Modular Platform

Towards a Product Family for a Series of Navy Support Vessels

R. J. Smit

TU Delft

DAMEN

Modular Platform

Towards a Product Family for a Series of Navy Support Vessels

by

R. J. Smit

to obtain the degree of Master of Science
at the Delft University of Technology,
to be defended publicly on Monday December 9, 2019 at 02:00 PM.

Student number:	4496078	
Report number:	SDPO.19.035.m	
Project duration:	March 11, 2019 – December 9, 2019	
Thesis committee:	Dr. A. A. Kana,	Delft University of Technology
	Prof. ir. J. J. Hopman,	Delft University of Technology
	Ir. M. B. Duinkerken,	Delft University of Technology
	Ir. J. Broekhuijsen,	Damen Schelde Naval Shipbuilding

The cover partially illustrates the design's problem domain. The picture was made by a crewmember of one of the navy support vessels of the Royal Netherlands Navy. Image from Facebook.

TU Delft Delft University of Technology

DAMEN

Glossary

To establish a common language and terminology with regard to modular product architecture design and production, a list of terms is defined.

- **System** - A collection of components which co-operate in an organised way to achieve a desired result [7]. In other words, a multiplicity of interacting components that collectively perform (a) significant function(s) [32].
- **Component** - In engineering this term refers to machine parts, software and humans [7].
- **Modularity** - The degree to which a system is made up of relatively independent but interlocking components or parts [45].
- **Modularisation** - The process of subdividing a product into a collection of distinct modules or building blocks with well-defined interfaces [19].
- **Module** - A collection of physical hardware and/or software components that build a dedicated function within the system. To be considered as a module, it has to fulfil a function. For example, a refrigerator in your home is a product, yet when built into an airplane it can be considered as a module, because it works by itself and yet is built into and part of another, larger product. [19]
- **Building Block** - A collection of physical hardware and/or software components that cannot be related to a certain function. A set of building blocks may build a module. Very often modularisation is illustrated with LEGO. In this context a LEGO bricks would be a building block and not a module. This is because the LEGO brick alone does not carry any functionality, but is has standardised interfaces. Many LEGO brick could however be composed to a module. Continuing the refrigerator example, the many parts that are needed to build a freezer could be considered building blocks. [19]
- **Modular Product** - A combination of building blocks, modules and if present, a core platform [19].
- **Core Platform** - Modules, building blocks and/or standardised components that are identical across the entire product family form the core platform [19].
- **Product Platform** - Sets of components, technologies, subsystems, processes, and interfaces that form a structure to develop a number of products to maximise commonality and minimise individual performance deviations [33]. The term product platform can be broken down into different types, by means of its architectural platform approach: modular platform, scalable platform, integral platform [19].
  - **Modular Platform** - Enabling product differentiation through adding, removing and/or substituting different modules or building blocks [19].
  - **Scalable Platform** - Variants of a product can be produced through shrinkage or extension of scalable variables. Scalable platforms are like identical copies of an original, just at a different scale [19].
  - **Integral Platform** - A technology that builds a base for products, technologies or processes. In other words, these are essential technologies that are reused within the product family [19].
- **Strategy** - The application of a high level plan to realise one or more goals. (In product development particularly, there is an inherent relationship between strategy and tactics, as tactics is the execution and assessment of the outcome of that plan.) [25]

Abstract

Because of increasing competition in the global shipbuilding market, the demand for ships with higher quality, lower lifecycle costs and shorter delivery lead time is growing. Advanced manufacturing technologies can partially address these challenges, but advanced design technologies are critical, since most design and manufacturing properties of a ship are influenced by the design decisions that are made in the early design stages. This makes a modular architecture platform approach very suitable. Moreover, it provides multiple opportunities to various stakeholders to benefit from. To clarify, standardisation means the use of identical components across multiple products and modularity means combining standardised components to create modules and/or building blocks.

This explains why Damen Schelde Naval Shipbuilding (DSNS) wanted to explore the appropriateness of product families including wide modularity and cross family modularisation for a series of navy support vessels of the Royal Netherlands Navy (RNLN). As a consequence, the primary research question of this study is: '*What is the optimal modular platform-based product development strategy for the replacement of a series of support vessels of the RNLN, viewed from a DSNS perspective?*'. In short, the vessels concerned perform hydrographic survey, logistic support, submarine support and marine training.

To identify the optimal modular design process for this case, a literature on modular platforms was evaluated, after which an existing modularity method, called Modular Function Deployment, was expanded by Systems Engineering design disciplines/theories. Hereby, key aspects of platforming and modularisation principles were taken into account. To summarise, the composed methods include:

- Concept design from a functional perspective.
- Various conceptual design domains for clarification.
- Ship's commonality in all design domains.
- Multi-platform principles that distinct a core platform, specific configurations and market specific modules.
- Modularity drivers that represent various stakeholder interests and the entire lifecycle of a ship. These are used to identify potential modules.

Subsequently, to explore the appropriateness of the composed method, a case study was carried out. To conclude, the case study shows the suitability of the method, because it is able to visualise, manage and clarify the conceptual development of this complex design. In addition, the case study carried out, serves as a guideline and indicates which aspects must have close attention, because of the encountered complications. In short, these are:

- Compiling a platform development team, including specialists, for the development of a more accurate and complete design.
- Expanding the hierarchical functional decomposition and the use of a bottom-up approach perspective. This helps to determine the functional level of the technical solutions to be modularised/standardised.
- Increasing the completeness and accuracy of the requirement statements. Aspects to be considered are performances, quantities and operational conditions. Thus, the operational profiles are very important.
- Identifying the optimal replacement strategy for the RNLN's fleet of navy support vessels. For example, a one-to-one ship replacement.

Preface

After finalising my bachelor's degree at the Maritime Institute 'De Ruyter' and receiving my Certificate of Competence for being an onboard maritime officer, I wanted to continue studying despite the pleasant experiences I had as a seafarer. Therefore, during my period as a second officer I decided to register myself for the bridging program for MSc Marine Technology, at Delft University of Technology. This is a key decision in my career that I have never regretted.

The subject of this research is in line with my background and gave me opportunities for personal growth. First of all, I am proud of the results, but more important for me is the process towards it. This was very satisfying, because it helped me to understand, manage and visualise a complex design. This kept me motivated and enthusiastic during the entire thesis project.

The research would not have been possible without the involvement and support of many people. In particular I would like to thank my supervisor from Damen Schelde Naval Shipbuilding, Ir. J. Broekhuijsen and my supervisor from Delft University of Technology, Dr. A.A. Kana. They guided me very well throughout the process and inspired me to make the most out of this study. The willingness to help, think along and discuss the subject is very appreciated. Furthermore, I would like to thank Prof. ir. J.J. Hopman for his useful advises during the meetings we had and to be chairman of my graduation committee. Also, I would like to thank Ir. M.B. Duinkerken for his willingness to be part of this and for assessing my work.

Last but not least, I would like to thank my family and friends for their endless support, help and love where possible. Special thanks to my father and Christine, who gave me great hospitality during my stays in Vlissingen.

I hope you will enjoy reading this report.

R. J. Smit
Delft, November 2019

Contents

List of Figures

List of Tables

List of Abbreviations, Acronyms & Symbols

Δ_{max}	Maximum Displacement
AIS	Automatic Identification System
AOR	Amphibious Operations Room
ARPA	Automatic Radar Plotting Aid
ATO	Assemble To Order
BMT	British Maritime Technology
BOA	Breadth Overall
CAPEX	Capital Expenditures
DE	Diesel Electric
DMO	Defence Materiel Organisation
DPM	Design Property Matrix
DSE	Design Space Exploration
DSGo	Damen Shipyards Group, Gorinchem
DSM	Design Structure Matrix
DSNS	Damen Schelde Naval Shipbuilding, Vlissingen
DTC	Design To Cost
DTF	Design To Function
DTV	Design To Value
D	Diesel
ECDIS	Electronic Chart Display Information System
EEBD	Emergency Escape Breathing Device
ETO	Engineer To Order
FRISC	Fast Raiding, Interception and Special Forces Craft
GPS	Global Positioning System
HM&E	Hull, Mechanical & Electrical
HOQ	House Of Quality
HVAC	Heating, Ventilation and Air Conditioning
Id.	Identifier
IMO	International Maritime Organization

LCC Lifecycle Cost

LCS Littoral Combat Ship

LOA Length Overall

MARPOL International Convention for the Prevention of Pollution from Ships

MAS Modular Adaptable Ship

MDS Modular Design Strategy

MD Modularity Driver

MEKO Mehrzweck-Kombination

MFD Modular Function Deployment

MIM Module Indication Matrix

MOPCO Modular Platform Concept

MTO Make To Order

MTS Make To Stock

M Mass

NAVAIS New, Advanced and Value-added Innovative Ships

OPEX Operational Expenditures

OSV Offshore Support Vessel

PMM Product Management Map

QFD Quality Function Deployment

RFLP Requirement-Functional-Logical-Physical

RHIB Rigid Hull Inflatable Boat

RNLN Royal Netherlands Navy

ROI Return On Investment

ROV Remotely Operated Vehicle

SE Systems Engineering

SIGMA Ship Integrated Geometrical Modularity Approach

SOLAS International Convention for the Safety of Life at Sea

TLR Technical Readiness Level

T Draught

URN Underwater Radiated Noise

$\mathbf{v}_{eco}$ Economic Velocity

$\mathbf{v}_{max}$ Maximum Velocity

VLS Vertical Launch System

V Volume

1

General Introduction

This chapter serves as an introduction to the research study. In short, it provides a brief insight in platforming and modularisation principles, presents the objective and the distilled research questions. Additionally, an outline of this thesis is presented, which briefly describes the structure.

1.1. The Potential Benefits of an Alternative Design Process

Damen Schelde Naval Shipbuilding (DSNS) is a Dutch shipyard and it is a continuation of the NV Koninklijke Maatschappij De Schelde. It is owned by the Damen Group and is situated in Vlissingen. The company was founded October 8, 1875, after shipbuilder Arie Smit had taken over the Marine Establishment, the wharf owned by the Dutch navy. Since 1875, DSNS delivered more than 400 vessels [64]. Now, DSNS wants to develop a modular product platform strategy for a series of support vessels of the Royal Netherlands Navy (RNLN). These vessel types perform hydrographic survey, logistic support, submarine support and marine training.

Traditionally, ship production is done according the production environment type Engineer To Order (ETO). In ETO, the engineering process and the production process are done after the customer order has been placed. Other production types are Make To Order (MTO), Assemble To Order (ATO) and Make To Stock (MTS). In MTO, the engineering design is available before the customer orders a product and production is done afterwards. In an ATO environment there is one or more defined product families, consisting multiple modules/building blocks. After a product is ordered, the modules are assembled in order to create the desired product. Lastly, MTS produces complete products and stores them in stock. To clarify the different production environments, see Figure 1.1. [61]

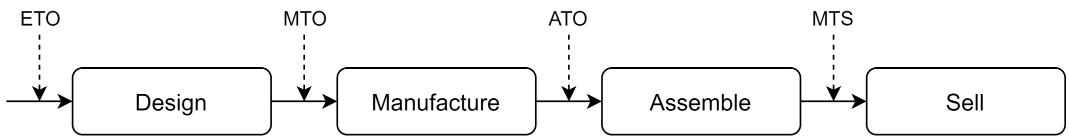


Figure 1.1: Types of Production Environments, adapted from [61]

Because of increasing competition in the global shipbuilding market, the demand for ships with better functionality, higher quality, lower costs, shorter delivery lead time and increased environmental friendliness, is growing. Although, advanced manufacturing technologies can partially address these challenges, advanced design technologies are considered critical, since most design and manufacturing properties of a ship are being influenced by the design decisions made in the early design stages [24]. Also, initial studies have suggested that cost savings and efficiency gains can be achieved by designing one class of ships for these types of support vessels [21].

Consequently, modularity can be the solution. As standardisation means the use of identical components across multiple products, modularity means combining standardised components to create modules and/or building blocks. This could reduce the required inventory and provide a more efficient supply chain [61]. In addition, the modular architecture platform approach offers multiple opportunities for various other stakeholders to benefit from. Stakeholders that can benefit are the client (shipowner), the contractor (shipyard or design office), authorities, regulatory bodies (e.g., class societies, IMO), the ship operator, the building yard and the subcontractors. For example, the production phase can have a shorter lead time because of parallel fabrication, but can also lead to improved procurement, material control, assembly methods, business processes and early outfitting and outsourcing. Additionally, during the operation phase, the owner can benefit from adaptability, evolutionary acquisition and/or mission flexibility depending on the opted strategy. Therefore, DSNS wants to explore the appropriateness of product families to include wide modularity and cross family modularisation.

1.2. Thesis Goal

The primary objective of this research is to identify the optimal platform-based product development strategy with a modular architectural platform approach. The principles of this platform should be applicable for different types of ships. Consequently, the research question is formulated as follows:

'What is the optimal modular platform-based product development strategy for the replacement of a series of support vessels of the Royal Netherlands Navy, viewed from a Damen Schelde Naval Shipbuilding perspective?'

In order to identify the answer, the following objectives are formulated in the form of questions:

1. What are the key aspects to create a successful modular product platform?
2. How can the appropriateness of modular platforming be determined for the potential product family?
3. Which strategic decisions should Damen Schelde Naval Shipbuilding make? In other words, what are potential modules for the series of support vessels of the RNLN and what are the modularity drivers for DSNS?

Hence, the study was focused on a methodical support for a modular design, that makes modularity manageable and understandable. The complete method is applicable for different ship types, selected to be familiarised, and can be used as an initial step in the realisation of an actual product platform. The problem approach is accessible and the time required to set up a case study for strategic decisions can be minimised. The disadvantage of an accessible generic method is the limited accuracy and to a certain extent its incompleteness. Therefore, a trade-off between the accessibility of the design domains[1] and the completeness of stating the requirements[2] is made in order to minimise the disadvantage.

The method helps and supports strategic decisions on how to start a product platform family. To be precise, it provides insight in the effects of platforming and modularisation principles on the products of the potential platform, in terms of overdesign and integration[3].

[1] In this study, the design domains are distincted into a problem- and a solution domain. Also, a distinction is made between a requirement-, functional-, logical architecture- and a physical design domain. The description of each term is dealt with in Chapter 4.

[2] The term requirements, regarding a design process, can be understood in several ways. In this context, it refers to capabilities, functions and technical solutions.

[3] Integration means the extent to which platforming can result in cost benefits. Either in engineering and production or in purchasing [42].

However, in the concept design phase of the design process not everything can be quantified. Therefore, value of the products, can be estimated by answering the following question: 'What is the maximum amount of money a specific person/company is willing to pay to satisfy his/her needs delivered by a product or service' [19]. This can also be translated into Equation 1.1, adapted from [19].

$$Value \sim \frac{Quality}{Lifecycle\ Cost} \tag{1.1}$$

1.3. Outline

To answer the research questions, this study examines and investigates several aspects. Firstly, Chapter 2 provides a theoretical framework by means of a literature review on product platforms and its architectural platform approaches, with modularity as main focus. To summarise, within the modularisation principles each modular application has its own strategic benefits, but can also have drawbacks, such as creating overdesign. Secondly, Chapter 3 describes the ship types that are assumed to have potential to become a product family. For each ship type, the mission statement is stated, as are the ship's features. This helps to have an overall picture and is the initial step to platforming and modularisation. Since the goal of this research is to create a product platform development strategy for a fleet of support vessels for the RNLN, it is important to know how the literature review and the ship types, considered for platforming, relate to each other. To identify modularity drivers and potential modules for this family, the method called Modular Function Deployment (MFD) is found most appropriate. To use MFD, a case study set up is developed by using systems engineering principles, which explores the several conceptual design domains. In short, Chapter 4 describes the method, after which the case study is described in Chapter 5 and lastly, for substantiating strategic decisions Chapter 7 provides a discussion related to all previous chapters.

2

Literature Review on Modular Platforms

During recent years many industries have moved from designing individual - 'one-of-a-kind' products or Engineered To Order (ETO) products - towards developing product platforms. Platforming, the sharing of products or processes across products, has become an important means of cost-sharing across industrial products [12, 49]. In this chapter, the literature on product platforms and modularisation principles is evaluated.

2.1. Introduction

Many companies these days are developing product platforms and designing families of products based on these platforms to provide a sufficient variety for the market, while maintaining the necessary economies of scale and scope within their manufacturing and production processes, according to Simpson [51]. In modular product development, platforms are a popular method to reduce complexity in products. Fuchs and Golenhofen [19] divide the product architecture into common modules/building blocks, specific configurations and market specific modules.

The benefits of platform planning are most effectively realised by its implementation in the front-end of product development. Because, as Simpson [51] states, it is the front-end of product development where the overall product strategy is defined and the elements of a potential new product or platform are identified. Moreover, it is here that an alignment between key markets, customer requirements, and underlying platform capabilities can yield the greatest benefits for downstream platform leverage.

Figure 2.1 illustrates the decision framework of product family design and development along the entire spectrum of product realisation according to the concept of design domains, illustrated by Suh [57]. The front-end issues are shown here as well. Jiao [29] tells that product platforms have been defined diversely, ranging from being general and abstract to being industry and product specific. Nonetheless, the principles are being explored between the functional domain and the physical domain.

According to Fuchs and Golenhofen [19] is the key, for a successful platform development, to focus on the common core platform concept. This means extracting all the market commonality between different market segments and mapping this into a common core architecture. The common core architectures is therefore a way of standardising, by combining all commonalities that are shared across the different market segments. This automatically means that the more market segments need to be addressed, the smaller the common core will become: as the degree of variety is higher, 'overlapping' between segments becomes smaller. Jiao et al. [29] state that it is commonality that entails the difference of the architecture of product families from that of a single product.

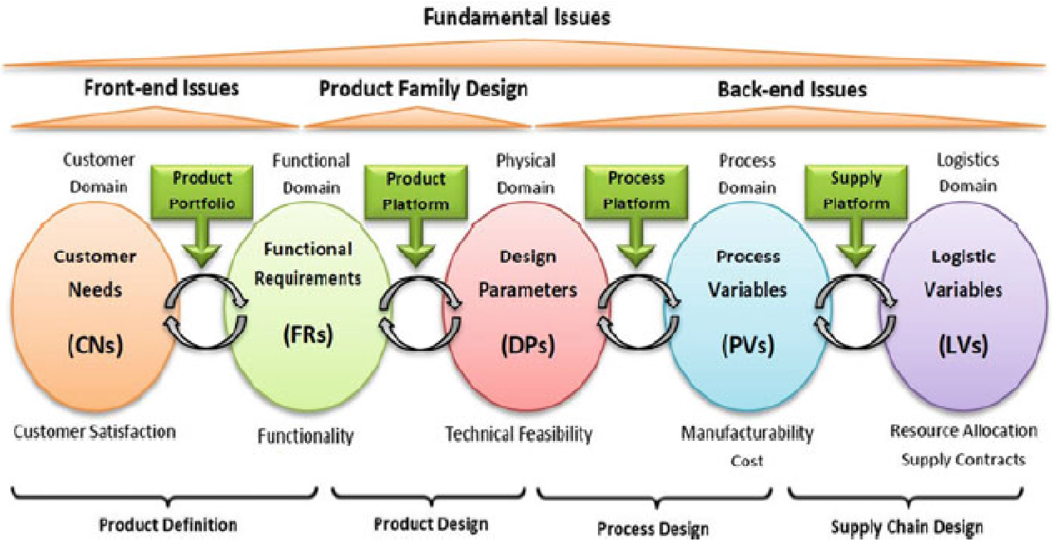


Figure 2.1: Overview of the Design Domains [29]

Obviously, shipbuilding is a different type of manufacturing than most other industries. For example, the automotive and the aeronautical industry have larger series size, the time required to develop a product is shorter and decision ownership is far more. Nieuwenhuis [42] clarifies this by saying that the series size in ship building is 1 to 10 (with development times of about 3 to 5 years), while for the automotive industry the series sizes ranges from 10,000 to more than 1,000,000.

2.2. Product Platforms

Two **basic approaches** for product family design are distinguished by Simpson [50]. The first is a top-down (proactive platform) approach wherein a company strategically manages and develops a family of products, based on a product platform and its derivatives. The second is a bottom-up (reactive redesign) approach wherein a company redesigns or consolidates a group of distinct products to standardise components to improve economies of scale. With respect to modularisation, none of them is wrong according to Fuchs and Golenhofen [19]. However, a proactive perspective gives modularisation more weight and importance .

Products are often a mixture of different kinds of platform types, according to Fuchs and Golenhofen [19]. The prominent classification of a single platform, be it top-down or bottom-up, is defined by Nieuwenhuis [42] into the following aspects:

- Architectural platform approach
- Platform leverage type
- Product property setting
- Number of platforms per family

Three types of **architectural platform approaches** exist, according to Fuchs and Golenhofen [19]:

- Modular approach - Simpson [51] defines this approach as the prominent platforming approach. With a modular approach, product family members are derived by substituting and/or removing modules, possibly complemented with individually designed product portions.
- Integral approach - According to Gonzales-Zugasti and Otto [23], this approach leads to a platform that is a single, monolithic part of the product, shared by all products within

the family. Individually designed portions are added to the platform to create a finished product.

- Scalable or parametric approach - As defined by Simpson [49], this approach provides a platform that has a number of scaling variables that can be used to ”stretch” or ”shrink” the platform in one or more dimensions to satisfy a variety of market niches .

The major difference between modular and integral architectures is the way that product features relate to components. In modular architecture, products have a one-to-one correspondence between a component and its function, while an integral product tends to have single components so interwoven that each may perform more than one function. A hull system is an example of technical solution that fulfils a variety of functions: buoyancy, stability, structural strength, containment and protection of cargo and machinery, storage of fuel, ballast water, potable water and other liquids and more. Any change in one of these functions, for example increasing the cargo hold capacity, will affect some or most of the other hull functions and even lead to influencing totally different functions such as the ship drive train. However, for modularisation it can also be beneficial to integrate technical solutions in order to create it a suitable work content for a group of standardised components. This group is then called a building block. The complete definition of a building block is stated in the Glossary of this report. To summarise, Fuchs and Golenhofen [19] made a quick overview of the key differences between the architectural approaches. This is illustrated in Table 2.1.

	Integral architectures	Modular architectures
Performance	Can be trimmed for highest performance (e.g., size, weight).	Typically compromises on performance, because of overdesign (e.g., over-sizing).
Product definition	Complex mapping from functional elements to physical elements. And/or interfaces between elements are coupled. Interfaces are poorly defined.	Each physical element implements one or a few functional elements in their entirety. Interfaces between elements are not coupled. Requires a clear definition of interfaces.
Product change	Any change in functionality, impacts several elements. Hard to change.	Any change in functionality, impacts only the element that carries the function. High flexibility.
Lifecycle	Integral architectures are typically in eras of a completely new technology development.	Modular architectures are typically superior if technologies overshoot mainstream customer requirements.
Organisation, teams	Tightly coupled development teams.	Decoupled, independent development teams that work in parallel.
Product variety	Effective for singular products and not effective for product families.	Effective for product families and not effective for singular products.

Table 2.1: Key Differences between Integral and Modular Architectures [19]

Platform leverage defines the ability of a platform to serve various market segments and performance ranges. Meyer et al. [39] and Fuchs and Golenhofen [19] identified three product platform leverage types:

- Horizontal leverage - The platform serves multiple market segments across a single performance tier. In other words, the platform serves various market segments, but the products are comparable regarding performance level [39]. Such a strategy is beneficial to target very different markets and to best satisfy both markets in terms of price and quality expectations [19].
- Vertical leverage - The platform serves a single market segment across a range of performance tiers [39].

- Beachhead/baukasten approach - The platform serves multiple market segments and multiple performance tiers [39]. This grid illustrates the modular platform [19]. A modular platform helps to address all the individual customer preferences and allows the personalising of products.

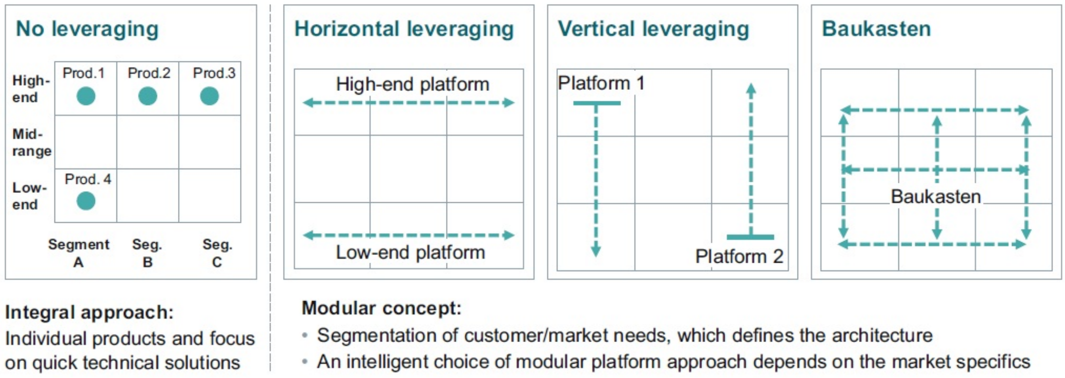


Figure 2.2: Platform Leverage Types [19]

The **product property setting** defines which of the product properties are incorporated within the platform strategy. Whenever a product property is not incorporated within the platform, the property is 'free' and can therefore potentially be varied across projects to provide the required customisation. Product properties can be incorporated within a platform strategy in different ways according to Nieuwenhuis [42]. They can either be:

- Fixed - Whenever a property is 'fixed', a single value is used for this property within the platform design.
- Bounded - For bounded properties, the number of possible values is reduced and bounded between two values. Intermediate values can either be discrete or continuous.

The last aspect that defines a platform strategy, according to Nieuwenhuis [42], is the **number of platforms**, this defines how many platforms are used to serve a potential product family.

According to Hölttä [26], a structured **platform development method** can be developed in the following steps:

1. Portfolio planning - Create platform a development team, analyse the present product range, define the future product range, market research, etc.
2. Carry out a method to define the appropriateness and the optimal platforming strategy - Define the platform type, select the indicators for platform evaluation, define the method to develop a platform, evaluate alternatives, etc.
3. System level design - Work out the design for the systems to be included in the platform based on the selected product development strategy to a level of detail as required. For example, by a Class Society.
4. Detail core module design - Detailed engineering of the system, to provide the required production information. Similar to current one-off detailed engineering.
5. Test and evaluate - Check if the design satisfies the requirements, evaluate the platform effectiveness, verify the design solutions, etc.
6. Deliver the platform solutions to the organisation - Make the solutions available within the product development department of the organisation, clarify the do's and don'ts, clarify design rationale, etc.
7. Use the product platform for new product development (after 'sales') - Develop the derivative products based on the product platform.

2.3. Modularisation Principles

Modularisation is not a new concept in the field of ship design, according to Choi [5]. It has received attention for efficient ship design and manufacturing, despite the fact that the design of an operation platform is challenging due to the conflicting requirements of multiple missions and the interface decisions that affect the level of flexibility of the operation platform. The most promising modular concepts on the market today are summarised in Table A.1 of Appendix A.

A fundamental idea in modern platform development is to design a so called modular core platform, rather than develop a traditional inclusive platform. Figure 2.3 illustrates how an inclusive platform targets all market segments at once, while in modular core platforms, the core platform refers to the element that all products share, thus excluding differentiating elements. [19]

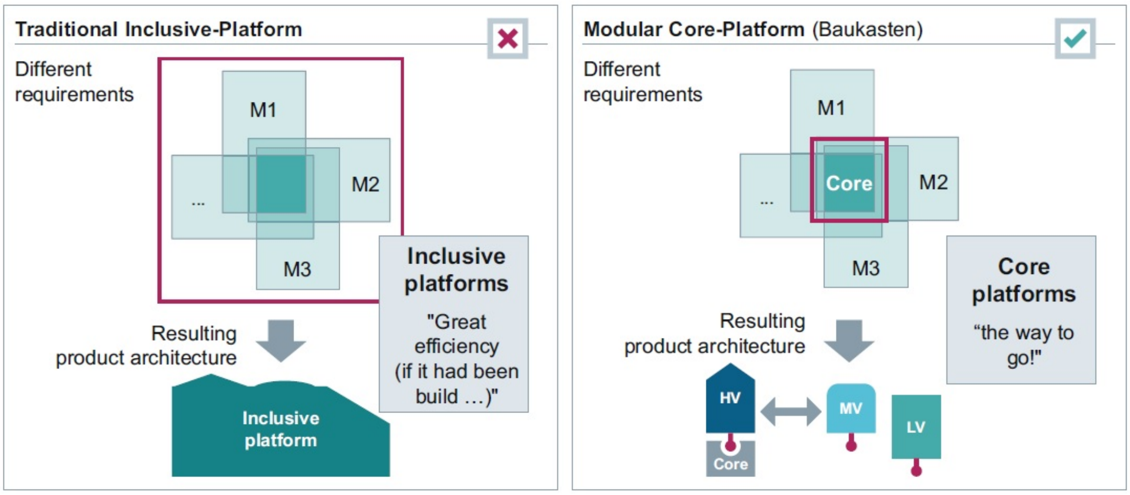


Figure 2.3: Traditional Inclusive Platform versus a Modular Core Platform [19]

According to Fuchs and Golenhofen [19], it is typically assumed that a product family has to be derived from a single platform, while in reality, many products/systems are a mixture of different kinds of platform types. Moreover, research shows that multi-platform approaches lead to better results. It is useful to realise how different platforms interact and affect one another. Furthermore, the key for a successful platform development is to focus on the common core platform concept. This means extracting all market commonality between different market segments by mapping it to a common core architecture. In other words, the common core architecture is a way of standardising, through combining all commonalities that are shared across the different market segments.

