individual system functions in logical series. After completing all seven SFDB’s, a final Systems Architecture Blank diagram is created to allocate the separate functions to entities and actors from outside the system.

5.5.5. Logical architecture

As a start, the transition of system functions has been performed by the tool. The major distinction between the system analysis and logical analysis is the location of the boundary of the system. Whereas at the system analysis external actors were involved, the logical analysis is more internally focused. However, this does not mean all systems functions should be rewritten. After having completed the transition, seven Logical Functional Dataflow Blank diagrams (LDFB’s) have been constructed and altered in a way they belong to the logical analysis.

5.5.6. Physical architecture

The last step of this modified ARCADIA-approach is the physical analysis, which adds functions required by the implementation as well as the illustration of the technical choices. Furthermore, behavioral components are highlighted at this stage. As with the other stages, a transition of logical functions is executed to enhance the process and guarantee all functions will be used in the physical analysis.

5.6. Coupling of NAF to Capella

At this stage, with the viewpoints identified from the NAF and the model being completed in Capella, the novelty of this thesis comes into play. The diagrams according to the requirements of the viewpoints should be developed in Capella. In a real-life test environment, the viewpoints for each stakeholder shall be established, meaning e.g. multiple C1-viewpoints can exist. Due to the reduced size of this proof of concept and the overlapping concerns from the two closely related stakeholders, each viewpoint shall only be represented once.

5.6.1. C1 - Capability Taxonomy

The first diagram to be represented originating from the NAF is the Capability Taxonomy viewpoint. Relations between capabilities, focused on breakdown-structured views are determined based on the stakeholder concerns. High-level capabilities will be broken down into scoped capabilities, the decomposed capabilities are easier to allocate further on in the process.

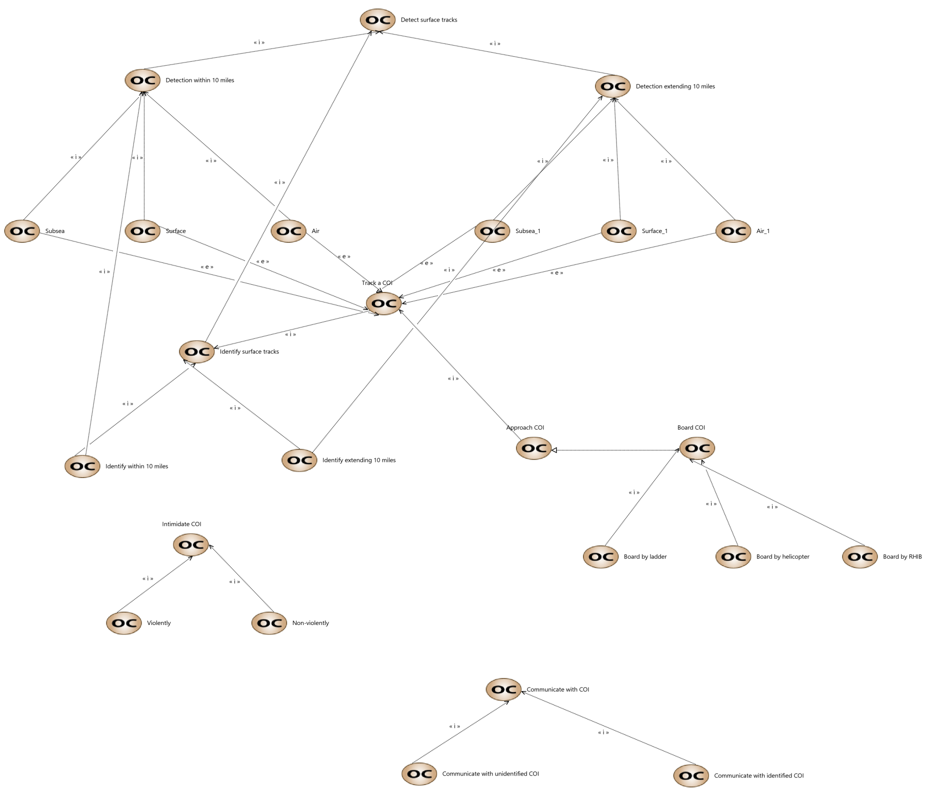


Figure 5.1: Operational Capabilities Blank relating capabilities

Figure 5.1 displays all high-level capabilities of which some have been broken down to create an example of distinctions made. The high-level capabilities are dependent on each other, except for the ‘intimidate COI’ and ‘communicate with COI’ capabilities, these are self-sufficient. The other capabilities are linked due to the interwoven system of the tool, this is the advantage of first creating a full-size system model in Capella and afterwards constructing the specific diagrams.

The operational analyst can determine, based on figure 5.1, for example which capabilities are more important to implement in the system when decisions have to be made regarding cost overruns. Capabilities with a central role, such as the ‘Board COI‘ are harder skip while the operational analyst can make a choice between the means of boarding. In this specific case, one could opt to eliminate the subcapability of boarding by helicopter since no relations are derived. However, valid this argument may seem, it should not be taken as a condition for eliminating capabilities because, in the case of ‘boarding a COI’, all sub-capabilities could be eliminated and the parent capability can not be executed anymore.

Relation to OFP-requirements
Indicating the relation with regards to the emphasized OFP-information results in a elimination of functional and physical information. A capability taxonomy deals with operational information during this specific case, therefore the use of an Operational Capability Blank is advised.

5.6.2. C2 - Enterprise Vision

The enterprise goals as such do not have an dedicated structured element in Capella, in order to include these visions, advised is to implement an Operational Capability Blank where the capabilities can be justified with the enterprise vision by including constraints. In reality, it is the contrary for the relation between capabilities and the enterprise vision. Capabilities are deemed to constrain the enterprise vision by, for example, the technological readiness level of certain technologies to fulfill a capability. In this proof of concept, the objectives of the MIFO are translated to enterprise visions. Two objectives are stated for the MIFO, the primary to determine if a merchant ship is in compliance with the reason for interdiction and secondary to gather intelligence about the COI.

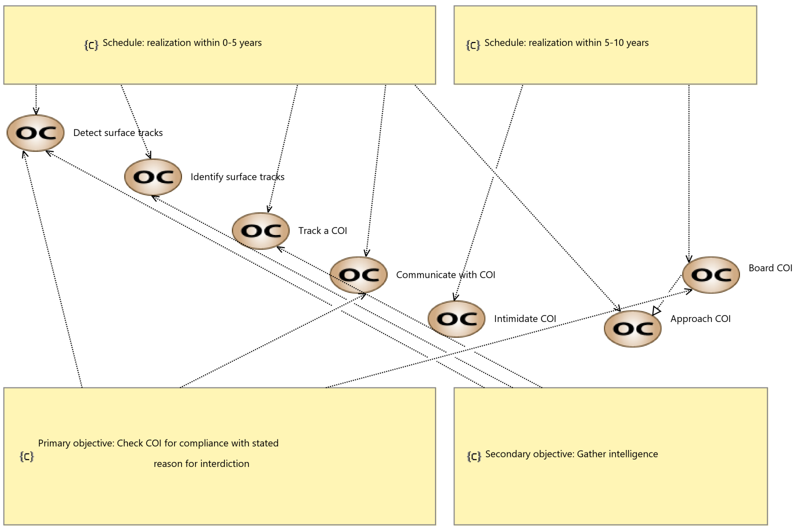


Figure 5.2: Operational Capability Blank including the strategic vision of the enterprise

An analysis of the C2-viewpoint, as given in figure 5.2, establishes reasons for the operational analyst to in- or exclude certain capabilities in the primary design. Based on the timeline of expected capabilities and the compliance to the primary objective, priority in the design effort should be given to the capabilities ‘detect surface tracks’ and ‘communicate with COI’.

Relation to OFP-requirements
Similar to the C1-viewpoint, capabilities are the mere source of information at this viewpoint. However, the time-constraints include a sort of secondary functional information flow meaning functionalities can not directly be coupled to the constraints, but based on the planning, functionalities can be executed to achieve the schedule. Furthermore, the primary and secondary objective, as depicted as constraints, indicate operational dependencies.

5.6.3. C3 - Capability Dependencies

On this limited scale, the dependencies between capabilities can be twofold, firstly by tracing back to the requirements and concluding which capabilities share the same requirements. However, another manner for defining the dependencies between capabilities is to include the taxonomy as presented at C1. According to these components, the relationships between the seven top tier capabilities is established, including the links between lower-tier capabilities. The result is presented in figure 5.3 by means of an Operational Capability Blank.

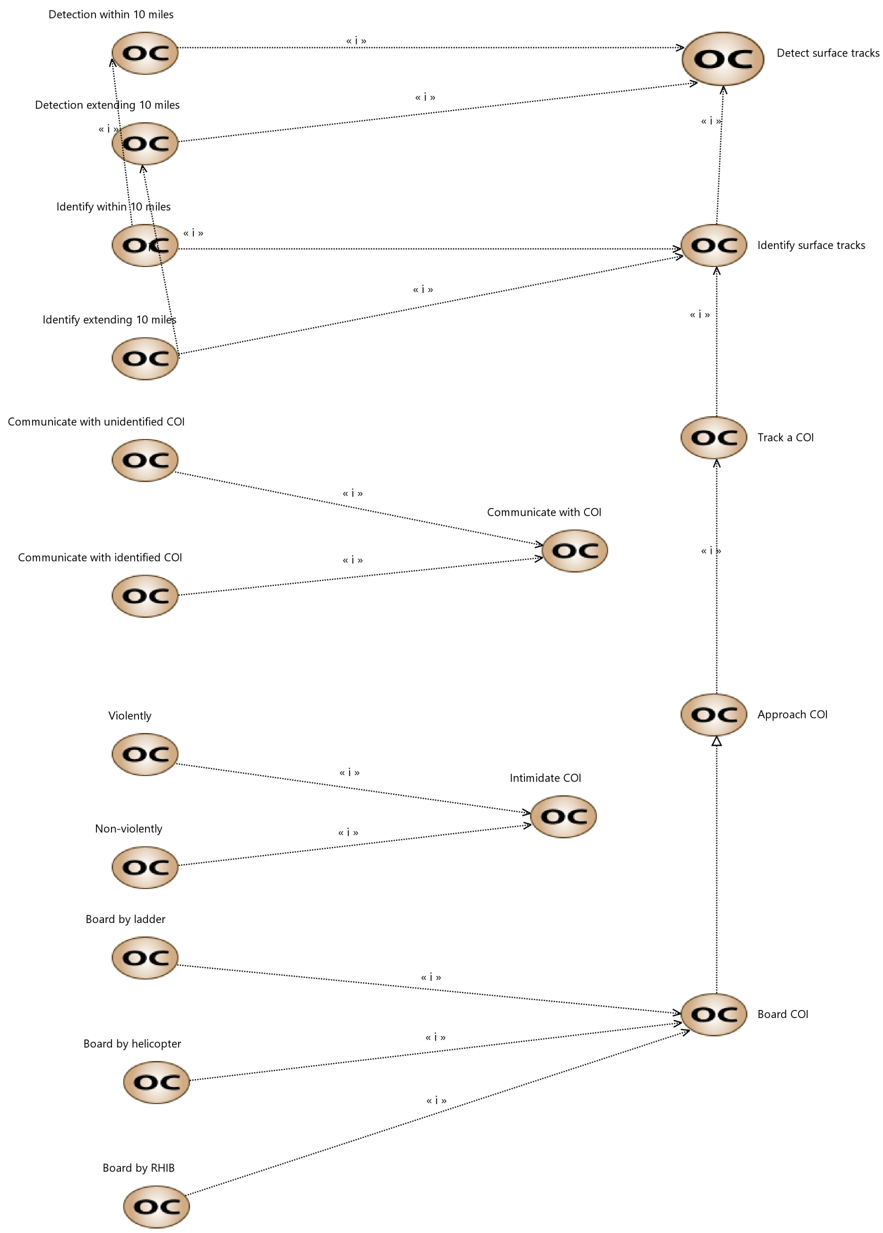


Figure 5.3: Operational Capability Blank indicating the dependencies between capabilities

The result of the C3-viewpoint is a chain of capabilities, similar to the functional chains as presented during the explanation of the model, however this chain of capabilities does not represent behavior but merely the most likeable path from the start of the detection until boarding. The two separate high-tier capabilities ‘communicate with COI’ and ‘Intimidate COI’ are not related to the path, indicating the options an operational analyst has during the design. It should be noted that the priority given at the previous viewpoint to the capability ‘communicate with COI’ does not have any influence on the dependencies between capabilities as presented here.

Relation to OFP-requirements

The elements used at this viewpoint are capabilities, hence operational information is the basis.

5.6.4. C4 - Standard Processes

The standard doctrinal processes will be investigated by allowing this viewpoint to be part of the systems architecture. One shall try to allocate the standard operational activities to the capabilities. In Capella, this relationship is not directly possible within the given set of diagrams, therefore a two-fold process should exploited. Firstly, an OCB is constructed in order to relate the capabilities with entities. Secondly, an OAB is used to connect the entities with operational activities. Only standard doctrinal operational activities shall be expressed in this viewpoint, hence a distinction has to be made. The distinction between the indicated standard doctrinal processes and exceptional operational activities has the objective to display the correct activities allocated to entities. Therefore a choice is made to limit the activities based on the criteria of internal independent functionalities, hence all functions dependent on external actions or information from outside the boundaries of the system are ignored at this viewpoint.

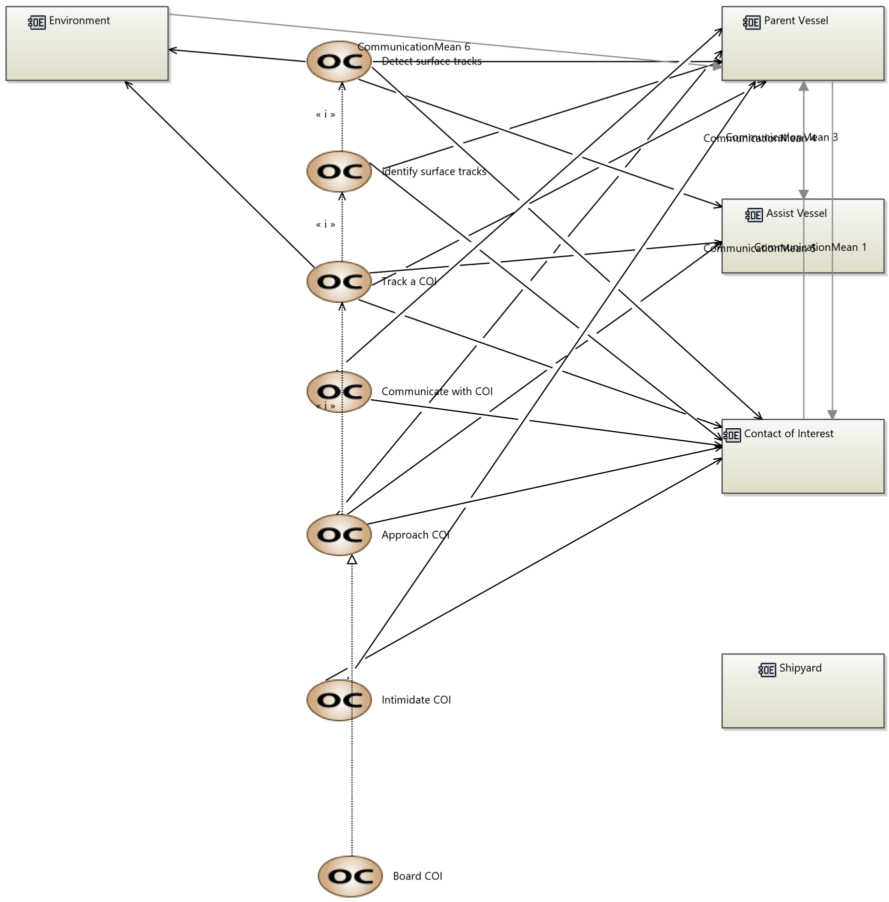


Figure 5.4: Operational Capability Blank relating capabilities with entities

The need of a presentation covered by two diagrams is not beneficial for the accessibility and ease of reproduction by the system modeler, hence a recommendation towards Capella is to allow diagrams connecting capabilities with operational activities directly.

Relation to OFP-requirements

The operational information is of main importance at this viewpoint, hence it aids to relate the operational analyst with these kind of information-flows.

5.6.5. C7 - Performance Parameters

This category is not specified in the MIFO but is deemed necessary for the applications of an operational analyst. The performance categories can be modelled as constraints in Capella, again by using an Operational Capability Blank diagram. The prescribed method for introducing the performance parameters is by identifying the measurement categories per capability. The diagram given in figure 5.6

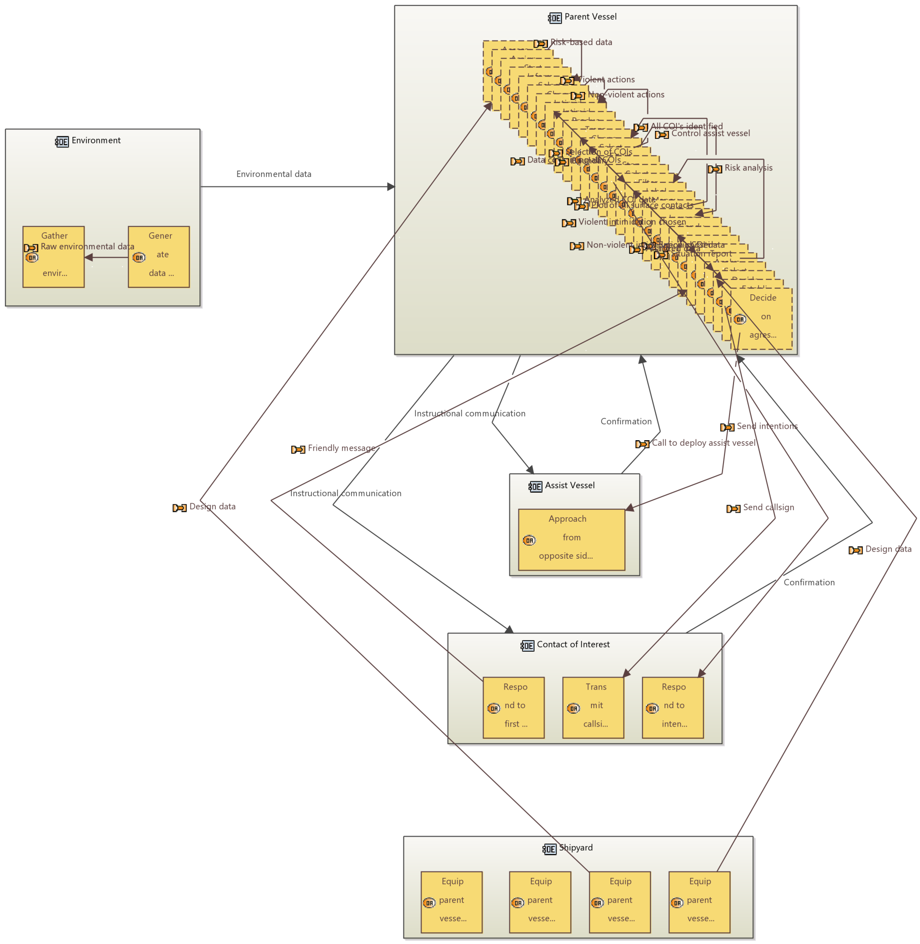


Figure 5.5: Operational Architecture Blank relating entities with operational activities

presents the measurement categories for the capability 'detect surface tracks'. The relationship between the capability and measurement category may be constructed, however, this is not to be done at the Capella model since the constraints specified here as measurement categories will be used as elements throughout the model and will conflict with other defined constraints. Obviously, the measurement categories will include the -ilities of the project, commonly prescribed as e.g. availability or flexibility.

Figure 5.6 helps the operational analyst in quantifying the capabilities and steering the subsequent steps of architecture, hence the measurement categories have been accomplished by required values. The operational analyst is able to determine the subsequent requirements for the capability by overlooking figure 5.6. Furthermore, by presenting the required performances of a capability, the choice for prioritization of these capabilities will be enhanced. The determination of the measurement categories is a subject apart, it is assumed that these are not over- or underestimated. In an ideal world, the operational analyst is also involved during the determination as one knows the possibilities of current shipyard capabilities. However, the client will be more persuasive during this phase.

Relation to OFP-requirements

The performance parameters are merely part of the operational information. For example, the required design speed of a vessel while conducting an boarding-operation has an operational character.

5.6.6. C8 - Planning Assumptions

The implementation of capabilities is bounded by constraints, these constraints can be either functional or non-functional. Examples of functional constraints include the minimum size of the boarding crew and non-functional constraints are concerned with the availability, redundancy, safety and quality of the

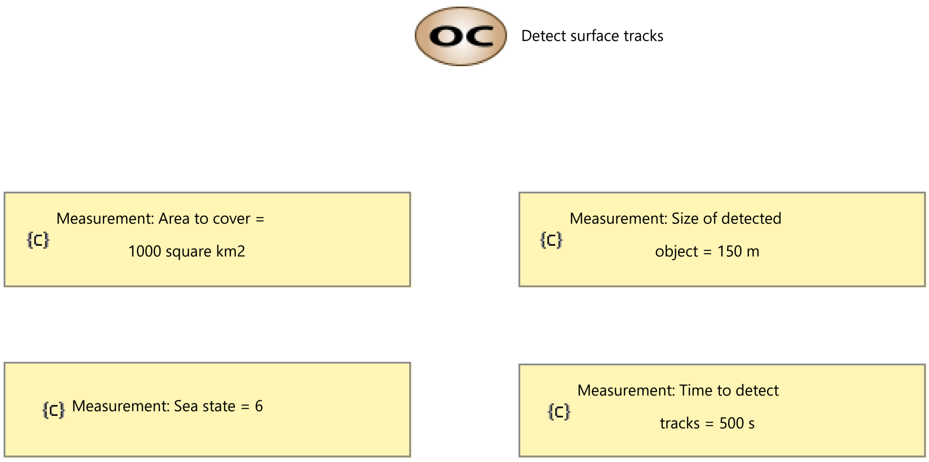


Figure 5.6: Operational Capabilities Blank representing the performance parameters

capability. Due to the proximity with the capability-breakdown as depicted in C1, this diagram can be retrieved from C1 and expanded with the constraints. An example is given in figure 5.7 for the capability 'board a COI'.

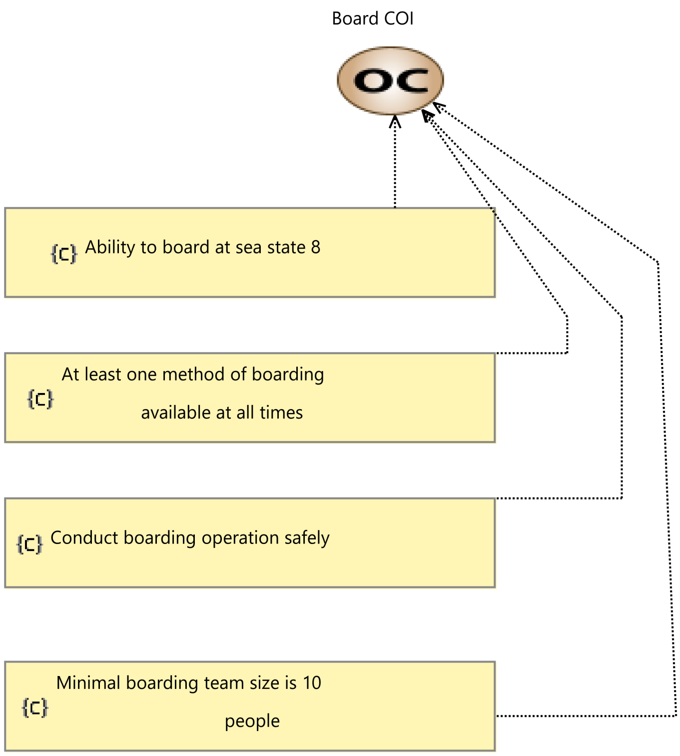


Figure 5.7: Operational Capabilities Blank relating a capability with constraints

The necessity of this viewpoint for the operational analyst is based on the effective integration of each capability throughout each layer of the architecture, concluding with a physical object fulfilling the constraints determined in the beginning of the project.

Relation to OFP-requirements
As indicated, the constraints can either be functional or non-functional. The latter tend to be a mix of operational and physical information, whereas the operational aspects are specified by physical

characteristics.

5.6.7. L1 - Node Types

The start of the logical specification begins with the identification of the logical entities in this L1 viewpoint. These logical entities are able to perform behavior independently and are therefore represented as logical components and logical actors in Capella. The diagram to fulfill these criteria is the Logical Architecture Blank. The optional traceability to capabilities is not effected within the logical layer of Capella. In order to identify all nodes relevant for the architecture, as the NAF prescribes, the logical component ‘boarding device’ is taken as example and further decomposed in the three different possibilities. In order to maintain the dependency with the capabilities as required, the requirement ‘board a COI with 10 crew’ is linked by a constraint to the high-level logical component.

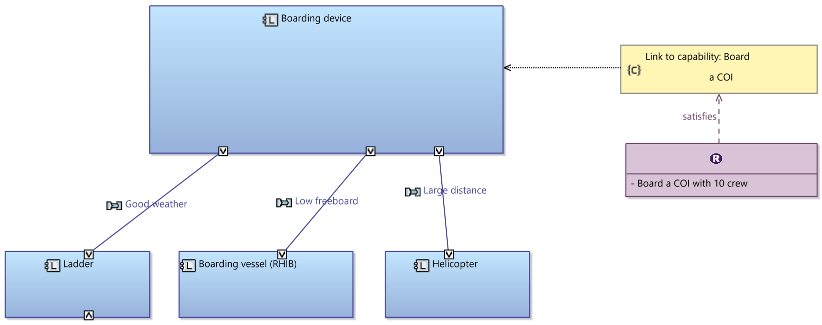


Figure 5.8: Logical Architecture Blank relating logical actors with a requirement

The figure presented in 5.8 displays a possible representation of the node types concerned with a part of the solution. As mentioned, logical components are used to indicate the behavioral aspects. The operational analyst is less concerned with such an representation but this view will help in consolidating towards an understanding of the solution. The traceability with regards to the operational capability is maintained and a link with the predefined user requirements is established. Figure 5.8 is a simplistic representation in the case of the MIFO but more complex projects will result in a multi-layered logical node taxonomy. The disadvantage of using an Logical Architecture Blank in Capella is the inability for implementing capabilities from the operational analysis, although user requirements can be added.

Relation to OFP-requirements

Behavioral aspects are a simulation of functional information derived from the relations between entities or subsystems comprising the system or a part of the system. The logical components are in fact physical objects representing functional information.

5.6.8. L2 - Logical Scenario

The scenario of logical nodes is similar to the definition of functional chains at the logical layer in Capella, hence a representation of the individual functional chains belonging to a separate distinct function is sufficient to address these concerns.

Relation to OFP-requirements

The current situation is derived from the logical analysis from Capella, hence the internal functional analysis is used to cover the concerns belonging to the L2-viewpoint. In the logical layer, system functions have already been defined and are further decomposed into smaller tangible functions. Therefore, it is fair to conclude that the relation with OFP-information at this level is purely functional.

5.6.9. L4 - Logical Activities

The logical activities and relationships between these activities are considered at this viewpoint, translated to the use in Capella, this basically constitutes the decomposition of system analysis functions to logical functions, hence the diagram responsible for this viewpoint shall present the relations between logical functions and logical functional chains.

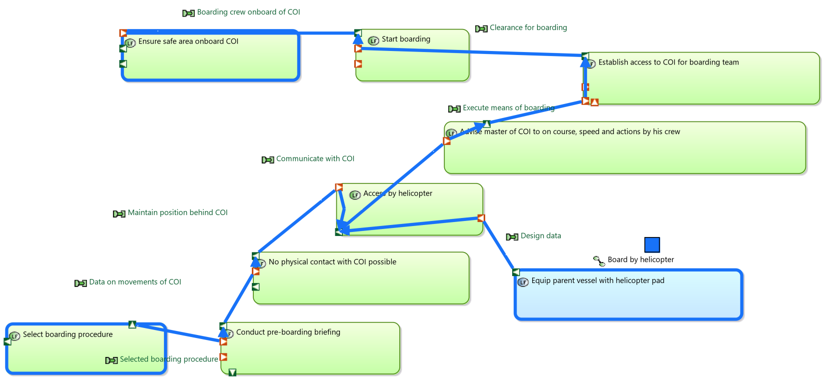


Figure 5.9: Logical Data Flow Blank diagram indicating a logical chain

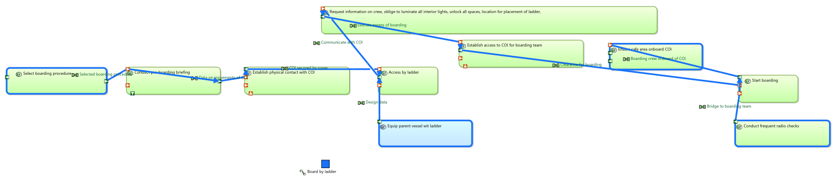


Figure 5.10: Logical Data Flow Blank diagram relating logical activities

In figure 5.10, the logical chain for the logical activity of boarding a COI by means of a ladder is depicted. During this stage of the design effort, the solution has been determined and the internal functional analysis commences. Such a diagram is constructed for each logical chain within the project. The advantage of presenting each logical chain separately is to gain knowledge in the processes involved and thereby enhance the operational planning. The operational analyst is especially interesting if the intended solution still meets operational capabilities, it is therefore recommended to present this viewpoint never without an Operational Capability Blank, as depicted in figure 5.3.

Relation to OFP-requirements
As already mentioned section 5.6.8, the information in the logical layer is purely functional, hence the information represented in the L4-viewpoint is functional. However, a strong dependency between the functional information and the operational needs as described in the Concepts-row of the NAF grid should not be underestimated.

5.6.10. L6 - Logical Sequence

As described at the L2 and L4 viewpoint, functional chains are used to define an order of occurrence in logical functions. A scenario can be made up out of multiple functional chains or fractions of these, it is at the L6-viewpoint where the chronological order of functional chains is presented. The functional chains are requested in a scenario-diagram and coupled in order to achieve the desired effect. In fact, this viewpoint gives an overview of all functional chains at logical level, presented in sequential order.

The result is an chaotic representation of the functions belonging to the logical chains, however due to the color scheme applied and the sequential order of the legend, this diagram adds value to the operational analyst. The details within the logical chains and each specific function is not relevant for this stakeholder, the question whether capabilities are successfully employed is what matters and this becomes clear by inspecting the start- and end logical chain.

Relation to OFP-requirements
The functional chain represents logical information, due to this origin, the term ‘functional information’ is maintained.

5.6.11. P1 - Resource Types

The required technological means and competences of the system will be identified at this viewpoint. A direct link between resource types and delivered capabilities should become visible by establishing

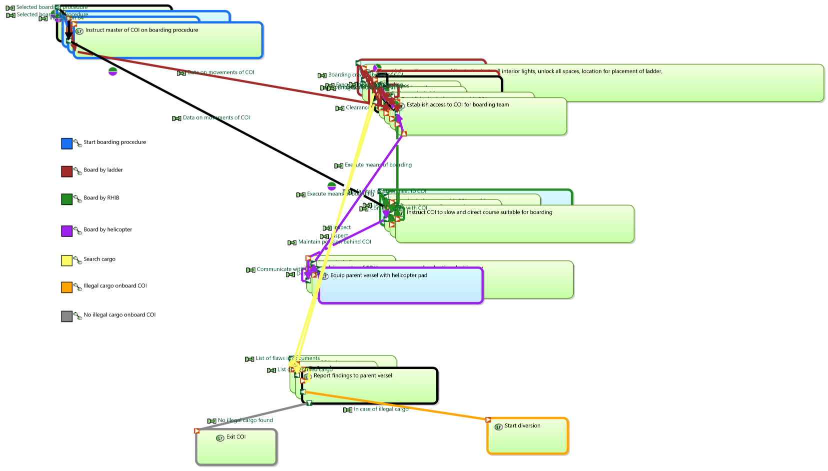


Figure 5.11: Logical Data Flow Blank diagram presenting a multitude of logical chains

this viewpoint, hence ignoring the ARCADIA-prescribed steps. At the physical architecture, there is however no possibility to directly couple operational capabilities to physical components. The other aspect of this viewpoint includes a representation of the performance characteristics of each resource and a specification of the interface protocols and hardware ports used between resources.