A larger number of platforms per family reduces the degree of overdesign. On the other hand, it also reduces the integration benefits. Nieuwenhuis [42] describes these two terms as:

- Degree of overdesign - The difference between the maximum performance of a design solution and the required performance of a design solution. When applying a platform-based strategy, overdesign is often inevitable, as otherwise the platform cannot be applied throughout a family. Overdesign has a strong effect on the performance of platforming strategies because it affect the costs during each stage of the product's lifecycle. Namely:
  - Engineering costs - Overcapacity for example results in larger components, which are more difficult to arrange within a given space, thus more effort is required to design a satisfactory arrangement and deliver the arrangement drawing.

  - Product/logistic costs - Overcapacity for example results in heavier components, which are more difficult to handle, harder to position, etc., resulting in higher outfitting efforts. Overcapacity with respect to the number of components results in more components that have to be placed, transported, etc., which could also increase the outfitting costs.
  - Purchase costs - Naturally, overcapacity also needs to be paid for. Higher degrees of overcapacity result in increased purchase costs.
  - Operational costs - Overdesign could increase operational costs when for example spare parts for larger components are more expensive, a higher number of components need to be maintained. (Please note that the opposite could be true as well, as through overdesign the quality level of a product could be higher than required, the load on components could be lower than in the one-off case reducing wear and tear for example)
- Degree of integration - The extent to which platforming can result in cost benefits. Either in engineering and production or purchasing.

Papanikolaou [44] declares that at the design stage, modularity can concurrently support both standardisation and diversification using a product platform strategy and lay the foundation for a configuration-based design process. Also, he states that modularity is relevant in the production phase in supply chain design and modular production (as it allows a shorter production time due to the parallel manufacturing and testing of modules), early production outfitting, production outsourcing and procurement packaging. It also improves the efficiency of dry dock operations, which is a shipyard's most valuable resource and it allows wider outsourcing options due to the standard interfaces. In the operation phase, modularity implies flexibility, providing opportunities for adapting the vessel's to changing markets, technologies, regulations and customer needs.

In short, key drivers for different stakeholders are summarised by Erikstad [12] as:

- Product variety and customisation
- Production efficiency
- Reduced lead time
- Product development and design
- Reduced risk
- Outsourcing and globalisation of supply chain

2.3.1. Modularity Types

The concept of modular design has a profound influence on the engineering design. Four types of modularity have been identified by Fixson [17], namely, product modularity, process modularity, organisation modularity and innovation modularity.

Modularity in product family design is subdivided, by Jiao et al. [29], in multiple viewpoints, involving functionality, solution technologies and physical structures. Correspondingly, there are three types of modularity associated with product families: functional modularity, technical modularity and physical modularity. These three types of modularity are characterised by specific measures of module interaction from a particular point of view.

- As for **functional** modularity, the interaction is exhibited by the relevance of functional requirements across different customer groups. Each customer group is characterised by a particular set of functional requirements. Customer grouping is done only from a functional view and is independent of the other two views, meaning it is solution-neutral.
- In the **technical** view, modularity is determined according to technological feasibility of design solutions. The interaction is thus judged by coupling design parameters to satisfy given functional requirements regardless of their physical realisation in manufacturing.

- In the structural view, **physical** interactions derived from manufacturability become the major concern of physical modularity. Modules can be linked in different ways. The types of physical modularity can be differentiated from each other based on interface diversity and the use of a main body. The different interface types within physical modularity are defined by Ulrich [59], Salvador [46] and the project NAVAIS [40] as:
  - Sectional modularity
  - Bus modularity
  - Slot modularity
    - Combinatorial modularity
    - Component-swapping modularity
    - Component-sharing modularity
  - Cut-to-fit (e.g., SIGMA-concept)
  - Mix modularity (e.g., mixture of paint ingredients)

To clarify the modularity types, Figure 2.4 illustrates each type. The two grey boxes within this image are not defined in literature.

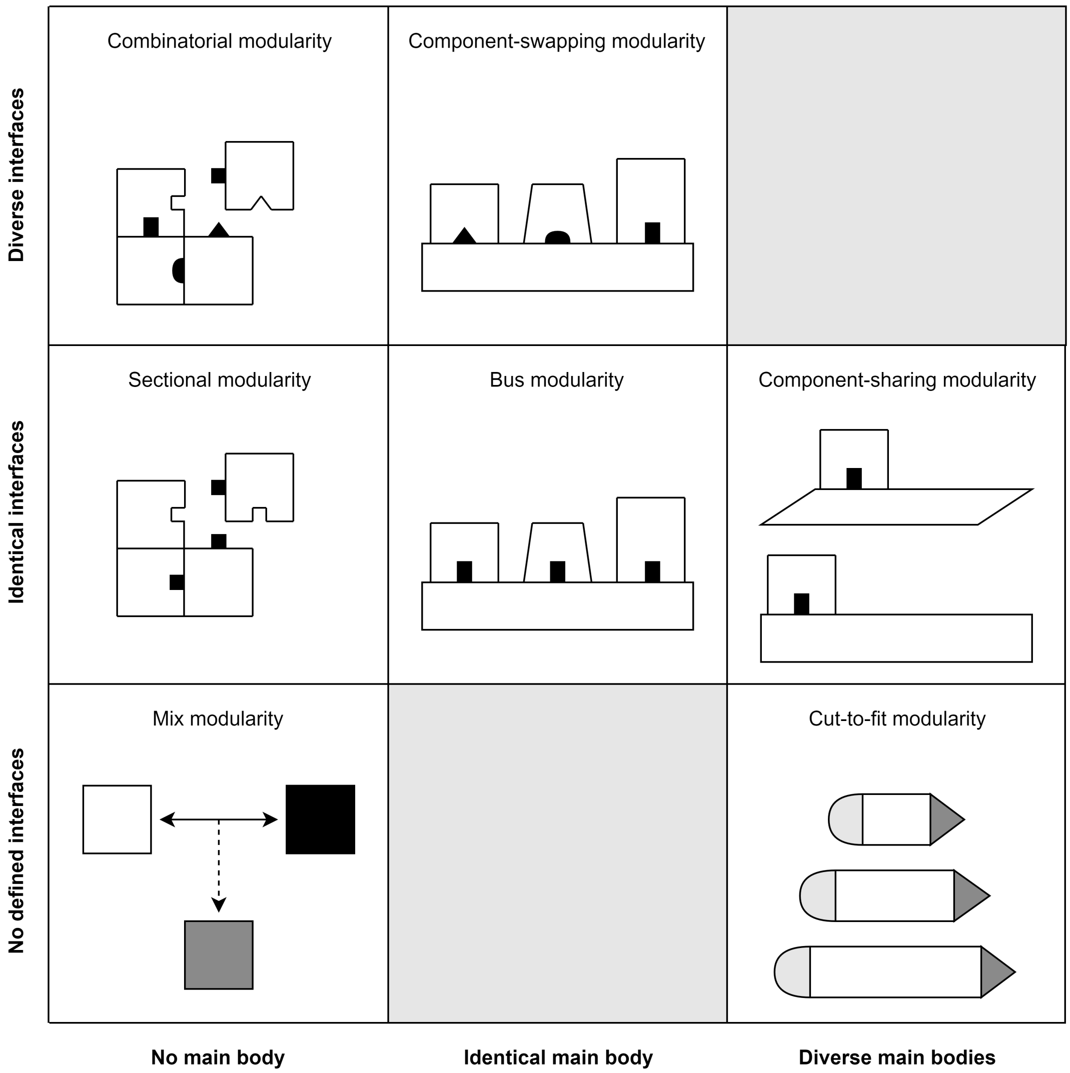


Figure 2.4: Illustration of Interface Types, adapted from [13, 40, 46]

Each modularity type is descrbied by Choi [5]. In sectional modularity, modules interface with each other through identical interfaces, whereas in bus modularity, modules interface with a main body using identical interfaces in what is known as a bus interface. In both combinatorial modularity and component-swapping modularity, there is no identical interface that all modules share globally. However, some modules share a common interface locally, which is called a slot. Each module in combinatorial modularity has its own slot and can be connected to other modules that have the same type of slot. Alternatively, in component-swapping modularity, modules interface with a main body through slots. The cut-off modularity can be used for example in shipbuilding to scale the ship's mid-body with no change to the bow and stern, according to Ulrich [59].

Also, Ulrich [59] states that to characterise modularity, the interaction among modules is important. Modules are identified in such a way that between-module (inter-module) interactions are minimal whereas within-module (infra-module) interactions may be high. Therefore, decomposition is the main concern of modularity.

2.3.2. Module Types and their Application

A module refers to a physical or conceptual group of components that share some characteristics, according to Jiao [29]. Modules are categorised, by Schank et al. [47], Choi [5] and the project NAVAIS [40], into the following types:

- Common modules for multiple classes and sizes of ships.
- Payload modules for mission flexibility.
- Self-contained modules for evolutionary acquisition.

Common modules (or interchangeable modules [40]) can be used across multiple classes and sizes of ships for **commonality or interchangeability**. However, a valuable modular design regarding hull, mechanical and electrical (HM&E) aspects of a ship, that could be used across multiple classes of ships, is difficult [47]. This means that no examples exists. Nevertheless, this module type can be specified in combinatorial modularity, component-swapping modularity, bus modularity and component-sharing modularity.

A second form of modularity is a modular installation in which the ship (often referred to as a sea frame) can accommodate various types of payload modules through defined interfaces and connections. This can be used for **mission flexibility**. The sea frame has space, structure and connection for these various modules. The ship can perform only one payload package mission at a time, but can change that mission by swapping out the modules that comprise a package. (Thus, this module type can be specified in bus modularity, component-swapping modularity and component-sharing modularity.)

Figure 2.5 illustrates the mission flexibility by modularity. Mission flexibility (or market flexibility) is an ability to switch missions. This allows a ship to be used for different types of missions at different times and it makes the value of the ship insensitive to the change of the operating context [5]. Examples of this kind of modular installations are the U.S. Navy LCS and the Royal Danish Navy's Absalon class ships [47].

For **evolutionary acquisition**, self-contained modules (or independent modules [40]) provide a plug-and-play capability with standard connections and interfaces within defined boundaries. These are typically used for a specific task (e.g., missile launch capability or communication network). Containers are an example of self-contained modules in commercial shipping. Self-contained modules have their greatest benefits when components of the module are expected to change over time [47]. However, the interface with the ship could be limited to a connection mechanism and power supply [40]. Therefore, this module type can be specified in bus modularity, component-swapping modularity and component-sharing modularity.

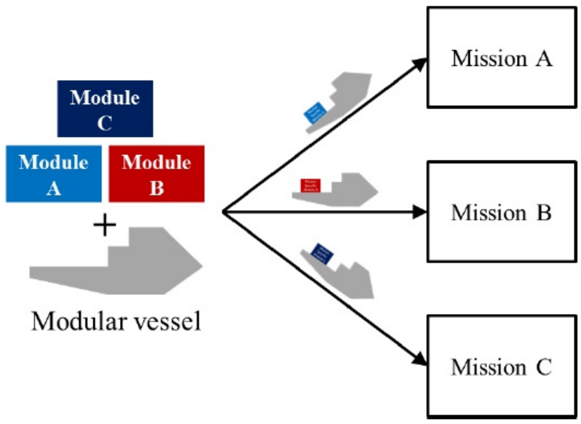


Figure 2.5: Example of Mission Flexibility by Modularity [5]

Figure 2.6 illustrates the difference between the two acquisition processes. Evolutionary acquisition is an investment strategy in which decision makers postpone investment decisions for modules waiting for more available information [5]. An example of a self-contained module is the Vertical Launch System (VLS) modules on Arleigh Burke-class destroyers [47].

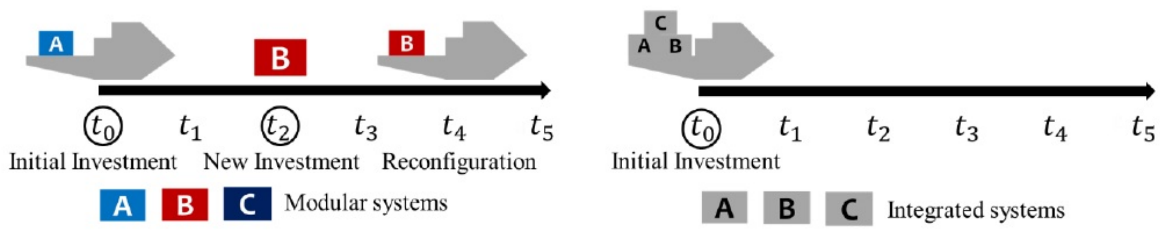


Figure 2.6: Evolutionary Acquisition (Left) versus Conventional Ship Acquisition (Right) [5]

For a flexible design, **adaptability** provides many advantages. Ships are expensive and remain in the fleet for a long time, often three decades or longer. During that time, they have to deal with the state of the economy, have to comply with legislation on emissions and meet other uncertainties (see Table 2.2 and Figure 2.7 for an illustration). Therefore, making the right investment is difficult for the shipowner. As missions and technologies change, the common response is to modernise a ship to accommodate the new mission or technology. But modernisation is expensive and the physical configuration of the ship may limit the possibilities. In some cases, the modernisation costs are so high that it is cheaper to retire the ship than to modernise it. [47]

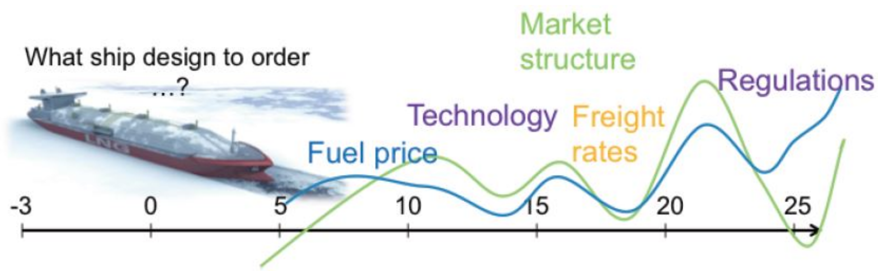


Figure 2.7: Uncertainty of Marine Systems in an Uncertain Operating Context [14]

One distinction between modularity and flexibility in ship design is that modularity sets defined interfaces within rigidly defined boundaries. Flexibility allows both the boundaries and the interfaces to change. A modular platform has a degree of flexibility, but it also has limits

Field	Example
Economic	Oil price, interest rates and supply/demand
Technology	Energy efficiency improvement and lifetime enhancement
Regulatory	SO_x/NO_x emissions and ballast water treatment
Physical	Sea ice, sea states, extreme weather, ports & canals

Table 2.2: Examples of Uncertainties in Marine System Design [14]

implied by the defined interfaces and fixed boundaries. A truly adaptable ship should not only be modular but also have the ability to expand boundaries and adjust interfaces. This definition of flexibility implies greater space as well as the ability (provided by additional space) to expand power, cooling, bandwidth and other ship services if and when needed. As shown in Figure 2.8, modularity and flexibility both contribute to the adaptability of a ship [47]. Regarding the type of modularities, modular adaptable ships can be defined by component-swapping modularity, in which a main body interfaces with add-on modules through slots [5].

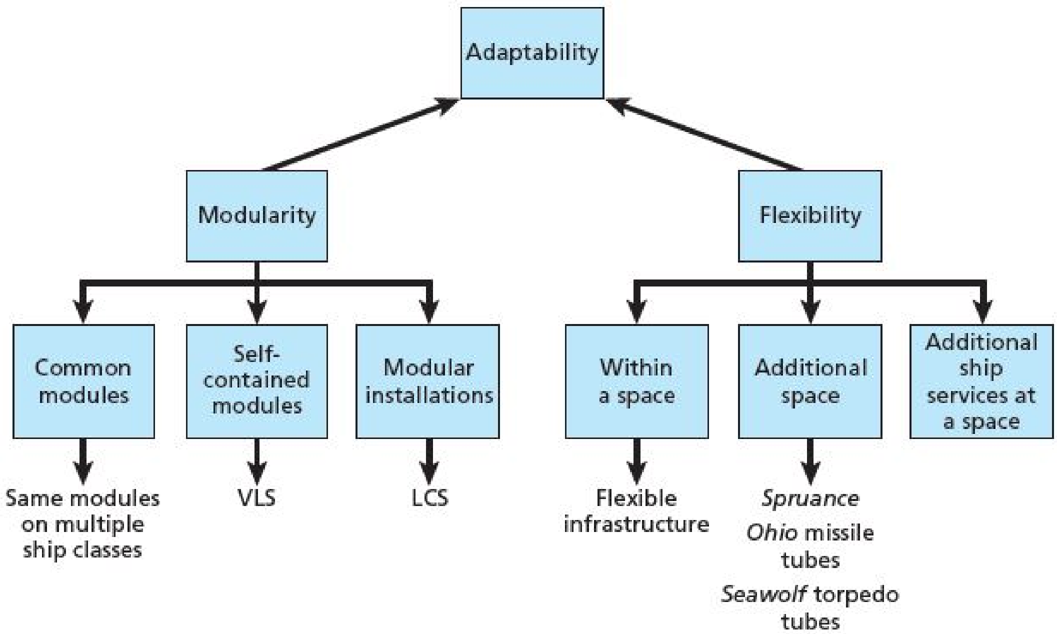


Figure 2.8: Distribution of Adaptability [47]

As mentioned, self-contained modules and modular installations set defined boundaries and interfaces. Flexible infrastructure allows the boundaries of a ship's functional space to change. Rather than requiring substantial hot work to make spaces larger or smaller during a ship's life to adapt to different systems or uses, flexible infrastructure allows quick changes of a space. This type of flexibility provides greater adaptability while reducing the cost of modernising in-service ships [47]. Forms of flexibility are:

- Within a space
- Providing additional space
- Providing additional ship services within a space

Norbert Doerry [10] created a simple matrixed taxonomy of design approaches, against the type of requirement environment, to point out when to opt for a Modular Adaptable Ship

(MAS) as illustrated in Figure 2.9 . Many Optimised Point Design are commercial ships and Navy Auxiliary vessels, while a Robust Design is for example a multipurpose vessel that has its service life allowance built in capability to meet threat over the whole lifetime [9].

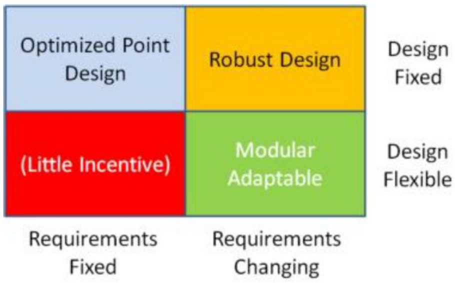


Figure 2.9: Matrix Taxonomy [10]

2.3.3. Modular Design Process

The various phases of a design process according to Damen Shipyards Group (DSGo) practices are [40]:

- Concept design - The process starts with the mission requirements that are usually specified by the ship owner and based on market scenarios. The concept design includes the ship type, deadweight or payload, type of propulsion, service speed, service area, endurance at sea, position keeping (eventually), class society and class notation.
- Preliminary design - Determination of main hull dimensions and form coefficients, and all elements necessary and sufficient to estimate OPEX and CAPEX. This means, having a preliminary hull geometry, arrangement and compartmentation (which is sufficient to estimate stability and mission-critical capacities), first estimate of propulsive power and ship lightweight.
- Contract design - Determination of the ship characteristics and main equipment, to be annexed to the contract: general arrangement, technical specification on functional level, diagrams of main piping systems.
- Basic design: Hull geometry suitable for model tests, class drawings, hydrodynamic calculations and component selection based on functional technical specification.
- Detail design: Details providing information for manufacture, assembly and testing: fairing of the body plan, defining all structural components, material specs and production information for cutting, shaping, assembling, joining and surface preparation of structures, pipes and other outfit items, integration and installation information for all equipment, applicable standards and norms.

The order of the phases differs between a conventional design and a modular design, as illustrated in Figure 2.10 and Figure 2.11. The modular design process has the advantage that the total time of this design process is shorter. In addition, the modules' library can be extended, upgraded or be used for other family products [40].

Figure 2.10: Conventional Design Process of DSGo [40]

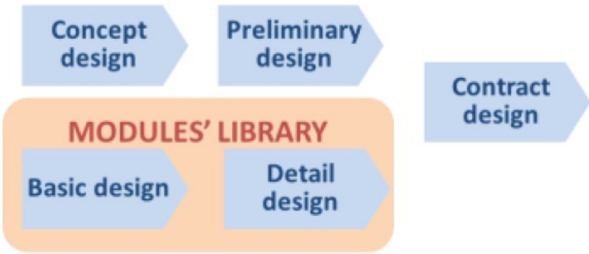


Figure 2.11: Modularisation Design Process of NAVAIS [40]

2.3.4. Methodical Support for Modular Design

To make modularity manageable and understandable, it is important to articulate on tangible assembled aspects, according to Stjepandić et al. [54]. In product modularity, the focus is on component separability and component combinability . Hence, this relates to:

- Commonality of modules - Component or modules that are used for various ship types within the product family.
- Combinability of modules - Technical solutions can be configured by combining components or modules.
- Function binding - There is a fixed allocation of functions to modules.
- Interface standardisation - The interfaces between the modules are standardised.
- Loose coupling - The interaction between components within a module are significantly higher than interactions between components of various modules.

Subsequently, Stjepandić et al. [54] partitioned information, to achieve modularity, into visible design rules and hidden design parameters. The visible design rules are basic decisions that affect subsequent design decisions. These rules consist of three categories:

- An architecture, which specifies system modules and their function.
- Interfaces with description of module interaction.
- Performance standards.

Hidden design parameters are decisions that affect the design only within the local module and can be defined later in the design process.

In the context of the entire lifecycle, modularity combines technical aspects with business aspects, both from a qualitative as a quantitative viewpoint. To clarify, see Figure 2.12 for an image, illustrated by Stjepandić et al. [54].

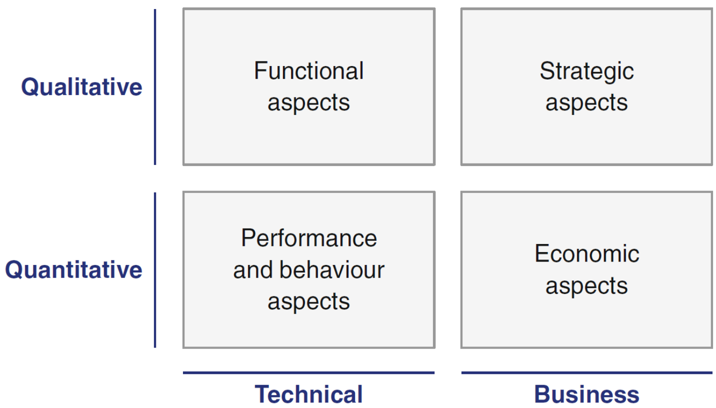


Figure 2.12: Aspects and Viewpoints of Modularity [54]

In short, Stjepandić et al. [54] state that from a business point of view, modularisation has three functions: make complexity manageable, enable parallel work and accommodate future uncertainty. Technically, it can be expressed with three measures: how components share direct interfaces with adjacent components, how design interfaces may propagate to nonadjacent components in the product and how components may act as bridges among other components through their interfaces.

Stjepandić et al. [54], Fuchs and Golenhofen [19] and Jiao [29] mentioned various methods to support modular design. These are:

- Axiomatic design [57] - Axiomatic design (AD) is a systems design methodology using matrix methods to systematically analyse the transformation of customer needs into functional requirements, design parameters, and process variables. Hereby, the attempt is made to build on the development of new products based on a system of axioms, which are based on mathematics or physics sciences.
- Function modelling or heuristic approach [55] - Functional modelling places product functions as a central idea for structuring of product into modules. The role of functional modelling is not only to clarify understanding of a design problem, but also to serve as core to the modular solution.
- Design Structure Matrix (DSM) [34] - The DSM can be used to define modules within a single product's architecture. In the component or function based DSM, components or functions are placed on the row and column headers of the matrix. Components or functions are then mapped against each other and their interactions are marked in the matrix. Once functions or components and their interactions are placed in the DSM, a clustering algorithm can be applied to group the functions or components so that the interactions within clusters are maximised and those between the clusters are minimised. Thus, the formed clusters are possible module candidates. In short, this is a technical oriented approach.
- Modular Function Deployment (MFD) [15, 16] - This modular support method discusses module candidates within a modular platform development project. The modularity drivers allow one to identify modules in a comprehensive way that helps to make product-strategic decisions. The MFD focuses on various strategic issues leaving the decisions about the functions and interfaces of the product to the designer.
- Variant Mode and Effects Analysis [3] - The Variant Mode and Effects Analysis approach helps to depict the impacts of product variants in all units of the enterprise from definition of the product program to distribution. It includes an evaluation of target costs and discovers cost saving potential by eliminating product variety that is not customer-perceived.
- Five-step algorithm [25] - A five-step algorithm of grouping and creating a dendrogram to find common modules across products for platforming a product family. It calculates the distance between any two modules or group modules into a hierarchical dendrogram that helps decide what function groups are similar enough to be replaced by a common module. To conclude, this approach seems to be too specific for this study, as only the functional domain is met.

2.4. Concluding Remarks

The key to a successful product platform development is to focus on the common core platform concept, which means extracting all the **commonality** between different ship types and mapping it to a common core architecture [19].

As a consequence, the **multi-platform principle** for the product family design must be considered. This often gives better results than one single platform [19]. This implies that in order to complete the product design, the product must consist out of specific configurations (i.e., modules and/or building blocks) that are not shared among all products within the family and market specific modules/building blocks. See Figure 2.13.

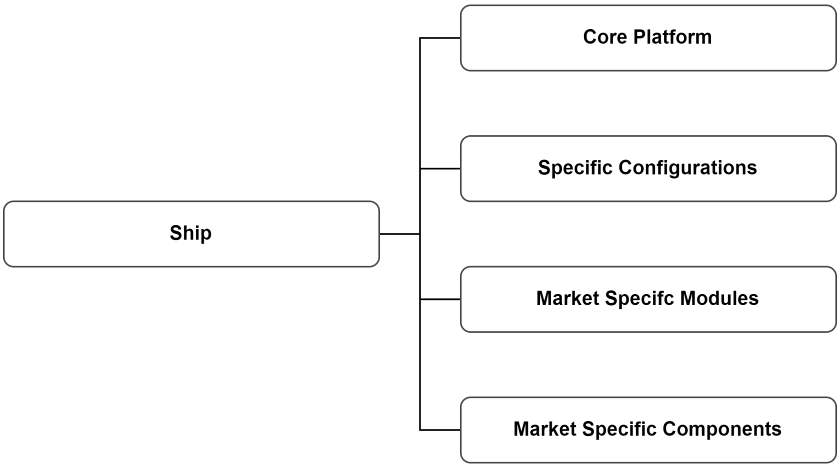


Figure 2.13: Product Decomposition with respect to the Product Family

Another objective in this research is to identify an **optimal** strategy. In other words, the purpose of designing a module or building block is to add value to the ship. This means increasing the quality, reducing the costs or reducing the lead time. In other words, the developed ship is better than the reference vessel. Therefore, this can mean that modules and building blocks are not necessarily preferable to single standardised components. Also, integral platforms should not be ignored and should be considered in the decision support.

The **top-down approach** (i.e., a proactive platform) is found to be most suitable for this study, as this approach gives modularisation more weight and importance, because functional decomposition is the main concern for modularity. This means the overall function of the product is described first, meaning the function of a product remains constant, while components and technologies can change in order to fulfil the original functions. [19]

The methodical support for modular design appropriate for this research is **Modular Function Deployment**. Because this method takes into account technical aspects and business aspects, both from a qualitative as a quantitative viewpoint. In other words, the entire lifecycle of the product and various stakeholder's perspectives are included. Other methods do not consider all aspects and viewpoints. Therefore, MFD is founded to be most appropriate for this study. According to Malmström and Malmqvist [34], MFD can also be combined with DSM in order to tackle technical and economical aspects. Because this study is limited by time, execution of both methods is not feasible.

3

Series of Support Vessels of the Royal Netherlands Navy

A good set of requirements for a ship is defined by the operational capabilities and functions she must possess. For platforming and applying modularisation principles it is important to know if improvement is possible for the future product range by the use of these principles. To enable this, the particulars of the reference vessels, their mission statements and features are described in this chapter.

3.1. Reference Vessels

The product platform to be developed will be based on five current operating vessel types of the RNLN. Namely, hydrographic survey vessel, logistic support vessel, submarine support vessel, marine training vessel and diving support vessel. For a brief overview of the main particulars of these ships, see Table 3.1.

Ship Type	Hydrographic Survey	Logistic Support	Submarine Support	Marine Training
(Class)name	Snellius; Luymes	Pelikaan	Mercuur	Van Kinsbergen
ID	A802; A803	A804	A900	A902
Year built	2003; 2004	2006	1987	1999
Indicative replacement	2033	2030	2026	2025
# in service	2	1	1	1
Δ_{max} [t]	1905	1727	1500	640
LOA [m]	81.4	65.4	64.8	41.5
BOA [m]	13.1	13.25	12	9.2
T [m]	4.0	3.0	4.33	3.3
v_{max} [kn]	13.0	14.5	14.0	13.0
v_{eco} [kn]	12.5 (seastate 4)	-	-	-
Range [nM]	12000	-	-	-
Crew	13	16	28	24
Passengers (tot.)	29	62	11	19
Power plant concept	DE	D	D	D
Shafts	1	2	2	2
Bow thruster	Yes	Yes	Yes (retractable)	Yes

Table 3.1: Ship Particulars [6, 20, 36, 41, 58]

3.2. Mission Description and Features

The mission of the vessel or platform is given by means of a brief description of what the vessel or platform should be able to do and where the vessel should operate. What all the vessels share is that Navy acquisitions do not have a particular Return On Investment (ROI) requirement, but they must satisfy a national security commitment at the least possible costs.