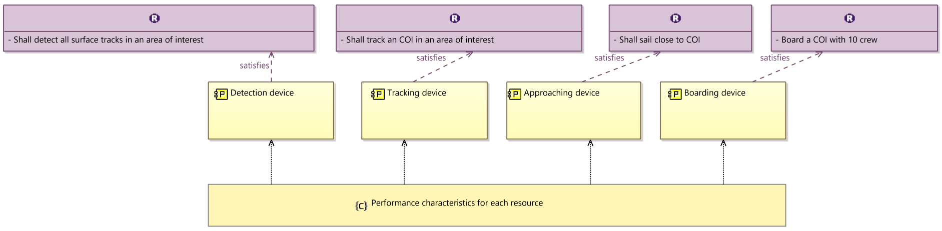


Figure 5.12: Physical Architecture Blank diagram relating physical components with requirements

Relation to OFP-requirements

As expected, at the first viewpoint of the Physical Resource Specifications, physical information is distributed over the diagram. At figure 5.12, the four blocks containing the devices are physical. Furthermore, the purple blocks represent operational requirements. Again, this is a smart way to cope with the coupling of operational and physical information while Capella does not allow it via the designated elements.

5.6.12. P2 - Resource Structure

The interaction between resources is presented with the purpose of corresponding to the logical architecture defined earlier on. Identifying the structure between resources serves as the link between the operational and physical architecture viewpoints. The structure gathers systems fulfilling a common capability. The suited representation in Capella to accomplish the requirements corresponding to the P2-viewpoint is a Physical Capability Blank Diagram (PCBD) presented in figure 5.13. Besides showing the relation between the requirements and node, a decomposition of one subnode is elaborated, being the propulsion-node of the helicopter. This exercise shows the level of decomposed artifacts, although it would be better at this stage to include detailed specifications about e.g. the type of turbine including the delivered power.

The layout specialist will use this viewpoint to match certain layout requirements with capabilities. In the end, the layout specialist has to deliver an arrangement complying to the predefined requirements.

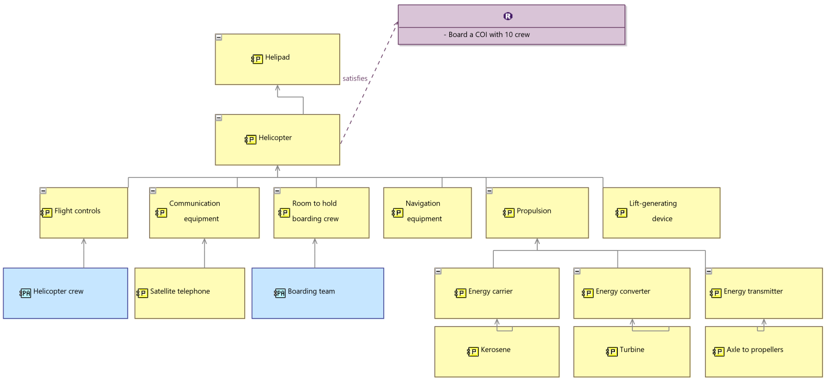


Figure 5.13: Physical Component Breakdown diagram decomposing a physical component and relating to a requirement

Relation to OFP-requirements

The node decomposition as depicted in figure 5.13 is a direct mark of physical information being distributed from the higher levels to the realisable lower levels.

5.6.13. P3 - Resource Connectivity

The specification of how the systems are connected is presented at this viewpoint in a more technologically detailed chosen manner scoped on the communication between systems. For example, the means of communication are presented including the specific communication protocols, bandwidth of communication channels (shortwave vs. longwave) and encryption methods for ensuring safe transfer of information. The idea is to realize a system functioning in an inter operable environment, hence the ability to communicate with various systems should be satisfied. The diagram depicted in figure 5.14 determines the communication between the boarding team and the COI. As prescribed by the NAF, the technological characteristics of the communication channel has to be displayed, hence the three constraints bound the interaction between the two actors. The manner the constraints are currently presented is still too vague due to a lack of technological knowledge at this area.

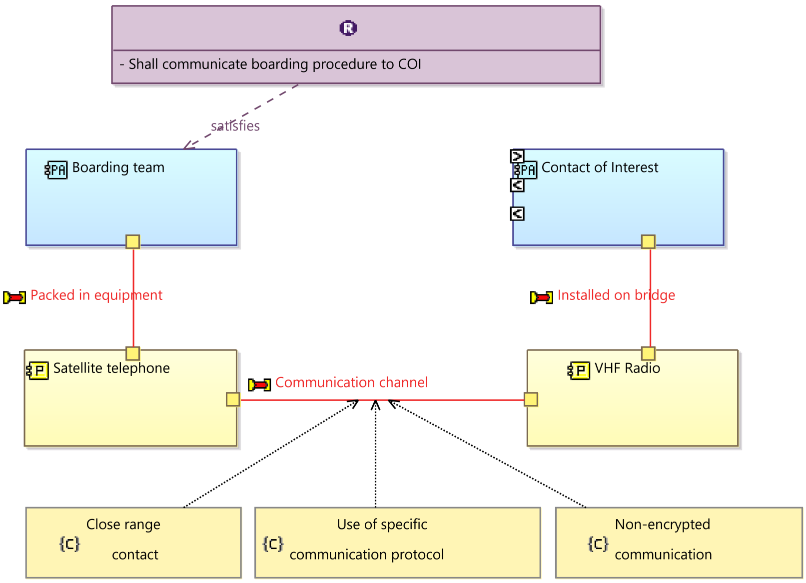


Figure 5.14: Physical Architecture Blank diagram indicating constraints for the communication and relationship with a requirement

The physical constraints will emerge when implementing this viewpoint in the architecture, hence the layout specialist has to cope with these constraints and deliver an arrangement without conflicting communication paths. The aim is to communicate effectively without constraint, therefore, together with engineering specialists, the layout specialist will design an arrangement without interference.

Relation to OFP-requirements
Given the technical solutions being presented in this viewpoint, the relation between physical information emerges. When a multitude of systems exist within the viewpoint, functional relationships will be inserted to indicate the need for a given communication path between these systems, the communication path should be further justified with the specification of communication. In order to determine the correct medium of communication, the layout specialist will have to rely on the experiences of field experts.

5.7. Review candidate architectures

In order to compose the appropriate systems architecture from the selected diagrams, a review of several possibilities is needed. In the case of only dealing with two stakeholders, the different options of systems architectures are limited. First of all, the needs for the respective systems architecture has to be defined, which differ depending on the phase of the project. Since this thesis is scoped at the ESSD, it is fair to conclude that the goal of the systems architecture with an operational analyst and layout specialist is to visualize the processes in order to realize a certain capability within the vessel. With this in mind, the systems architecture has to capture the initial set of requirements for the capability up to and including the physical implementation within the vessel. Since the systems architecture is made up out of different viewpoints and various selections can be made once an extensive agglomeration of viewpoints is gathered, the limited PoC does not endure these selections and the set of all viewpoints assembled form the systems architecture.

5.8. Selection of best suited architecture

According to the method, this step in the process is aimed at selecting the best suited architecture for the specific goal. However, as concluded from the prioritization of the two stakeholders, no interests, powers or influences together are preceded above one another. The suited architecture therefore is a composition of the diagrams resulting from all viewpoints as elaborated in section 5.6.

The best suited systems architecture in this case is an architecture which starts with a randomly chosen capability and ends with the physical realisation of the capability. In essence, this is what the ARCADIA-method takes care of. For the sake of this PoC, the goal of the systems architecture is set to reveal the capability of ‘Detection‘ throughout the model, which will be established by representing all diagrams as presented at section 5.9. The list below provides the foundation of the ARCADIA-methodology, the systems architecture shall obtain a similar structure.

1. Administration of effort: describe e.g. the definitions, methodology and compliance to other applications

2. Operational Analysis: include the Concept-row

3. System Analysis: include the Service-row

4. Logical Analysis: include the Logical Specifications-row

5. Physical Analysis: include the Physical Resource Specifications-row

5.9. Comprising the systems architecture

The systems architecture is the final product and includes a selection of viewpoints considered. There is no predetermined fixed order of what constitutes within a systems architecture, the only condition is fulfilment on the objective. In essence, the systems architecture should cover the full life-cycle of a product or project. However, a systems architecture could have another goal in mind, whereas within this thesis, the systems architecture is determined to be a way of expressing the stakeholder’s influence during the project. Ideally, a systems architecture should be constructed separately for each stakeholder, wherein modifications of one systems architecture will be applied to all other architectures. This mirrors the working principles of an MBSE-approach to obtain a single source of truth. Based on the inconclusive prioritization of stakeholders in the specific case of this PoC, the systems architecture is defined as the agglomeration of all applicable viewpoints.

The order of diagrams aids the stakeholder in effectively applying changes in the design. Since the selection of viewpoints is not strict and various distinctive roads can be taken to deliver the desired effects, a guideline for ordering the diagrams is outlined in the summation below. The guideline is based on the ARCADIA-methodology, hence it idealizes the combined effort of the NAF architectural framework and the Capella-based system modeling techniques. The guideline has a strict order and derivations are not beneficial for the intended scope of the architecture. However, not all elements are obliged to exist within the architecture (Farhangi and Konur, 2018).

1. Administration of effort: describe e.g. the definitions, methodology and compliance to other applications
2. Operational Analysis: include the Concept-row
3. System Analysis: include the Service-row
4. Logical Analysis: include the Logical Specifications-row
5. Physical Analysis: include the Physical Resource Specifications-row

5.10. Conclusion

The viewpoints resulting from the concerns of both stakeholders have been constructed based on the limited information at hand. Therefore, the success criteria, as established in section 5.2, shall be used as a way to conclude on the results of this proof of concept.

5.10.1. Feedback on success criteria

Firstly, the majority of the requested diagrams is presented. The benchmark had been set at 90% and from all diagrams used, only one was harder to define. This is the L5-viewpoint which should display the effects in a given Exchange Scenario. The reason for not being able to construct this diagram is due to the Capella model, where no practice had been given to the implementation of scenarios. An area for improvement would be to emphasize during the modeling in Capella on the scenarios.

The next success criteria was based on the effortless procedures required to construct the diagrams. As this attempt was the first exercise of creating diagrams as requested by the NAF, it is not realistic to include this criteria given the lack of experience. Although the choice for some specific diagrams and the creation of them took hours, the main problem in the early stages was figuring out all the possibilities in Capella. Gaining experience or conducting the creation of diagrams by an experienced system modeler will improve the fulfillment of this succes criteria.

Upscaling the diagrams to include more stakeholders or more details is difficult due to the tailoring of each diagram. Preferably, a template should be constructed for each viewpoint with clear definitions of the concepts in Capella versus the concepts at the NAF. A start of this template can be made but the purpose in the end will be lost due to the endless creativity of system modellers in Capella. In the ideal world, one should opt to create the Capella model based on the template, instead of the other way around.

The traceability of requirements is definitely improved in the visualizations by means of showing requirements throughout all layers of Capella. The functionalities within Capella are able to trace the requirements but a representation for the specific needs is harder to define, therefore viewpoints have been established.

The resulting systems architecture gives a good indication of the needs of the two stakeholders, however, the diagrams should be elaborated with all variants in order to obtain a complete systems architecture. At this time, a stakeholder interested in a certain capability is satisfied up and to the physical layer, but not all capabilities have been included. More time and effort is needed to construct the systems architecture for all seven capabilities, but this is out of scope for this proof of concept.

Lastly, the added value of the obtained architecture can be shown based on the satisfied needs of the stakeholders. As long as the operational analyst is able to decide on the effectiveness of capabilities and the layout specialist can make functioning arrangements without conflicting with other spaces, the added value has been proven.

5.10.2. Capella and the NAF

Without focusing on the success criteria, some remarks can be made regarding the interaction of Capella with the NAF. Firstly, as already mentioned in at the description of the diagrams, it was not possible to connect conventional capability elements to, e.g. physical components.

Secondly, due to the single source of truth concept, Capella automatically modifies diagrams when new, e.g. physical nodes have been created. It is therefore necessary to check each diagram after having completed all creations. The undesired elements can easily be deleted from the specific diagram without losing them in the model, but care should be taken to avoid ‘stray elements’.

6

Demonstrating the method for the design of a Stan Patrol vessel

The model is based on the Stan Patrol 5509 vessel, designed and built successfully in series at DAMEN. The capabilities of these kind of vessels involve multi-mission strategies, while at the same time being versatile and reliable. The equivalence between this model and the one used during the proof of concept is imminent, both are used for surveillance and interdiction operations. Due to these similarities, the case study is a logical subsequent step within the same domain.

6.1. Stakeholder analysis

In the following chapter, the case study will be described which was executed based on the method as explained in section 4. The test-case is developed by DAMEN Naval via non-classified information. A stakeholder analysis has been conducted with 11 naval-specific stakeholders in order to close the gap with the limited analysis during the Proof of Concept and reality. The end result of the stakeholder analysis is to uncover the concerns of each stakeholder by means of a structured approach. Having the concerns uncovered, a matching process starts with the conventional viewpoints from the NAF. Since the quantity of concerns addressed while executing this case study are a multitude of the concerns addressed during the Proof of Concept, the 'best suited' definition has been established to organize the diagrams and select the most relevant systems architecture to represent the stakeholders concerns.

6.2. Selection of method

Based on the limited time available, confidentiality and global spread of stakeholders, a selection of the methods to conduct the stakeholder analysis has been made. Identification of stakeholders has been executed by means of small focus groups, consisting of both supervisors of this thesis. Differentiating and categorising of stakeholders is executed by a top-down approach including a power-interest grid, see figure 6.2, representing several important attributes. Lastly, the relationships between stakeholder have been investigated by means of social network analysis. The objectives of the stakeholder analysis are two-folded: primarily in order to reveal a prioritization of stakeholders based on different attributes and secondly by identifying the concerns per stakeholder. These concerns are essential when developing the systems architecture while using the NAF.

Since the influence of each stakeholder is different for each part of the ESSD, a selection has to be made for a considered phase of the ESSD. The phases considered in ESSD are 'Market Research', 'Marketing & Sales', 'Proposal' and 'Contract', as depicted at the V-model in figure 6.1.

6.3. Identification of stakeholders in shipbuilding industry

Knowledge and experience of the focus group is vital for obtaining an complete overview of the main stakeholders. Although the focus group is of relatively young age, given the academic experience on topics such as distributed networks, confidence has increased to obtain the main stakeholders. Below,

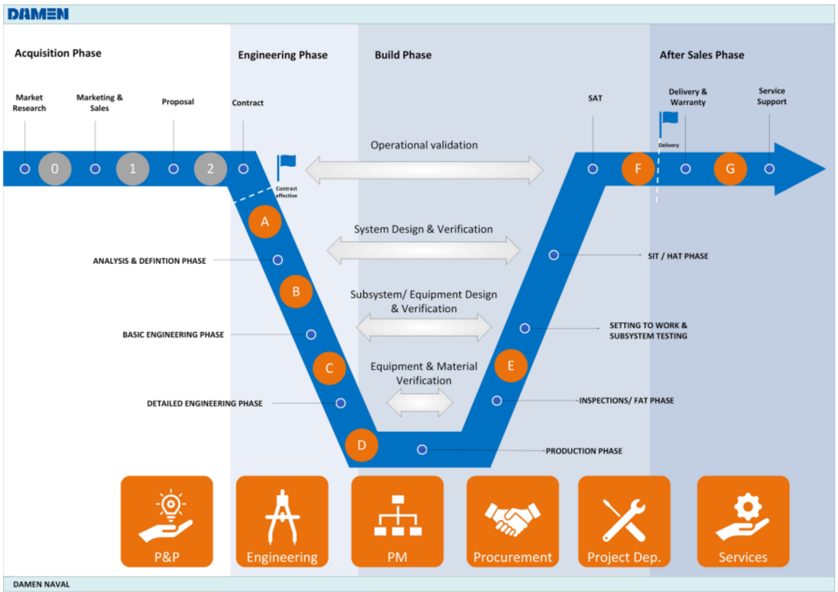


Figure 6.1: V-Model as used at DAMEN Naval (DAMEN Naval, 2021)

a list of the identified main stakeholders is presented, of which a distinction can be made between external stakeholders and DAMEN-internal stakeholders.