3.2.1. Hydrographic Survey Vessel

A hydrographic survey vessel focuses on intelligence gathering at sea, i.e., hydrographic and oceanographic surveillance for civilian and military purposes in order to provide information on Dutch, parts of the Caribbean and other areas of operation. This is not done only in safe waters like the North Sea, but also in hostile waters. In those areas merchant hydrographic survey vessels do not want, or are not allowed, to enter. However, it is still important that all seas are surveyed, especially those areas where information about the seas is poor. Besides intelligence gathering, this ship type can perform Rapid Environmental Assessments for amphibious operations and she can be used for general military operations. For example, she can operate as support vessel for minesweeper operations training Beneficial Archer. Also, she takes part in flag display nationally and internationally, assists with maritime scientifically research for the Department of Defence and assists with calamities at sea (e.g., disaster relief, pollution control or oil spill recovery). [38, 41]

Figure 3.1: Hydrographic Survey Vessel - Luymes (A803) [38]

For a picture of the reference vessel see Figure 3.1. The main equipment of this ship type is without a doubt the sensor suite to perform bathymetry in different areas with either shallow waters or deep waters. The sensors are placed in a blister under the keel in the forward and mid-ship section. Sensors and systems installed are single-beam- and multi-beam echo sounders, high speed side sonar, magnetometer, ultra-short baseline, hull-mounted searchlight sonar, motion sensor, sweep system and a moving vessel sound velocity profiler. Together with the sensors, it is important that the hull and the propulsion system are designed in such a way that the radiated sounds and its resulting noises are minimised. A notable characteristic is the hull-form with a single propeller and diesel-electric propulsion. For loading and unloading equipment, an A-frame is installed at the aft deck. To perform hydrographic operations in shallow waters and doing amphibious operations, sloops are used. The main operational room is the Hydrographic processing room (30 m^2) with adjacent plotter room (10 m^2). Furthermore, the crypto room (12 m^2) and the electrical workshop (12 m^2) are of importance. The ships movement are damped by an anti-roll tank. The fact that the crew size for the Snellius and the Luymes is changed from 2 (1 each) to 3 (rotating every 4 months) to maximise the availability of the ships, suggests the ships are often operational. With respect to multi-functional availability, this can imply that the replaceable platforms will not often be available for other tasks. On the other hand, multi-functionality has more benefits, e.g., logistics, maintenance and the fact the ship can be strategically located geographically to have less waste time with long transits. [6]

3.2.2. Logistic Support Vessel

This ship type is used for logistic transport, supporting operations (i.e., deployment of military units to maintain public order) and train of the Marine Corps and the coastguard of the Netherlands Antilles & Aruba. Furthermore, it assists the station ship of the marine in the Caribbean. The station ship (a changing vessel) is for law enforcement, coastguard operations and drugs control. During natural disasters in this area, she can assist quickly with required material, personnel and humanitarian aid. [37]

Figure 3.2: Logistic Support Vessel - Pelikaan (A804) [37]

For a picture of the reference vessel see Figure 3.2. The Pelikaan has a lot of cargo capacity for logistic supply operations. The design payload includes 4 Land Rovers, 4 trucks, 1 water trailer, 1 generator, 1 forklift, 1 shovel and 2 containers. Therefore, two cargo holds are available (165 m^2 + 95 m^2) and free space on the deck (310 m^2). (However, expected is that the future ship will require more cargo space.) Cargo is shifted between shore and ship by means of a crane that is installed at centre of the deck. Furthermore, the ship can transport 70 tons of fresh water and in addition to the considerable loading capacity, there is a lot of room in the accommodation. In addition to the cabins for 16 crew members, 62 Marines can also remain on board, because the Pelikaan must also be able to operate as a support vessel during exercises and Amphibious Operations of the Marine Corps and coast guard. Therefore, a few operational rooms have been installed behind the bridge (e.g., amphibious operations room (AOR)) with a total area of 35 m^2. For disembarkation, Fast Raiding, Interception and Special Forces Crafts (FRISC's) are used. [6]

3.2.3. Submarine Support Vessel

The torpedo training ship's primary task is to support (four Dutch Navy) submarines. In particular with regard to torpedoes. The ship is often used as a mock target for training torpedoes, which she then safely picks up. The submarines need this support, because an important task is to test the torpedo tubes after regular maintenance periods. Moreover, taking into account the reduction of marine vessels, the Mercuur is also used for operations for which she was not designed for originally. For example, she sails in combined task operations where the maximum speed is relatively low (14 knots) which causes operational limitations. [36, 41]

Figure 3.3: Submarine Support Vessel - Mercuur (A900) [36]

For a picture of the reference vessels see Figure 3.3. The arrangement of the Mercuur is specifically designed to handle torpedoes. Two torpedo holds exist, each provided with an elevator: one at the aft ship at the J-deck (90 m^2) and one at foreship at the K-deck (55 m^2). The front hold gives access to the torpedo tube that is used for tests. At the H-deck on starboard side, an access - from the open work deck in the aft until the torpedo elevator in the foreship - exist. The Mercuur has a full maintenance street for the torpedoes. A torpedo is lifted via a special trench at the aft onto the open work deck (100 m^2). From the aft deck it can proceed to the torpedo disassembling room (40 m^2) from which there is access to two consecutive workshops for parts (16 m^2 + 10 m^2). From the disassembling room, the torpedo can either go via the torpedo elevator to the aft torpedo room or further to the foreship, to the torpedo assembling room (50 m^2). From there it can go through a corridor to the forward torpedo elevator which gives access to the forward torpedo room. The handling of torpedoes is very delicate work, especially because of the dangerous fuel. Otto fuel II, burns from 130°C and does not require oxygen to burn, meaning it cannot be extinguished with foam, powder, navel or a blanket. Moreover, extremely poisonous and explosive acid is released during ignition. The rooms, where the torpedoes are handled, are painted white to clearly see the coloured fuel in the event of a leak. Normally, the Mercuur operates supported by submarines. Therefore, it is important that the ship can come along a submarine safely and precisely. For this, the Mercuur has a retractable bow thruster that can give both lateral propulsion force and forward propulsion force. At the aft deck an A-frame in combination with a few winches and a crane are installed. To improve the ship movements an anti-roll tank is installed. However, the ship appears to be very uncomfortable in bad weather, which may be caused by the fact that the ship was shortened by 20 meters during the design. In addition, to prevent training torpedoes from being lost, a passive sonar has been installed to follow the launched torpedoes. The ship is also equipped with an underwater telephone to communicate with the submerged submarines and it is equipped with a torpedo launcher (for Mark 48-torpedoes). [6, 41]

3.2.4. Marine Training Vessel

Mostly, this type of vessel is used as a training vessel. Although, sometimes she is used for other tasks. For example, in 2009 she had to support the Danish Coastguard and in 2010 Van Kinsbergen had to search for a crashed model-airplane in the English Channel (which was successful). [35]

Figure 3.4: Marine Training Vessel - Van Kinsbergen (A902) [35]

For a picture of the reference vessels see Figure 3.4. The most important characteristic of Van Kinsbergen's design is that, in addition to a regular navigation bridge with all equipment, it also has a training bridge. Furthermore, she is equipped with a rigid hull inflatable boat (RHIB). [6, 41]

4

Method to Evaluate the Appropriateness of Modular Platforming

The literature review in Chapter 2, helps to understand the concept description of platforming, identifies key aspects for a successful modular platform and describes modularisation principles. Together with the vessel description, in Chapter 3, this forms the basis for identifying the objective. Subsequently, this chapter contains the method that describes the problem approach that supports and helps to make strategic decisions.

4.1. Introduction

The objective of this research is to identify the optimal modular platform-based product development strategy for a series of support vessels of the RNLN, viewed from a DSNS perspective. To create an actual product platform, Hölttä [26] defines steps required to achieve this. (The complete list is described in Paragraph 2.2.) The first two steps define how the objective can be identified. Namely by:

1. Portfolio planning - Create a platform development team, perform a market search, analyse the present product range, define the future product range.
2. Carry out a method to define the appropriateness and optimal platforming strategy - Define the platform type (i.e., architectural approach, leverage type, property setting and number of platforms), select indicators for platform evaluation, define a method to develop the platform.

Accordingly, to clarify these activities, the description of the activities are categorised by goal and plan. In other words, the research objective and its origin, and the procedure to achieve this. Subsequently, this results in the following list:

- The objective and its origin correspond to the activities described in the step portfolio planning. These are summarised as:
  - Market research - The desired product family is based on a series of support vessels of the RNLN. The current operating vessels are relatively old and need to be replaced in the short term. The indicative replacement of these vessels are illustrated in Table 3.1 in Chapter 3.
  - Present product range - The reference vessels and their mission statement are described in Paragraph 3.2. They consist out of two hydrographic survey vessels, a logistic support vessel, a submarine support vessel and/or a marine training vessel.
  - Future product range or business strategy [52] - The platform and modules/building blocks should be applicable for these support vessels. Moreover, platforming and modularisation principles should lead to an improvement of the ship's Design to

Value aspects. In other words, the future design concept should be as good or better than a traditional ETO design concept, in order to improve the stakeholder's satisfaction and to gain competitive advantage [19]. This can be achieved by [61]:

  - ◊ Minimising the lifecycle costs. Regarding platforming this means minimising overdesign and maximising the degree of integration [42].
  - ◊ Maximising the quality. This can be achieved by [44]:
    - · Improving the functionality
    - · Increasing the availability (i.e., maintainability, robustness, reliability [18])
    - · Increasing the variety
    - · Increasing environmental friendliness
    - · Increasing flexibility (for upgrading and adapting technologies)
  - ◊ Minimising the delivery time of the ship.

- The plan or problem approach is explained in the following paragraphs of this chapter. To summary, it consist the platform aspects:
  - – Basic architectural approach - The top-down approach provides more weight and importance to modularisation, as described in Paragraph 2.4.
  - – Architectural platform approach - Naturally, a modular approach.
  - – Leverage type - Because of the varying requirements of each vessel within the potential product family the leverage type is defined as beachhead approach.
  - – Methodical support for modular design - The method, most appropriate for this study, is Modular Function Deployment. In Paragraph 2.4, different modularity methods are compared, which shows that MFD provides the most support and help to make strategic decisions.

Since this study is limited by time constraints and can only be conducted by a relatively small development team, a generic method turned out to be most suitable to set up a case study. This means that, in order to explore the front end phases of the product development, the method is applicable to make a trade-off between accessibility of the conceptual design domains and completeness in terms of defining the requirement statements[1], in order to minimise the disadvantage. In addition, this approach is in line with MFD.

[1] The meaning of a requirement statement is explained in the next paragraph.

4.2. Case Study Set Up

The design approach to evaluate the ship types from a functional perspective, is based on Systems Engineering (SE). To be more specific, the exploration of the conceptual design domains, to set up this case, is composed and adapted from:

- Requirement Engineering [7]. This clearly describes how the problem domain can be formulated by an engineer and can be translated into the solution domain.
- A variant of the V-model approach. Namely, the Requirement-Functional-Logical-Physical (RFLP) approach [40]. To enable a better exploration of the domains, a clear distinction is made between the requirement-, the functional-, the logical- and the physical domain.
- The Integral Cooperation project of DSNS et al. [56]. This project makes a clear distinction between operational systems and support systems. This makes the complexity of the ship systems more understandable.

Altogether, this results in the roadmap as illustrated in Figure 4.1. Obviously, this approach is composed to perfectly match a modularity method. This method is fully described in Paragraph 4.3 and is called Modular Function Deployment (MFD) [52]. Hence, some of its steps overlap with the aforementioned disciplines/theories. In short, the steps that are grey are (also) part and of the MFD. However, step 3 to 5 are composed of additional methodical support.

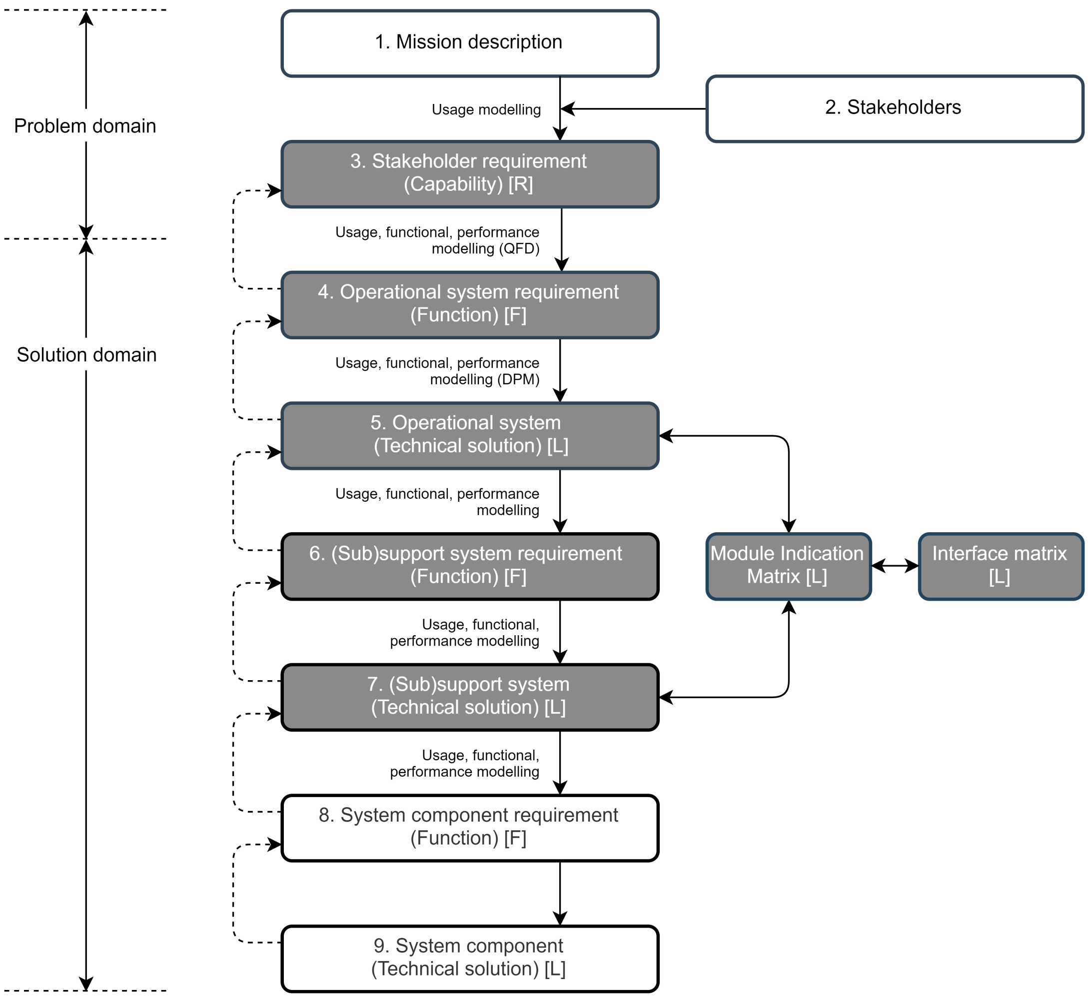


Figure 4.1: Requirement Analysis Model, adapted from [7, 40, 52, 56]

The starting point is the problem domain. This is the domain in which a system will be operating. Therefore, it is important to look at requirements from an operational point of view. Then, in order to find out what the product should be capable of, the stakeholder requirements or capabilities must be defined. For the specification of the requirements, the starting point is to identify the stakeholders as they are a legitimate source for requirements and constitute to the process of developing stakeholder requirements. By using usage modelling, the stakeholder requirements are formulated.

To clarify, the problem domain is explained according the steps of the roadmap, illustrated in Figure 4.1:

1. The initial step involves the mission description for each vessel type. This is required as this represents the need or objective of the specific vessel.
2. Step 2 involves the stakeholders. This means people, who will directly interact with the ship, but also other people and organisations that have interests in her existence. [7]
3. The stakeholder requirements correspond with the requirement engineering design domain ([R]). These requirements mainly relate to capabilities and constraints thereof. These capabilities must be described through means of a tree diagram, in order to manage the complexity. A capability statement expresses a (single) capability required by one or more identified stakeholder types. A typical capability requirement takes the following form: The <*stakeholder type*> shall be able to <*capability*>. [7].

Once a sound set of stakeholder requirements exists, that defines what the stakeholders wants to be capable of, it is possible to begin to think about potential technical solutions. This process is known as establishing the system requirements and is part of the solution domain. A typical system requirement takes the following form: The <*technical solution*> shall <*function*>. Naturally, in this expression one can add aspects like performance, an object, quantity and/or an operational condition for more detail. [7]

The process of this domain is also clarified according to the steps of the roadmap, illustrated in Figure 4.1:

4. Instead of immediately going straight to a design, it is good to first determine what characteristic the system must have, regardless the final detailed design. In other words, this process is about establishing functions that fulfil the capabilities (i.e., stakeholder requirements) and is step 4. The corresponding design domain is called the functional design domain ([F]). To visualise the complexity of this step, a functional decomposition (i.e., tree diagram) must be used.
5. Subsequently, an engineer assigns a technical solution to a specific function. This part of the design process is also called the logical architecture domain ([L]). Consequently, the obtained technical solutions are the input for the 'Module Indication Matrix' and the 'Interface Matrix'. These latter two steps are described in the next paragraph.

6 - 9. Finally, step 6 and the steps onwards are illustrated in the roadmap (Figure 4.1) in order to clarify the complexity of the ship systems' design and to make it understandable and manageable. However, due to the limited information input and the time constraint of this study, no explicit solutions (i.e., logical architecture designs for the support systems) are used as input for the 'Module Indication Matrix' and 'Interface Matrix'.

In addition, the aim regarding the final concept is that the system is safe, should perform as required and must comply to regulations. Some of these are non-functional requirements or constraints and are not taken into account in this part of the conceptual design, but must certainly be taken into account when making decisions. Furthermore, one design domain of the RFLP of the RFLP approach that is not included in the roadmap is called the physical design domain, because this is not a part of the front-end issues of the concept design.

4.3. Modular Function Deployment (MFD)

The previously described steps are used to have an input (i.e., technical solutions) for the Modular Function Deployment (MFD). In short, this method helps to identify modules or building blocks from a functional perspective and could form a base for choosing a certain strategy. However, it is important to understand that the results are and should only be the starting point for a discussion on grouping module candidates. [19]

4.3.1. Product Management Map (PMM)

As organised in the Modular Function Deployment, the information, data and knowledge gathered of the ship types can be illustrated into a collection of matrices known as the Product Management Map (PMM) [52]. For an illustration see Figure 4.2.

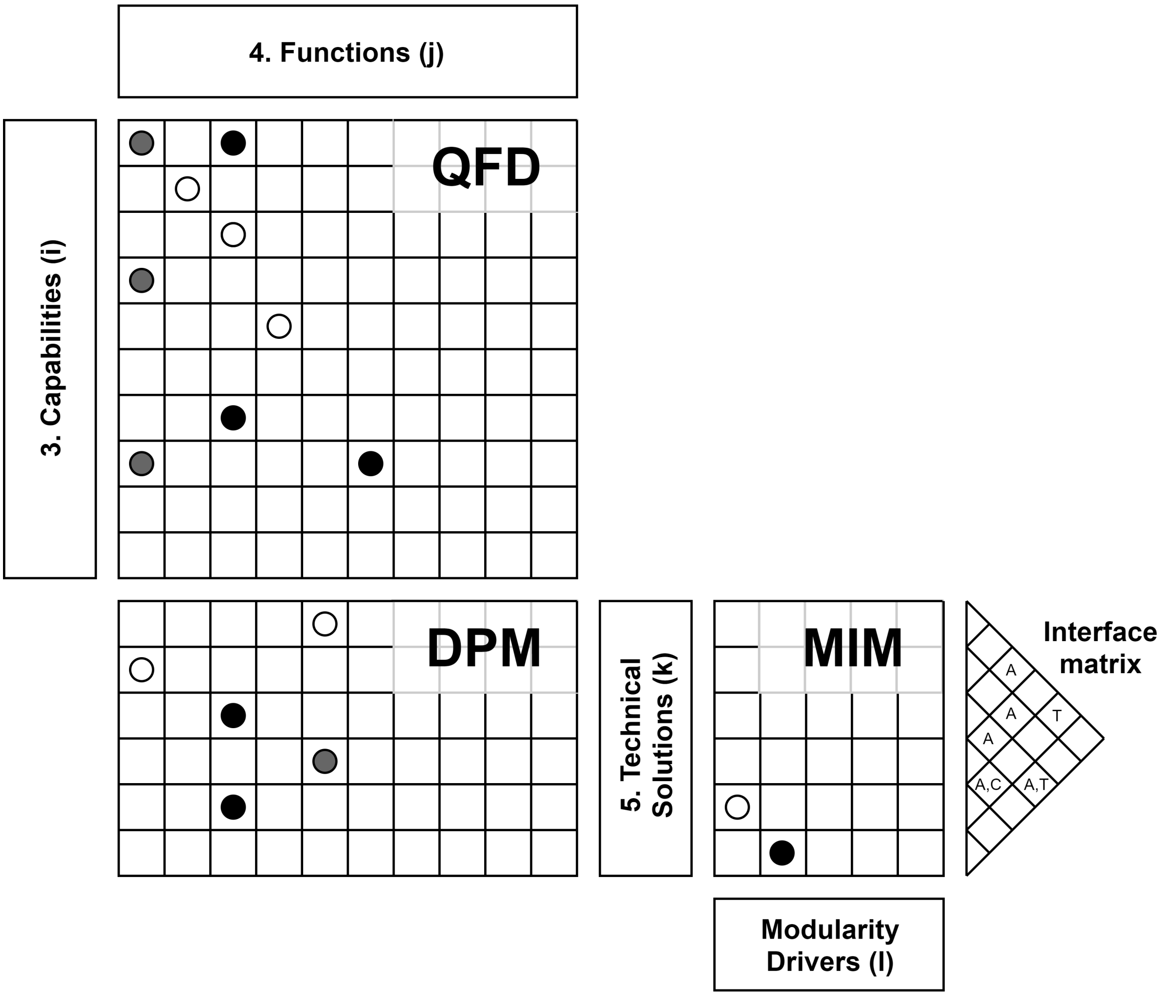


Figure 4.2: Product Management Map, adapted from [52]

The MFD considers several stakeholders during the different life cycle phases. In other words, the method compromises view points from different areas of responsibility and experience. These are called the Voice of Customer, Voice of Engineer and Voice of Business. Definitions of these concepts typically refers to at least one of the following three key conceptual attributes [52]:

- The module containment - Responding to a **Voice of Customer** perspective that the module will contain a function bearing a technical solution that is identified by taking into account quality and cost. Typically represented by the sales and/or marketing function.

- The physical limits of the module - Representing the **Voice of Engineer** in its need to manufacture modules that properly fit together. Collects input from engineering, manufacturing, quality, supply chain and the after market.
- Modularity driver - Reflecting to the **Voice of Business** in configuring a product variant using a module. Shareholders, corporate officers, or others involved in corporate governance who determine which value discipline is crucial to the success of not only the product but the business as a whole.

Figure 4.3 illustrates how these aspects relate to the mentioned matrices of the Product Management Map [25].

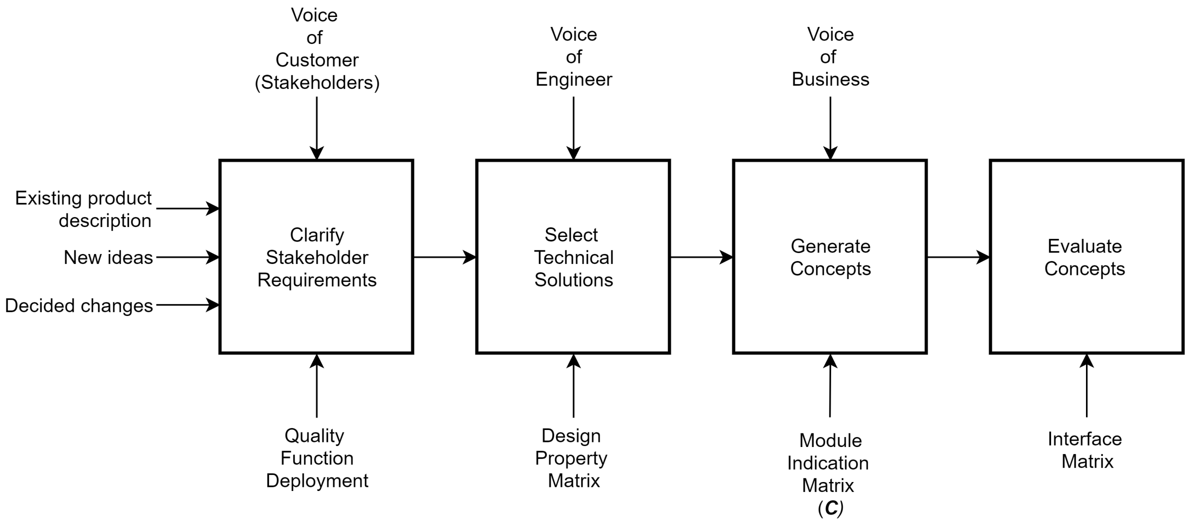


Figure 4.3: MFD Roadmap, adapted from [25]

The first matrix - **Quality Function Deployment** (QFD) - is where the stakeholder requirements are mapped against functions. Consequently, these functions are mapped to systems in the matrix called **Design Property Matrix** (DPM). In other words, this matrix is the solution domain with its system requirements. Consequently, the **Module Indication Matrix** (MIM) maps the system and its functions against the modularity drivers. The MIM matrix is where each function carrier, that is mapped against a modularity driver, is discussed one by one and is ranked. The rating scale, for the aforementioned matrices, are defined in Table 4.1.

Description QFD/DPM	Description MIM	Score	Symbol
Strong relationship	High impact	9	●
Moderate relationship	Medium impact	3	● (grey)
Weak relationship	Low impact	1	○
No relationship	No impact	0	

Table 4.1: Rating Scale

Lastly, the module concepts are evaluated in step four by considering how the modules will be physically joined together using standardised module interfaces. These are illustrated in the last matrix called **Interface Matrix**. The physical interfaces are distinguished by attachment, transfer, spatial and control & communication [8]:

- Attachment interface - This is a physical connection. This puts the pieces together or connects them physically to one another.
- Transfer interface - Provides a conduit for power or media to transfer from one module to another.

- Command & control interface - Determines how the state of a component is communicated and/or controlled by other components.
- Spatial interface - Determines the boundary between modules. It is the spatial location and volume a component can occupy.

For the denotation of the type of interface in the Interface Matrix, see Table 4.2.

Denotation	Interaction taxonomy
A	Attachment
T	Transfer
S	Spatial
C	Command & control

Table 4.2: Types of Interfaces

4.3.2. Module Indication Matrix (MIM) and its Modularity Drivers

In the MIM matrix, 12 modularity drivers are mapped against functions or technical solutions. For the purpose of this report, the 12 modularity drivers are given an index called $\boldsymbol{L}$, consisting elements l_1 until l_{12}. These modularity drivers allow one to identify modules in a comprehensive way that helps to make product strategic decisions. This means that modularity drivers are found to cover the entire product lifecycle. Also, modularity drivers cover a wide spectrum of voices as the product moves through its lifecycle, as illustrated in Figure 4.4. This coverage ensures that all stakeholders will be taken into account. [52]

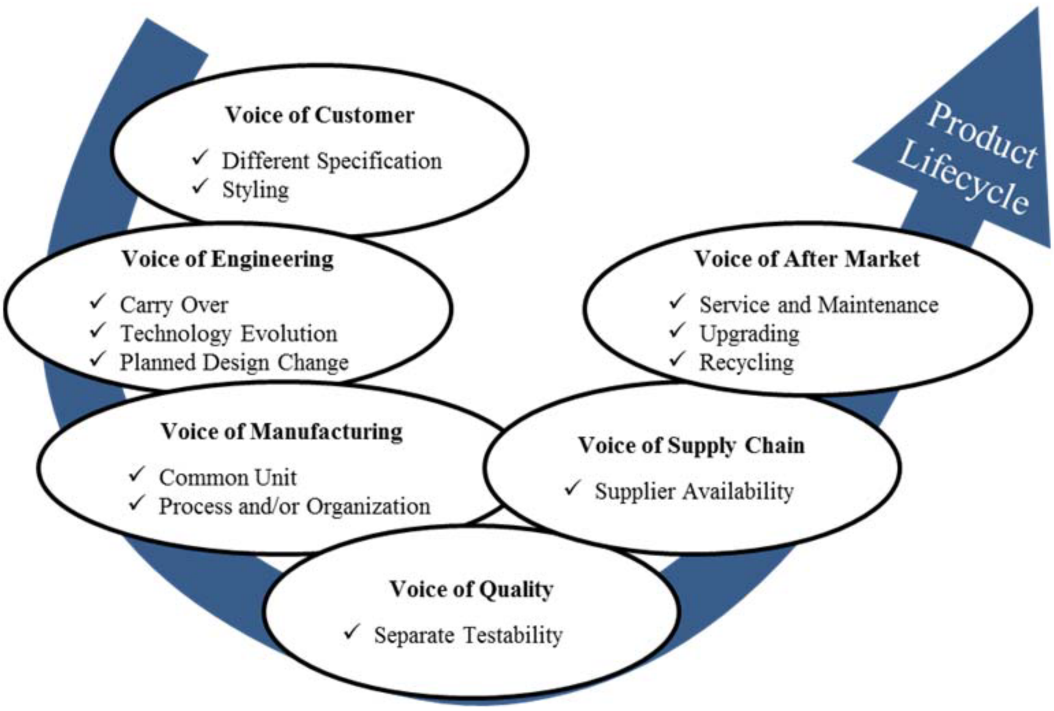


Figure 4.4: Modularity Drivers Positioned along a Product Lifecycle Stream [52]

The **Voice of Customer** reflects the need of variance for a product platform. Two module drivers are available to describe this voice:

l_1 *Different/technology specification* - Imparts the strategic need for a market specific technical solution in the product platform. When assigning this to one or a few parts of the product, the solution should not spread throughout the entire product. [19, 25]

l_2 *Styling* - Imparts the strategic need for brand driven appearance variance in the product platform as it is influenced by fashion and trends. Also, it means the possibility of altering the style without causing disruptions in the product as a whole. Styling modules typically concerns the visible parts (e.g., form and/or colour). [11, 19, 25]

The **Voice of Engineering** addresses the need to manage modules of the architecture that will have or will not have a planned design change during the platform's lifetime or modules that will go through a technology shift based on changing customer demands. (Note: this voice is not the same as the before mentioned Voice of Engineer.) Three modularity drivers address the engineering perspectives:

l_3 *Carry over* - Imparts strategies of technology re-use across generations for the product platform. I.e., no changes are expected and the technical solution of the product can be reused from an earlier product. [11, 19, 25]

l_4 *Technology push or technology evolution* - Imparts the development of technology during the lifecycle, driven by external forces outside the company. This can cause a technology shift or a radically change of customer demands. It will be important to accommodate the interfaces so that new technology can be introduced and replace the module in question. [11, 19, 25]

l_5 *Product planning or planned design change* - Imparts company internal strategies to launch new product, meet changing customer requirements, or decrease product costs. In other words, it takes into account intentions to change or develop part of the product. [11, 19, 25]

The **Voice of Manufacturing** strives to maintain a consistent, effective and efficient manufacturing process. Two modularity drivers that strengthen this approach are:

l_6 *Common units* - Imparts the strategy that a required function must have the same physical form in principally every product variant. This is usually the core platform. [19, 25]

l_7 *Process and/or organisation* - Imparts the strategy that there is a suitable collection of technology driven work content, for a manufacturing cell or work group. Hence, a specific efficient process could mean a shorter delivery lead time. For example, this could be achieved by similar types of operations that can be placed in the same team work area to enable atomisation and/or pedagogical assembly for example. [11, 19, 25]

The **Voice of Quality** seeks to improve the manufactured quality of a product. The following modularity driver is applied to address this:

l_8 *Separate testing* - Imparts strategies where functions can be tested independently of the product. The possibility of separately testing each module before delivery to final assembly may contribute to significant quality improvements, due to reduced feedback times. [11, 25]

The **Voice of Supply Chain** provides manufacturing with the material and component it needs to build the product a customer desires. The modularity driver that addresses this is called:

l_9 *Purchase, supplier availability or black box engineering* - Imparts strategies to outsource 'black box' technology in a module. In other words, a specialist/vendor can deliver the technical solution as a complete standard module instead of individual parts. This can balance the manufacturing and development capacity and reduces purchasing work.

Consequently, this could reduce the logistics costs. (The type of modules is also called black box module.) [19, 25]

The addition of non-factory accessories, parts, service or upgrades refers to the **Voice of Aftermarket**. This state of the lifecycle occurs once the product has been released to the marketplace. The following three modularity drivers support this voice:

l_{10} *Service and maintenance* - Imparts strategies where service on a product is an important customer value. For example, a damaged service module can quickly be replaced by another, because it is easily detachable. This leads to fast service. (The type of modules is also called service module.) [19, 25]

l_{11} *Upgrading* - Imparts strategies that extend the product lifetime or improve the product performance. It offers customers the opportunity to change the product in the future. [11, 25]

l_{12} *Recycling* - Imparts strategies that enable codes regarding the disposal of hazardous as well as homogeneous materials. The number of different materials can be limited and environmentally hostile materials can be kept in the same module. (The type of module is also called recycling module.) [11, 19, 25]

4.3.3. Questionnaire

To quantify the impact of the modularity driver to the technical solution or function, a questionnaire exists that helps one to discuss and support the assessment in the MIM matrix. [19]:

l_1 *Different specification* - Is this part <*strongly, fairly, to some extent, not*> influenced by specific requirements?

l_2 *Styling* - Is this part <*strongly, fairly, to some extent, not*> influenced by trends and fashion in such a way that form and/or colour has to be altered or should it be tied to a trademark?

l_3 *Carry over* - Are there <*strong, medium, any, no*> reasons that this technical solution should be a separate module, because the new design can be carried over to future product generations?

l_4 *Technology push* - Is there <*great, medium, some, no*> risk that this part will go through a technology shift during the product lifecycle?

l_5 *Product planning* - Are there <*strong, medium, some, no*> reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan?

l_6 *Common unit* - Can this function have the same physical form in <*all, most, some, none*> of the product variants?

l_7 *Process and/or organisation* - Are there <*strong, medium, some, no*> reasons why this part should be a separate module because

(a) A specific or specialised process is needed?

(b) It has a suitable work content for a group?

(c) A pedagogical assembly can be formed?

(d) The lead time will differ extraordinary?

l_8 *Separate testing* - Are there <*strong, medium, some, no*> reasons why this part should be a separate module because its function can be tested separately?

l_9 *Purchase* - Are there <*strong, medium, some, no*> reasons that this part should be a separate module because

(a) There are specialists that can deliver the technical solution as a black box?

(b) The logistics cost can be reduced?

(c) The manufacturing and development capacity can be balanced?

l_{10} *Service and maintenance* - Is it possible that <*all, most, some, none*> of the service repairs will be easier if this part is easy detachable?

l_{11} *Upgrading* - Can <*all, most, some, none*> of the future upgrading be simplified if this part is easy to change?

l_{12} *Recycling* - Is it possible to keep <*all, most, some, none*> of the highly polluting material or easy recyclable material in this part (material purity)?

In short, the aim of the questionnaire and the description of the modularity drivers in Paragraph 4.3.3, is to improve the understanding and the consistency in the ranking of the impact of a modularity driver to a technical solution.

4.4. Concluding Remarks

The purpose of this method is to explore not only the problem domain, but also the solution domain taking into account the entire lifecycle of the product and its stakeholders. As addressed in Chapter 2, the implementations in the front-end issues of the design process have major impact to the final ship's design.

According to the roadmap of this method, illustrated in Figure 4.1, the process seems to stop at the logical architecture domain. However, this is not the case. To be able to make decisions in the earlier phases, phases later in the lifecycle must be explored as well. In other words, it includes collecting input from engineering, manufacturing, quality, supply chain and the after market by using a methodical support for modular design. Namely, the MFD evaluates the extent of impact for each modularity driver against each technical solution. This helps to decide whether platforming is appropriate.

The next chapter, shows the execution of this method. Naturally, in this report the case study is about the series of navy support vessels of the RNLN.

5
Case Study Compilation

The product family design discussed in this case, is based on the reference vessels described in Chapter 3. The set up or description of the conceptual design process is structured in the same chronological order as the roadmap, illustrated in Figure 4.1. The purpose of this case study is to obtain results that help and support in making strategic decisions. Hence, the results of the case study are analysed in Chapter 6, after which they are discussed in Chapter 7.

5.1. Exploration of the Conceptual Design Domains

To set up this case study, conceptual design domains were explored in an iterative manner, in order to obtain a conceptual design of the potential product platform.

5.1.1. Mission Description - Step 1

The initial step of the method, in order to evaluate the appropriateness of modular platforming, is to define the mission description for each type of vessel. For the descriptions and for a better understanding of the vessel types, see Chapter 3.

5.1.2. Stakeholders - Step 2

Stakeholders are parties that are (in)directly involved with the ship, but are also other people and organisations that have interests in hers existence [7]. In this case study only the operator's point of view is used. In short, the reason for this is that DSNS wants to design a ship for its client. This means, the crew of RNLN has to be able to perform their mission with the ship. Accordingly, the view of this stakeholder is decisive to enable DSNS to understand the ship and to initiate a structured design process.

Naturally, there are more stakeholders which can increase the completeness of the case study. However, by using only this view, the completeness of the capability spectrum is almost entirely covered and the time required for the case study was within the limit of the time constraint. This is because the operator is the key stakeholder for these type of support vessels, as he/she is in charge of the vessel and responsible to accomplish the mission. Moreover, the operator is in close contact with other stakeholders, so automatically, the capability requirements of other stakeholders are included indirectly.

For an impression of other stakeholders, S. van den Berg [60] made a compilation:

- Ship owners - Shipowner could be an individual, a company or institution equipping and exploiting the vessel to ship cargo or to perform a specific mission.
- Ship financiers - Ship financiers have to make an investment analysis for their financing activities regarding ships. Changing economical and technical environments could have consequences to the value of the ship and therefore it is important for them to evaluate

the risks and opportunities involved in the investment. Besides this, the RNLN does not have ROI requirement.

- Regulators - Regulating parties, such as governments and the IMO could also have an interest in the problem. For example, the emission regulations.
- Port authorities - Responsibilities of port authorities include the facilitation of fuel bunkering and port access for ships.
- Other stakeholders - Parties which could also have an interest in the problem, even though indirect, are shippers, pilots and third party logistic companies.

5.1.3. Stakeholder Requirements - Step 3

The capability tree diagram conducted for the potential product family is described in this section. An illustration of the upper levels of this tree diagram is shown in Figure 5.1.

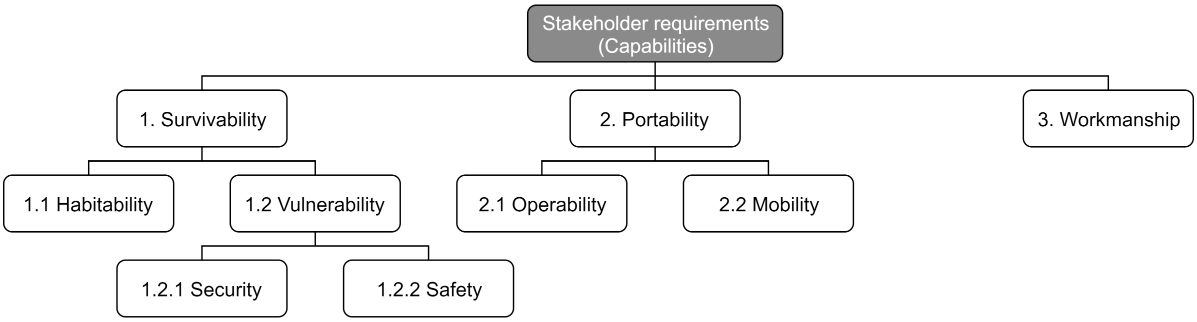


Figure 5.1: Capability Tree Diagram

Naturally, the complexity of these capabilities is reduced by further elaborating this tree diagram and defining the statements of the requirements. This resulted in the stakeholder requirements, illustrated in Table 5.1 and Table 5.2.

Id.	Requirement statement	Capability
1	The operators shall be able to survive while at sea.	Survivability
1.1	The operators shall be able to habitat.	Habitability
1.1.1	The operators shall be able to drink/eat.	Habitability
1.1.2	The operators shall be able to sleep/rest.	Habitability
1.1.3	The operators shall be able to do laundry.	Habitability
1.1.4	The operators shall be able to do sanitary needs.	Habitability
1.2	The operators shall be able to minimise vulnerability.	Vulnerability
1.2.1	The operators shall be able to secure stability and buoyancy.	Security
1.2.2	The operators shall be able to be self-protecting in case of emergencies.	Safety
1.2.2.1	The operators shall be able to extinguish a fire.	Safety
1.2.2.2	The operators shall be able to abandon ship.	Safety
1.2.2.3	The operators shall be able to rescue a person fallen in the water.	Safety
1.2.2.4	The operators shall be able to quickly react in case of an emergency.	Safety
1.2.2.5	The operators shall be able to start-up a dead ship.	Safety
2	The operators shall be able to sail in the required operational areas.	Portability
2.1	The operators shall be able to control the mission execution.	Operability
2.1.1	The operators shall be able to navigate safely and securely, at all times.	Operability

Table 5.1: Stakeholder Requirements (1/2)

Id.	Requirement statement	Capability
2.1.1.1	The operators shall be able to acquire navigational data.	Operability
2.1.1.2	The operators shall be able to operate systems remotely.	Operability
2.1.2	The operators shall be able to control the systems remotely.	Operability
2.1.3	The operators shall be able to maintain the ship's systems.	Operability
2.2	The operators shall be able to be mobile at sea or in the port.	Mobility
2.2.1	The operators shall be able to longitudinal translate the ship.	Mobility
2.2.2	The operators shall be able to rotate the ship.	Mobility
2.2.3	The operators shall be able to create a force in transversely direction.	Mobility
2.2.4	The operators shall be able to moor and unmoor in desired ports.	Mobility
2.2.5	The operators shall be able to do station keeping.	Mobility
3	The operators shall be able to perform mission specific work.	Workmanship
3.1	The operators shall be able to do hydrographic surveillance.	Workmanship
3.1.1	The operators shall be able to measure draughts in shallow waters.	Workmanship
3.1.2	The operators shall be able to measure draughts in deep waters.	Workmanship
3.1.3	The operators shall be able to minimise ship's roll movement.	Workmanship
3.1.4	The operators shall be able to acquire the measurement data.	Workmanship
3.1.5	The operators shall be able to survey the sea bottom.	Workmanship
3.2	The operators shall be able to transit cargo.	Workmanship
3.2.1	The operators shall be able to (un)load cargo.	Workmanship
3.2.2	The operators shall be able to store cargo.	Workmanship
3.2.3	The operators shall be able to secure the cargo.	Workmanship
3.3	The operators shall be able to support submarines.	Workmanship
3.3.1	The operators shall be able to detect torpedoes.	Workmanship
3.3.2	The operators shall be able to pick up torpedoes.	Workmanship
3.3.3	The operators shall be able to handle/maintain torpedoes.	Workmanship
3.3.4	The operators shall be able to communicate with submerged submarines.	Workmanship
3.4	The operators shall be able to give marine training.	Workmanship
3.4.1	The operators shall be able to educate students.	Workmanship

Table 5.2: Stakeholder Requirements (2/2)

5.1.4. System Requirements - Step 4 & 5

To translate the problem domain to the solution domain, the stakeholder requirements are assigned to functions and technical solutions. Each technical solution is dedicated to one function in order to meet the modularisation principles. This resulted in the system requirements, illustrated in Table 5.3, Table 5.4 and Table 5.5.

Id.	Requirement statement
1	The ship shall provide survivability.
1.1	The accommodation shall provide hotel facilities.
1.1.1	The cabins shall provide sleeping facilities.
1.1.2	The comfort systems shall provide comfort/sanitary facilities.
1.1.2.1	The fresh water system shall provide fresh water.
1.1.2.2	The plumbing drainage system shall treat the grey and black water.

Table 5.3: System Requirements (1/3)

Id.	Requirement statement
1.1.2.3	The Climate control system shall control the air properties.
1.1.3	The day room shall provide facilities for leisure possibilities.
1.1.4	The galley and mess room shall provide restaurant facilities.
1.1.5	The laundry facility shall provide laundry possibilities.
2.2.6	The electric power system shall provide electric power to hotel systems.
1.2	The ship shall provide security for cargo, machinery and accommodation spaces.
1.2.1	The hull system shall provide buoyancy and stability.
1.2.1.1	The hull shall secure watertight integrity.
1.2.1.2	The frames shall secure structural integrity.
1.2.1.3	The ballast system shall provide possibilities to optimise the stability in all loading conditions the ship is designed for.
1.3	The ship shall provide safety features in case of emergency situations.
1.3.1	The rescue boat shall support rescue operations at sea.
1.3.2	The life raft shall provide an alternative for abandoning the ship.
1.3.3	The fire fighting system shall support crew for extinguishing a fire (and detecting a fire).
1.3.4	The emergency alarm system shall inform the crew of an emergency/critical situation.
1.3.5	The emergency electrical power generation system shall back-up the electric power system during a black out.
2	The ship shall move from one waypoint to another.
2.1	The ship shall provide control centres for the crew.
2.1.1	The bridge shall provide a look out of the surrounding of the ship and navigational equipment.
2.1.1.1	The navigational data acquisition systems shall provide the crew navigational data.
2.1.1.2	The navigational control system shall provide the crew control over navigational systems remotely.
2.1.2	The engineering control system shall provide the crew systems information.
2.1.3	The electrical control panels shall provide the crew control of electric driven systems remotely.
2.1.4	The workshop facilities shall provide the crew space and tools for doing maintenance/repair work.
2.2	The ship shall sail agilely.
2.2.1	The propulsion system shall move the ship in longitudinal direction.
2.2.1.1	The prime mover system shall provide mechanical power.
2.2.1.2	The propulsor shall convert the rotating mechanical power into translating mechanical power.
2.2.1.3	The transmission system shall transfer mechanical energy generated by the prime mover to the propulsor.
2.2.1.4	The transmission system shall transfer the thrust generated by the propulsor to the hull system.
2.2.2	The steering gear system shall alter course if commanded to.
2.2.3	The bow thruster shall create a force in transversely direction for movement.
2.2.4	The mooring system shall forestall free movement free movement of the ship on water.
2.2.5	The anchor system shall forestall drifting away due to wind or current.
2.2.6	The electric power system shall provide electric power to all systems. (Hotel, auxiliary and propulsion)
2.2.6.1	The electrical power generation architecture shall generate electric power for the electric consumers.
2.2.6.2	The electrical distribution system shall distribute the electrical power.

Table 5.4: System Requirements (2/3)

Id.	Requirement statement
3	The ship shall perform mission specific work.
3.1	The hydrographic data acquisition system shall provide hydrographic data.
3.1.1	The sloops shall support possibilities to do hydrographic surveillance in shallow waters.
3.1.2	The echo sweep system shall provide measurement possibilities in shallow waters.
3.1.3	The echo sounders shall provide draught measurement data.
3.1.4	The magnetometer shall detect magnetic object under the seafloor.
3.1.5	The side scan sonar shall detect object on the seafloor.
3.1.6	The ROV shall support the operation remotely.
3.1.7	The hydrographic control room shall display and process the data.
3.1.8	The anti-roll system shall provide better seakeeping.
3.2	The ship shall transfer cargo.
3.2.1	The cargo system shall (un)load cargo.
3.2.2	The cargo hold/deck shall provide.
3.2.3	The cargo securement shall secure the cargo.
3.3	The ship shall assist submarines.
3.3.1	The torpedo system shall pick up torpedoes.
3.3.2	The torpedo system shall provide maintenance facilities.
3.3.3	The communication system shall provide communication facilities for submerged submarines.
3.3.4	The passive sonar shall track and follow fired torpedoes.
3.4	The ship shall support the education of marine students.
3.4.1	The training bridge shall support training the marine students.

Table 5.5: System Requirements (3/3)

5.2. Application of the MFD Method

The obtained results, described in the previous section, are used as input for the MFD method. In the MIM each function carrier, mapped against a modularity driver, is discussed and ranked separately. For the purpose of this report, besides the modularity drivers, the group of technical solutions is also structured by an index. The technical solutions are given the index set called $\boldsymbol{K}$, consisting elements k_1 until k_{45}. Both the indices and its elements are illustrated in Table 5.6 and Table 5.7.

K	**Technical solution**
k_1	Cabin
k_2	Fresh water system
k_3	Plumbing drainage system
k_4	Climate control system
k_5	Day room
k_6	Restaurant facilities
k_7	Laundry facilities
k_8	Hull
k_9	Frames
k_{10}	Ballast system
k_{11}	Rescue boat
k_{12}	Life raft
k_{13}	Fire fighting system
k_{14}	Emergency alarm system
k_{15}	Emergency electrical power generation system
k_{16}	Navigational data acquisition systems
k_{17}	Navigational control system
k_{18}	Engineering control system
k_{19}	Electrical control panels
k_{20}	Workshop facilities
k_{21}	Mechanical power generation architecture
k_{22}	Propulsor

K	**Technical solution**
k_{23}	Transmission system
k_{24}	Steering system
k_{25}	Bow thruster
k_{26}	Mooring system
k_{27}	Anchor system
k_{28}	Electrical power generation architecture
k_{29}	Switchboard
k_{30}	Sloop
k_{31}	Echo sweep system
k_{32}	Echo sounder (multi-beam)
k_{33}	Magnetometer
k_{34}	Side scan sonar
k_{35}	ROV
k_{36}	Hydrographic processing systems
k_{37}	Anti-roll tank
k_{38}	Cargo handling system
k_{39}	Hold/deck
k_{40}	Cargo securement
k_{41}	Torpedo handling system
k_{42}	Maintenance street
k_{43}	Communication system
k_{44}	Passive sonar
k_{45}	Training bridge

Table 5.6: Index ***K*** - Technical Solutions

L	**Modularity driver**
l_1	Different specification
l_2	Styling
l_3	Carry over
l_4	Technology push
l_5	Product planning
l_6	Common unit

L	**Modularity driver**
l_7	Process/organisation
l_8	Separate testing
l_9	Purchase
l_{10}	Service/maintenance
l_{11}	Upgrading
l_{12}	Recycling

Table 5.7: Index ***L*** - Modularity Drivers

In addition, the stakeholder requirements and the system requirements, described in Paragraph 5.1, are structured in matrices according to the **PMM** and are illustrated in Appendix B.1 until Appendix B.5, in order to illustrate the relationship among the design domains. In short, this shows the relationship among **capabilities**, **functions** and **technical solutions**.

5.2.1. MIM

Accordingly, the Module Indication Matrix is illustrated in Table 5.8 together with its input. For the decision support for each ranking, see Appendix B.6.

As a reminder, the ranking between technical solution and modularity driver is indicated by symbols implying the impact:

- High impact (●)
- Medium impact (◐)
- Low impact (○)

For a detailed description of the MIM, see Paragraph 4.3.

	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}
k_1			●			●	●		●			
k_2	○		○	○		◐	○		◐			
k_3	○		○			◐	○		◐			
k_4	○		○			◐	○		◐			◐
k_5			◐			◐	●		●			
k_6	○		◐			◐	◐	○	◐			○
k_7	○		◐			◐	●		●	○		
k_8			◐			◐	●		●			
k_9			◐			◐	●		●			
k_{10}			○			○	○		○			
k_{11}			●			●	●		●			
k_{12}			●			●	●		●			
k_{13}			○	○		◐	○		◐	○	○	
k_{14}							○		○			
k_{15}				◐	◐	◐	○		◐	○	○	
k_{16}				○		◐	◐		●			
k_{17}						◐	◐		●			
k_{18}						◐	◐		●			
k_{19}						○	○		◐			
k_{20}			○			◐	◐		○			
k_{21}			○	◐	◐	◐	○			○	○	
k_{22}	●						●		●			
k_{23}	○		○	○	○	◐	◐		○			
k_{24}			○			◐	◐		◐			
k_{25}	○		○			◐	●		●			
k_{26}			◐			◐	◐		○			
k_{27}			◐			◐	◐		○			
k_{28}			○	◐	◐	◐	○		○	○	○	
k_{29}	○		○			◐	◐		◐	○		
k_{30}	●						●		●			
k_{31}	●				○		●		●		◐	
k_{32}	●				○	○	●		●		◐	
k_{33}	●				○		●		●		◐	
k_{34}	●				○		●		●		◐	
k_{35}	●				○		●		●		◐	
k_{36}	●						●		●		◐	
k_{37}	◐		○			○	◐		○			
k_{38}	◐					○	◐		◐			
k_{39}	◐					○						
k_{40}			●			◐	◐		◐			
k_{41}	●						●		●			
k_{42}	●						◐	○	◐			
k_{43}	●						◐		●			
k_{44}	●						●		●		◐	
k_{45}	●						◐		◐		○	

Table 5.8: Module Indication Matrix Scoring

5.2.2. Interface Matrix

Step four of the MFD method defines the interfaces among the technical solutions. To summarise, the interactions of the logical architectures are judged by the need of coupling design parameters in order to meet the functional requirements. In technical modularity, this is done regardless the physical realisation in manufacturing. The obtained results are illustrated in Table 5.9 and Table 5.10.

As reminder, the interfaces are categorised by:

- Attachment (A)
- Transfer (T)
- Command & control (C)
- Spatial (S)

For a detailed description of the interfaces, see Paragraph 4.3.

	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	k_9	k_{10}	k_{11}	k_{12}	k_{13}	k_{14}	k_{15}	k_{16}	k_{17}	k_{18}	k_{19}	k_{20}	k_{21}	k_{22}	k_{23}
k_1		T	T	T				S	A				T	T									
k_2			T		T	T	T	S	A										C, T				
k_3					T	T	T	S	A										C, T				
k_4					T	T	T	S	A										C, T				
k_5								S	A				T	T									
k_6								S	A				T	T									
k_7								S	A				T	T									
k_8									A, S	A, S	S	S	S	S	S	S	S	S	S	S	S		S
k_9										A	A	A	A	A	A	A	A	A	A	A	A		A
k_{10}																			C, T				
k_{11}																							
k_{12}																							
k_{13}																			C	T			
k_{14}																							
k_{15}																			C, T				
k_{16}																							
k_{17}																					C, T		
k_{18}																					C, T		T
k_{19}																				C, T	C, T		
k_{20}																							
k_{21}																							
k_{22}																							
k_{23}																							
k_{24}																							
k_{25}																							
k_{26}																							
k_{27}																							
k_{28}																							
k_{29}																							
k_{30}																							
k_{31}																							
k_{32}																							
k_{33}																							
k_{34}																							
k_{35}																							
k_{36}																							
k_{37}																							
k_{38}																							
k_{39}																							
k_{40}																							
k_{41}																							
k_{42}																							
k_{43}																							
k_{44}																							
k_{45}																							

Table 5.9: Interface Matrix (1/2)

	k_{24}	k_{25}	k_{26}	k_{27}	k_{28}	k_{29}	k_{30}	k_{31}	k_{32}	k_{33}	k_{34}	k_{35}	k_{36}	k_{37}	k_{38}	k_{39}	k_{40}	k_{41}	k_{42}	k_{43}	k_{44}	k_{45}
k_1						C, T																
k_2						C, T																T
k_3						C, T																T
k_4						C, T																T
k_5						C, T																
k_6						C, T																
k_7						C, T																
k_8	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
k_9	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
k_{10}						C, T																
k_{11}																						
k_{12}																S						
k_{13}						C, T										S						
k_{14}						C, T										T			T			T
k_{15}						C, T																
k_{16}						C, T																
k_{17}	C, T	C, T				C, T																
k_{18}	C, T	C, T				C, T																
k_{19}	C, T	C, T	C, T	C, T		T		C, T	C, T	C, T	C, T	C, T	C, T	C, T	C, T			C, T	C, T	C, T	C, T	C, T
k_{20}						C, T																
k_{21}						C, T																
k_{22}																						
k_{23}																						
k_{24}						C, T																
k_{25}						C, T																
k_{26}						C, T																
k_{27}						C, T																
k_{28}						C, T																
k_{29}								C	C	C	C	C	C	C, T	C, T			C, T	C, T	C, T	C, T	C, T
k_{30}													C, T			S						
k_{31}													C, T									
k_{32}													C, T									
k_{33}													C, T									
k_{34}													C, T									
k_{35}													C, T									
k_{36}																						
k_{37}																						
k_{38}																						
k_{39}																						
k_{40}																						
k_{41}																						
k_{42}																						
k_{43}																						
k_{44}																						
k_{45}																						

Table 5.10: Interface Matrix (2/2)

5.3. Concluding Remarks

In this chapter, the performed case study is compiled according to the method, described in Chapter 4. The results from Paragraph 5.2 serve as support for making strategic decisions. However, to make these results useful, they require first an analysis, taking into account the key aspects for creating a successful platform. In the next two chapters, the MIM and the Interface Matrix are evaluated.

6 Analysis of the MIM Results

This chapter interprets the results from the Module Indication Matrix. The first step towards a successful (modular) platform is to find functional commonalities among the ship types of the potential product family. This step is addressed by grouping the technical solutions after applying the MFD. Additionally, main modularity drivers for DSNS are identified and the potential for modularity for each technical solution is determined.

6.1. Introduction

To verify the influence of the modularity drivers regarding the potential modular platform and to identify potential modules from a logical architecture perspective, the results of the MIM are analysed. To enable a clear analysis, it is important to indicate the elements of the matrices in an understandable way. Therefore, the MIM is represented as a $k \times l$ matrix $\boldsymbol{C}$.

$$\boldsymbol{C} = \begin{bmatrix} c_{1,1} & c_{1,2} & \cdots & c_{1,l} \\ c_{2,1} & c_{2,2} & \cdots & c_{2,l} \\ \vdots & \vdots & \ddots & \vdots \\ c_{k,1} & c_{k,2} & \cdots & c_{k,l} \end{bmatrix} = \begin{bmatrix} c_{1,1} & c_{1,2} & \cdots & c_{1,12} \\ c_{2,1} & c_{2,2} & \cdots & c_{2,12} \\ \vdots & \vdots & \ddots & \vdots \\ c_{45,1} & c_{45,2} & \cdots & c_{45,12} \end{bmatrix} = \begin{bmatrix} \mathbf{l_1} & \mathbf{l_2} & \cdots & \mathbf{l_{12}} \end{bmatrix}$$

As a recap, the 12 modularity drivers are illustrated in Table 6.1 showing their relation with the various voices. Furthermore, Simpson et al. [52] aligned the modularity drivers with three value disciplines. These can help to form the desired way of managing a business.

Voice of 'X'	Modularity driver	L	Value Discipline
Customer	Different specification	l_1	Customer intimacy
	Styling	l_2	Customer intimacy
Engineering	Carry over	l_3	Operational excellence
	Technology push	l_4	Product leadership
	Product planning	l_5	Product leadership
Manufacturing	Common unit	l_6	Operational excellence
	Process and/or organisation	l_7	Operational excellence
Quality	Separate testing	l_8	Operational excellence
Supply Chain	Purchase	l_9	Operational excellence
After Market	Service and maintenance	l_{10}	Customer intimacy
	Upgrading	l_{11}	Customer intimacy
	Recycling	l_{12}	Operational excellence

Table 6.1: Relation between Voice of 'X', Value Disciplines and Modularity Drivers, adapted from [52]

6.2. Modularity Drivers

Firstly, the modularity drivers were evaluated using the MIM's input to ultimately compare them with each other. This helped to understand why DSNS should create a modular platform. Furthermore, it supported the indication of potential modules and their strategic goal. In Figure 6.1, the relative weight of each modularity driver for this potential modular platform, is illustrated in a bar diagram.