- Legislative parties
- Customer
- User
- Shipyard
- Enemies/commercial competitors
- Taxpayers
- External suppliers
- External subcontractors
- System integrators
- Engineering specialists
- Plan & Approval
- System modelers

6.4. Differentiating and categorizing of stakeholders

As stated in the introduction, differentiating the stakeholders is executed firstly by assessing the power and relative interest of each of them. The power-interest grid reveals a ranking of stakeholders based on their respective impact of influence but does not entail information about other attributes such as legitimacy and urgency. Since the goal of this section of the stakeholder analysis is to obtain a prioritized list of stakeholders, more detail is needed besides the power-interest attributes to construct this list. Therefore, attributes as urgency and legitimacy are added to the categorization in order to specialize the intentions of stakeholders and increase the level of detail. The result obtained is presented in figure 6.2, at which the colors indicate if a stakeholder is supportive (green), neutral (orange) or contradictory (red). Supportive stakeholders are collaborating on the project with the same goals and objective in mind based on the project, neutral stakeholders do not have any interest in the project but are more concerned with the laws and guidelines assuring the product suffices to safety-standards. Contradictory stakeholders are not involved during the execution of a project but could become interesting when addressing conflicting interests. The power-interest grid is divided into four quarters indicating the relative position of a stakeholder based on their levels of power and interest. The first quarter, a stakeholder with high power and low interest, indicates to keep the respective stakeholder content with the project and advises to update on areas of the project that might interest them the most. Stakeholders in the second quarter, a high power and high level of interest, should be managed closely and efforts of the project team should be focused on this group. The third quarter, where stakeholders have low power and low interest, should be provided with the minimum amount of communication and updates in order to fulfill their expectations. In the last quarter of low power and high interest, stakeholders should be well informed and approached for advice and support.

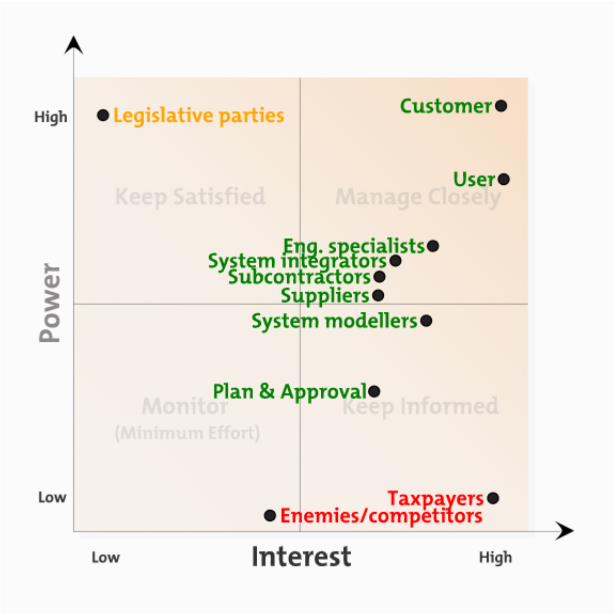


Figure 6.2: Power-interest grid of stakeholders

A summation of the scores per attribute will lead to a score per stakeholder, on which a direct link to the priority list is constructed. Depending on the timescale of the process, these attributes are weighted differently. Given the fact that this thesis is concerned with the ESSD, as defined in section 1, the weighing of the attributes is addressed to the processes contained in the ESSD: acquisition- and contract phase. Before defining the score of each stakeholder, an explanation of the attributes is given.

The weighting of attributes is given in table 2.1 according to the expected behavior of stakeholders during the ESSD. As can be deduced, the power-attribute has attained the nominal score of 1, since this attribute is most convincing in addressing the influence of stakeholders. On the contrary, 'interest' has been given the lowest score due to the passiveness of this attribute. An stakeholder may have infinite interest in a certain design aspect, however their interest does not awaken the motivation of a decision-maker to actually inhibit the demands. The attributes 'urgency' and 'legitimacy' are almost equally weighted, with legitimacy being a fraction more important to the decision-makers. How urgent an demand for action from an stakeholder may be, whenever it is not within an certain legal framework, common set of rules or on defined common grounds, the influence of the stakeholder will diminish. This argumentation reveals the weights, as defined in table 2.1.

At this stage, the subsequent step is to apply an Likert-scale score system to the 11 stakeholders, as identified at section 6.3. Multiplying the score per attribute times the applied weight and adding all terms reveals the total weighted score per stakeholder, presented in the last column of table 6.1.

The results of the prioritization analysis are not as evident as expected. The lowest score is obtained by external suppliers, whereas the system modellers gained the most points. The higher scores correspond to an higher position on the prioritization list, logically, lower scores will be placed lower on the list. Scoring the stakeholders is a process covered with boundary conditions and scenario-specific

Stakeholders	Power	Interest	Urgency	Legitimacy	Total weighted score
Legislative parties	5	0	3	5	11.1
Customer	5	5	5	1	11.8
User	4	4	4	1	9.6
Shipyard	3	5	5	4	12.2
Enemies/commercial competitors	1	5	1	1	5
Taxpayers	2	4	3	1	6.9
External suppliers	1	4	1	1	4.5
External subcontractors	2	4	3	1	6.9
System integrators	3	3	4	5	11.3
Engineering specialists	4	5	5	1	10.8
Plan & Approval	5	5	5	1	11.8
System modellers	4	3	5	5	13

Table 6.1: Categorization of stakeholders

constraints. For the example used at this case study, the scenario is the ESSD and boundary conditions involve the intended use of this analysis. Since the analysis serves as an input to review suited systems architectures.

- Scenario-based information
- Constraints by purpose of analysis
- Constraints by effects

The score as used in this particular example is given from the perspective of stakeholders having an influence on the design of the systems architecture, hence system modellers score the highest points. The difference between external suppliers and enemies, both scoring the lowest amount of points, is minimal and the statement of their limited influence on the systems architecture is justified based on this evaluation. The most remarkable result is the score of the shipyard, being the second highest. It could be argued that including a general 'shipyard' within the analysis is redundant due to the other stakeholders involved working at the shipyard. However, the term 'shipyard' includes all physical aspects of the design process, e.g.storage of steel, fabrication, conservation and installment of systems, hence the influence being large during system modeling since these form most of the technical constraints. The ultimate need for this prioritization is to resolve conflicts occurring during the representation of specific concerns.

6.5. Profiling stakeholders

After having categorized the stakeholders by the appropriate attributes next task is to identify the concerns per stakeholder. The concerns are of major influence on the architecture effort since these are the main input to model stakeholders. Identifying the concerns is not part of any conventional stakeholder analysis method but is added based on the NAF and structural elements that constitute to an architectural framework. The level of detail is kept manageable, hence concerns are specified to a minimum. In the end, the concerns raised are helping to develop the method and not to solve the problem pragmatically.

6.5.1. Legislative parties

The term 'legislative parties' is comprehensive and therefore incorporates innumerable parties out of scope for this thesis. The restriction in legislative parties is based on the ESSD, hence only the parties concerned with the design of an vessel are incorporated such as the IMO's Sub-Committee on Ship Design and Naval Ship Code ratified by the NATO. The main concern of legislative parties is if a design complies to the current law and regulations. The designer should therefore follow certain guidelines which help to accomplish an effort within the boundaries of the legalities. The presentation of information to legislative parties should cover the concerns as summed up below. The ESSD is not the only phase during the design of a vessel in which legislative parties are interested, however it is the most important phase due to the amount of decisions being made in a limited time span. The concerns for the legislative parties have been summed up below, the general character of these concerns confirms to the behavior of these parties.

- Implementation of law: general laws such as working conditions for crew onboard
- Safety requirements: e.g. implementation of Safety of Life at Sea (SOLAS)
- Environmental requirements: emission regulations
- Combatant requirements: armament being used is in line with the regulations of a country or agreements of a treaty between countries, e.g. the design of nuclear weapons being restricted

The dichotomy for legislative parties and design of naval vessels is present, law is in highly technological projects mostly lagging. Hence the dialogue between legislative parties and designers of naval vessels is important. A developed system may not comply to the laws and regulations, but these can be altered with proper argumentation in order to approve a new technology. In this way, not only technological advances mark the naval domain, but legislative growth as well.

6.5.2. Customer

The customer is competent to make the final decision on ordering an vessel, but is as well the one starting the process by expressing interest in a specific naval design, company or addressing their operational needs. The customer is, in the naval domain, a governmental body requiring an naval asset. Each government is unique in a sense of the outsourcing the tasks. The Defence Material Organization (DMO) for example being individual during the concept phase, hence more information is available at the customer before introducing a shipyard in the process. This process has been transformed over the past years due to a shortage of staff at DMO, hence more conceptual work is required by the shipyard. Therefore, concerns such as the threat assessment are still included here but are also of interest for the shipyard and constructed in a different way. For the use of this test case, DMO is exploited as customer. The following concerns have been identified for the customer.

- Capability management: the implementation of capabilities during the design effort
- Capability planning: a timeline of when certain capabilities are needed in the strategy of the customer
- Acquisition management: bureaucratic process to gather the information in order to approve acquisitions by the government
- Interoperability: adaptability of the new asset within the current fleet
- Scenario specification/threat assessment: creating the concept of operations based on the investigation into future missions

6.5.3. User

At non-governmental projects, the user is usually the same as the customer. However, at governmental projects, the user could be different. In the case of DMO being the customer, the user is the Royal Netherlands Navy. Operational subjects are more of concern to the user, the interest is in the functionality of the design instead of the administrative and financial concerns.

- User requirements: operational and physical requirements demanded by the user
- Experience-based capability management: establishing and controlling of the capabilities based on previous missions at older assets
- Operational analysis: aligning the vessel with the skills of the crew

6.5.4. Shipyard

The shipyard being the constructor of the design, hence is more physically concerned with the project. It takes care of the project management tasks and aims to deliver a vessel on time and within the budget.

- Configuration management: assembly of subsystems into general arrangement
- User requirements: installation of equipment to fulfill the needs of the user
- Stakeholder management: manage all stakeholders by updating on progress, decisions made and unpreventable changes in the design
- Scenario specification/threat assessment: establishing the concept of operations if deemed necessary

6.5.5. Enemies/commercial competitors

The enemies or commercial competitors are outside of the design process, however it is advised to include them during the analysis since they are in fact a stakeholder of the test case. The interest of this group of stakeholders should be seen as a bidirectional link; they are eager to obtain information from the design team and the design team is eager to establish their current status of capabilities. The advantage of including stakeholders within the systems architecture is, firstly, to establish a threshold of minimum capabilities to fulfill and secondly to be aware of presence and possible technological leap in the nearby future.

- Capability management: identifying the new capabilities of the asset in order to adjust the defending force, improve the assault assets or increase technological advances in the enterprise vision

6.5.6. Taxpayers

Another passive stakeholder in governmental projects only is the group of taxpayers, civilians and companies paying taxes for the facilities and security a country has to offer. Expenditure of these budgets is approved by elected representatives. In order to get a budget approved, a majority of these representatives should be in favour, hence the constituency is satisfied with the costs and gains. The project is influenced by these taxpayers through societal responsible undertakings; the project can not, for instance, have plans to determine the life-cycle of an asset to be replaced by demolition on so called beaches in Bangladesh. Concluding, the influence of taxpayers is on the financial side of the project. Concerns address the management of these acquisitions.

- Acquisition management: justification of the source and target of the finances being allocated to a defense project

6.5.7. External suppliers

The external suppliers are involved as a one-way contact, information from the shipyard is distributed to the suppliers. The required product parameters are established by the shipyard and ordered, external suppliers have to fulfill their products to these parameters and should be able to prove this. In order to deliver the products in time, information about the production planning is required.

- Product specification: details of the required competencies of subsystems to be delivered
- Production planning: information on the planning as to fit the delivery of goods
- Low-level requirements: specific technical details originating from mid-level requirements, e.g. the required amount of air to be recirculated by the components of the HVAC system

6.5.8. External subcontractors

On the contrary to external suppliers, external subcontractors have a tighter contact to the design processes and are required to design components on their own. Therefore, interest in the mid-level requirements is demanded.

- Production planning: the need to address the delivery of goods originating from the external subcontractors
- Mid-level requirements: requirements originating from high-level requirements to inform the subcontractors about their flexibility in the design, e.g. the need for an FiFi system connecting specific accommodations

6.5.9. System integrators

Integration of systems is the task of this group of stakeholders. Adjusting the interfaces between components in order to achieve a system capable of delivering the required demands is of main concern.

- Integration management: combining functional systems in order to address the demanded capabilities
- Capability management: relating the capabilities to the requirements

6.5.10. Engineering specialists

Given the complexity of the naval domain, engineering specialists are required to include the sophisticated technologies within the design. Each discipline requires multiple specialists in order to deliver the capabilities. Furthermore, all complex systems have to behave in a beneficial manner to accomplish the stated mission. The concerns of engineering specialists are based on the realization of the system, hence the summation below gives an overview of these concerns.

- Low-level user requirements: physical requirements to address the naval specific subjects such as vulnerability and safety
- Capability delivery: realisation of capabilities in form
- Interoperability: technical support to comply to standards

6.5.11. Plan & Approval

The Plan & Approval (P&P) department of a shipyard is, with collaboration of the sales department, responsible for the prime contact with a customer. The initial requirements are transformed into a concept design, including the budgetary discussions and planning. The concerns of this group include, amongst others, the management of capabilities and elucidation of user requirements. The other concerns are given in the subsequent summation.

- Acquisition management: financial administrative tasks to support the execution of the project
- Capability management: addressing financial consequences when choices between capabilities have to be made
- Customer engagement: attracting customers by offering appealing prices and keeping the customers informed during the process of changes in budget
- User requirements: compiling a concept design and thereby addressing the initial requirements of the user

6.5.12. System modelers

Last but certainly not least are the system modelers being profiled based on their concerns. As system modeling is the art of combining all disciplines into a digital model, the concerns are mainly addressed by the integration of different systems, components and the traceability back to requirements. Essentially, system modelers acquire the Capella model as used during the Proof of Concept of this thesis.

- Integration management: preventing compatibility issues when combining various systems
- Systems engineering: supporting the project board by following the V-model and delivering models of specific elements on time

	Operational	Functional	Physical
Legislative	x		x
Customer	x	x	
User	x		
Shipyard	x	x	x
Enemies/commercial competitors	x		
Taxpayers	x		x
External suppliers			x
External subcontractors		x	x
System integrators	x	x	
Engineering specialists		x	x
Plan & Approval	x	x	
System modelers		x	x

Table 6.2: Relation of stakeholders with OFP-requirements

6.6. Viewpoints

This section specifies the selection of viewpoints corresponding to the identified concerns, furthermore, all constructed diagrams will be discussed. The representation of the obtained diagram will be presented and the essence of the relevant stakeholder shall be specified. Lastly, the visibility of OFP-information is highlighted.

6.6.1. Selection of viewpoints based on stakeholders

Based on the specification of the concerns of each stakeholder, as given in section 6.5, the corresponding viewpoints within the scope of the NAF can be selected. Table 6.3 presents these selected viewpoints. As can be concluded from this overview, the concerns from various stakeholders can be expressed by similar viewpoint, e.g. the C1-viewpoint is of interest for the customer, but as well for the taxpayer and system integrator.

Stakeholder	Selected viewpoints
Legislative parties	L1, L8, P8
Customer	C1, C3, C7, C8, Cr, L2, L3
User	C1, C3, C5, L1, L2, L8
Shipyard	C2, C4, Cr, L1, L2, L5, L6, L2-L3, L8, Lr
Enemies/commercial competitors	C1, C3
Taxpayers	C1, C3, Cr
External suppliers	P2
External subcontractors	L1, L2, L8, P2, P8
System integrators	C1, C3, C8, P2
Engineering specialists	P1, P2, P3, P8, L3
Plan & Approval	C1, C3, C7, L4, L6
System modelers	C4, L4, P1, P2, P3, P7

Table 6.3: Selection of NAF viewpoints corresponding to each stakeholder

6.6.2. Project model

According to the ARCADIA-philosophy, the model is constructed in four separate layers: operational, system, logical and physical. The difference with the model constructed at the proof of concept is the use of a requirements package at Capella. The system modelers team at DAMEN Naval created the Capella model based on a Stan Patrol vessel. Starting with the main set of requirements and ending in the physical layer of ARCADIA with the components allocated to functions.