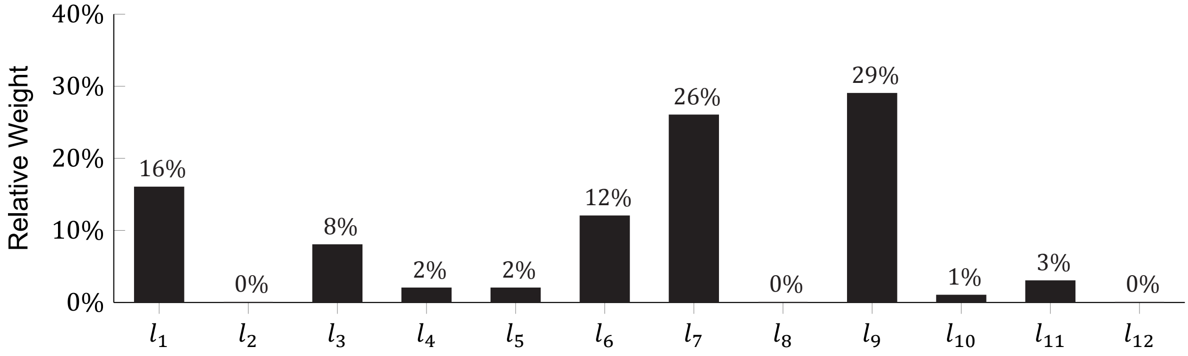


Figure 6.1: Relative Weight of Modularity Drivers - Total Platform

Before analysing Figure 6.1, the MIM's input was further analysed. Striking is two groups of technical solutions that have the same, or non-contradictory, modularity drivers. Therefore, the technical solutions are categorised into common technical solutions and market specific technical solutions in order to improve the evaluation process. This is also in line with a key aspect for creating a successful platform, namely commonality. The **common technical solutions** are $k_1, \ldots, k_{29}$ and the **market specific technical solutions** are $k_{30}, \ldots, k_{45}$. The relative weight of the modularity drivers is illustrated Figure 6.2.

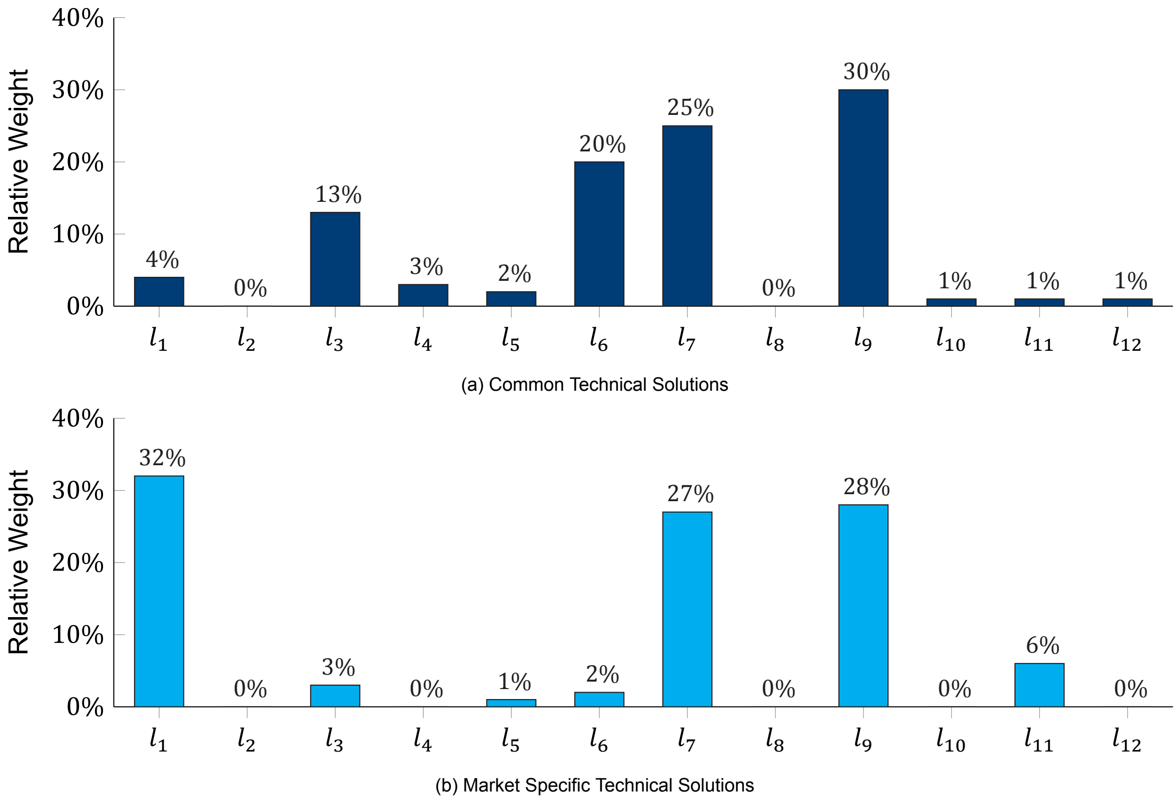


Figure 6.2: Relative Weight of Modularity Drivers - Subdivided Platform

All these relative weights are obtained from the modularity driver scoring, summarised in Table 6.2.

	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}
$\sum_{k=1}^{45} c_{kl}$	134	0	70	13	15	102	220	2	248	6	27	4
$\sum_{k=1}^{29} c_{kl}$	17	0	60	13	10	95	121	1	145	6	5	4
$\sum_{k=30}^{45} c_{kl}$	117	0	10	0	5	7	99	1	103	0	22	0

Table 6.2: Modularity Driver Scoring - Total Platform

Obviously, there is a difference in scoring between the types of platform groups. The main modularity drivers for DSNS that help to indicate common potential modules and make strategic decisions are:

- Carry over (l_3)
- Common unit (l_6)
- Process/organisation (l_7)
- Purchase (l_9)

On the other hand, the main modularity drivers for the market specific group of technical solutions are:

- Different specification (l_1)
- Process/organisation (l_7)
- Purchase (l_9)
- Upgrading (l_{11})

The modularity driver *upgrading* did not score very high in the latter group. Nevertheless, it is considered a main modularity driver for market specific technical solutions, as it represents the value discipline customer intimacy, besides the modularity driver *different specification*. Obviously, this modularity driver did not score very high, because of the dominance of the other three. Nonetheless, for some technical solutions this one is of significant importance, as can been seen in the MIM.

Subsequently, these main modularity drivers are used for the procedure identifying potential modules per group. Furthermore, the modularity drivers that have less impact to the two groups as a whole, will not be excluded entirely, because they may provide important information for some technical solutions.

6.3. Potential Modules

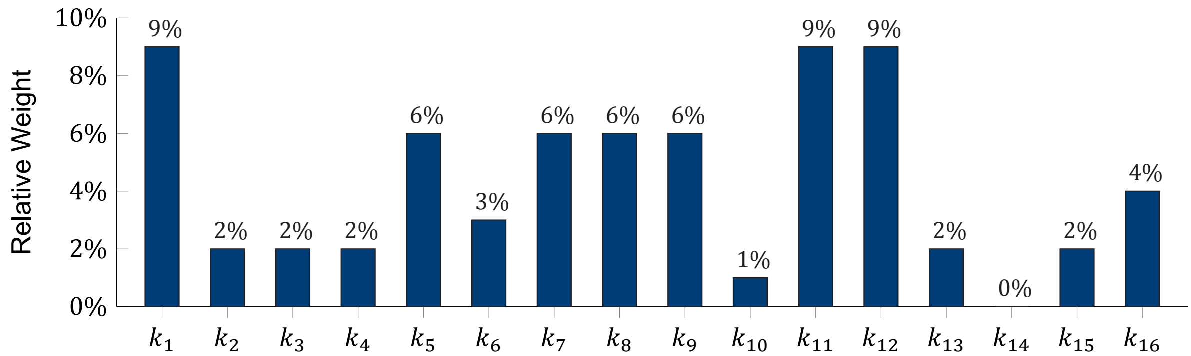
To identify potential modules, the sums of the main modularity drivers per technical solution are calculated. Also, the sums of all the modularity drivers (MD) per technical solution are calculated, because a great difference between the sums indicate technical solutions that have specific modularity drivers. Overall, this resulted in Table 6.3 for the **common technical solutions**, where the symbol '●' indicates technical solutions that have specific modularity drivers.

K	Common technical solution	Sum of all MD	Sum of main MD	
k_1	Cabin	36	36	
k_2	Fresh water system	10	8	
k_3	Plumbing drainage system	9	8	
k_4	Climate control system	12	8	
k_5	Day room	24	24	
k_6	Restaurant facilities	15	12	
k_7	Laundry facilities	26	24	
k_8	Hull	24	24	
k_9	Frames	24	24	
k_{10}	Ballast system	4	4	
k_{11}	Rescue boat	36	36	
k_{12}	Life raft	36	36	
k_{13}	Fire fighting system	11	8	
k_{14}	Emergency alarm system	2	2	
k_{15}	Emergency electrical power generation system	15	7	●
k_{16}	Navigational data acquisition systems	17	15	
k_{17}	Navigational control system	15	15	
k_{18}	Engineering control system	15	15	
k_{19}	Electrical control panels	5	5	
k_{20}	Workshop facilities	8	8	
k_{21}	Mechanical power generation architecture	16	8	●
k_{22}	Propulsor	27	18	●
k_{23}	Transmission system	11	8	
k_{24}	Steering system	10	10	
k_{25}	Bow thruster	23	22	
k_{26}	Mooring system	10	10	
k_{27}	Anchor system	10	10	
k_{28}	Electrical power generation architecture	14	6	●
k_{29}	Switchboard	12	10	

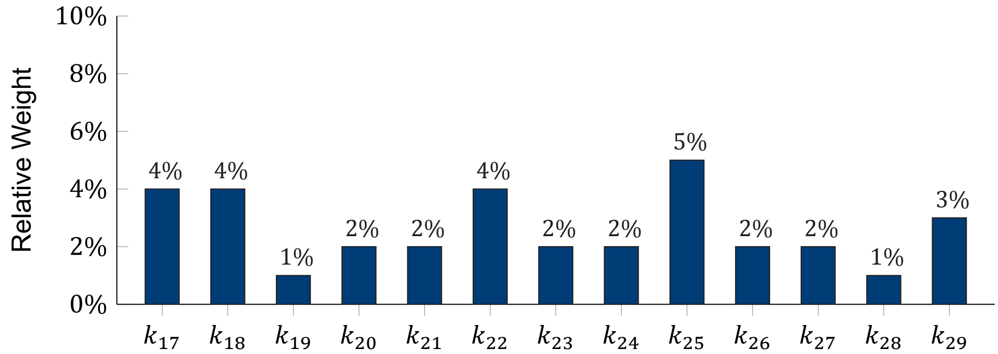
Table 6.3: Common Technical Solution Scoring ($k_1, \ldots, k_{29}$)

The obtained results from the MIM matrix, illustrated in Table 6.3, are used to calculate the relative weight of each common technical solution. For this calculation, only the impact of the main modularity drivers is used.

This resulted in Figure 6.3a and Figure 6.3b. (The sum is not exactly 100%, because all the percentages are rounded to integer numbers.)



(a) Relative Weight of Common Technical Solutions ($k_1, \ldots, k_{29}$) (1/2)



(b) Relative Weight of Common Technical Solutions ($k_1, \ldots, k_{29}$) (2/2)

Figure 6.3: Relative Weight of Common Technical Solutions ($k_1, \ldots, k_{29}$)

The approach to identify potential modules among the **market specific technical solutions** is exactly the same as the one used for the common technical solutions. Subsequently, this resulted in Table 6.4 and Figure 6.4.

K	Market specific technical solution	Sum of all MD	Sum of main MD
k_{30}	Sloop	27	27
k_{31}	Echo sweep system	31	30
k_{32}	Echo sounder (multi-beam)	32	30
k_{33}	Magnetometer	31	30
k_{34}	Side scan sonar	31	30
k_{35}	ROV	31	30
k_{36}	Hydrographic processing systems	30	30
k_{37}	Anti-roll tank	9	7
k_{38}	Cargo handling system	10	9
k_{39}	Hold/deck	4	3
k_{40}	Cargo securement	18	6
k_{41}	Torpedo handling system	27	27
k_{42}	Maintenance street	16	15
k_{43}	Communication system	21	21
k_{44}	Passive sonar	30	30
k_{45}	Training bridge	16	16

Table 6.4: Market Specific Technical Solution Scoring ($k_{30}, \ldots, k_{45}$)

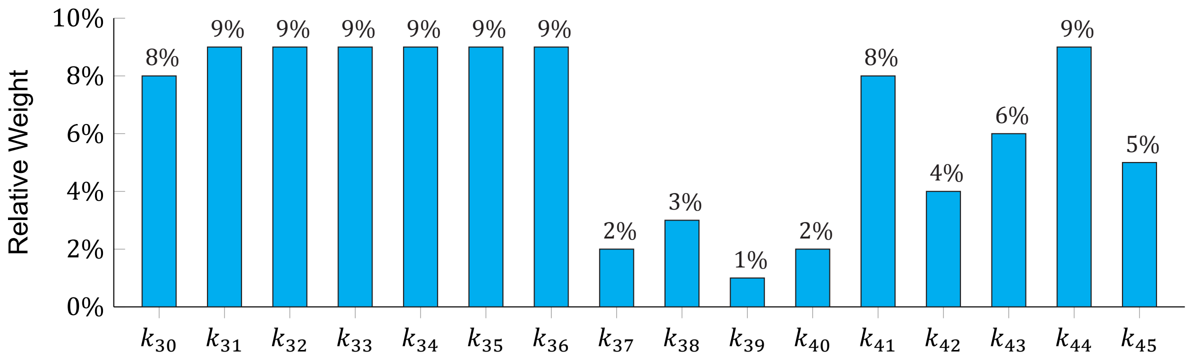


Figure 6.4: Relative Weight of Market Specific Technical Solutions ($k_{30}, \ldots, k_{45}$)

To summarise, the results of Figure 6.3a and Figure 6.3b expose common technical solutions that have relative high/medium potential for modular design. These are further discussed in the next chapter. The potential modules are:

- High potential (7% - 9%)
  - Cabin (k_1)
  - Rescue boat (k_{11})
  - Life raft (k_{12})
- Medium potential (4% - 6%)
  - Day room (k_5)
  - Laundry facilities (k_7)
  - Hull (k_8)
  - Frames (k_9)
  - Navigational data acquisition systems (k_{16})
  - Navigational control systems (k_{17})
  - Engineering control systems (k_{18})
  - Propulsor (k_{22})
  - Bow thruster (k_{25})

The market specific technical solutions, that have potential for a modular design, are exposed in Figure 6.4 and are also further discussed in the next chapter. These potential modules are:

- High potential (7% - 9%)
  - Sloop (k_{30})
  - Echo sweep system (k_{31})
  - Echo sounder (multi-beam) (k_{32})
  - Magnetometer (k_{33})
  - Side scan sonar (k_{34})
  - ROV (k_{35})
  - Hydrographic processing systems (k_{36})
  - Torpedo handling system (k_{41})

  - Passive sonar (k_{44})
- Medium potential (4% - 6%)
  - Maintenance street (k_{42})
  - Communication system (k_{43})
  - Training bridge (k_{45})

Technical solutions that (also) have other significant modularity drivers, besides the identified main modularity drivers for DSNS, are:

- Emergency electrical power generation system (k_{15})
- Mechanical power generation architecture (k_{21})
- Propulsor (k_{22})
- Electrical power generation architecture (k_{28})
- Cargo securement (k_{40})

Despite the high score of the cargo securement (k_{40}), this technical solution is not further discussed in the report. This technical solution has only a minor influence on the rest of the design process, because of the small interaction and the small affect on the rest of the product.

Then, the modularity driver the propulsor (k_{22}) is not sharing with the other common technical solutions is *different specification*. This is due to the fact that the physicality is not likely to be common among the ship types.

The other technical solutions (k_{15}, k_{21}, k_{28}) mentioned are impacted by the modularity drivers *technology push* and *product planning* and are discussed in the next chapter.

6.4. Concluding Remarks

In this chapter, the results are analysed from a platform perspective and a modular design perspective. Firstly, for better results it is important to realise how different platforms interact and affect one another. As a start, the technical solutions are grouped by modularity drivers. Also, an indication is given whether a technical solution is a modular candidate or not.

In the next chapter, the results of the MIM and the Interface Matrix are (further) discussed to be able to make substantiated strategic decisions in the end.

7
Discussion on Modular Design Properties of Potential Modules

This chapter connects the obtained results from the Module Indication Matrix and the Interface Matrix and the learnings from the literature review in Chapter 2. In other words, this is used as a guideline to support decisions towards a physical product platform.

7.1. Introduction

To apply the multi-platform principle, it is important to understand how the different platforms interact and affect one another. Therefore, the potential modular designs are distinguished by the degree of commonality and the type of modular driver. To clarify, Figure 2.13 in Chapter 2 provides a clear product decomposition with respect to commonality and market specifics.

Then, as a guidance to substantiate decisions towards a physical product platform and to clarify the potential modules, the following aspects are considered:

- Taking into account the degree of technical detail of the function carriers. Some of the concept descriptions, in Appendix B.6, are too general and therefore restricted to make substantiated decisions. Also, some subfunctions require support functions/systems. In this study these are not yet defined.
- Determining the strategic reason for modularisation of a technical solution. This could be commonality, mission flexibility, evolutionary acquisition, adaptability or other modularity drivers defined by the MFD method. In addition, expectations in terms of change regarding the potential module are important.
- Examining the possibility of manufacturing technical solutions into modules or building blocks. In other words, there must be a suitable work content for a group of standardised components. Therefore, things to consider are:
  - The degree of distribution throughout the ship and the interfaces.
  - A technical solution may not have a suitable work content, while integrated with another technical solution it becomes suitable.
- Examining whether a technical solution is physically feasible.
  - Determine whether technical solutions require multiple variants.
  - In other words, the product property setting of the (integrated) technical solutions can be defined as fixed, bounded or free.
  - Determine what physical interface type is most appropriate for the technical solution, both from a ship perspective and a module perspective.

– This information can also be used to determine whether the technical solution can be carried over to products not considered for this product family.

Consequently, an overview is made by stating the modular design property settings of every technical solution with potential for a modular design. These modular design property settings include:

1. Variants - The product property settings define how the product properties are incorporated within the platform strategy. However, due to the early design phase of this study, only the required amount of variants can be determined. In addition, the relation among these variants can be determined. In Paragraph 2.2, this concept is evaluated.
2. Module type - Modules can be categorised into several types. For a detailed description, see Paragraph 2.3.2.
3. Modularity type I - In physical modularity, modules can be linked in several ways. For the different types of interfaces, see Paragraph 2.3.1. In this context, the 'I' refers to modularity, taking into account the module's interfaces/interaction with the ship.
4. Modularity type II - The 'II' refers to the internal modularity of the potential module. Namely, the module itself can be built out of other modules and/or building blocks.
5. Design - This comprehends the comparison of the design approach with the requirement environment. For a more detailed description, see Paragraph 2.3.2 and in particular Figure 2.9.
6. Carry over - This modularity driver does not only tell something about (un)expected requirement changes, but also includes the potential to reuse the modular design for other ships that are not considered in this study.

7.2. Core Platform

According to the results of the MFD method, the function carriers, listed in Table 7.1, have the greatest potential for a modular design. For the core platform these modules are called common modules. Each one has its own modular properties as discussed below.

K	**Potential Module**
k_1	Cabin
k_5	Day room
k_7	Laundry facilities
k_8/k_9	Hull/Frames
k_{11}	Rescue boat
k_{12}	Life raft
k_{16}	Navigational data acquisition systems
k_{17}	Navigational control system
k_{18}	Engineering control system
k_{22}	Propulsor
k_{25}	Bow thruster

Table 7.1: Core Platform

Cabin

This logical architecture has transfer interfaces with the comfort systems and an attachment interface with the frames. Also, this function carrier is not distributed throughout the ship. Due to the type of interfaces, its relatively simple logical architecture and the minimal chance for changing requirements, makes it an ideal module. The cabin requires multiple variants, because of the difference in cabins between the rankings of the crew (officers and petty officers). These variants can have fixed or bounded property settings and can be used for each ship type. Therefore, bus modularity is found most appropriate. In other words, standardising the physical interfaces for the module variants. Another reason for modularisation is the possibility of carrying over the potential design, as it may also be suitable for other ships that are not part of the potential product family. To clarify, this is summarised and illustrated in Table 7.2.

Design Property	Remark
Variants	Multiple (fixed or scalable)
Module type	Common
Modularity type (I)	Bus
Modularity type (II)	Combinatorial
Design approach	Optimised point design
Carry over	Potential

Table 7.2: Modular Design Properties - Cabin

Day Room and Laundry Facilities

The day room and laundry facilities are not integrated technical solutions, but share the same modular design properties. The logical architectures roughly correspond with the cabin, in terms of interfaces from a technical perspective, the relatively simplicity of the technical solutions and the chance of changing performance requirements during the lifecycle of the product. In conclusion, a modular design for these technical solutions is suitable. These technical solutions require both two variants, because of the difference in complement among the vessel types of the potential product family. Again, the property settings can be the fixed or bounded for both product variants and bus modularity seems most appropriate, which means the physical interfaces of the two variants are standardised. Just like the cabin, this potential modular design is suitable to be carried over, because of the global use of this concept. To clarify, this is summarised and illustrated in Table 7.3.

Design Property	Remark
Variants	Two (fixed or scalable)
Module type	Common
Modularity type (I)	Bus
Modularity type (II)	Combinatorial
Design	Fixed
Carry over	Potential

Table 7.3: Modular Design Properties - Day Room and Laundry Facilities

Hull/Frames

The hull and the frames should be integrated, because combining them makes it a suitable work content for a modular design when taking into account the production perspective. Obviously, these function carriers have interfaces with all other technical solutions, as illustrated in the Interface Matrix. Therefore, its design is not as flexible as other technical solutions that have less interfaces. One logical interface type for this integrated technical solution is to design this as the main body for bus modularity or component swapping modularity and can be called a self-contained module. Because of the difference in displacement between the product variants (1,000 to 2,000 tonnes), one variant (fixed property settings) for this building block would create, most-likely, too much overdesign. Therefore, cut-to-fit modularity is found to be most appropriate, as this makes it possible to minimise the degree of overdesign, while maximising the degree of integration. This means that the properties will be bound for this building block. (One example of such a design is the SIGMA concept of

DSNS.) Naturally, during the design process it should consider all other technical solutions because of the interfaces it has with other technical solutions. This means, that the design is partly flexible, because of the core platform (B), described in Paragraph 7.3. The extent of carrying over this potential design concept depends on the bounded property settings and the expected displacement constraints. Nonetheless, besides the RNLN, there can be other customers that may be interested in this concept in the future. To clarify, this is summarised and illustrated in Table 7.4.

Design Property	Remark
Variants	Variable (bounded settings)
Module type	Common building blocks
Modularity type (I)	Component swapping, main body
Modularity type (II)	Cut-to-fit
Design	Fixed and partly flexible
Carry over	Potential

Table 7.4: Modular Design Properties - Hull/Frames

Life Raft and Rescue Boat

Because of the low number of interfaces (i.e., one attachment interface), the independency, no expected changing requirements and physically compactness of these function carriers, they have a high potential for a self-contained modular design. Another modularity driver is *purchase*, because vendors can deliver these potential modules as black box modules. However, a module with combinatorial modularity is more appropriate, as maintenance can be performed more easily, because of the understandable interfaces. For DSNS, *carry over* is not a direct modularity driver, but it is indirectly. Because a specialist or vendor can serve a bigger market, which is beneficial for optimising the product and lower acquisition cost caused by a higher scale of production. To clarify, this is summarised and illustrated in Table 7.5.

Design Property	Remark
Variants	1
Module type	Common, self-contained
Modularity type (I)	Bus
Modularity type (II)	Combinatorial or black box
Design	Fixed
Carry over	High potential (for a vendor)

Table 7.5: Modular Design Properties - Life Raft and Rescue Boat

Navigational Data Acquisition Systems

Naturally, this technical solution contains several specific subsystems each performing their own function regarding navigation. Nonetheless, in the conceptual design phase these systems are relatively similar in terms of modular design properties. The systems are spread through the ship, but by creating compact building blocks this disadvantage can be minimised. This makes each system a potential module. An important modularity driver is again 'purchase'. A vendor can create these as black box modules and can serve also other customers than DSNS. Since every ship is equipped with the similar navigational systems, the potential to sell this module to other customers is high. Furthermore, fixed boundaries would be ideal regarding fixed requirements and interfaces with other technical solutions. For example, the hull/frames. To clarify, this is summarised and illustrated in Table 7.6.

Design Property	Remark
Variants	1
Module type	Common
Modularity type (I)	Component swapping
Modularity type (II)	Combinatorial or black box
Design	Fixed
Carry over	High potential (for a vendor)

Table 7.6: Modular Design Properties - Navigational Data Acquisition Systems

Navigational Control System and Engineering Control System

The approach to determine the modular design corresponds with the one for navigational data acquisition systems. The description for these systems are not very detailed, but sufficient enough to determine the design properties. A modularity driver for these systems is the consequence its relative complexity. Therefore, a specialist can balance the manufacturing and development capacity, by designing this as a black box module. For example a console. Another thing to consider is the inclusion of product specific input for these modules. To clarify, this is summarised and illustrated in Table 7.7.

Design Property	Remark
Variants	1 or variable (bounded settings)
Module type	Common
Modularity type (I)	Bus
Modularity type (II)	Combinatorial or black box
Design	Fixed
Carry over	Low potential (for a vendor)

Table 7.7: Modular Design Properties - Navigational and Engineering Control System

Propulsor

The propulsor must meet many physical boundary conditions to be efficient. Within this potential product family, these vary among the ship types. For example, this can be caused by difference in operational profile, displacement and hull form. Therefore, modularisation principles for this technical solution are not found to be beneficial. Nonetheless, the architectural approach for the propulsor can still be called modular as it fulfils one function. To clarify, this is summarised and illustrated in Table 7.8.

Design Property	Remark
Variants	4 (fixed settings)
Module type	Common
Modularity type I	Bus
Design approach	Fixed
Carry over	Low potential (for a vendor)

Table 7.8: Modular Design Properties - Propulsor

Bow thruster

The most important interfaces of the bow thruster are the transfer and control interfaces it has with the switchboard and the attachment interface with the frames. In addition, this function carrier is not distributed throughout the ship. Therefore, the type of interfaces, its relatively simple logical architecture and the minimal chance for changing requirements make it an ideal module. One constraint for the submarine support vessel is that the bow thruster is retractable. This suggests that two variants for this module will be desired. To clarify, this is summarised and illustrated in Table 7.9.

Design Property	Remark
Variants	One or two (fixed settings)
Modularity type I	Component swapping
Modularity type II	Combinatorial or black box
Design approach	Optimised point design
Carry over	High potential (for a vendor)

Table 7.9: Modular Design Properties - Bow Thruster

7.3. Specific Configurations

In Paragraph 6.3 of the previous chapter, some common technical solutions are highlighted, because of a difference in the modularity drivers. These technical solutions are stated in Table 7.12.

K	Potential module
k_{15}	Emergency electrical power generation system
k_{21}	Mechanical power generation architecture
k_{28}	Electrical power generation architecture

Table 7.10: Specific Configuration

This difference was caused by the impact of specific modularity drivers to these function carriers. Namely *technology push* and *planned product change*. This implies that these technical solutions are expected to have changing requirements because of expected or unexpected changes in demands. In short, this is caused by the client's ambition to reduce its fossil fuel consumption, while technical alternatives are not mature enough yet in terms of mass, volume, capital and operational expenditures, TRL and the logistic availability of fuel. For this reason, a suitable modular application for the technical solutions is adaptability. In other words, this problem can be approached by planning a replacement during the lifecycle by technical solutions that fulfil the client's ambition, once these alternatives are mature enough.

However, the degree of commonality for these technical solutions is hard to define in the logical architecture domain, as performance details per function are missing for example. Furthermore, the type of power plant concept is not yet decided, which automatically means that the support systems are also unknown yet.

However, there are several reasons to design a diesel electric or a diesel hybrid concept, applicable for each ship type, namely because of:

- Increasing flexibility, which is part of adaptability.
- Minimising under water radiated noise, which is beneficial for the environment and the execution of the mission.
- The advantages it brings for commonality. Grouping of standardised component is relatively simpler, compared to other power plant concepts.
- A high technical readiness level, meaning less risk of unexpected repair costs.

The main concern for applying adaptability is the hull/frames. This design determines the extent of flexibility, because of the spatial and attachment interfaces between them. Therefore, to design the hull/frames, it is very important to have a plan regarding the replacement, in order to know its consequences in terms of volume and mass.

Furthermore, it is important to understand the aspects that influence the physical commonality of the platform. Namely, the extent of similarity between the operational profiles, operational areas and displacements of the ship types. To create commonality, some performance requirements may need some adjustment or specific configurations (i.e., modules and/or building blocks) that are not entirely shared among all ships within the family may be a solution. For example, one ship requires one generator, while another ship type requires two.

Then, these subsystems are likely to be build by a specialist, because of their complexity. Furthermore, because of the ship specifics in terms of performance, the chance this technical solutions will be carried over is small. To clarify, the aim of this platform is summarised and illustrated in Table 7.9.

Design Property	Remark
Variants	Multiple
Module type	Common
Design	Flexible
Carry over	Low potential (for a vendor)

Table 7.11: Modular Design Properties - Power Plant Concept

7.4. Market Specific Modules

Market specific technical solutions are expected not to change or to go through a technology push. Also, technical solutions are not expected to spread throughout the ship. Also, they are required to be on the ship during the entire operational lifetime. Therefore, strategies like mission flexibility or evolutionary acquisition do not qualify. However, modularity drivers, like upgrading may be important during the mid-life upgrade of these vessels.

K	Potential module	Ship type
k_{30}	Sloop	Hydrographic survey
k_{31}	Echo sweep system	Hydrographic survey
k_{32}	Echo sounder (multi-beam)	Hydrographic survey
k_{33}	Magnetometer	Hydrographic survey
k_{34}	Side scan sonar	Hydrographic survey
k_{35}	ROV	Hydrographic survey
k_{36}	Hydrographic processing room	Hydrographic survey
k_{41}	Torpedo handling system	Submarine support
k_{42}	Maintenance street	Submarine support
k_{43}	Communication system	Submarine support
k_{45}	Training bridge	Marine Training

Table 7.12: Market Specific Potential Modules

From a production perspective it would be beneficial if market specific technical solutions, that have a suitable work content for a group of standardised components, would be designed as modules.

To further define the potential modules, these technical solutions are grouped again. The technical solutions that are not expected to be upgraded are: torpedo handling system, maintenance street and training bridge. However, they can still benefit from a modular design during the ship's production. For clarification, the design properties of the potential modules are summarised and illustrated in Table 7.13.
In comparison with the previous mentioned technical solutions, the others do also have the modularity driver *upgrade*. For clarification, the design properties of the potential modules are summarised and illustrated in Table 7.14.

Design Property	Remark
Variants	1
Module type	Self-contained
Modularity type (I)	Bus or Component swapping
Modularity type (II)	Black box or combinatorial
Design	Fixed
Carry over	Low potential (for a vendor)

Table 7.13: Modular Design Properties of Potential Modules not impacted by the MD *upgrade*

Design Property	Remark
Variants	1
Module type	Self-contained
Modularity type (I)	Bus or Component swapping
Modularity type (II)	Black box or combinatorial
Design	Fixed
Carry over	High potential (for a vendor)

Table 7.14: Modular Design Properties of Potential Modules impacted by the MD *upgrade*

7.5. Concluding Remarks

This chapter elaborates on the identified potential modules by stating the modular design properties. In order to go towards the physical design domain of the design process it is important to understand the modularisation principles regarding each specific technical solutions. Hence, this provides support to continue the design in an understandable manner, as it visualises the modules, taking into account the entire lifecycle, while having a view from various stakeholders important for DSNS.

8 Conclusions and Recommendations

This thesis describes the research performed to find the optimal modular platform-based product development strategy to replace a series of support vessels of the RNLN viewed from a DSNS perspective. To achieve this, a method is composed out of design disciplines/theories that provides input for to methodically support modular design. The latter one considers modularity aspects to assess the impact of modularity drivers and to identify potential modules. Subsequently, a case study has been carried out to illustrate whether the composed design approach is appropriate. This chapter contains the conclusions and recommendations made.

8.1. Conclusions

Shipyards have to deal with increasing competition in the global marketplace, because demands for ships with more quality, lower lifecycle costs and shorter delivery lead time is growing. The focus of this research is to find out how these aspects can be met, for a series of support vessels of the RNLN, through the application of platforming and modularisation principles. The conclusions are formed by looking back on the research objectives, as set in Chapter 1, after which the main research question is answered.

8.1.1. Objectives

1. *What are the key aspects to create a successful modular product platform?*

   The benefits of platform planning are most effectively realised by its implementation in the front-end of the product development, i.e., the conceptual design phase. The key to a successful product platform development is to focus on the common core platform concept, rather than developing a traditional inclusive platform, that targets all market segments at once. This means that all commonality between the different ship types has to be extracted and accordingly be mapped in a physical common core architecture.

   Subsequently, to complete ship design also consists of specific modular configurations that are not shared among all ships within the product family and market specific modules/building blocks that will be attached to a modular product. In short, the multi-platform principle for the product family design provides better results than an traditional inclusive platform.

   Furthermore, it is important to understand how different platforms interact and affect one another. Among modular platforms, this can be defined through the modularisation principles, that include the type of modularity, the type of physical interface and the cause for modularisation. In addition, the top-down approach (i.e., a proactive platform) is found to be most suitable for the Royal Netherlands Navy support vessels, because functional decomposition gives modularisation more weight and importance.

2. *How can the appropriateness of modular platforming be determined for the potential product family?*

   The most suitable methodical support to evaluate the suitability of modular platforming in the conceptual design phase, from a functional perspective, is the Modular Function Deployment (MFD). This method helps to identify modules or building blocks from a functional perspective and identifies modularity drivers that can form a base for choosing particular strategy. It includes view points from different areas of responsibility and considers the entire lifecycle of the vessel. In short, MFD comprises economical and technical aspects in the comprehensive form of modularity drivers, such as:

   - Different specifications
   - Styling
   - Technology push
   - Product planning
   - Common unit
   - Process and/or organisation
   - Separate testing
   - Purchase
   - Service and maintenance
   - Recycling

   However, before this modular support method can be applied, a case study has to be set up, that explores the requirement engineering, functional and logical architecture design domains for the ship types. This helps to arrive at technical solutions in a structured way. Results from the case study set up are used as input for the so called 'Module Indication Matrix' with its modularity drivers and 'Interface Matrix'.

   To conclude, this modular method serves as a starting point that helps to make strategic decisions. Hence, the appropriateness of modular platforming for the series of navy support vessels of the RNLN can be identified.

3. *Which strategic decisions should Damen Schelde Naval Shipbuilding make? In other words, what are potential modules for the series of support vessels of the RNLN and what are the modularity drivers for DSNS?*

   This study focuses on the development of multiple platforms including a core platform. As a consequence, the function carriers, obtained from the case study set up, are split into a common and a market specific group. The results of the MFD method are used determine the difference in impact of the modularity drivers among the two groups. Hence, MFD identifies potential modules and helps to understand the difference between the modules in terms of interaction, interfaces, physicality and modularity drivers. This results in different platforms and modular design properties of the potential modules.

   To conclude, the strategic decisions are made after a structured analysis is performed, from which multiple platform plans are described. These are, a core platform consisting out of modules with each its own modular design properties, a platform with specific configurations for the power plant concept. And finally, a market specific platform that can be split into modules that require an upgrade during the lifecycle and those that serve the ship entire lifecycle. The main modularity drivers for the core platform are:

   - Common unit
   - Process/organisation
   - Purchase

- Carry over

The main modularity drivers for the specific configurations (i.e., adaptable platform) are:

- Technology push
- Product planning
- Common unit

The main modularity drivers for the potential market specific modules are:

- Different specification
- Process/organisation
- Purchase
- Upgrading[1]

As a result, this means for DSNS that the focus should be on conventional value disciplines (i.e., operational excellence and customer intimacy), but also on product leadership, because of the adaptable platform plan. This is a consequence of the identified modularity drivers for each distinct group of potential modules.

When modularity is implemented in the design process, it can lead to shorter lead time thanks to parallel production, pedagogical production and shorter delivery times, effective maintenance thanks to standardisation, lower logistics costs for both shipyard and customer. Moreover, the adaptable platform can enable product leadership, because of its flexible design that takes into account changing requirement aspects.

8.1.2. Highlights

The main conclusion of this study is based on the three objectives and answers the main research question:

What is the optimal modular platform-based product development strategy for the replacement of a series of support vessels of the Royal Netherlands Navy, viewed from a Damen Schelde Naval Shipbuilding perspective?

The MFD method used in this study is suitable to make an first start to go to a physical modular platform. It offers a structured approach to make substantiated decisions, as this is done according a complete and accurate analysis of modularity in the front-end of a ship's development design process.

The case study set up, demonstrates the approach for visualisation and for managing and understanding this complex design, while taking into account business and technical aspects of the entire lifecycle. Furthermore, the conducted case study, confirms that the composed design method meets all key aspects for the development of an optimal modular platform. Because it involves and considers:

- Concept design from a functional perspective.
- Various conceptual design domains for clarification.
- Ship's commonality in all design domains.
- Multi-platform principle, making a distinction between a core platform, specific configurations and market specific modules.
- Modularity drivers, representing several voices and the entire lifecycle of a ship.

[1] 'Upgrading' is only a modularity driver for a subgroup of the market specific modules.

Moreover, the case study shows that the methodical support for a modular design, actually provides useful information. Because it reveals the modularity drivers, potential modules, interaction and interfaces of the ship design. Hence, modular design properties of each potential module can be quantified. This serves as a start to go to an optimal physical architecture for Damen Schelde Naval Shipbuilding. The next paragraph contains some recommendations to improve the integrity of the method, based on complications that were encountered during the case study of this report.

8.2. Recommendations

The results and evaluation of the case study, are promising and can be considered as a good starting point for implementation in the design process. However, further research is recommended, which can improve the reliability of the proposed design. Another recommendation is about effectively incorporating all design aspect and modularisation principles in the design process.

First of all, the benefits of platform planning are most effectively realised by implementation in the front-end of the product development. Therefore, it is important to look into the completeness and accuracy of the case study set up. This means:

- The conceptual design domains should be re-explored by a platform development team including specialists. This will result in a more complete and accurate design process.
- The functional decomposition of the ships should consist out of more hierarchic levels and must be further decomposed. Otherwise, the main function could be too superficial, causing a technical solution that is spread throughout the ship. This could mean a lot of interaction and interfaces with the rest of the ship and a work content that is not suitable for standardisation. Obviously, the technical solutions that have a too superficial description in the case study scored relatively low in the MFD as potential module.
- The requirement statements need a more detailed description. Aspects that are missing in the functional statements are details in terms of performance, quantities and operational conditions. Therefore, important to consider are the operational profiles. For example, the function statement: 'To move in longitudinal direction' can be further defined by adding details, like the maximum speed, the endurance speed and the endurance range in a certain seastate, the fuel consumption limits and the underwater radiated noise. To do this, it is important to know the operational profile of each ship type.
- The case study assumes a one-to-one replacement for the fleet of series of support vessels, while this may not be the optimum plan. For example, it may be possible to design one ship that can fulfil two mission statements, instead of designing two ships, each of which is able to carry out one mission. That is why a study about this must be included in the design process.

In addition, a bottom-up basic design approach can help to determine the level in the functional/technical hierarchy to be standardised. In other words, the level where the bottom-up approach and the top-down approach meet, will be interesting to use as input for the 'Module Indication Matrix' and 'Interface Matrix'. To clarify, design aspects for standardisation by using the bottom-up approach should be considered. The following list is defined by Hopman [27] and could provide support to make decisions:

- Prescriptive rules & regulations
- Standard principle design solutions
- Standard materials
- Yard/supplier standards

- Standard/existing components
- Standard/existing (modular systems)
- Configurations
- Parametric designs
- Modular ship designs
- Standard ship designs with add-ons

Another methodical support that can help is called the Design Structure Matrix (DSM). Especially, for production it is important to understand how modularisation principles can help to improve the process. In other words, it helps to visualise and optimise technical dependencies between components/systems.

9

Reflection

With completing the literature review on product platforms and modularisation principles, I was able to understand the problem statement and to set out a plan to identify the objective of this study. By combining standard design disciplines with modularisation principles from literature I composed a method.

However, once this method was established, I did not yet fully understand the design process with its different phases, domains, standardisation principles and its iterative design exploration to identify the technical solutions. During the execution of the case study, the sailing experience I have on product tankers and a multi-purpose vessel, contributed to help me understand and to carry out the case study set up for acquiring technical solutions.

These were used as input for the 'Module Indication Matrix' and the 'Interface Matrix' of the MFD. Important for me was that I had to be certain that these technical solutions were as complete and as accurate as possible, because an alteration would mean a lot of additional work in the rest of design process. Namely, the impact of 12 modularity drivers are determined for each technical solution.

This part of the MFD tool was complicated for me and required some dedication and commitment. It took me some time before I was able to understand the content of each modularity driver and to give a reliable decision support for the impact of each modularity to the technical solution. Also, the work was quite a lot, since I had to make 540 ratings including corresponding decision support. On the other hand, this was really useful for understanding the modularisation principles.

Overall, I have experienced this research as very positive. First of all, the results of the case study are satisfactory for me, but more important is the fact that it was really helpful to understand and to learn how to manage and to visualise the development process of such a complex design.

Bibliography

[1] APC. Transmitting acoustic signals through water: echo sounding. URL https://www.americanpiezo.com/blog/transmitting-acoustic-signals-echo-sounding/. Last accessed August 16, 2019.

[2] Aspect. Magnetometer survey. URL http://www.aspectsurveys.com/survey-services/geophysical/magnetometer/. Last accessed August 16, 2019.

[3] B. Bergman, J. de Mare, S. Loren, and T. Svensson. Robust design methodology for reliability: exploring the effect of variation and uncertainty. *Wiley, Chichester*, 2009.

[4] Øystein Brekke. Modular capabilities on offshore support vessels. Master's thesis, Norwegian University of Science and Technology, 2012.

[5] Minjoo Choi. *Modular Adaptable Ship Design for Handling Uncertainty in the Future Operating Context*. PhD thesis, Norwegian University of Science and Technology, 2018.

[6] Bob De Smedt. Vervanging klein bovenwater, initiele vergelijking capaciteiten met damen mrav en lst series. Unpublished, 2018.

[7] Jeremy Dick and Elizabeth Hull. *Requirement Engineering*. Springer, 4 edition, 2017.

[8] Andrea Dobberfuhl and Mark W. Lange. Interfaces per module, is there an ideal number? 2009.

[9] Norbert Doerry. Setting the stage: Modular adaptable ship imperative, 2018.

[10] Norbert Doerry and Philip Koenig. Modularity and adaptability in future u.s. navy ship designs. In *MECON 2017*, 2017.

[11] Eggen, Øystein. Modular product development - a review of modularization objectives as well as techniques for identifying modular product architectures, presented in a unified model. 2003.

[12] Stein Ove Erikstad. Modularisation in shipbuilding and modular production. 2009.

[13] Stein Ove Erikstad. Design for modularity: Volume 1: Optimisation of ship design and operation for life cycle. 2019.

[14] Stein Ove Erikstad and Carl Fredrik Rehn. Handling uncertainty in marine systems design - state-of-the-art and need for research. 2015.

[15] G. Erixon and B. Ostgren. Synthesis and evaluation tool for modular designs. *International conference on engineering design*, 1993.

[16] A. Erlandsson, G. Erixon, and B. Ostgren. Product modules - the link between qfd and dfa? *The International Forum on Product Design for Manufacture and Assembly*, 1992.

[17] S.K. Fixson. Modularity and commonality research: past developments and future opportunities. 2007.

[18] MAN Energy Solutions France. Workshop - validation pyramid. Unpublished, 2019.

[19] Christoph Fuchs and Franziska J. Golenhofen. *Mastering Disruption and Innovation in Product Management*. Springer, 2019.

[20] Rinze Geertsma. Casestudy emissieloze hulpvaartuigen km. Unpublished, 2019.

[21] Rinze Geertsma. *Autonomous control for adaptive ships with hybrid propulsion and power generation*. PhD thesis, Delft University of Technology, 2019.

[22] Rinze Geertsma and M. Krijgsman. Alternative fuels and power systems to reduce environmental impact of support vessels. In *MECCS 2019*, 2019.

[23] Javier P. Gonzales-Zugasti and Kevin N. Otto. Modular platform-based product family design. *ASME Design Engineering Technical Conferences and Computer and Information in Engineering Conference*, 2000.

[24] P. Gu, D. Xue, and A.Y.C. Nee. Adaptable design: concepts, methods, and applications. 2009.

[25] K. Hölttä, V. Tang, and W. Seering. Modularizing product architectures using dendrograms. *International conference on engineering design*, 2002.

[26] Katja Hölttä-Otto. *Modular Product Platform Design*. PhD thesis, Helsinki University of Technology, 2005.

[27] Hans Hopman. Goal-based design - maritime tech. Unpublished, 2015.

[28] Marine Insight. Bow thrusters: Construction and working, 2019. URL `https://www.marineinsight.com/tech/bow-thrusters-construction-and-working/`. Last accessed August 3, 2019.

[29] Janxin Roger Jiao, Timothy W. Simpson, and Zahed Siddque. Product family design and platform-based product development. *Springer Science+Business Media*, 2007.

[30] Hans Klein Woud and Douwe Stapersma. *Design of Propulsion and Electric Power Generation Systems*. IMAREST, 2002.

[31] Kongsberg. Echosounder sweep system. URL `https://www.kongsberg.com/maritime/products/mapping-systems/mapping-systems/single-beam-echo-sounders/echosounder-sweep-system/`. Last accessed August 15, 2019.

[32] Alexander Kossiakof, William N. Sweet, Samuel J. Seymour, and Steven M. Biemer. *System Engineering Principles And Practice*. Wiley, 2 edition, 2011.

[33] L. Li, G.Q. Huang, and Stephen T. Newman. Interweaving genetic programming and genetic algorithm for structural and parametric optimization in adaptive platform product customization. *Elsevier*, 2007.

[34] J. Malmstr om and J. Malmqvist. Tradeoff analysis in prodcut structures: A case study at celcius aerotech. *Proceedings of NordDesign'98*, 1998.

[35] Marineschepen. Van kinsbergen (a902) marineopleidingsvaartuig, 2016. URL `https://marineschepen.nl/schepen/vankinsbergen.html`. Last accessed April 23, 2019.

[36] Marineschepen. Zr. ms. mercuur (a900) torpedowerkschip, 2017. URL `https://marineschepen.nl/schepen/mercuur.html`. Last accessed April 18, 2019.

[37] Marineschepen. Pelikaan ondersteuningsvaartuig, 2017. URL `https://marineschepen.nl/schepen/pelikaan.html`. Last accessed April 23, 2019.

[38] Marineschepen. Snelliusklasse hydrografische opnemingsvaartuigen (hov), 2019. URL `https://marineschepen.nl/schepen/snellius.html`. Last accessed April 18, 2019.

[39] Marc H. Meyer and Alvin P. Lehnerd. *The power of product platforms*. The Free Press, 1997.

[40] NAVAIS. Chapter 1-2-3. Unpublished, 2018.

[41] Royal Dutch Navy. The royal netherlands navy in focus, for security at and from the sea. 2015.

[42] Jan Jaap Nieuwenhuis. *Evaluating the appropriateness of product platforms for Engineered-To-Order ships*. PhD thesis, Delft University of Technology, 2013.

[43] Offic of Coast Survey. Hydrographic survey equipment. URL `https://nauticalcharts.noaa.gov/learn/hydrographic-survey-equipment.html`. Last accessed August 14, 2019.

[44] Apostolos Papanikolaou, editor. *A Holostic Approach to Ship Design*. Springer, 2019.

[45] Jeroen Pruyn. Attuning of requirements and kpi's. Unpublished, 2018.

[46] F. Salvador, C. Forza, and M. Rungtusanatham. Modularity, product variety, production volume, and component sourcing: theorizing beyond generic prescriptions. *Elsevier*, 2002.

[47] John F. Schank, Scott Savitz, Ken Munson, Brian Perkinson, James McGee, and Jerry M. Sollinger. *Designing Adaptable Ships, Modularity and Flexibility in Future Ship Designs*. RAND Corporation, 2016.

[48] Damen Schelde Naval Shipbuilding. System description statement. Unpublished, 2018.

[49] Timothy W. Simpson. Product platform design and customization: Status and promise. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 18, 2003.

[50] Timothy W. Simpson, Jonathan R.A. Maier, and Farrokh Mistree. Product platform design: method and application. *Res Eng Design*, 13, 2001.

[51] Timothy W. Simpson, Zahed Siddique, and Jianxin Jiao, editors. *Product Platform And Product Family Design, Methods and Applications*. Springer, 2006.

[52] Timothy W. Simpson, Jianxin Jiao, Zahed Siddique, and Hölttä-Otto, editors. *Advances in Product Family and Product Platform Design*. Springer, 2014.

[53] Douwe Stapersma, J. Pinkster, and J.W. Frouws, editors. *Design of Advanced Marine Vehicles (Reader)*. Delft University of Technology, 2000.

[54] Josip Stjepandić, Nel Wognum, and Wim J.C. Verhagen, editors. *Concurrent Engineering in the 21st Century*. Springer, 2015.

[55] R.B. Stone, K.L. Wood, and R.H. Crawford. A heuristic method for identifying modules for product architectures. *Design Studies*, 2000.

[56] Elena Stroo-Merodo and Marnix Krikke. Integral cooperation - defining the functions and requirements of a vessel. 2013.

[57] N.P. Suh. Axiomatic design: advances and applications. *Oxford University Press*, 2000.

[58] Marine Traffic. Vessel details, 2019. URL `https://www.marinetraffic.com/`. Last accessed February 15, 2019.

[59] Karl Ulrich. The role of product architecture in the manufacturing firm. *Elsevier*, 1995.

[60] Seb Van Den Berg. Low carbon shipping - a decision support tool for the implementation of co_2 reducing measures. Master's thesis, Delft University of Technology, 2018.

[61] Tom van der Beek, Theresia van Essen, and Jeroen Pruyn. Optimizing inventory strategy for modular shipbuilding. In *International Conference on Computer Applications in Shipbuilding 2019*, 2019.

[62] Wikipedia. Antiroll tanks, . URL `https://en.wikipedia.org/wiki/Antiroll_tanks`. Last accessed August 17, 2019.

[63] Wikipedia. Remotely operated underwater vehicle, . URL https://en.wikipedia.org/wiki/Remotely_operated_underwater_vehicle. Last accessed August 17, 2019.

[64] Wikipedia.en. Damen schelde naval shipbuilding, 2018. URL https://en.wikipedia.org/wiki/Damen_Schelde_Naval_Shipbuilding. Last accessed March 20, 2019.

A

Modular Concepts

Type	Target	Objective	Application
Standard Flex	Navy	Increase flexibility. Fleet reduction.	Operation
MEKO	Navy	Increase opportunities in on board systems in design. Cost reduction in building. Improvement in survivability.	Construction/ Operation
MOPCO	Navy	Increase flexibility in design and operation. Cost reduction in building.	Construction/ Operation
BMT Venator	Navy	Increase operational flexibility.	Operation
Ulstein MDS	OSV	Increase flexibility in design. Reduce design and construction cost and time	Construction
LCS	Navy	Flexibility in operation with modular capabilities	Operation
SIGMA	Navy	Increase flexibility in design. Reduce design and construction cost and time. Designing for tomorrows changes	Construction

Table A.1: Modular Concepts on the Market [4]

B

PMM

B.1. Capabilities - Step 3

The capabilities are structured by means of an index called ***I***. As a recap, this is step 3 of the roadmap, illustrated in Figure 4.1 in Chapter 4.

I	Id.	Statement
i_1	1.1.1	The operators shall be able to drink/eat.
i_2	1.1.2	The operators shall be able to sleep/rest.
i_3	1.1.3	The operators shall be able to do laundry.
i_4	1.1.4	The operators shall be able to do sanitary needs.
i_5	1.2.1	The operators shall be able to secure stability and buoyancy.
i_6	1.2.2.1	The operators shall be able to extinguish a fire.
i_7	1.2.2.2	The operators shall be able to abandon ship.
i_8	1.2.2.3	The operators shall be able to rescue a person fallen in the water.
i_9	1.2.2.4	The operators shall be able to quickly react in case of an emergency.
i_{10}	1.2.2.5	The operators shall be able to start-up a dead ship.
i_{11}	2.1.1.1	The operators shall be able to acquire navigational data.
i_{12}	2.1.1.2	The operators shall be able to operate systems remotely.
i_{13}	2.1.2	The operators shall be able to control the systems.
i_{14}	2.1.3	The operators shall be able to maintain the ship's systems.
i_{15}	2.2.1	The operators shall be able to longitudinal translate the ship.
i_{16}	2.2.2	The operators shall be able to rotate the ship.
i_{17}	2.2.3	The operators shall be able to create a force in transversely direction.
i_{18}	2.2.4	The operators shall be able to moor and unmoor in desired ports.
i_{19}	2.2.5	The operators shall be able to do station keeping.
i_{20}	3.1.1	The operators shall be able to measure draughts in shallow waters.
i_{21}	3.1.2	The operators shall be able to measure draughts in deep waters.
i_{22}	3.1.3	The operators shall be able to minimise ship's roll movement.
i_{23}	3.1.4	The operators shall be able to acquire the measurement data.
i_{24}	3.1.5	The operators shall be able to survey the sea bottom.
i_{25}	3.2.1	The operators shall be able to (un)load cargo.
i_{26}	3.2.2	The operators shall be able to store cargo.
i_{27}	3.2.3	The operators shall be able to secure the cargo.
i_{28}	3.3.1	The operators shall be able to detect torpedoes.
i_{29}	3.3.2	The operators shall be able to pick up torpedoes.
i_{30}	3.3.3	The operators shall be able to handle/maintain torpedoes.
i_{31}	3.3.4	The operators shall be able to communicate with submerged submarines.
i_{32}	3.4.1	The operators shall be able to educate students.

Table B.1: Capabilities

B.2. Functions - Step 4

The functions are structured by means of an index called $\boldsymbol{J}$. As a recap, this is step 4 of the roadmap, illustrated in Figure 4.1 in Chapter 4.

J	Id.	Statement
j_1	1.1.1	The provide sleeping facilities.
j_2	1.1.2.1	To provide fresh water.
j_3	1.1.2.2	To treat the grey and black water.
j_4	1.1.2.3	To control the air properties.
j_5	1.1.3	To provide facilities for leisure possibilities.
j_6	1.1.4	To provide restaurant facilities.
j_7	1.1.5	To provide laundry possibilities.
j_8	1.2.1.1	To secure watertight integrity.
j_9	1.2.1.2	To secure structural integrity.
j_{10}	1.2.1.3	To optimise the stability.
j_{11}	1.3.1	To support rescue operations at sea.
j_{12}	1.3.2	To provide an alternative for abandoning the ship.
j_{13}	1.3.3	To support crew for extinguishing a fire (and detecting a fire).
j_{14}	1.3.4	To inform the crew of an emergency/critical situation.
j_{15}	1.3.5	To back-up the electric power system during a black out.
j_{16}	2.1.1.1	To provide the crew navigational data.
j_{17}	2.1.1.2	To provide the crew control over navigational systems remotely.
j_{18}	2.1.2	To provide the crew systems information.
j_{19}	2.1.3	To provide the crew control of electric driven systems remotely.
j_{20}	2.1.4	To provide the crew space and tools for doing maintenance/repair work.
j_{21}	2.2.1.1	To provide mechanical power.
j_{22}	2.2.1.2	To convert the rotating mechanical power into translating mechanical power.
j_{23}	2.2.1.3	To transfer mechanical energy generated by the prime mover to the propulsor.
j_{24}	2.2.2	To alter course if commanded to.
j_{25}	2.2.3	To create a force in transversely direction for movement.
j_{26}	2.2.4	To forestall free movement free movement of the ship on water.
j_{27}	2.2.5	To forestall drifting away due to wind or current.
j_{28}	2.2.6.1	To generate electric power for the electric consumers.
j_{29}	2.2.6.2	To distribute the electrical power.
j_{30}	3.1.1	To support hydrographic surveillance in shallow water.
j_{31}	3.1.2	To provide hydrographic data in shallow water.
j_{32}	3.1.3	To provide draught data.
j_{33}	3.1.4	To detect magnetic objects under the seafloor.
j_{34}	3.1.5	To detect objects on the seafloor.
j_{35}	3.1.6	To support hydrographic surveillance remotely.
j_{36}	3.1.7	To display and process data.
j_{37}	3.1.8	To provide better sea-keeping.
j_{38}	3.2.1	To (un)load cargo.
j_{39}	3.2.2	To provide volume for cargo.
j_{40}	3.2.3	To secure cargo.
j_{41}	3.3.1	To pick up torpedoes.
j_{42}	3.3.2	To provide maintenance/handling facilities for torpedoes.
j_{43}	3.3.3	To provide communication facilities.
j_{44}	3.3.4	To track and follow fired torpedoes.
j_{45}	3.4.1	To support training the marine students.

Table B.2: Functions

B.3. Technical Solutions - Step 5

The technical solutions are structured by means of an index called $\boldsymbol{K}$. As a recap, this is step 5 of the roadmap, illustrated in Figure 4.1 in Chapter 4.