6.6.3. Representation of viewpoints

With a complete Capella project model at hands, the construction of viewpoints according to the requirements from the NAF can start. In the subsequent subsection, the selected viewpoints are elaborated and explained. Furthermore, the relation with regards to stakeholders of interest and the respective viewpoints is explained.

C1 - Capability Taxonomy

The first requested diagram gives an overview of the capabilities and decomposed sub-capabilities. Seven distinctive groups of capabilities emerge from the analysis of the taxonomy The meaning of this diagram in the context of the naval domain is to eliminate uncertainties when starting with a feasibility study into the possible solutions. Traditionally, the customer will deliver the high-level capabilities, where after the Plan & Approval team will elaborate on the wishes and starts to include the technical opportunities.

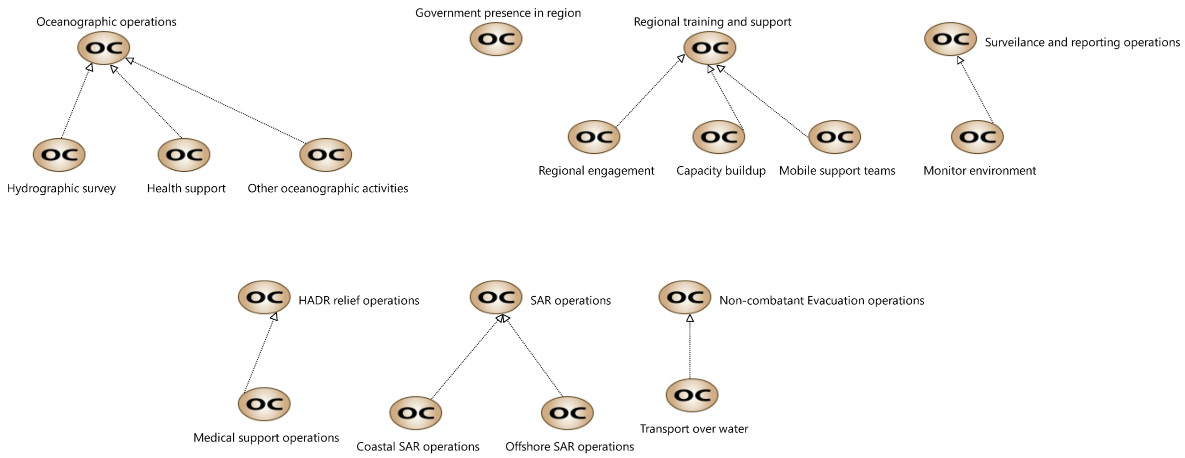


Figure 6.3: Operational Capability Blank diagram presenting capabilities and sub-capabilities in a hierarchy

Other stakeholders interested in this viewpoint are the taxpayers due to the curiosity of knowing where their taxes are spend on, furthermore, they could obstruct the program by exerting pressure on the elected representatives. The enemies and commercial competitors are just as interested in the capability taxonomy, unraveling the capabilities and anticipating on an expected vessel will make the new-build useless. Lastly, the system integrators have interest in the taxonomy due to the integration of systems cooperating to deliver the predicted mission. The relation with OFP-information is solely linked to the operational domain.

C3 - Capability Dependencies

The next viewpoint derived from the NAF is concerned with the identification of relationships between capabilities. An example of the full model is given in figure 6.4, which makes a distinction between two sub-capability groups. The primer subgroup investigates the domain of SAR operations, being in coastal areas or offshore. The second subgroup discloses information about the intended tasks. The revelation of two different kind of sub-capabilities obliges to address these with different labels. Hence, the capabilities revealing the strategic domain of the capabilities will be named domain-specific capabilities. The group indicating the tasks associated within each domain is referred to as task-specific capabilities. The taks-specific capabilities are presented in figure 6.4 as 'Medical support operations', 'Transport over water' and 'Monitor environment'. The interest of stakeholder is comparable to the interest as indicated at the C1-viewpoint, presented in section 6.6.3.

C4 - Standard Processes

The representation of the C4-viewpoint should be visualized by a two-fold process, as concluded from section 5.6.4. Therefore, the first diagram presents the link between a capability and the entities involved, and the diagram depicted in figure 6.6 relates the entities further with operational activities. For this case, the choice has been made to select the 'Government presence in region' capability. Such

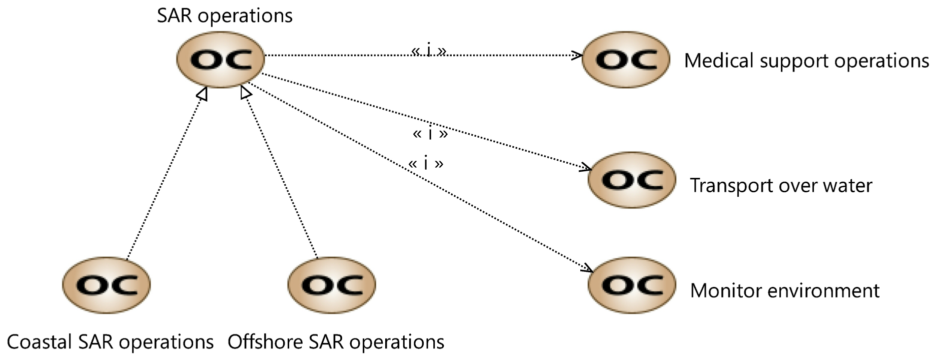


Figure 6.4: Relating capability groups

an overarching capability demands refinement. The three entities are the government, local population and civilian crew. The government serves as the body of authority for a certain mission in a certain area, where the civilian crew will sail too. The local population facilitates the presence of the vessel by issuing port allowance. The stakeholder of interest is the shipyard and the system modeller. The shipyard, meaning the physical assets of the shipyard responsible for the construction of the vessel, will favour the use of this viewpoint to insert design features able to connect to the entities, such as certain communication devices in order to establish contact with the government via secured connection or to the local population via less-secured connections. The system modeler sets the boundaries of the respective system model, hence knowing the entities aids in ascertaining these boundaries and deliberately making choices as to which stakeholder to include at a specific stage.

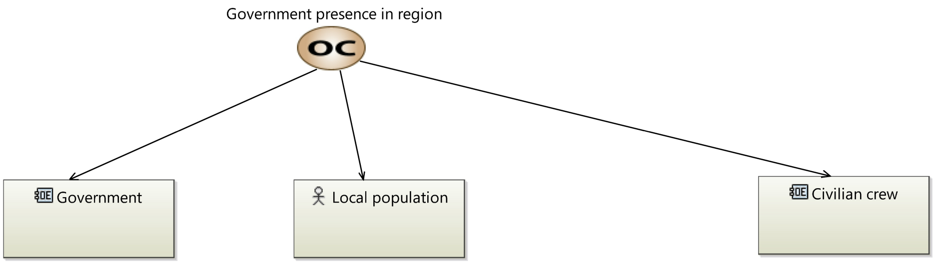


Figure 6.5: Operational Capability Blank relating capabilities and entities

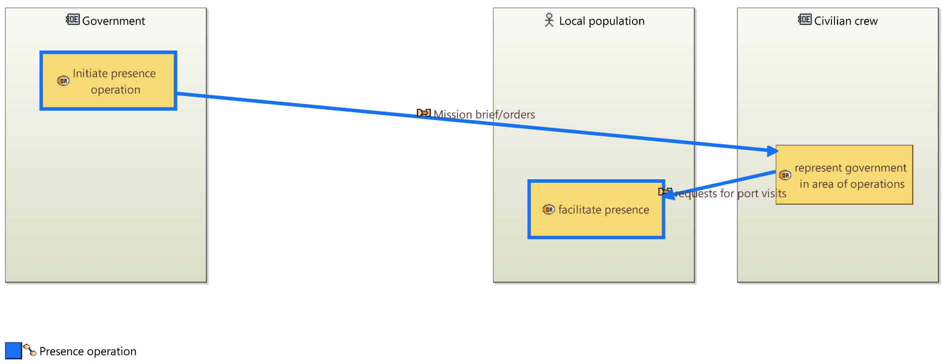


Figure 6.6: Operational Architecture Blank relating entities with operational activities

C5 - Effects

The effect of the capability 'Government presence in region' is modelled as a constraint on the diagram, which is presented in figure 6.7. It seems obvious to reveal the effect of this specific capability and in this case the effect is limited to one. Although, when considering more effect corresponding to a capability, this viewpoint adds more value to the needs of stakeholders. The relevance of this effect for the architecture effort is to indicate the impact of the capability. If, for example, a choice has to be made between capabilities, the ones with the lowest impact could be neglected from the end product. In order to conduct an operational analysis, the effects contribute to a prediction of the behavior of the architecture. This is not solely defined for the operational analysis, an analysis of non-functional properties such as availability or security makes use of this viewpoint as well due to effects such as ‘operate in restricted area’ or ‘establish safe haven for incoming national cargo vessels’. The user is the sole stakeholder interested in this view, implying decisions are taken by an onboard command and control unit instead of at the strategic defense unit. Overseeing the effects of a capability will help the crew in ordering their tasks and complying to the mission profile.

Figure 6.7: Operational Capability Blank relating capabilities with effects

C7 - Performance Parameters

All capabilities should have some form of performance inherited in the consequences of their behavior, otherwise the capability is deemed to be pointless. As explained during the Proof of Concept, the performance parameters are presented at the C7-viewpoint. Figure 5.6 displays these parameters for the capability ‘Government presence in regions’, whereas the first performance parameter is indicating the number of operational days present in the area of operations and the second reveals the number of times the vessel has visited ports. The two concerned stakeholders are the customer and Plan & Approval office. The former being interested is the investment was worth the money, hence the performance indicates how well the product is able to conduct missions and tells the customer about the employability. The Plan & Approval office tries to sell the product and is concerned with the initial design phase, hence for their feedback into the design process, quantitative values are important to increase the efficiency of a subsequent effort. Furthermore, as is familiar at DAMEN Naval, reusability of components or sections is key and therefore, implementing repositories with well evaluated components reduces cost, schedule and risk.

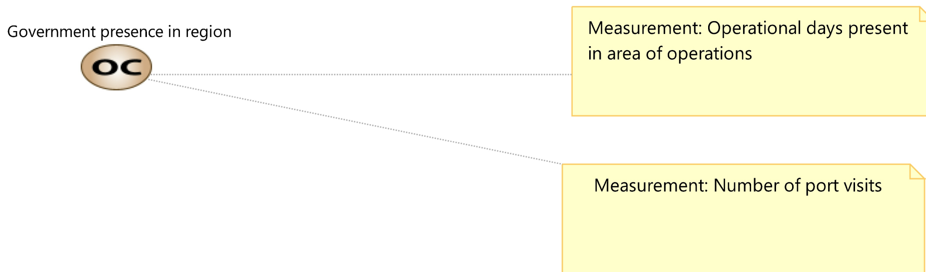


Figure 6.8: Operational Capability Blank relating capabilities with measures of performance

C8 - Planning Assumptions

The last viewpoint from the Concepts-row is concerned with identification and description of assumptions made during the implementation of capabilities. Figure 6.9 is a simplistic overview of such an assumption, determining that the capability ‘Government presence in region’ should be available for at least 300 days per year. The distinction between a planning assumption and performance parameter is meager, however it is fair to say that planning assumptions are hypothetical and performance parameters are feedback of the envisioned product. The customer is concerned with this viewpoint since it is the sole stakeholder demanding certain availability of the vessel during operations.

Figure 6.9: Operational Capability Blank relating capabilities with planning assumptions

L1 - Node Types

The node types used throughout the model are represented in this diagram with primary goal of identifying the nodes relevant for the architecture. As can be seen from figure 6.10, logical nodes are classified in a manner similar to a systems taxonomy, hence the logical node 'Stan Patrol' is decomposed into nine subnodes. For further detailing, the logical node 'Nautical/Communication' is further subdivided into four smaller nodes. The system modeller has accomplished requirements traceability for this layer within the ARCADIA method by relating the requirement 'a ship must provide external communication means' to the lowest logical node 'External communication system'. In the same diagram, a depiction of logical actors is presented, clearly with the simple goal of identifying them within the system. Logical actors serve as the collaborating entities for the solution. An addition to this diagram could be to include the traceability to capabilities, but as earlier explained, this is not straight forward to accomplish in Capella. The stakeholders interested in this viewpoint are the legislative parties, user, shipyard and external subcontractors. The former as a first iteration on what laws to base the design on. A ship has to comply to various different regulatory standards, hence a first indication of these standards is advised, which is only possible by providing the sketch of the solution in the form of logical nodes. Users have to agree to the logical nodes since they have to deal with the solution in the end. Shipyards on the contrary, have to establish the logical nodes in physical aspects and therefore need to address their yard capabilities on the plans a designer may have. External subcontractors, taking part in the process of shaping the design, need to understand their opportunities and may use this diagram to identify conflicting technology. In such cases, the diagram as presented in figure 6.10 is not sufficient and has to be further decomposed. However, a clear distinction should still be in place between this diagram and the subsequent representation of the P1-viewpoint.

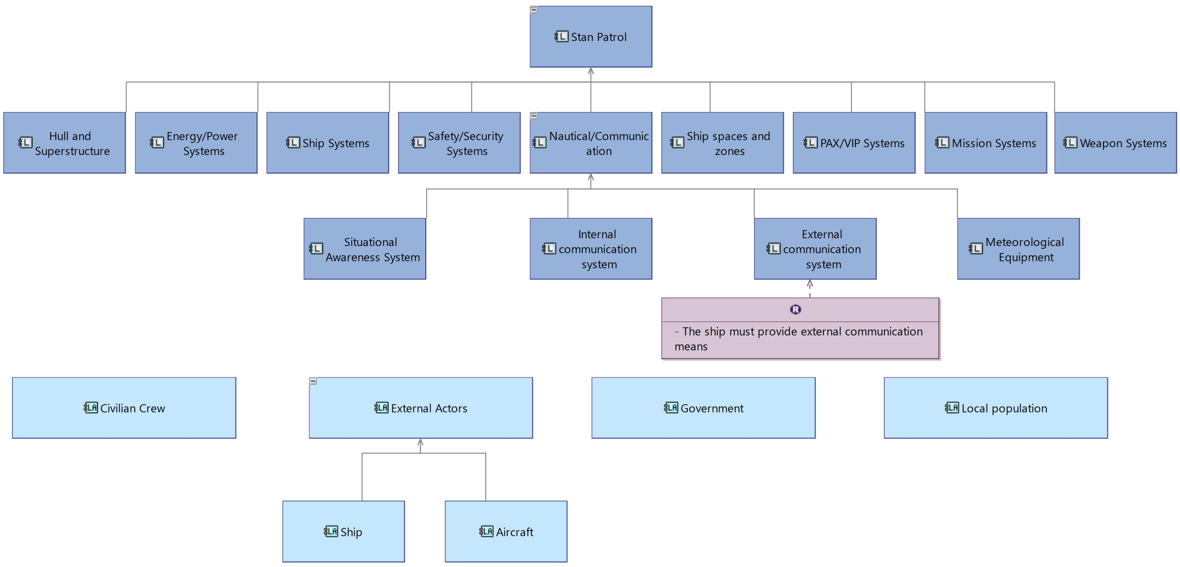


Figure 6.10: Logical Capability Breakdown Diagram identifying all node types

L2 - L3

The bridge between a logical scenario and node interactions has been achieved by the diagram referenced in figure 6.11. For the situation based depiction, a scenario has been modelled to achieve the detection of hazards in the area with corresponding environmental conditions and presence of other surface objects. The blue and green colors of the boxes can be neglected since these correspond to the allocation in the complete Capella model. The main interactions between logical functions are shown in this diagram, idealised by functional exchanges with corresponding labels such as the 'object position' or 'radar reflection'. The main stakeholder involved with this viewpoint is the shipyard, due to the reason of communicating the architecture purpose towards the e.g. client.