K	Id.	Technical solution
k_1	1.1.1	Cabin
k_2	1.1.2.1	Fresh water system
k_3	1.1.2.2	Plumbing drainage system
k_4	1.1.2.3	Climate control system
k_5	1.1.3	Day room
k_6	1.1.4	Restaurant facilities
k_7	1.1.5	Laundry facilities
k_8	1.2.1.1	Hull
k_9	1.2.1.2	Frames
k_{10}	1.2.1.3	Ballast system
k_{11}	1.3.1	Rescue boat
k_{12}	1.3.2	Life raft
k_{13}	1.3.3	Fire fighting system
k_{14}	1.3.4	Emergency alarm system
k_{15}	1.3.5	Emergency electrical power generation system
k_{16}	2.1.1.1	Navigational data acquisition systems
k_{17}	2.1.1.2	Navigational control system
k_{18}	2.1.2	Engineering control system
k_{19}	2.1.3	Electrical control panels
k_{20}	2.1.4	Workshop facilities
k_{21}	2.2.1.1	Mechanical power generation architecture
k_{22}	2.2.1.2	Propulsor
k_{23}	2.2.1.3	Transmission system
k_{24}	2.2.2	Steering system
k_{25}	2.2.3	Bow thruster
k_{26}	2.2.4	Mooring system
k_{27}	2.2.5	Anchor system
k_{28}	2.2.6.1	Electrical power generation architecture
k_{29}	2.2.6.2	Switchboard
k_{30}	3.1.1	Sloop
k_{31}	3.1.2	Echo sweep system
k_{32}	3.1.3	Echo Sounder (multi-beam)
k_{33}	3.1.4	Magnetometer
k_{34}	3.1.5	Side scan sonar
k_{35}	3.1.6	ROV
k_{36}	3.1.7	Hydrographic processing systems
k_{37}	3.1.8	Anti-roll tank
k_{38}	3.2.1	Cargo handling system
k_{39}	3.2.2	Hold/deck
k_{40}	3.2.3	Cargo securement
k_{41}	3.3.1	Torpedo handling system
k_{42}	3.3.2	Maintenance street
k_{43}	3.3.3	Communication system
k_{44}	3.3.4	Passive sonar
k_{45}	3.4.1	Training bridge

Table B.3: Technical Solutions

B.4. Quality Function Deployment (QFD)

The QFD matrix provides the relations between capabilities and functions. This matrix is represented by Table B.4, Table B.5 and Table B.6.

	j_1	j_2	j_3	j_4	j_5	j_6	j_7	j_8	j_9	j_{10}	j_{11}	j_{12}	j_{13}	j_{14}	j_{15}	j_{28}	j_{29}
i_1		●		●		●										●	●
i_2	●			●	●											●	●
i_3					●		●									●	●
i_4	●	●	●	●												●	●
i_5								●	●	●							
i_6													●	●			
i_7												●					
i_8											●						
i_9														●		●	●
i_{10}															●		

Table B.4: QFD (1/3)

	j_{16}	j_{17}	j_{18}	j_{19}	j_{20}	j_{21}	j_{22}	j_{23}	j_{24}	j_{25}	j_{26}	j_{27}	j_{28}	j_{29}
i_{11}	●												●	●
i_{12}		●		●									●	●
i_{13}			●										●	●
i_{14}					●									
i_{15}						●	●	●					●	●
i_{16}									●				●	●
i_{17}										●			●	●
i_{18}											●		●	●
i_{19}												●	●	●

Table B.5: QFD (2/3)

	j_{30}	j_{31}	j_{32}	j_{33}	j_{34}	j_{35}	j_{36}	j_{37}	j_{38}	j_{39}	j_{40}	j_{41}	j_{42}	j_{43}	j_{44}	j_{45}	j_{28}	j_{29}
i_{20}	●	●					●										●	●
i_{21}			●		●		●										●	●
i_{22}								●									●	●
i_{23}						●											●	●
i_{24}				●			●										●	●
i_{25}									●								●	●
i_{26}										●								
i_{27}											●							
i_{28}															●			
i_{29}												●					●	●
i_{30}													●					
i_{31}														●				
i_{32}																●		

Table B.6: QFD (3/3)

B.5. Design Property Matrix (DPM)

The DPM matrix provides the relations between functions and technical solutions. This matrix is represented by Table B.7, Table B.8 and Table B.9.

	j_1	j_2	j_3	j_4	j_5	j_6	j_7	j_8	j_9	j_{10}	j_{11}	j_{12}	j_{13}	j_{14}	j_{15}
k_1	●														
k_2		●													
k_3			●												
k_4				●											
k_5					●										
k_6						●									
k_7							●								
k_8								●							
k_9									●						
k_{10}										●					
k_{11}											●				
k_{12}												●			
k_{13}													●		
k_{14}														●	
k_{15}															●

Table B.7: DPM (1/3)

	j_{16}	j_{17}	j_{18}	j_{19}	j_{20}	j_{21}	j_{22}	j_{23}	j_{24}	j_{25}	j_{26}	j_{27}	j_{28}	j_{29}
k_{16}	●													
k_{17}		●												
k_{18}			●											
k_{19}				●										
k_{20}					●									
k_{21}						●								
k_{22}							●							
k_{23}								●						
k_{24}									●					
k_{25}										●				
k_{26}											●			
k_{27}												●		
k_{28}													●	
k_{29}														●

Table B.8: DPM (2/3)

	j_{30}	j_{31}	j_{32}	j_{33}	j_{34}	j_{35}	j_{36}	j_{37}	j_{38}	j_{39}	j_{40}	j_{41}	j_{42}	j_{43}	j_{44}	j_{45}
k_{30}	●															
k_{31}		●														
k_{32}			●													
k_{33}				●												
k_{34}					●											
k_{35}						●										
k_{36}							●									
k_{37}								●								
k_{38}									●							
k_{39}										●						
k_{40}											●					
k_{41}												●				
k_{42}													●			
k_{43}														●		
k_{44}															●	
k_{45}																●

Table B.9: DPM (3/3)

B.6. MIM - Decision Support

In this section, a description of every technical solution is given. Then, each modularity driver per technical solution is discussed according to the questions from the questionnaire, described in Paragraph 4.3.3. This serves as support for the indicated impact of the modularity driver. The sentence, written italic, is the answer to the modularity driver's unique question. In this sentence, the word made bolt, indicates the modularity driver's impact to the logical architecture.

B.6.1. Cabins (k_1)

A room used as a living quarter by (an) officer(s) or passenger(s). Hence, the room is integrated with a sanitary room, bed, desk and electric power supply. (Another possibility is that the sanitary room is apart from the cabin.) The cabins can be subdivided into several types of cabins, each one assigned to a specific ranking officer or passenger.

l_1 *This part is **not** influenced by varying requirements.*
The requirements of the crew and passengers on board each type of vessel within the potential product family is expected to be the same. Therefore, the cabins can be standardised for the whole product family.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the cabin is be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the cabin will have one neutral standard design.

l_3 *There are **strong** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
Within this market segment, a cabin is a relatively conservative concept. Its construction is not complex and is not expected to change or develop. However, not all requirements are always constant. For example, the desired cabins of the potential product family must be bigger than current installed cabins. Nonetheless, the future technology or concept of the next generation ships will have no to small changes.

l_4 *It is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the current concept matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change causing a technology push is not expected. Also, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
The purpose of the cabins is that they fulfil their functionality during the whole lifetime of the ship. Therefore, a change of this concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **all** of the product variants?*
The physical form of the cabins can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require multiple cabins, the production process could become leaner if a cabin would be designed as a module. Hence, robotics in manufacturing may be a cost saver. Moreover, a cabin has a suitable collection of technology driven work content for a manufacturing cell.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*

A cabin is not a complex concept and its functionality can be determined without a practical test. Therefore, separately testing does not add value.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
As the concept already consists several modules, designing the whole as a black box module would not provide many advantages. However, for some parts within this cabin, it could reduce logistics costs. For example, the mattress or a chair.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
A cabin and its interior can be designed in such a way, no service repairs are required during the lifetime of the vessel. Detachability would not add value.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficient in terms of performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
The functionalities of the concept can probably not be recycled, because of the wear after the lifecycle of the vessel. However, its material can.

B.6.2. Fresh Water System (k_2)

The fresh water system is equipped for: production, replenishment, transfer and distribution of fresh water, cold potable water and hot potable water. The system consists of several sub-systems: fresh water production system, water storage and transfer system, fresh water supply system, cold potable water distribution system, hot potable water distribution system, window wash system, technical fresh water system and reagent grade water system. [48]

l_1 *This part is **to some extent** influenced by varying requirements.*
The requirement of this system is that it provides sufficient fresh water for the people on board during the whole lifetime. Hence, variables that determine the eventual capacity of the system are the amount of persons on board and the interaction of the system itself, i.e., provision of fresh water can either come from storage or generation. As the complement per ship type differs, this system may vary among the vessel types.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, this system will have most likely one neutral standard design.

l_3 *There are **any** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
An essential support system for operation of the fresh water generator is one that provides heat. Nowadays, this heat is provided by a high temperature cooling water system used for cooling a combustion engine. This is also energy efficient as it works as waste heat recovery. However, this prime mover may be replaced in the future by another technology that is less pollutant. Subsequently, this could mean the requirement for another type of support system. Nonetheless, for the short term no unexpected changes are expected. For the long term, there is a minor change that the total support system or only the heat source may be replaced. This could mean that next generation ships require another system or technology.

l_4 *There is **some** risk that this part will go through a technology shift during the product lifecycle.*
As mentioned before, a part of this system may change caused by a technology push. The rest of the system is not expected to undergo unexpected changes during the life-

time. Because current technologies match the desired functionality, the TRL is of a high standard and are compliant with regulations during the lifetime of the ship. Moreover, a replacement would increase the capital expenditures and would not add much value.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
The purpose of the fresh water system it that it fulfils its functionality during the whole lifetime of the ship. A planned replacement would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants?*
Because of the varying performance requirements of this system within the potential product family, the system is not expected to be similar physically for each ship type.

l_7 *There are **some** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
Because every ship requires a fresh water system, some parts of the potential module(s) or building blocks could be designed in such a way that the production process could be shorter. Hence, robotics in manufacturing may be a cost saver. Moreover, some function carriers have a suitable collection of technology driven work content for a manufacturing cell. The level of the subdivision of the main function to be modularised is hereby important.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
Most of the functionalities within this system can be tested separately by simulation, such as transferring fluids or generation fresh water. However, the storage of fresh water can only be tested after installation.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
For some (sub)function carriers of the system it would be beneficial cost wise, to design them as black box modules. For example, the pumps or the fresh water generator.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Also, it would add value if some (sub)function carriers would be built as a module, as detachability would make a service repair easier.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept already suffices. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
The functionality of the function carriers can probably not be recycled, because of the wear after the lifecycle of the vessel. However, its material can.

B.6.3. Plumbing Drainage System (k_3)

The function of the sewage system is: to collect black water, to store black water in a holding tank, transfer the black water overboard, to a shore connection or to a sewage treatment unit, to treat black water in the sewage treatment unit to a standard in accordance with MARPOL before discharge overboard and transferring black water to the sewage treatment unit by gravity or vacuum. The function of the grey water system is to collect grey water and to treat grey water in the sewage treatment unit to a standard in accordance with MARPOL before discharge overboard. [48]

l_1 *This part is **to some extent** influenced by varying requirements.*

The requirement of this system is that it treats all sewage before discharging it into the sea. Hence, variables that determine the eventual capacity of the system are the amount of persons on board. As the complement per ship type differ from 78 to 39 man, this system only influenced by varying requirements in terms of performance.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are **any** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
As long as ships are manned, a sewage treatment system is required. The indicative production of the potential product family will happen in the short term. In other words, the (sub)function carriers of this technical solution can be carried over within this family. Also for the long term, it is expected these type of ships are manned. However, it is possible the manning is reduced in the future.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
A technology push for this system is not likely to happen as the current technology matches the desired functionality and the TRL is of a high standard. Also, the current technology complies to regulations during the lifetime of the ship. Moreover, a replacement would have a negative influence to the capital expenditures. In other words, an unexpected change is not expected.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
The purpose of the sewage treatment system it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add value.

l_6 *This function can have the same physical form in **most** of the product variants.*
Because of the varying performance requirements of this system within the potential product family, the system is not expected to be similar physically for each ship type.

l_7 *There are **any** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
Because every ship requires a sewage treatment system, some parts of the potential module(s) or building blocks could be designed in such a way that the production process could be shorter. Hence, robotics in manufacturing may be a cost saver. Moreover, some function carriers of the sewage treatment system have a suitable collection of technology driven work content for a manufacturing cell, such as the tank.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
Most of the functionalities within this system can be tested separately by simulation, such as transferring fluids.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
For some (sub)function carriers of the system it would be beneficial cost wise, to design them as black box modules. For example, the pumps and tank.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Also, it would add value if some (sub)function carriers would be built as a module, as detachability would make replacing the module easier.

l_{11} ***None*** *of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficient in terms performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
The functionality of the function carriers can probably not be recycled, because of the wear after the lifecycle of the vessel. However, its material can.

B.6.4. Climate Control System (k_4)

The climate control system in general has the following functions: control of the compartment conditions (temperature and humidity) in the habitable and accessible spaces, in order to create a comfortable and safe environment for the crew and special personnel, control the internal humidity of habitable spaces, supply of cooling air to machinery, temperature control of mechanical ventilated compartments, to provide an overpressure to the outside air (with closed door), control of the specific compartment conditions for stored goods or installed equipment. [48]

l_1 *This part is* ***to some extent*** *influenced by varying requirements.*
The variable that determines the eventual capacities of the system is the volume of the accommodation and bridge. The difference of the complement per ship type means automatically a difference in volume per accommodation. Therefore, only the requirements vary in terms of performance.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are* ***any*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The system is a reliable and conservative technology. Therefore, its construction is not expected to change or develop a lot. For the short term, this technology is expected to be carried over, but also for the long term there is a big change this will happen.

l_4 *There is* ***no*** *risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Also, such a change would have a negative influence to the capital expenditures.

l_5 *There are* ***no*** *reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
The purpose of the HVAC system it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add value.

l_6 *This function can have the same physical form in* ***most*** *of the product variants.*
Because of the varying performance requirements of this system within the potential product family, the system is not expected to be similar physically for each ship type.

l_7 *There are* ***some*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
Because every ship requires a HVAC system, some parts of the potential module(s) or building blocks could be designed in such a way that the production process could be shorter. Hence, robotics in manufacturing may be a cost saver. Moreover, some

function carriers of the sewage treatment system have a suitable collection of technology driven work content for a manufacturing cell, such as the tank.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
Most of the functionalities within this system can be tested separately by simulation, such as transferring fluids, compressing fluids or transferring air.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Because it is a relatively big system with many (sub)function carriers it would not be beneficial to design it as a black box module. Also, replacing the entire module would be expensive while replacing one component would suffice already.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
As mentioned before, replacing the entire module is not beneficial. Consequently, it is not necessary to design the system in such a way that modules are easy detachable.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficient in terms of performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} *It is possible to keep **most** of the highly polluting material or easy recyclable material in this part.*
The cooling fluid this system consists is environment unfriendly. Also, its functionalities may not be used again, but its materials can be used for other purposes.

B.6.5. Day Room (k_5)

The day room provides facilities for leisure activities for the crew.

l_1 *This part is **not** influenced by varying requirements.*
The requirement of this system is that it provides facilities for leisure activities for the people on board during the whole lifetime. Hence, variables that determine the eventual capacity of this concept are the amount of persons on board, because it should provide enough space. As the complement per ship type differ from 78 to 39 man, the concept is only influenced by varying requirements in terms of performance.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the day room is to be functional for the user. Fashion and trends can play a role in this, as this can have influence to the moral of the people on board. However, the capital expenditures must be minimised and only small changes regarding fashion and trends are expected. For example, a television or game console can be replaced easily, while the furniture does not require replacement necessarily.

l_3 *There are **medium** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The day room is a relatively conservative concept. Its construction is not complex and is not expected to change or develop. However, some performance requirements may change in the future, but this can be solved easily by designing a new module for its (sub)function carrier(s), such as a closet.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the current concept matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology causing a technology push is not expected. Also, such a change would have a negative influence to the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One priority of the day room is that it fulfils its functionality during the whole lifetime of the ship. Therefore, a change in one of the concepts will not happen, as this would increase the capital expenditures and would not add value.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of the function carriers within this concept can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type. However, the space of this room will differ definitely, because of the difference in complement per ship type.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carriers within this room, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
A day room is not a complex concept and the functionalities it possess can be determined without a practical test. Separately testing does not add value.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
As the concept already consists several modules, designing the whole as a black box module would not provide many advantages. However, for some parts within this room, it could reduce logistics costs. For example the couch and chair.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
A day room and its interior can be designed in such a way, no service repairs are required during the lifetime of the vessel. Detachability would not add value.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficient in terms of performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
The functionalities of the concept can probably not be recycled, because of the wear after the lifecycle of the vessel. However, its material can.

B.6.6. Restaurant Facilities (k_6)

The galley and the messroom provide restaurant facilities. I.e., place for preparing, storing, cooking, baking, frying food, cleaning dishes and a place for consuming the meal.

l_1 *This part is **to some extent** influenced by varying requirements.*
The requirement of this system is that it provides restaurant facilities for the people on board during the whole lifetime. Hence, variables that determine the eventual capacity of this concept is the amount of persons on board. As the complement per ship type differ from 78 to 39 man, the concept is influenced by only varying requirements in terms of performance.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the restaurant facilities is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised.

Therefore, most likely its facilities will have one neutral standard design.

l_3 *There are **medium** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The messroom, galley and refrigeration plant are relatively conservative concepts. Its construction is not complex and is not expected to change or develop. However, some performance requirements may change in the future, but the technology or concept will be the same.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the current technology and concept match the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology causing a technology push is not expected. Also, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One priority of the restaurant facilities is that it fulfils its functionality during the whole lifetime of the ship. Therefore, a change of this concept or technology will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of some of the function carriers within this concept can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type. However, the space of the galley, mess room and refrigerator room will differ definitely, because of the difference in complement per ship type.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carriers within this room, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver.

l_8 *There are **any** reasons why this part should be a separate module because its function can be tested separately.*
Most of the subfunction carriers can be tested separately by simulation, such as an oven, compressor for the refrigerant or exhaust hood.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
For some (sub)function carriers it would be beneficial to design it as a black box module, because its technology is relatively complex. For example, the oven or dishwasher.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
A messroom and its interior can be designed in such a way, no service repairs are required during the lifetime of the vessel. Detachability would not add value.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficient in terms of performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} *It is possible to keep **some** of the highly polluting material or easy recyclable material in this part.*
At the end of the lifetime, the functionalities of the function carriers are not expected to be reliable or usable anymore. However, the materials can be used for other purposes.

B.6.7. Laundry Facility (k_7)

The laundry room provides facilities to clean clothing. I.e., room equipped with washing- and drying machines.

l_1 *This part is **to some extent** influenced by varying requirements.*
The requirement of this system is that it provides facilities for washing clothes during the whole lifetime. Hence, variables that determine the eventual capacity of this concept is the amount of persons on board, because it should provide capacities. As the complement per ship type differ from 78 to 39 man, the concept is only influenced by varying requirements in terms of performance.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the laundry room is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the room will have one neutral standard design.

l_3 *There are **medium** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The laundry facility is a relatively conservative concept. Its construction is not complex and is not expected to change or develop.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the current concept matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology causing a technology push is not expected. Also, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One priority of the day room is that it fulfils its functionality during the whole lifetime of the ship. Therefore, a change of this concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of some of the function carriers within this concept can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type. However, the space of the room will differ definitely, because of the difference in complement per ship type.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carriers within this room, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
Some of the subfunction carriers can be tested separately by simulation, such as a washing machine or dryer.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
For some (sub)function carriers it would be beneficial to design it as a black box module, because its technology is relatively complex. For example, the washing machine or dryer.

l_{10} *It is possible that **some** of the service repairs will be easier if this part is easy detachable.*

For some subfunction carriers, such as the washing machine and the dryer it would give an advantage for replacement if this module would be easy detachable.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficient in terms of performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the technical solution is not expected to be reliable or usable anymore. However, the materials can be used for other purposes.

B.6.8. Hull (k_8)

The hull is the watertight enclosure of the ship that secures watertight integrity in order to be buoyant.

l_1 *This part is **not** influenced by varying requirements.*
The variable that determines the form and dimensions of the mono-hull is the performance requirement to minimise the resistance when sailing, while being buoyant. Four ship types, within the potential product family, have a displacement between 1000 and 2000 tons, namely the hydrographic survey, submarine support, logistic support and the marine training. [22] The displacement of the diving support vessels is smaller.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. But also the looks of the vessel is of importance. However, trends within shipping industry are relatively conservative and will not change tremendously.

l_3 *There are **medium** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
As mentioned before, the displacement of 4 ship types of the potential product family is between 1000 and 2000 tons and requires a mono-hull. In other words, this could mean that a potential module can be used for some product variants of the next generation, i.e., ship types of the potential product family. Nonetheless, the technical solution among all ship types is the same.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the current technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change in technology causing a technology push is not expected. Also, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
The purpose of the hull is that it fulfil its functionality during the whole lifetime of the ship. Therefore, a change of this concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **medium** of the product variants.*
The ship types having almost the same displacement, may also have the same physical form. However, some ship types are installed with mission specific equipment that have to be taken into account when designing the hull.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
The ship types requiring the same hull, could be designed in such a way, i.e., build out of building blocks, that the production process could be shorter. Hence, robotics in

manufacturing may be a cost saver.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
A hull is not a complex technology and its functionality can only be tested once installed.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
This part is relatively big and designing it as a black box module is not possible. Moreover, designing it as a black box the function should be integrated with (an)other function(s).

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
A hull can be designed in such a way, no service repairs are required during the lifetime of the vessel. Detachability would not add value.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficient in terms of performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system cannot be used anymore. However, the materials can be used for other purposes.

B.6.9. Frames (k_9)

The hull's frames shall secure structural integrity, i.e., resist internal and external forces.

l_1 *This part is **not** influenced by varying requirements.*
The variables that determine the construction and strength of the frames are the arrangement, volume and weight of the systems. The five ship types differ in this a lot. Therefore, it could be that each ship type must be designed with an unique construction.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the construction will have one neutral standard design.

l_3 *There are **medium** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
As mentioned before, each ship type is expected to be designed with its unique construction. In other words, a potential module variant could only be used for exactly the same ship. The change this module would be used for a next generation ship is minor. Nonetheless, the technical solution is the same among all ship types.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because this part of the product is a fundamental system for other systems, as it secures the structural integrity of the whole ship, a technology change of this system would require very high effort to replace. Also, it would increase the capital expenditures. In other words, an unexpected change in technology, causing a technology push is not expected.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
The purpose of the frames is that it fulfil its functionality during the whole lifetime of the ship. Therefore, a change of this concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants.*
Also, the physical form of the construction of the frames cannot be same among all ship types, because of the varying requirements per ship type. However, some standardisation may be possible as are potential building blocks.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
Standardisation of some of the function carriers could mean a shorter production process. Hence, robotics in manufacturing may be a cost saver.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The frame construction is not a complex technology and its functionality can only be tested once installed.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
As the components are relatively simple, designing the whole as a black box module would not provide many advantages. Moreover, it is not suitable work content for a group.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
The frames can be designed in such a way, no service repairs are required during the lifetime of the vessel. Detachability would not add value.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficient in terms of performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system cannot be used anymore. However, the materials can be used for other purposes.

B.6.10. Ballast System (k_{10})

The ballast system shall correct general trim to optimise the stability of the ship due to different loading conditions and fuel consumption. It is arranged to ensure that water can be drawn from any tank or the sea and discharged to any other tank or the sea as required to trim the vessel. The principle equipment or components a conventional ballast systems consist of are tanks, valves, pumps, sea chests, outlet and filters. [48]

l_1 *This part is **not** influenced by varying requirements.*
The capacity of the ballast system is mainly depend on the difference in stability between sailing conditions. For example, the logistic support vessel is required to carry a lot more cargo than the marine training vessel. Therefore, the former ship type requires more performance capacity of the system compared to the latter one, as the difference in tons between being loaded or being unloaded is a more.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the construction will have one neutral standard design.

l_3 *There are **any** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
As mentioned before, within the potential product family there are varying performance

requirements. However, the technical solution may be shared among all potential product types.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Also, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
The purpose of the ballast system it that it fulfils its functionality during the whole lifetime of the ship. A planned change of this concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **some** of the product variants.*
Because of the varying performance requirements of this system within the potential product family, the system is not expected to be similar physically for each ship type for all subfunction carriers. However, some may be shared among ship types. For example, pumps, filters, manholes and valves.

l_7 *There are **some** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
Because every ship requires a ballast system, some parts of the potential module(s) or building blocks could be designed in such a way that the production process could be shorter. Hence, robotics in manufacturing may be a cost saver. However, the level of the subdivision of the main function to be modularised is hereby important.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
Most of the functionalities within this system can be tested separately by simulation, such as to float. Also, testing its main function is possible.

l_9 *There are **some** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
As the subfunction carriers are relatively simple technology, designing the whole as a black box module would not provide many advantages.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Most of the system can be designed in such a way, no service repairs are required during the lifetime of the vessel. Detachability would not add value. For the parts that require maintenance, only a replacement of a component would suffice and would be more cost efficient.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficiently satisfying. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.11. Rescue Boat (k_{11})

This boat is designed to rescue one or more persons in distress and is lowered into the water by a crane in general. For operation the rescue boat must be in accordance to a standard of SOLAS.

l_1 *This part is* ***not*** *influenced by varying requirements.*
This function carrier is common for all ship types within the potential product family and requirements do not vary a lot.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the rescue boat is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the rescue boat will be designed as one standardised product applicable for the whole lifetime of the vessel.

l_3 *There are* ***strong*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The current technology is a reliable one. Therefore, for the short term it is not expected to change or develop much and is likely to be carried over. However, for the long term its propulsion may be replaced by a more sustainable technology.

l_4 *There is* ***no*** *risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Also, such a change would increase the capital expenditures.

l_5 *There are* ***no*** *reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this part is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in* ***all*** *of the product variants.*
The physical form of the function carriers within this concept can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type.

l_7 *There are* ***strong*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver.

l_8 *There are* ***no*** *reasons why this part should be a separate module because its function can be tested separately.*
Most of the functionalities within this system can be tested separately by simulation. However, this driver is only interesting for a subcontractor of DSNS, as Damen will not develop and manufacture this technical solution by itself most likely.

l_9 *There are* ***strong*** *reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing it as a black box module would be beneficial, because it consists out of advanced components interacting with each other to fulfil the subfunctions. If a specialist could deliver this as a black box, logistics costs could be reduced.

l_{10} *It is possible that* ***none*** *of the service repairs will be easier if this part is easy detachable.*
Also, it would add value if the function carrier would be built as a module, as detachability would make unforeseen service repair easier.

l_{11} ***None*** *of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality

of the concept is already sufficient in terms of performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.12. Life Raft (k_{12})

Life rafts are provided as a life-saving appliance on every seagoing ship, in addition to the lifeboats. Life rafts are much easier to launch than lifeboats. In case of emergency situations, evacuation from the ship can be done without manually launching any of them as the life rafts are designed with an auto-inflatable system. For operation the rescue boat must be in accordance to a standard of SOLAS.

l_1 *This part is* ***not*** *influenced by varying requirements.*
This function carrier is common for all ship types within the potential product family and requirements do not vary a lot.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the life raft is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the life raft will be designed as one standardised product functioning for the whole lifetime of the vessel.

l_3 *There are* ***strong*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The system is a reliable technology. Therefore, its construction is not expected to change or develop a lot. For the short term, this technology is expected to be carried over, but also for the long term.

l_4 *There is* ***no*** *risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Also, such a change would increase the capital expenditures.

l_5 *There are* ***no*** *reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this system is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in* ***all*** *of the product variants.*
The physical form of the function carriers within this concept can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type.

l_7 *There are* ***strong*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver.

l_8 *There are* ***no*** *reasons why this part should be a separate module because its function can be tested separately.*
Most of the functionalities within this system can be tested separately by simulation.

However, this driver is only interesting for a subcontractor of DSNS, as Damen will not develop and manufacture this technical solution by itself most likely.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing it as a black box module would be beneficial, because it consists out of advanced components interacting with each other to fulfil the subfunctions. If a specialist could deliver this as a black box, logistics costs could be reduced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Also, it would add value if the function carrier would be built as a module, as detachability would make unforeseen service repair easier.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already sufficient in terms of performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.13. Fire Fighting System (k_{13})

A ship is fitted with various types of fire retardant and fire fighting equipment as to fight any kind of fire in order to extinguish it as soon as possible before it turns into a major catastrophic situation. Fire fighting equipment that is used on board ships are: Fire retardant bulkhead, fire doors, fire dampers, fire pumps, fire main piping and valves, fire hoses and nozzles, fire hydrants, portable fire extinguishers, fixed fire extinguish system, inert gas system, fire detectors and alarms, remote shut and stop system, EEBD, fire fighter's outfit. In general, fire extinguishing systems can be distinguished into foam fire extinguishing system, fixed gas fire extinguishing system and fresh water fire extinguishing system. Also, they can be categorised into portable and fixed equipment. [48]

l_1 *This part is **not** influenced by varying requirements.*
The variable that may cause different requirements among the ship types are the size of the ship and its type of transported cargo.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, the function carriers will have most likely one neutral standard design.

l_3 *There are **some** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
As described in the system description, this technical solution consists a lot of function carriers. The equipment and subsystem(s) that are installed on conventional ships are reliable and conservative technologies. Therefore, potential and already existing modules are not expected to change or to develop. For the short and long term, this technology is expected to be carried over.

l_4 *There is **some** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology during the lifetime of the vessel, causing a technology push, is not expected. Moreover, such a change would have a negative influence to the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
The purpose of the fire fighting system is that it fulfils its functionality during the whole lifetime of the ship. However, some equipment may expire and must be replaced. Naturally, a replacement would increase the capital expenditures. Nonetheless, safety is an important aspect in the shipping industry and the function carriers of this technical solution must comply to these regulations and be reliable.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of some of the function carriers of this technical solution can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type. However, for some subsystem the varying capacities between the ship types can cause difference in the physical form.

l_7 *There are **some** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carriers, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver. Also, some of the equipment is a suitable collection of technology driven work content for a manufacturing cell. E.g., doors and portable fire extinguishers.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
Some of the (sub)function carriers can be tested separately, such as a portable fire extinguishers, doors or pumps.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some equipment as a black box module would be beneficial, as they have to comply to strict regulations and its construction is precise. If a specialist could deliver this, the logistics costs could be reduced.

l_{10} *It is possible that **some** of the service repairs will be easier if this part is easy detachable.*
Also, it would add value if some function carriers would be built as a module, as detachability would make service repair easier.

l_{11} ***Some** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities the system consist are expected not to be used again as each equipment must comply to strict regulations. However, the materials can be used for other purposes.