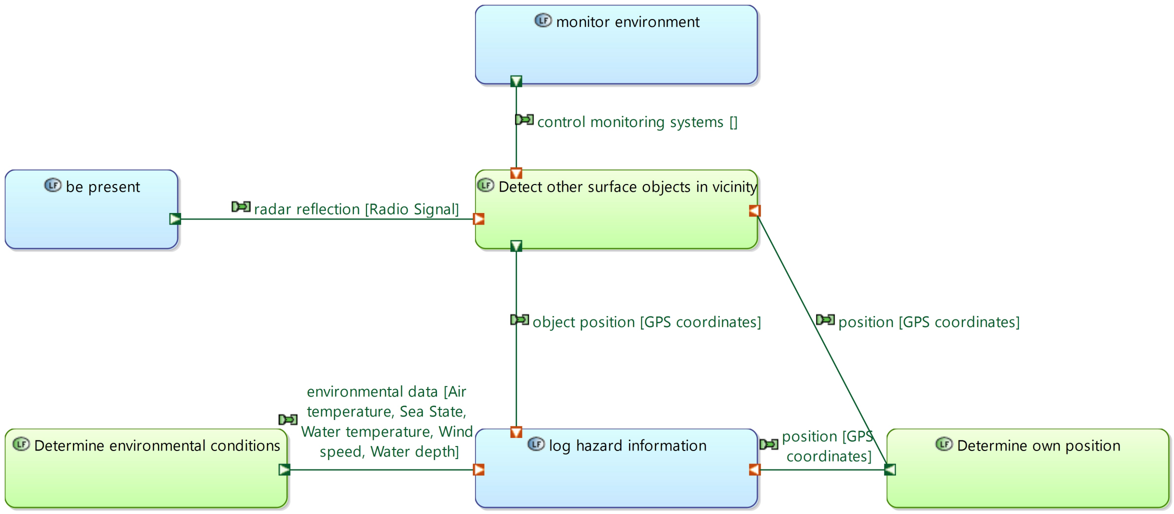


Figure 6.11: Logical Component Breakdown Diagram depicting an operational situation

L4 - Logical Activities

A portion of the logical activities is presented in figure 6.12, objects are similar to the ones used in figure 6.11 but in this case, the objects are associated to nodes such as logical actors and logical components. The dependency of the model on the object 'Detect other surface objects in vicinity' becomes clear given the crossroad of logical processes coming together. The stakeholder of interest for using this diagram is the Plan & Approval department of DAMEN due to the capturing of requirements possible, although not explicitly displayed at the example of figure 6.12. Furthermore, this diagram helps with the determination of business processes and workflows. Therefore, providing this diagram early on in the process of the design of a new vessel will help in defining the concept of operations.

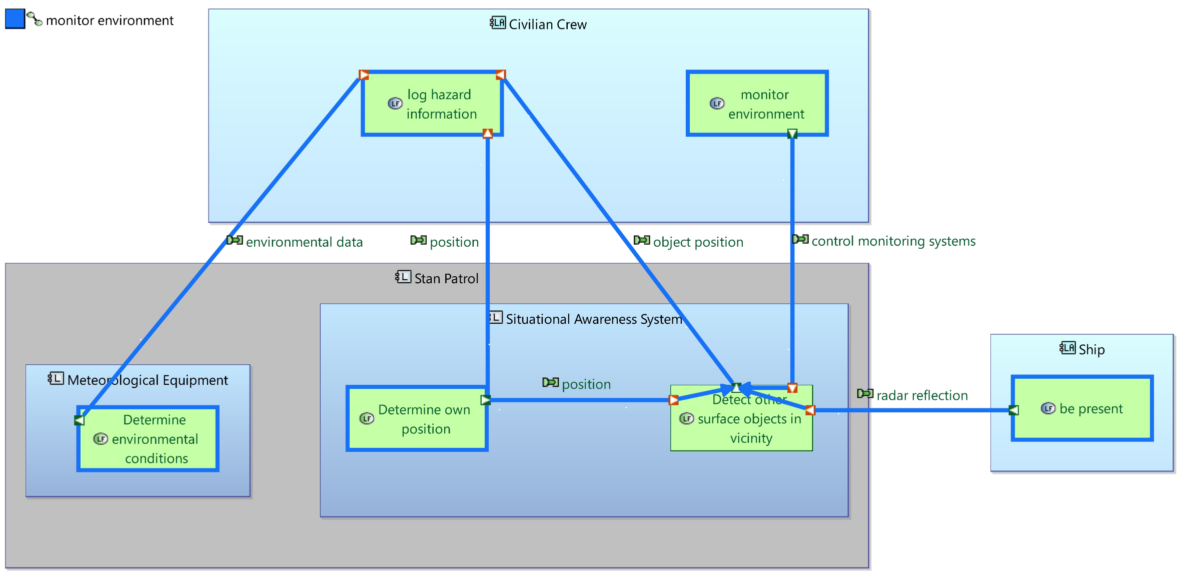


Figure 6.12: Logical Architecture Blank depicting logical activities

L5 - Logical States

As expressed during the proof of concept, nodes may vary in their states during the execution of a scenario. The diagram depicted in figure 6.13 shows the initial and final phase of the transition, affected by a certain identification state. The external trigger is activating the transition, this external trigger is depicted by the ‘Identification State‘ This particular identification state could be in the form of an influence on the operational state. The shipyard is the sole stakeholder showing interest in this diagram since the scenario specification is visualized.

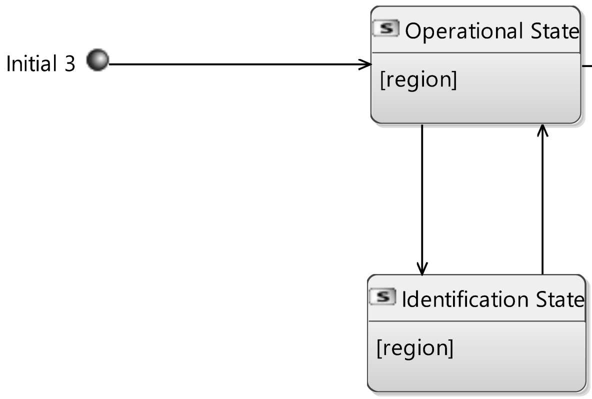


Figure 6.13: Model State Machine diagram presenting a state transition

L6 - Logical Sequence

The chronological sequence of activities is the obtainable result after having worked out the diagram, as depicted in this case study at figure 6.14. Four logical actors are included in the scenario in the top blue boxes, of which the middle two are parts of the systems solution and the outer ones are external. Within the scenario, a loop can be observed for the determination of the position influenced by certain environmental conditions. Furthermore, the same logical functions are used as identified in figure 6.12, only in a top-down chronological order. The shipyard and the Plan & Approval office are the stakeholders of interest for this specific diagram. The latter because of the user requirements specification stemming from this scenario diagram and the former due to the operational planning. Clearly, one could set up an analysis of operational events given the scenarios and adding to this analysis is an behavioural estimation of the process a possible product from this diagram.

L7 - Information Model

The information model is, just as the Logical States diagram depicted in figure 6.13, a fundamental diagram which shows relations between types of information. It helps in defining the organic structure of a model by relating e.g. functions with capabilities, hence an inexperienced stakeholder is able to understand a complicated model by relying on an information model. Figure 6.15 represents a part of the information model, describing the relation of a function belonging to a capability. The model can be extended by providing all data classes and describing the relations between classes.

P1 - Resource Types

The first diagram in the last layer of the NAF grid is the Physical Resource Specifications layer, of which the Resource Types is the primary diagram. It links the identified logical nodes with the technical specifications and is therefore a final step of structuring the information originating from the viewpoints as selected in this case study. In figure 6.16 are the logical nodes given in the upper right corner and the physical actors in the upper left corner. The most useful parts of this diagram are the elements highlighted in yellow. Based on the categorized manner, the execution of a design process is given. Ideally, more technical detail is preferred at this diagram in order to specify the hardware details and interface protocols between components, however for the presented case study, the current level of detail is sufficient. Application in a scale-up version will oblige to include these details. The stakeholders uttermost interested in this viewpoint are the engineering specialists and the system modelers. The

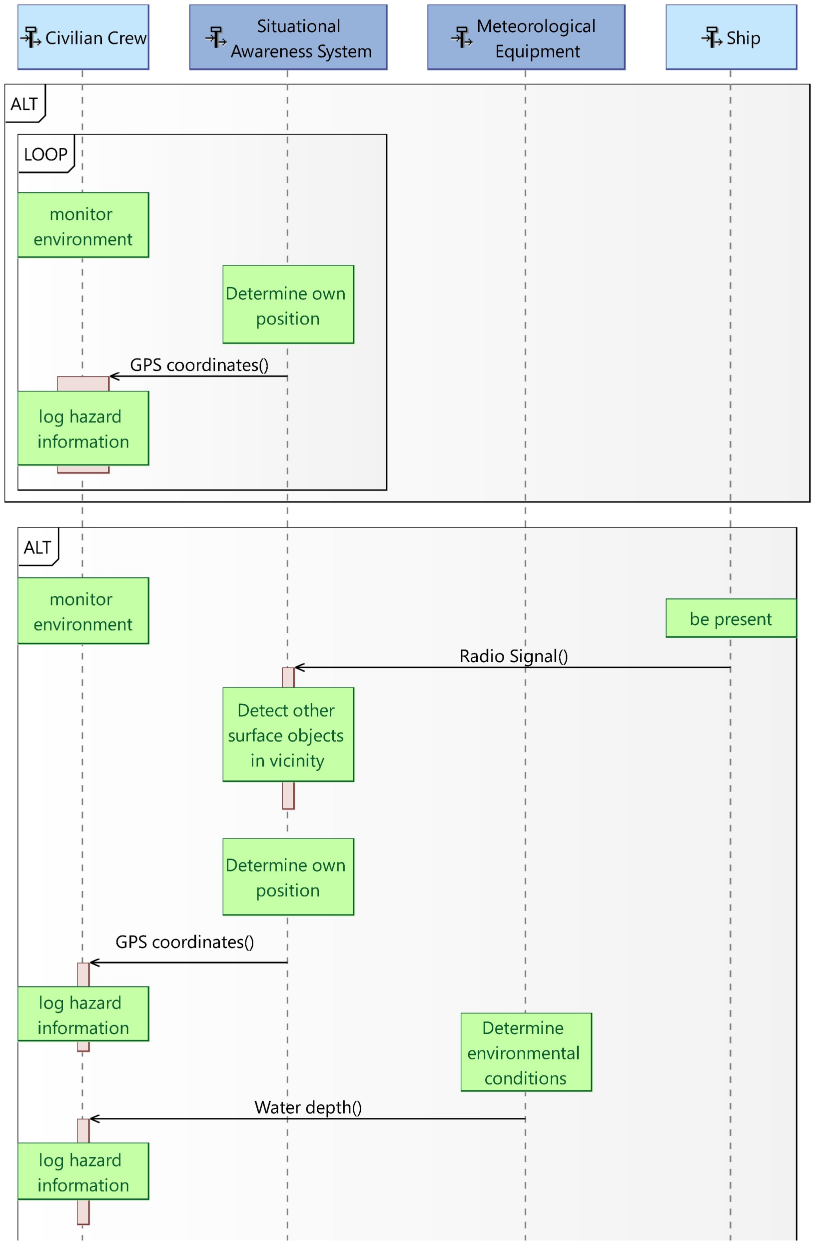


Figure 6.14: Interchange Scenario diagram presenting chronological sequence of activities

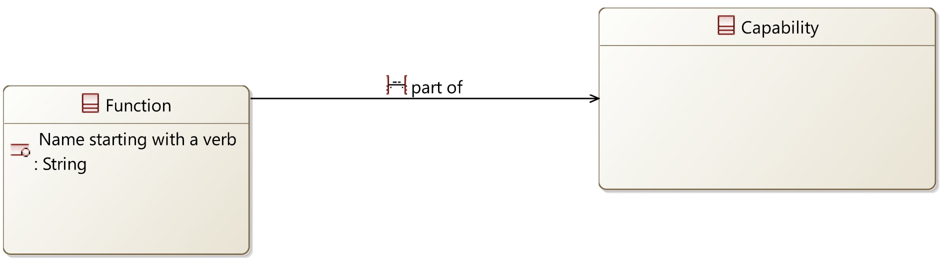


Figure 6.15: Class diagram depicting the relation of a function with respect to a capability

former due to their specialism in detailed components and therefore the specification of interfaces between these components, and the latter because integration of the lowest tier components is essential for the development of requirements and delivery of capabilities.

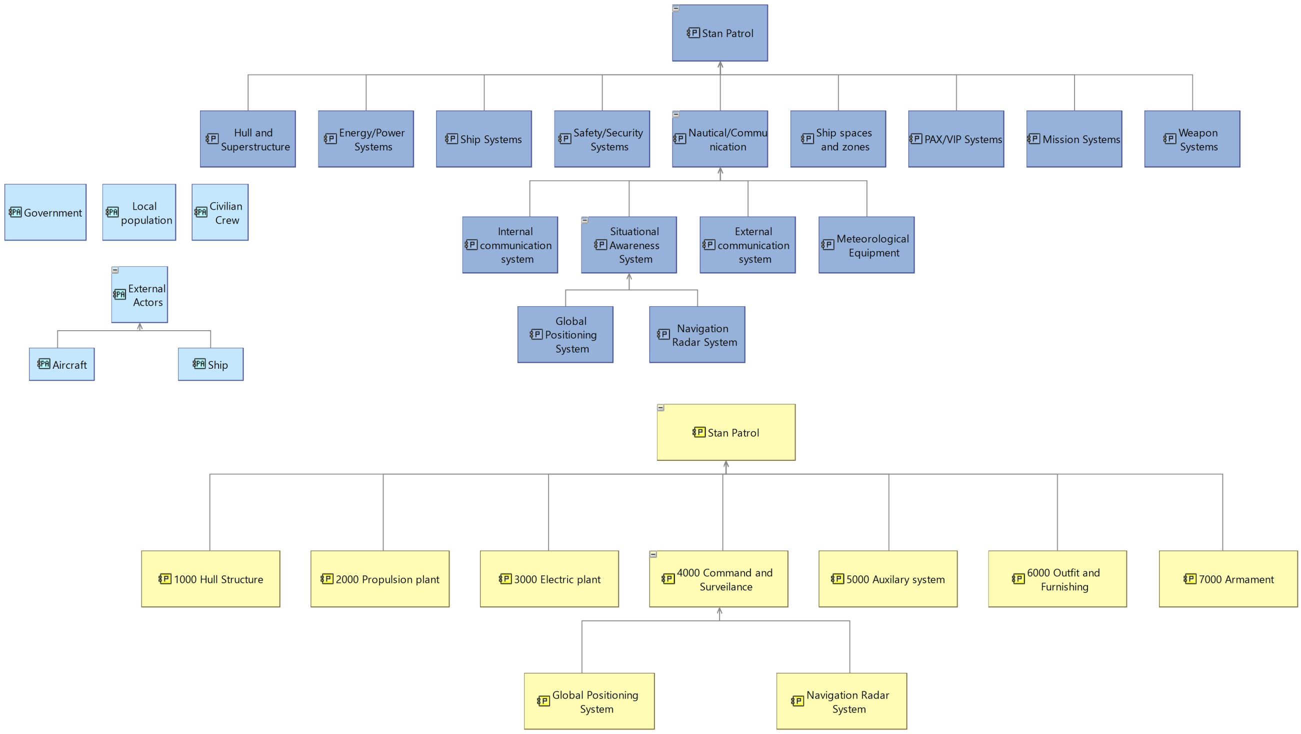


Figure 6.16: Physical Capability Breakdown diagram presenting the various resource types

P2 - Resource Structure

Just as with the logical layer, the interaction between physical nodes is displayed at the P2-viewpoint, as depicted in figure 6.17. The use of a logical actor and logical nodes in this viewpoint is preferred, since this viewpoint has a goal to show how the physical architecture views interact to realize the logical architecture. The interaction has been established by a component exchanges in Capella, illustrating the interaction of the civilian crew with the situational awareness system. The interested stakeholders are numerous, beginning with the external suppliers. This group of stakeholders has to, during this stage of the process, deliver functionalities within components capable of collaborating with other components from other external suppliers. The next group of stakeholder involved is the external subcontractors, for practically the same reason as the external suppliers. System integrators are benefiting from this information as well; all components delivered externally or fabricated in-house have to be integrated in some fashion which is the task of the system integrators. Engineering specialists and the Plan & Approval office have to be interested as well, given the level of detail included in this viewpoint. The figure as depicted in 6.17 is just an example and should be elaborated in more detail to be efficient in the process.

P3 - Resource Connectivity

The details regarding the communication relationships are addressed at this viewpoint, hence more attention is raised on the specification of e.g. communication encryption methods, frequencies or capacities. The diagram depicted in figure 6.18 presents the communication links and protocols between physical actors or physical entities. The stakeholders interested in the details regarding connectivity of resources are the engineering specialists and system modellers. The former due to the technicalities involved in the physical design, heuristic-leading knowledge provides the basis for decision-making in the type of components designed by the engineering specialists. System modelers need to know, besides their interest in the resource structure as defined at the viewpoint discussed at 6.6.3, compatibility issues for certain technical systems.

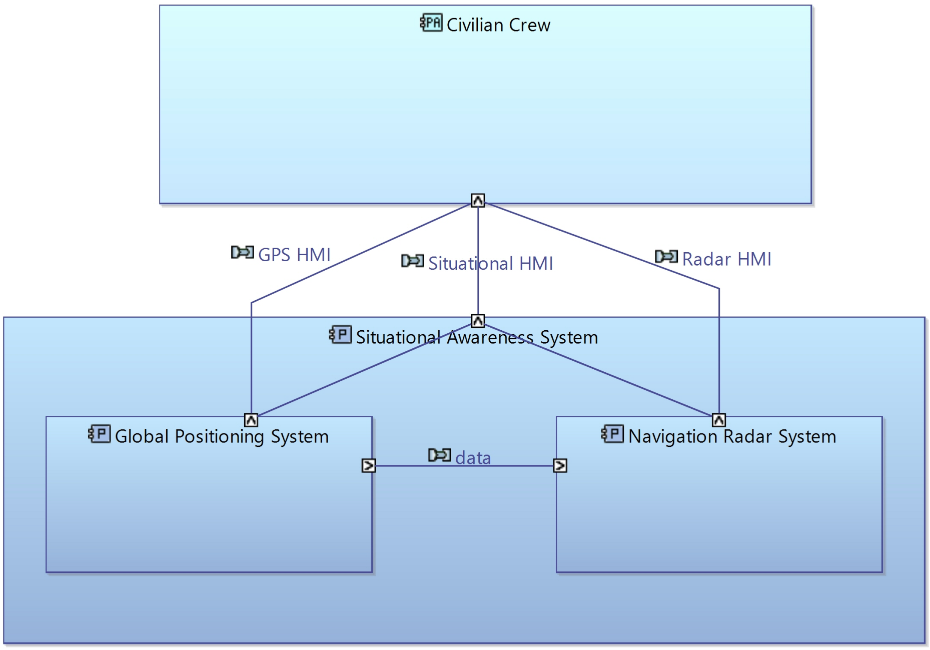


Figure 6.17: Physical Architecture Blank diagram relating physical nodes

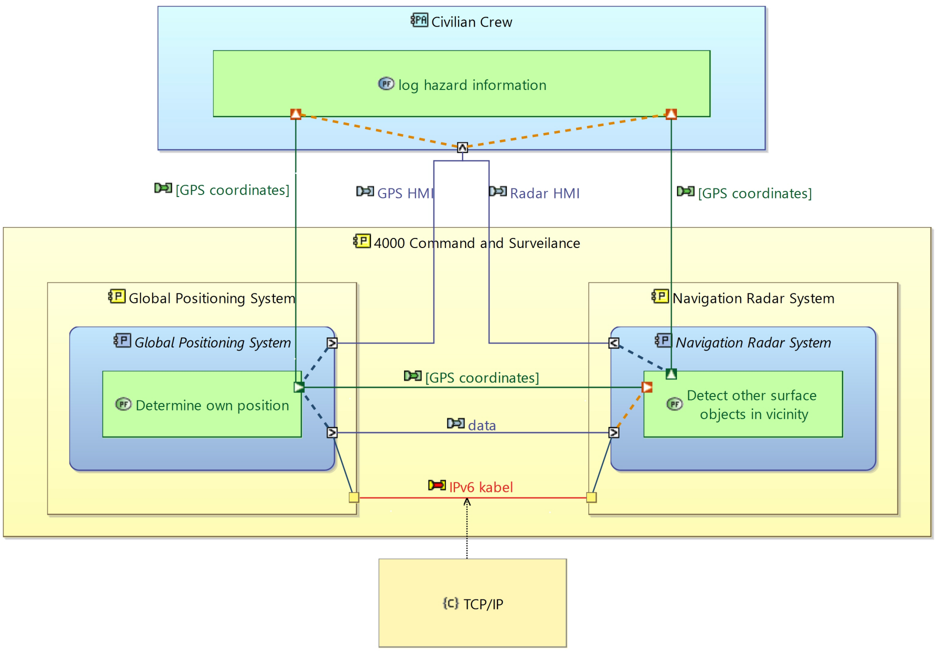


Figure 6.18: Physical Architecture Blank diagram depicting resource connectivity

P4 - Resource Functions

The allocation of functions to resources shall be specified at this viewpoint, as a counterpart to the L4-viewpoint behaving in the same way at the logical layer. The functional connectivity is established by relating the required inputs for resources to functions defined in earlier stages, hence some sort of indirect two-folded link with requirements traceability is maintained. The diagram shown in figure 6.19 relates to the working principles of the Situational Awareness System with respect to the civilian crew, defined as a Human Machine Interface (HMI). The main type of data transferred corresponds to the GPS-coordinates, which are necessary to determine the position of the Stan Patrol with respect to the environment and hence the other objects in the vicinity. The internal functions are given in by the green-colored blocks and due to the Capella software strategy for establishing transfer of data flows, an exchange between the logical actor ‘Civilian crew’ and logical component ‘Situational Awareness System’ in the form of a HMI is modelled. The specific example shown in this diagram is a minor representation of the possibilities, in order to fully benefit from the information in this diagram, all internal functions as identified at the logical analysis should be presented with their corresponding resources. The stakeholders gaining from the information presented in the diagram 6.19 are mainly the system modelers. This particular group of stakeholders is inflicted with the modeling of processes, project or business based, and therefore has to gain knowledge about the interactions between actors and components to increase the productivity in modeling the workflow.

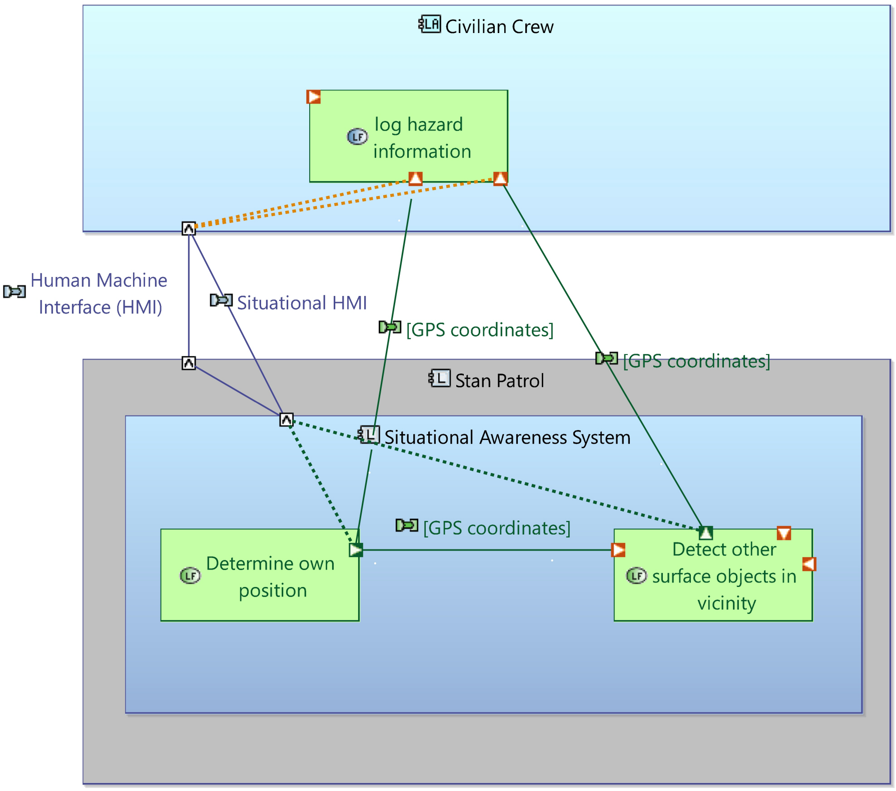


Figure 6.19: Physical Architecture Blank relating functions with actors and entities

6.6.4. Additional viewpoints

The method, as prescribed in chapter 4, states an obligatory evaluation of the concerns addressed by the viewpoints from the model. In the case of the naval stakeholders as addressed in the previous analysis, all concerns have been coupled to the corresponding viewpoints, hence no generation of additional viewpoints is necessary.

6.6.5. Define best suited architecture

The term ‘best suited’ has to be defined for the particular case of the objective of the case study. The selected viewpoints could form many system architectures, each with a purpose for presenting certain sets of information. In order to present the appropriate architecture for the given problem, the purpose is translated into criteria for ‘best suited’ architecture. Since these criteria are varied, stakeholders should be revised to include the correct criteria. An example is the need of a project manager to investigate the relevance of an external supplier to a physical element, hence the traceability from physical to capabilities should be visualized in order to rationalize on the importance. This is especially necessary when changes occur in the final design and complications may arise due to unsatisfied requirements. The criteria stated in section 4.1.11 are utilized, a majority of the viewpoints should be originating from the NAF and requirements are traceable. The suitability of a systems architecture depends on the predetermined drivers. Drivers vary based on the purpose, hence a systems architecture varies given a certain objective. The objective of the systems architecture for this case study is to reveal the relationship between a general set of requirements and the specified component structure. An architecture complying 'the most' to this objective is deemed suitable.

6.6.6. Comprising the systems architecture

Continuing from the definition of the 'best suited' architecture for the intended purpose, a final decision of the systems architecture for the case study is concluded on. The general set of requirements is captured in the OCB's, relating capabilities with each other and with other entities. The system analysis takes care of the external functional decomposition and logical analysis for the internal decomposition. The physical analysis connects the internal functions with corresponding components and enhances the information by providing details regarding e.g. the communication protocols. The systems architecture is, similar to the PoC, an agglomeration of all viewpoints. Beforehand, it was expected to retrieve a variety of diagrams upon which a selection could be made. In the end, the scope of the case study was too limited to focus on separate architectures. A next iteration of the case study, with more detailed information regarding the Stan Patrol, will eventually result in a more disparate collection of diagrams, hence a better fit for the less generic objective can be achieved.

6.7. Conclusion

The results of the case study were evaluated with regards to the similar success criteria as were used during the proof of concept in order to maintain consistency. The concerns identified during the stakeholder analysis are all represented by diagrams during the case study, hence the first success criteria is fully satisfied.

The ease in obtaining diagrams was harder with respect to the proof of concept. One of the main reasons is the increase in stakeholders and accompanied information. However, due to the experience in Capella of members belonging to the system modeling team at DAMEN Naval, the effort to construct the diagrams was less when compared to the efforts endured at the Proof of Concept.

The size of the model representing the case study is significantly more detailed with respect to the Proof of Concept and approaches reality better. The question arises whether further upscaling of the model is realistic since all necessary information is present at the current diagrams, however the restrictions of the case study should not be ignored. These restrictions result in abstractions of reality and cause the model to deviate, hence upscaling is a value-added attribute. Especially the diagrams from the Physical Resource Specifications (P1, P2 and P3) are suitable for upscaling since not all technical choices are included. The capability decompositions in C1 are less suited for upscaling since the information with regards to capabilities is covered. The added value with regards to the current system modeling effort is hard to demonstrate, but given the enthusiasm of the SM-team and their willingness to support this research, it intrinsically indicates added value. It is not possible to quantify the added value at the current stage.

The most important success criteria is the improvement of the traceability of requirements. In the diagrams from the case study, the sole in introducing requirements is the L1-L8 diagram stating that the ship should provide external communication means. Based on this singular requirement, concluding on an improvement of traceability is not possible. However, as proven at the proof of concept, the possibility of inserting requirements in Capella and linking them to elements is present. The reason for missing requirement-elements in the diagrams is due to the normal work processes of the SM-team, which uses another program for requirements management instead of the built-in requirements package at Capella. It was therefore a novelty to include the requirements via this way. The proof of concept used this requirements package which resulted in the abundance of requirements. However, the capabilities presented at C1 are originating from a set of requirements, so without showing the explicit requirements, a certain traceability is achieved by the capabilities.

At last, the success criteria define two statements about the agglomerated viewpoints, which form a systems architecture given certain demands. The information used in the case study was part of the ESSD and the systems architecture is concerned about the ESSD. The needs of stakeholders are all addressed, but an improvement could be made to include a feedback loop by reviewing the stakeholders and reflecting in their needs.

7 Conclusions

The final step is to conclude, discuss and recommend on the findings in order to solve the research objective and improve future investigations. The research gap indicated a hard to establish relationship between stakeholders and requirements, specifically when considering the implementation of systems modeling in the context of MBSE. The tasks conducted during this research with regards to system modeling have taken care of the research gap by developing a systematic method to relate stakeholders with requirements. The objective, as presented in Chapter 1, was to develop and demonstrate a methodology to relate stakeholders with requirements during the early stages of naval ship design. The systematic method has been developed and demonstrated by means of a Proof of Concept (chapter 5) and a Case Study (chapter 6). The results of these demonstrations with regards to the predefined success criteria can be found in the related sections. This chapter firstly aims to discuss the results of the method, proof of concept and case study, followed by an answer to each of the research questions as stated at section 1.4. This section will furthermore evaluate the predetermined success criteria for each of the cases. Lastly, the influence on the business-case of DAMEN Naval will be explained and the global impact by means of a societal-ethical analysis is emphasized.

7.1. Discussion

This section will evaluate the predetermined success criteria for each of the cases and discusses the designed method. Furthermore, the influence on the business-case of Damen Naval will be explained and lastly the global impact by means of a societal-ethical analysis is emphasized

7.1.1. Success criteria

The predetermined success criteria, which have been used at the Proof of Concept and Case Study, have to be evaluated in order to define certain improvements on the process. A reflection on the results allows to present feedback on these criteria. From the list of success criteria, as presented in section 5.2, two are relevant to be discussed in this section since the other criteria can 100% be fulfilled or not.

The first one is about the upscaling of diagrams which has to be taken into account. Assessing the ability of a model to evolve effortless over time is not a simple task and could potentially be enhanced by performance parameters. Hence, quantitatively guiding the change of diagrams assures a similar or increased quality of the model. The reason for enhancing the evolvability of a model is due to the information growth in the early stages of a project. For example, diagrams constructed at the beginning should be supplemented with the additional information, hence resulting in increasing sizes of diagrams. The performance parameters such as Measures of Performance (MoP) or Measures of Effectiveness (MoE) have been suppressed during this research, as will be highlighted in the subsequent section concerning future work.

The second criteria to be discussed is the improvement of requirements traceability, one of the main advantages of system modeling in the context of MBSE. Assessing the diagrams on requirements traceability is easier with respect to the upscaling-criteria, but is highly influenced by the constructor of diagrams. The differences with the Proof of Concept and Case Study expose this indifference, the former has implemented more requirements from the requirements-package whereas the latter was less focused on inserting requirements. Preventing the accidental absence of requirements in the diagrams can be realised by demanding visibility of requirements in all four layers (operational, system, functional and physical), hence this success-criteria could be rewritten in the form of: Requirements shall be implemented in a minimal of one diagram per specific layer (operational, system, logic, physical).

7.1.2. Discussion of the method

The method performs well when all concerns can be addressed from the NAF, however one of the pitfalls is the creation of additional concerns not addressed by the NAF. The generic applicability of the NAF will prevent the creation of additional viewpoints in most cases. The guidelines, as stated in section 4.1.9, help to cope with the creative process of constructing viewpoints. It is acknowledged that this creativity could be subdued by rigid criteria. Therefore, as will be presented in section 8.1, the need to investigate older architectural frameworks will be discussed.

Furthermore, the inclusion of an iterative process in the method does resolve the issue when using the sequential NAF in relation to a design process. However, more emphasis should be given on the adaptability of the method with regards to shipbuilding processes as used at DAMEN Naval.

The method in the current form assumes a permanent set of stakeholders, however, in practice, this set of stakeholders is subject to change. Incorporating these changes results in identifying the diagrams to be altered, constructing new diagrams based on different concerns and combine these with the existing diagrams to generate the systems architecture.

At last, lacking in the current developed method is the identification of responsibilities across the company to execute the various blocks numbered 1 up and to 12. These blocks could be distributed over the various design teams in order to establish a mutual understanding of the tasks and preventing expensive rework. Also, further implementation plans could be arranged. This has not been addressed in this research as such implementation is very much dependent on the actual organisational and project structure at DAMEN Naval.

7.1.3. Proof of Concept

The limitations of the proof of concept include the amount of stakeholders taken into account and ability to not fully relate all requirements in the diagrams. The choice for a small set of stakeholders, comprising of a layout specialist and operational analyst, has been taken deliberately in order to focus on the translation of the NAF to Capella. This limitation has been resolved during the Case Study.

The second limitation is the inability to relate all extracted requirements, as presented in section 5.5.2. Demonstrating the traceability of requirements is not about inserting all requirements but about proving a certain recurrence of a requirement over all diagrams, hence it is sufficient to limit on one or a small set of requirements. However, the characteristics of certain requirements differ and it is therefore advised to improve this proof by including all requirements. The diagrams have been constructed according to the capabilities of Capella, hence the advised representation according to the NAF has been ignored in most of the cases and diagrams were constructed to comply to the general needs of a viewpoint. This is not a shortcoming of the tool but rather the interpretation of the NAF with respect to Capella. Therefore, a recommendation is to investigate the implementation of other proposed representations, e.g. in a tabular form , with regards to the functionalities of Capella. However, the use of dataflow- and breakdown diagrams resulted in uniformity across all diagrams, which eases the comprehension of stakeholders and ensures a certain technical benchmark to develop systems architectures.

At last, the Service-row of viewpoints has been omitted since the start of the construction of diagrams and no efforts have been undertaken to investigate the necessity. It was advised to start without the Service-row in order to enhance on understanding the NAF and reducing complexity. The usability of this Service-row could be investigated in further research.

7.1.4. Case Study

The Case Study has been executed with a set of 12 stakeholders which have been rated according to four attributes during the prioritization. The first limitation results from this prioritization, presented in table 6.1. The range of scores originating from five stakeholders is between 10 and 12, which does rise questions regarding the quality of the ranking and makes prioritization impossible.

Furthermore, the representation of a selection of diagrams could be more tailored to the needs of the respective stakeholders, especially the diagrams in the capability-row. Options are to add the responsible actors in these diagrams. The difference with the diagrams constructed at the Proof of Concept and Case Study originates from the executed party, the PoC has been constructed by the writer of this thesis while the diagrams from the Case Study were constructed by members of the system modeling team at DAMEN Naval. The more complicated and technically detailed diagrams, such as the one depicted in figure 6.18, are a result of the different executions. The transfer of knowledge could have been improved by a more detailed handover of requested diagrams, but the writer had chosen to rely on the experience of the system modeling team members. Another lacking factor was the planning of the research, which resulted a time-critical performance of the generation of diagrams in Capella by the system modeling team members. It is therefore advisable to iterate this process once more by including all 47 viewpoints from the NAF.

The classification of requirements, according to the OFP-principle, was a choice made during this research. The choice originated from the ARCADIA-method which works with a similar distinction. However, other classifications such as a general functional versus non-functional classification, or more detailed classification between e.g. missions and capabilities could work as well, but has to be investigated. Depending on the project and the involved team, a classification should be chosen which suits the skills and experience of the design team in order to prevent delays. The more simplistic distinction between functional and non-functional could save time for smaller projects, but with projects consisting of thousands of requirements, detailed classification are preferred such as the OFP-classification as used during this research.

At last, the identified stakeholders are process-oriented, while a selection of product-oriented stakeholders could be meaningful as well. It is beneficial to scope on product-specific stakeholders, such as the crew or captain, during the e.g. later stages of ship design when they have adopted their specific roles within the vessel and daily tasks are known. But including the product-oriented stakeholders during the ESSD could be beneficial for the process as well, further iterations of this research should prove their value within the ESSD. As this thesis is concerned about the early stages of ship design, the process itself is key while during the, for example, testing stages, product-oriented stakeholders become more relevant while some of the early stakeholders will be important for validation.

7.2. Answers to research questions

The research questions, as stated in Chapter 1, will be answered in this section.

7.2.1. "What is the problem when relating stakeholders with requirements in the ESSD?"

The main problem preventing the establishment of the relationship between stakeholders and requirements is the complexity and evolving character of information needs. The complexity of information makes it hard to define the needs for a method in order to relate these two disciplines, while the evolving character represents the dynamic environment of the naval domain, as described in section 2.1. The problem has arisen, in part, due to the transition towards MBSE and the corresponding rise of system modeling in naval ship design, hence a structured approach is necessary to cope with these fundamental disciplines.

7.2.2. "How is the NATO Architectural Framework able to relate stakeholders with requirements?"

The NAF is an architecture framework which supports the systematic decomposition of a project or enterprise by means of viewpoints. These viewpoints form a fit for purpose systems architecture. The NAF aids in forming the relation between stakeholder and requirements by the decomposition of an organization into 47 viewpoints, divided over five levels of abstraction. These views are assembled on 'the grid' in which each viewpoint has a different function in terms of stakeholder usage, as described in section 3.2. Based on a set of stakeholders, and after having conducted a stakeholder analysis to grasp the concerns, viewpoints can be selected. Each viewpoint specifies the obligatory and voluntary elements to be included in the representation. Due to the variable requirements, interpretations of viewpoints differ greatly and it is therefore necessary that this thesis made efforts in translating the NAF-viewpoints to Capella, which is executed in Chapters 4 and 5.

7.2.3. "What are the criteria for the development of a method suitable of relating stakeholders with requirements?"

The development of the method is constrained by the NAF and therefore should fit the Architecture Development Methodology (ADM) as explained in the NAF at section 3.1. The ADM is a method embedded within the NAF to construct systems architectures and has a highly iterative character, because the 8 steps have to be revised once a subsequent step is finished. Therefore the method in this thesis should have an iterative loop as well. However, addressing the ADM to system modeling processes at DAMEN Naval requires a new approach which is the reason for the design of a new method. Furthermore, the method should be generic and should not exclude any stakeholders based on their concerns. Given the adaption to the system modeling processes within DAMEN Naval, the implementation of the method into common practices is assured.. Therefore the method should be compatible with the Capella-software. The last criteria for the method is to be reusable and applicable during each phase (e.g. concept, basic, detailed, production, testing, validation) of a project, because it is not mandatory to start with the method at the start of a project, although this is strongly advised. However the focus of this thesis is scoped on the ESSD, because this is the phase where currently most value can be gained by means of requirements management. For a detailed explanation of the method, the reader is referred to Chapter 4.

7.2.4. "How to demonstrate if the method is capable of establishing the required relationship?"

Demonstration of the method has occurred in a two-fold process, the first step was to apply the method on a limited set of requirements during the proof of concept in Chapter 5. The second step was to apply the method on a more realistic set of design parameters during the case study, based on a Stan Patrol vessel in Chapter 6. The results of these two tests have revealed the preferred relationship between stakeholders and requirements as each concern of a stakeholder is addressed by a viewpoint. The viewpoints, originated from the NAF, are the tools to decompose a Capella project model into subsets of information, tailored for the information needs of individual stakeholders. Therefore, by selecting and constructing the appropriate viewpoints based on a stakeholder analysis, a direct link between the requirements in Capella and the stakeholders at the viewpoints has been achieved. Furthermore, viewpoints frame the context of the problem, hence the combination of the direct link and representation of the context establishes the required relationship.

7.3. DAMEN Naval business-case impact

The results of this research, a method to relate stakeholders with requirements, is part of a number of activities with in DAMEN Naval focused on the development of a system modeling capacity. To support the contribution of this work to that process, this section will elaborate on the benefits of the results for DAMEN Naval by improving the system modeling processes.

7.3.1. Cost reduction

The major advantage of systems modeling, which is in the end decisive during budgeted projects, are non-material cost reductions. By means of process improvements, these cost savings could be achieved. Systems modeling helps to reduce the cost by earlier detection of design flaws, noticing of unaddressed requirements and provision of relevant fit-for-purpose information to all stakeholders. The results of this thesis help in the improvement of the current system modeling processes by streamlining stakeholder-oriented activities, these mentioned savings are therefore a partial beneficial consequence of this research. However, the risks of devoting more time on research into stakeholder's needs and classifying requirements could contribute to higher expenditures.

The set of requirements will change over the lifespan of a project, especially given that the process of ship design in the naval domain is extensive in time when compared to other ship design processes. This research will help with the improvement of change management by a quick understanding of the involved stakeholders, the dialogue between stakeholders shall be initiated right after any changes have been identified and therefore reducing the impact on the project.

7.3.2. Risk reduction

The idea of modeling systems before construction instead of the other way around is to reduce the risks involved within the systems itself and between the interfaces of related systems. This method contributes to a integrated approach by a tighter coupling of stakeholders into the process, hence risks involving dealing with these stakeholders are mitigated. The efforts on system modeling, however time-consuming these could be in the earlier stages, will be beneficial by identification of incompatible systems, missing information or conflicting requirements. The mitigation of these risks shall be developed and executed before major expenditures of a project are being made.

Furthermore, the prevention of miscommunication, which is a major cause of risks during projects, is improved by the introduction of the method presented in this thesis. Achieving a common understanding of the requirements between all involved stakeholders is essential and beneficial for risk reduction. At last, by conducting systems modeling and using the proposed method for relating stakeholders with requirements, exploration of alternative solutions is promoted. As the method suggests to construct different architectures from different viewpoints, the system modeling processes will benefit to subject their models to alternative solutions.

7.4. Societal-ethical impact

Since the research includes major stakeholders, the benefits to the most important ones will be listed, followed by the impact on society and the environment. But before discussing the influence on stakeholders, a comment on the impact of this research in general has to be made. The research was focused on naval vessels, objects with a high degree of ethical disputes. Is it a defense system, or a way of invading countries and claiming territory? Therefore, one has to put the impact of naval vessels versus the impact on stakeholder by this method into perspective and consider the relative importance of this research when trying to deal with global ethical dilemmas. However, stakeholders will benefit from the implementation of this method by a smoother work process, faster transactions to and from the shipyard and clarity in the most up-to-date status of information.

The workload of system modelers will be reduced by preventing rework and improving the communication between stakeholders. A reduction of the workload will benefit the system modelers and translates into a better working environment.

Looking even further outside the boundaries of the existing pool of stakeholders, by increasing the efficiency of the design process at the naval domain, on-time delivery of naval vessels saves costs. Ultimately, taxpayers will pay less for their security.

The influence on the environment is assumed to be reduced by improving the efficiency of system modeling, processes will reduce in time, hence less computers will run in order to support the projects. However, the computational power gained by increasing the model size is unknown and could eventually balance the gains in energy reduction.

8
Recommendations and evaluation

8.1. Further research

This last section will elaborate on the recommendations for further research, as is noted during the process. Three points are highlighted which are deemed suitable as valuable subsequent steps in improving the current work.

8.1.1. Quantitative assessment of architecture

Quantifying the obtained systems architecture has been done during this research by predefined success criteria. Although these criteria fulfill the current state of research, assessing the architecture and selecting a best suited type requires indicators which are easier to compare. Therefore, it is suggested to to investigate the applicability of key performance indicators (KPI's) on the construction and selection of architectures.

8.1.2. Combination of architectural frameworks

As mentioned in section 2.4.4, the most recent developed architectural framework has been used. However, in the case of addressing stakeholder concerns which are not included in the viewpoints from the NAF, a combination of various architectural frameworks should be investigated. The method, as elaborated in chapter 4, currently prescribes the construction of additional viewpoint by guidelines. An investigation into the applicability of viewpoints from older architectural frameworks, which are designed with a different goal, may be beneficial for the construction of additional viewpoints. The guidelines are hereby eliminated and a more structured manner of the creation of additional viewpoints can be found.

8.1.3. Automatic modeling by Python

Since a year, Capella has published an add-on for their tool under the name 'Python4Capella'. The add-on achieves to extract, import and update information from Capella models automatically by using Python as programming tool. The entire system modeling process can not be automated, but tasks such as scenario modeling and exploring alternatives could be automated in Python. Moreover, recurring tasks can be easily automated hence saving precious time during the early stages of naval ship design. Further research should investigate the consequences of automatic modeling on the system modeling processes at DAMEN Naval.

8.2. Perspective on the future

Looking back on the last decades of developments in ship design processes and observing the swift transition from the iterative spiral by Evans up and to the current system engineering practices, it is only fair to believe in an even as swift transition towards Model Based Systems Engineering.

The practicalities of MBSE will influence all stakeholders in naval ship design processes but, after having solved the numerous challenges, an effective and collaborative environment is created which enhances the work of the naval architect. The integration of advanced technological systems, which become more interrelated due to their high power consuming characteristics, will be less of a challenge and the risks involved shall be mitigated sooner.

Looking even further into the future, assuming that MBSE is implemented within 15 years, autonomous sailing for naval purposes can be examined more thoroughly and the effects and consequences of sailing with less crew onboard are clear. The role of a naval architect in will be in the form of a digital systems integrator, overseeing the process of the integration of various models and understanding the requirements for autonomous vessels. The repositories and libraries accumulated over the years by conducting system modeling processes will help in the construction of modular designs, hence in the near future the majority of vessels will be modular with uniform compartments.

8.3. Evaluation

Now the year has passed and research comes to an end, a reflection on the subject, process and performance will be given.

8.3.1. Reflection on subject

At the initial phase of the research, all efforts were centered around understanding the current MBSE practices in various industries. It was intriguing for me to learn about the advantages and challenges of turning towards MBSE, and learning about the ongoing initiatives in e.g. the aerospace industry, where MBSE has been implemented for the last 15 years, was valuable. However, connecting the ongoing efforts with the current research was hard and looking back, not necessary for the specific objective of relating stakeholders with requirements. The subject itself is abstract, while knowing about the other current and historic design approaches, grasping the idea of MBSE and trying to imagine how to implement such a new approach within a company was daunting. Furthermore, the last part of the method indicates the construction of system architectures. After reading a lot about the theories and differences of system architectures, it remains hard to conclude on a suited architecture and this is, therefore, one of the lacking parts of this thesis. However, by conducting a test with more requirements and stakeholders, the construction of a systems architecture will become more visible and easier.

8.3.2. Reflection on process

The start of this research was characterized by an infinite iterative spiral, not fully understanding the need and up and foremost not able to understand the position of systems modeling within DAMEN Naval. Straight from the beginning, it was clear Capella had to be used, days were spent by learning the program, attending a 3-day workshop and practising on tutorials. However, looking back, it was more valuable to focus on getting the problem clear and discussing with employees from DAMEN Naval about their current efforts. After three months, the backbone of the research became structured and work was centered towards systems architectures and architecture frameworks.

The high degree of abstractness of the problem resulted in time consuming efforts and losing focus at the initial stages and halfway during the research. Maintaining a helicopter-view was sometimes hard, but due to good efforts of the supervisors, I was constantly pushed back in track.

8.3.3. Reflection on performance

As motivated as I was at the start of the project in November, I could not have imagined feeling down and desperate during the spring of 2022. The thesis was constantly playing mindgames and relaxing was not possible. This influenced the performance and motivation which resulted in delays, lack of communication between the supervisors and ambition-less times. I would advise everyone starting such an abstract subject with the following tip: go on holiday at least once every 3 months! Furthermore, perhaps the most beneficial aspect of my performance during the project was letting go of perfectionism, delays at handing in status updates resulted in less feedback than desired. Starting the feedback-loop earlier in the process could have helped me in improving the performance and at the end, result of the thesis.

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