B.6.14. Emergency Alarm System (k_{14})

The alarm and safety system detects and reports alarms and events to the operator when abnormal conditions occur. Most of the individual systems have an interface with the control rooms and/or bridge system. Alarms may also be presented on the displays of these systems. The types of alarms are: fire detection and alarm, man over board alarm, lock-in alarm (cold/cool/refrigerator rooms), hospital alarm, audio visual machinery spaces alarm and gas detection alarm. [48]

l_1 *This part is **not** influenced by varying requirements.*
The function carriers of this system are common for every ship type within the potential

product family. Therefore, there are no varying requirements.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the emergency alarm system is that it is functional. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will be designed as one standardised product operationable for the whole lifetime of the vessel.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
Every merchant or navy ship is installed with an emergency alarm system. The equipment and subsystem(s) that are installed on conventional ships are reliable and conservative technologies. Therefore, potential and already existing modules are not expected to change or to develop. For the short and long term, this technology is expected to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this part is it that it fulfils its functionality during the whole lifetime of the ship. A planned change will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **none** of the product variants.*
The physical form of the function carriers within this concept can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type.

l_7 *There are **some** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
Most of the functionalities within this system can be tested separately by simulation, such as its audible or visual functions.

l_9 *There are **some** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some subfunction carriers as a black box module would be beneficial, as they have to comply to strict regulations and its construction is pretty precise. By doing this, the logistics costs could be reduced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Also, it would add value if some function carriers would be built as a module, as detachability would make service repair or replacement easier.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionalities of the concept are already providing sufficient performance. Also, an eventual

enhancement would mean an increase of the capital expenditures.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities the system consist are expected not to be used again as each equipment must comply to strict regulations. However, the materials can be used for other purposes.

B.6.15. Emergency Electrical Power Generation System (k_{15})

A blackout is the condition that brings the whole ship to a standstill. Blackout condition is a scenario on a ship, wherein the main propulsion plant and associate machinery and other auxiliaries stop operating due to failure of the power generation system of the ship. To back-up this scenario, the electric power emergency system generates electric power in case this happens. In order to do so, the emergency generator is: self-ventilating, self-regulating, self-exiting and brush-less, according to Class rules. [48]

l_1 *This part is* ***not*** *influenced by varying requirements.*
The capacity of the emergency power generation system is mainly depend on the difference in required power during an emergency situation. The ship types within the potential product family may have different electrical consumers.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will be standardised.

l_3 *There are* ***no*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The preference for a certain type of technology depends on the required power, (future) regulations, operational and capital expenditures, logistic infrastructure with respect to the energy source, mass and volume and the TRL. As the regulations regarding emission has become and are becoming stricter, the technology entered a transition period. Therefore, in the short term, the current technology may not change, but in the long term a technology it will. However, the product platform, considered in this research, to be developed, will be built in the short term.

l_4 *There is* ***medium*** *risk that this part will go through a technology shift during the product lifecycle.*
As mentioned before, this technical solution entered a transition period. Because the TRL of the technology alternatives are not yet of a high standard, and the other aspects are also disadvantageous compared to the current technology, it is hard to predict what the change will be in the future. However, the initial installed technology may not be the best function carrier during the whole lifetime.

l_5 *There are* ***medium*** *reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
Since Navy Vessels have a midlife upgrade the client can opt for a strategy where the technology will be replaced by another one that is more environmental friendly. However, this would automatically mean an increase in capital expenditures. Also, the support systems may be different or its desired capacities may change.

l_6 *This function can have the same physical form in* ***most*** *of the product variants.*
The physical form of the function carriers within this concept may differ among the vessel types within the potential product family, as its performance requirements may vary.

l_7 *There are* ***some*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*

As all ships require the same function carrier, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver. However, the level of the subdivision of the main function to be modularised is hereby important.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance of some parts of this system is important. Normally, a client opts for certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing it as a black box module would be beneficial, because the technical solution consists out of advanced components interacting with each other to fulfil the subfunctions. If a specialist could deliver this as a black box, logistics costs could be reduced.

l_{10} *It is possible that **some** of the service repairs will be easier if this part is easy detachable.*
As the mass and volume of the technical solution is expected to be relatively big, an detachable module would not add value. Also, the system is intended to be functional during the whole lifetime of the vessel, thus a replacement or a service repair where the module will be detached is not expected.

l_{11} ***Some** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.16. Navigational Data Acquisition System (k_{16})

Modern day facilities and automation onboard a ship provide the seafarer several advanced equipment systems that provide accurate data to support the voyage. To give an impression, the following systems are enlisted: gyro compass, radar, magnetic compass, auto pilot, X-band radar system, S-band radar system, ARPA, automatic tracking aid, speed & distance log device, echo sounder, ECDIS, AIS, GPS, rudder angle indicator, voyage data recorder, rate of turn indicator, navigational lights, ship whistle, voyage plan. They are all integrated with each other. [48]

l_1 *This part is **not** influenced by varying requirements.*
The function carriers are common for all ship types within the potential product family and requirements do not vary. However, its performance requirements may vary.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the function carriers is to be functional for the user. Fashion and trends, in terms of hardware, do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will be designed as standardised products. Then, the displaying of data, the possibility to plot and to input data, may be influenced by trends, in terms of software. However, this does not really effect the physical concept.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The working principle of the subfunction carriers, in terms of hardware, are pretty conservative and are not likely to change in the short term. The computers that process

and analyse the data are likely to become better, but this part of the potential module is easy to replace. Furthermore, these modules can be used over several ship types. For the long term, the sensors and processing system will be outdated.

l_4 *There is **some** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would have a negative influence to the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
This technical solution is required during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditure. However, a replacement of function carriers by future ones with better performances, could be interesting.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of the function carriers can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carriers, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver. However, the level of the subdivision of the main function to be modularised is hereby important.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some (combined) function carriers as a black box module would be beneficial, because the technical solution consists out of advanced components interacting with each other to fulfil the subfunctions. If a specialist could deliver this as a black box, logistics costs would be reduced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Function carriers that are expected to be replaced or that require service repair, such as the processing part of the system, would benefit from a design that is easily detachable.

l_{11} ***Some** of the future upgrading can be simplified if this part is easy to change.*
Furthermore, upgrading the function carriers with respect to processing data, are likely to happen.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.17. Navigational Control System (k_{17})

To navigate safely and securely, the seafarer can operate the navigational systems remotely. This main function consists out of several subfunctions, such as, to transmit a signal coming from the navigational data acquisition system, to receive this signal, to process this signal and to output the signal, so that the navigational machinery can execute the initial signal coming from the bridge. This also works vice versa, as the operator at the bridge receives information about the status of the machinery.

l_1 *This part is **not** influenced by varying requirements.*
The function carriers of this system are common for every ship type within the potential product family. Therefore, there are no varying requirements.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the navigational control system is that it is functional. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will be designed as one standardised product functional for the whole lifetime of the vessel.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
Every merchant or navy ship is installed with a navigation control system for safe navigation. The equipment used on conventional ships are reliable and conservative technologies. Therefore, potential and already existing modules are not expected to change or to develop. For the short and long term, this technology is expected to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would have a negative influence to the capital expenditures. However, a change in the propulsion system or steering system may also cause some changes for this system.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this part is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of the function carriers within this concept can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver. However, the level of the subdivision of the main function to be modularised is hereby important.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
Most of the functionalities within this system are relatively simple and do not require a separate test.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
As the concept is relatively simple, designing the whole as a black box module would not provide many advantages. However, for some parts, it could reduce logistics costs,

if the function carriers are designed and manufactured by a specialist.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
The function carriers can be designed in such a way, no service repairs are required during the lifetime of the vessel. Detachability would not add value.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionalities of the concept are already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.18. Engineering Control System (k_{18})

The engineering control systems provide the engineer information of several systems from a remote location. This helps the engineer to have a better overview of the operating process of the ship's systems and helps detecting and avoiding early stadium failures. The type of data to be transmitted is totally dependent on other systems. However, the main function can be subdivided into subfunctions: to generate a signal, to transmit a signal, to receive a signal, to process a signal and to output/display the signal. The type of signal can be pressure, electric power, temperature and flow.

l_1 *This part is **not** influenced by varying requirements.*
The function carriers are common for all ship types within the potential product family and requirements do not vary. However, its performance requirements may vary.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the function carriers is to be functional for the user. Fashion and trends, in terms of hardware, do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will be designed as standardised products. Then, the displaying of data, the possibility to plot and to input data, may be influenced by trends, in terms of software. However, this does not really effect the physical concept.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The working principle of the subfunction carriers, in terms of hardware, are pretty conservative and are not likely to change in the short term. The computers that process and analyse the data are likely to become better, but this part of the potential module is easy to replace. Furthermore, these modules can be used over several ship types. For the long term, the sensors and processing system will be outdated.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
This technical solution is required during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditure. However, a replacement of the function carrier that processes the data, by one that is better in terms of performance, could be interesting.

l_6 *This function can have the same physical form in* ***most*** *of the product variants.*
The physical form of the function carriers can be the same among all vessel types within the potential product family, as its purpose and its stakeholders are the same for every vessel type.

l_7 *There are* ***medium*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carriers, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver. However, the level of the subdivision of the main function to be modularised is hereby important.

l_8 *There are* ***no*** *reasons why this part should be a separate module because its function can be tested separately.*
The performance of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment.

l_9 *There are* ***strong*** *reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some (combined) function carriers as a black box module would be beneficial, because the technical solution, in terms of software and hardware, consist out of advanced components interacting with each other to fulfil the subfunctions. If a specialist could deliver this as a black box, logistics costs would be reduced.

l_{10} *It is possible that* ***none*** *of the service repairs will be easier if this part is easy detachable.*
Function carriers that are expected to be replaced or that require service repair, such as the processing part of the system, would benefit from a design that is easily detachable.

l_{11} ***None*** *of the future upgrading can be simplified if this part is easy to change.*
Furthermore, upgrading the function carriers with respect to processing data, are likely to happen.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.19. Electrical Control Panels (k_{19})

Normally, the electrical control panels are the place from which the engineer is able to control the power distribution manually and thus start or cut-off the electric power supply to the electricity consumer. Furthermore, the engineer can control the condition of the machinery, as the amperage of the electricity consumer is displayed here, as is a possible earth fault. The main function of this system is to provide (remote) control of electricity consumer.

l_1 *This part is* ***not*** *influenced by varying requirements.*
The requirements between function carriers for electrical consumers may vary. However, if the function is subdivided into several functions, the variation in requirements is becoming less. Therefore, at a certain function level, function carriers can be standardised and used for the whole product family.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the electrical control panel is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will have one neutral standard design.

l_3 *There are* ***no*** *reasons that this technical solution should be a separate module because*

the new design can be carried over to coming product generations.
Every subfunction is likely to be standardised and since every ship is installed with electrical consumers, it also likely these type of potential modules can be carried over to future ships.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Also, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this system is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **some** of the product variants.*
On the level of the main function the potential module is likely to have multiple variants physically, while a function level deeper, the subfunction carrier is not influenced by this variation of requirements.

l_7 *There are **some** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships have several electrical consumers, multiple electrical control panels are required. Therefore, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver. However, the level of the subdivision of the main function to be modularised is hereby important.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The components the function carrier consist of are not very complex. Therefore, separately testing does not add value.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
If a specialist could deliver this as a black box, logistics costs would be reduced and the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Function carriers that are expected to be replaced or that require service repair, such as safety devices like fuses, would benefit from a design that is easily detachable.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionalities of the concept are already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.20. Workshop Facilities (k_{20})

The workshop is a room where the engineer can do welding, cutting, (dis)assembling, maintenance, cleaning, all kinds of measurements and store his/hers tools. The main function of the workshop facilities is described as provide support for maintenance and repair work.

The main equipment in the workshop is: lathe, milling machine, saw bench, pedestal drilling machine, pedestal grinder, electric welding plant and electrode drying cabinet. [48]

l_1 *This part is* ***not*** *influenced by varying requirements.*
The requirement of this system is that it provides space and tools for doing maintenance and repair work. Hence, variables that determine the eventual capacity of the facility is the amount of work, the kind of work and the amount of people who will use the facility. As the mission statement per ship type varies, some requirements could differ as well. However, most of the function carriers are expected to be common among all ship types within the potential product family.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this facility is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, this facility will have most likely one neutral design for its facilities.

l_3 *There are* ***some*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The workshop facilities are relatively conservative concepts. It technical solutions are not expected to change. However, some performance requirements may change in the future, but this can be solved easily by designing a new module for its subfunction carrier, such as a smaller or bigger working air reservoir.

l_4 *There is* ***no*** *risk that this part will go through a technology shift during the product lifecycle.*
Because the current concepts match the desired functionalities, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology causing a technology push is not expected. Also, such a change would have increase the capital expenditures.

l_5 *There are* ***no*** *reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
Another priority of the facilities is that it fulfils its functionality during the whole lifetime of the ship. Therefore, a change in one of the concepts will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in* ***most*** *of the product variants.*
The physical form of the function carriers may be different between ship types, because of the difference in required capacities. E.g., the capacities of the working air system or welding system. Perhaps the modules can be divided into two different physical ones.

l_7 *There are* ***medium*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carriers within this room, the production process could become leaner if some of these function carriers would be designed as a module. Hence, robotics in manufacturing may be a cost saver.

l_8 *There are* ***no*** *reasons why this part should be a separate module because its function can be tested separately.*
For some function carriers of the working air system or welding system, a separate test would provide some benefits.

l_9 *There are* ***no*** *reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some equipment as a black box module by a specialist would be beneficial, as its construction high tech. This would reduce the logistics costs.

l_{10} *It is possible that* ***none*** *of the service repairs will be easier if this part is easy detachable.*

Designing some equipment as a black box module would be beneficial, as detachability would make service repairs or replacement easier. For example the replacement of gas bottles used for welding.

l_{11} ***None*** *of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would increase the capital expenditures.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.21. Mechanical Power Generation Architecture (k_{21})

The propulsion architectures for ships can be classified into the following categories [21]:

- Mechanical propulsion - Propulsion provided by one or more prime movers.
- Electrical propulsion - Propulsion provided by one or more electric motors.
- Hybrid propulsion - Propulsion provided by a combination of one or more prime movers and electric machines.

l_1 *This part is* ***not*** *influenced by varying requirements.*
The capacity of the mechanical power generation system is mainly depend on the operational profile and the resistance of the hull. Therefore, the ship types within the potential product family may have different performance requirements.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will be standardised.

l_3 *There are* ***some*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The ambition of the Netherlands Ministry of Defence has declared to reduce its fossil fuel dependency by at least 20% in 2030 and by at least 70% in 2050. (This is more stringent than the initial strategy agreed by IMO). For opting a technology, aspect that should be taken into account are the mass and volume of the system, the estimated capital and operational expenditure, technology readiness level (TRL), logistic availability of the fuel and the estimated yearly CO2 emissions. [22] Assuming that the mechanical power generation is not achieved by electrical propulsion, the type of prime mover to be installed is determinative whether the technology will be carried over or not. The conventional prime mover (i.e., internal combustion engine running on fossil fuel) does not meet the ambition of 2030. However, the technology that is less or not dependent on fossil fuel is not mature enough yet. Nonetheless, for the short term, the conventional function carrier may be carried over until a more environment friendly technology is developed. Assuming the propulsion architecture is electrical, no changes are expected and the technology will be carried over for a longer period certainly.

l_4 *There is* ***medium*** *risk that this part will go through a technology shift during the product lifecycle.*
If the initial installed propulsion architecture is electric, a technological shift is not expected as the current technologies match the desired functionality and the TRL is of a high standard. Also, they comply to all regulations during the entire lifetime of the ship. However, if the initial installed propulsion architecture is mechanical or hybrid, the technology may be shifted during the vessel's lifetime. As mentioned before, this technology entered a transition period, because regulations regarding emissions has

become and are becoming stricter. Because the TRL of the technology alternatives are not yet of a high standard and the other aspects are also disadvantageous compared to the current technology, it is hard to predict what the change will be in the future. Nonetheless, an eventual technology shift for these type of propulsion architectures is unavoidable.

l_5 *There are **medium** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
Assuming that the propulsion architecture is electrical, a planned change in technology is not expected, as it fulfils its functionality and meets all requirements and ambitions. On the other hand, assuming the propulsion architecture is hybrid or mechanical, a planned change is not ruled out. Since Navy Vessels have a midlife upgrade the client can opt for a strategy where this technology will be shifted by another one that is more environmental friendly, during this upgrade. However, this would automatically lead to an increase in capital expenditures. Another disadvantage of such a replacement could mean a reduce in endurance, as the density and the energy density are different per energy source and the efficiency differs per technology. But also different (performances of the) support systems may be required.

l_6 *This function can have the same physical form in **most** of the product variants.*
The varying performance requirements between the ship types could mean a variation in the physical form. However, an electrical propulsion could solve this by installing one or multiple electric motors in order to meet the variation in desired power capacities per ship type while having one physical form.

l_7 *There are **some** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
If all ship types will be installed with the same function carriers, the production process could become leaner. Hence, robotics in manufacturing could be a cost saver.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing it as a black box modules would be beneficial, because the technical solution consists advanced components, interacting with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **some** of the service repairs will be easier if this part is easy detachable.*
As the mass and volume of the technical solution is expected to be relatively big, a detachable module would not add value with respect to replacement or service repairs. However, for some subfunction carriers, detachability would be an advantage for maintenance.

l_{11} *It is possible that **some** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*

At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.22. Propulsor (k_{22})

The most common propulsor is the screw propeller. Other types are the waterjet and the Voith Schneider. A propeller generates thrust by means of lift on the blades that rotate at an angle of attack relative to a flow. The most commonly used propulsors are the fixed pitch propeller, controllable pitch propeller or a propeller equipped with a duct [30]. Another distinction between propellers is the difference between a conventional/subcavitating or a supercavitating propeller. [53]

l_1 *This part is **strongly** influenced by varying requirements.*
The geometry of a propeller, in particular the blades, is very important in terms of efficiency and cavitation. A propeller will be custom-made to suit the ship and its propulsion system. Propeller, ship and the rest of propulsion system need to be matched to fit all operational conditions in a satisfying manner [30]. Because of these aspects it is expected that every ship requires their own specific requirements.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The geometry of a propeller, in particular the blades, is very important in light of efficiency and cavitation. A propeller will be custom-made to suit the ship and its propulsion system. Propeller, ship and the rest of propulsion system need to be matched to fit all operational conditions in a satisfying manner. [30] Therefore, it is not likely the propeller will be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected within technology, causing a technology push, is not expected. Also, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **none** of the product variants.*
As mentioned before, the geometry of the propeller is of importance. Hence, the physical form of this function carrier is not expected to be the same for each ship type.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if some of these function carriers would be modularised to a certain extent. Hence, robotics in manufacturing would be a cost saver.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The components the function carrier consist of are not very complex. Therefore, separately testing does not add value.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There*

are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.
Designing it as a black box module(s) would be beneficial, because the technical solution consists advanced components, interacting with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
This function carrier can be designed in such a way, no service repairs are required during the lifetime of the vessel. Detachability would not add value. Also, maintenance does not require dismantling.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.23. Transmission System (k_{23})

The transmission system can also be classified into the following categories [21]:

- Mechanical propulsion architectures have either a direct connection or connection through a gearbox.
- Electrical propulsion architectures have either a direct connection or connection through a gearbox.
- Hybrid propulsion architectures have a connection through a gearbox.

l_1 *This part is **to some extent** influenced by varying requirements.*
The variables that determine the capacities of the system are the nominal power to be transmitted and the type of propulsion architecture. Assuming that the ship types of the potential product family are installed with the same type of propulsion architecture, there will still be a difference in performance requirement in terms of power.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised.

l_3 *There are **some** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, its capabilities and capacities are determined by the kind of propulsion architecture. Therefore, to be carried over, the requirements should be exactly the same.

l_4 *There is **some** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **some** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen,

as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of the function carriers may be different between ship types, because of the difference in required capacities and capabilities.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if some of these function carriers would be modularised to a certain extent. Hence, robotics in manufacturing could be a cost saver. Also, this system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are **some** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing it as a black box module(s) would be beneficial, because the technical solution consists advanced components, interacting with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
This function carrier can be designed in such a way, no service repairs are required during the lifetime of the vessel. Detachability would not add value. Also, maintenance does not require dismantling.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.24. Steering System (k_{24})

The function of the steering system is to move, stop and hold its corresponding rudder at any specified angle over the entire ship's speed range. Steering is possible from the wheelhouse under normal conditions and locally in the steering gear compartment under emergency conditions. The total system can be subdivided into three parts - control equipment, a power unit and a transmission to the rudder stock. Another possible design is to alter the course of a ship by the use of azimuth thrusters. [48]

l_1 *This part is **not** influenced by varying requirements.*
Two variables that determine the rate of turn of the ship are the physical form of the hull and speed of the vessel. However, the desired rate of turn at a certain condition is up to the client. In other words, the required power the steering system should deliver in order to create a moment may differ per ship type.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*

The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised.

l_3 *There are* ***some*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The current technology is not likely to change. However, the a future ship to be produced must have the same displacement and require about the same manoeuvre capabilities to qualify for such a module.

l_4 *There is* ***no*** *risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are* ***no*** *reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in* ***most*** *of the product variants.*
The physical form of the function carriers may be different between ship types, because of the difference in required capacities and capabilities.

l_7 *There are* ***medium*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if this function carrier would be modularised to a certain extent. Hence, robotics in manufacturing could be a cost saver. Also, this system is a suitable work content for a group.

l_8 *There are* ***no*** *reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are* ***medium*** *reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing it as a black box module(s) would be beneficial, because the technical solution consists advanced components, interacting with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that* ***none*** *of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***None*** *of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*

At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.25. Bow Thruster (k_{25})

Bow thrusters are a specifc type of propeller-shaped system fitted either on the bow (forward part) and stern part (known as stern thruster) of the ship. They are smaller in size than the ship's propeller and increase the manoeuvrability of the vessel at lower speeds. Generally, side thrusters that are transverse thrusters are placed in a duct. [28]

l_1 *This part is **to some extent** influenced by varying requirements.*
The variable that determines the desired power output of the bow thruster is the desired manoeuvrability. Another aspect that should be taken into account is whether the system should be retractable. The desired capacities and capabilities may differ per ship type as the system should fulfil its (performance) requirements while being not too expensive.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised.

l_3 *There are **some** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities do not necessary meet the (performance) requirements for every ship type. This could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of the function carriers may be different between ship types, because of the difference in required capacities and capabilities. For example, the submarine support vessel requires a retractable bow thruster.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if this function carrier would be modularised to a certain extent. Hence, robotics in manufacturing could be a cost saver. Also, this system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing it as a black box module(s) would be beneficial, because the technical solution consists advanced components, interacting with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.26. Mooring System (k_{26})

The main function of this system is to forestall free movement in her berth. To achieve this, several systems fulfil the further subdivided main function. Nowadays, the following equipment can be found onboard ships: chocks, warping rollers, single fairleads, double fairleads, bollards and naturally winches and ropes.

l_1 *This part is **not** influenced by varying requirements.*
The goal of this system is to forestall free movement when the ship is in port. This means it needs to counteract any external force, such as forces caused by wind or current. The external forces that are expected can differ per ship type, because of difference in size of the vessel.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised.

l_3 *There are **medium** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology for each function carrier is not likely to change. However, its capabilities and capacities may not be common for each ship type. Therefore, a potential single module variant is not applicable for every ship type.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants.*

The physical form of the function carriers may be different between ship types, because of the difference in required capacities and capabilities.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if this function carrier would be modularised to a certain extent. Hence, robotics in manufacturing could be a cost saver. Also, this system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are **some** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some function carriers as a black box module(s) would be beneficial, because the technical solution consists advanced components and/or interact with each other. For example, the winches or ropes. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.27. Anchor System (k_{27})

The anchor system must forestall that the ship drifts away at anchorage. To achieve this, several systems must fulfil the further subdivided main function. In general, the current system consists out of an anchor, chain, power unit, chain locker, hawse pipe and a washing system.

l_1 *This part is **not** influenced by varying requirements.*
The goal of this system is to forestall drifting away. This means it needs to counteract any external force, such as forces caused by wind or current. The external forces that are expected can differ per ship type, because of difference in size of the vessel.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised.

l_3 *There are **medium** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*

The technology for each function carrier is not likely to change. However, its capabilities and capacities may not be common for each ship type. Therefore, a potential single module variant is not applicable for every ship type.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of the function carriers may be different between ship types, because of the difference in required capacities and capabilities.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carrier, the production process could become leaner if this function carrier would be modularised to a certain extent. Hence, robotics in manufacturing could be a cost saver. Also, this system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are **some** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some function carriers as a black box module(s) would be beneficial, because the technical solution consists advanced components and/or interact with each other. For example, the power unit. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage, such as the band brake of the power unit. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the whole unit is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.28. Electrical Power Generation Architecture (k_{28})

The electrical power generation architectures can be classified in [21]:

- Combustion power supply - Power supply from combustion engines only.
- Electrochemical power supply - Power supply from electrochemical sources, such as fuel cells, only.
- Stored power supply - Power supply from energy storage, such as batteries, fly-wheel or ultra capacitors only.
- Hybrid power supply - Power supply from a combustion of two or more types of power supply.

Performance parameters of the system include the endurance of each process activity (e.g., transit, mobilisation, loading & offloading), fuel consumption, emissions and the underwater radiated noise.

l_1 *This part is **not** influenced by varying requirements.*
The capacities of the electrical power generation system are mainly depend on the operational profile and the required power of the mechanical power generation architecture, especially if it is electrical or hybrid propulsion. Assuming that every ship type is installed with the same mechanical power generation architecture and the electrical power generation architecture, the system will still differ in performance requirements.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will be standardised.

l_3 *There are **some** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The ambition of the Netherlands Ministry of Defence has declared to reduce its fossil fuel dependency by at least 20% in 2030 and by at least 70% in 2050. (This is more stringent than the initial strategy agreed by IMO). For opting a technology, aspect that should be taken into account are the mass and volume of the system, the estimated capital and operational expenditure, technology readiness level (TRL), logistic availability of the fuel and the estimated yearly CO_2 emissions. [22] The type of prime mover to be installed is determinative whether the technology will be carried over or not. The conventional prime mover (i.e., internal combustion engine running on fossil fuel) does not meet the ambition of 2030. However, the technology that is less or not dependent on fossil fuel is not mature enough yet. Nonetheless, for the short term, the conventional function carrier may be carried over until a more environment friendly technology is developed.

l_4 *There is **medium** risk that this part will go through a technology shift during the product lifecycle.*
Assuming the initial installed propulsion architecture is a prime mover running on fossil fuel, the technology may be shifted during the vessel's lifetime. As mentioned before, this technology entered a transition period, because regulations regarding emissions has become and are becoming stricter. Also, the TRL of the technology alternatives are not yet of a high standard and the state of the other aspects are also disadvantageous compared to the current technology, it is hard to predict what the change will be in the future. Nonetheless, an eventual technology shift for these type of propulsion architectures is unavoidable.

l_5 *There are **medium** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
Since Navy Vessels have a midlife upgrade the client can opt for a strategy where this technology will be shifted by another one that is more environmental friendly, during this upgrade. However, this would automatically lead to an increase in capital expenditures.

Another disadvantage of such a replacement could mean a reduce in endurance, as the density and the energy density are different per energy source and the efficiency differs per technology. But also different (performances of the) support systems may be required.

l_6 *This function can have the same physical form in* ***most*** *of the product variants.*
The varying performance requirements between the ship types could mean a variation in the physical form. However, the desired power output for each ship type can also be met by installing the right amount of modules.

l_7 *There are* ***some*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
If all ship types will be installed with the same function carriers, the production process could become leaner. Hence, robotics in manufacturing could be a cost saver.

l_8 *There are* ***no*** *reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are* ***some*** *reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing it as black box modules would be beneficial, because the technical solution consists advanced components, interacting with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that* ***some*** *of the service repairs will be easier if this part is easy detachable.*
As the mass and volume of the technical solution is expected to be relatively big, a detachable module would not add value with respect to replacement or service repairs. However, for some subfunction carriers, detachability would be an advantage for maintenance.

l_{11} *It is possible that* ***some*** *of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.29. Switchboard (k_{29})

The power distribution system enables the distribution of electrical power to the consumers on the ship. First of all, the main switchboard distinguishes itself from others by the amount of voltage and the type of current, i.e., alternating or direct. The main function of the main switchboard is to provide electric power to electricity user. However, the subfunctions depend on the type of energy conversion system. For example, a prime mover and its generator generate AC-power. Hereby, it is of importance that the incoming alternating current is synchronised with the other generator(s). Also, the frequency and the voltage have to match. Other working principles for the subfunctions such as distributing, transmitting and displaying consumed power are shared between switchboards that operate with different energy conversion systems.

l_1 *This part is **to some extent** influenced by varying requirements.*
The function carriers or working principles of this system are common for every ship type, assuming that the electric power generation architecture is also the same for every ship type. However, the desired power and the type of electrical consumers determine how the eventual design of the switchboard. In other words, the function carrier of the main function is not expected to be common for every ship type. However, the function carriers for the subfunction could be common.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this technical solution is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will be standardised.

l_3 *There are **some** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
As mentioned before, the function carriers for the subfunctions could be common per ship type. Hence, the chance these function carrier will be carried over also increase.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form of the function carriers may be different between ship types, because of the difference in required capacities and capabilities.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
One reason for designing this part as a module is that it has a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some function carriers as a black box module(s) would be beneficial, because the technical solution consists advanced components and/or interact with each other. For example, the power unit. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **some** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into

multiple subfunctions. However, replacement of the whole unit is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.30. Sloop (k_{30})

A sloop is a small boat that is used for hydrographic operations in shallow waters. As the main ship cannot enter areas with shallow waters and to gather data in those areas, the sloop is a good solution.

l_1 *This part is **strongly** influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **none** of the product variants.*
As the function carrier will be used for one ship type, there will be a single physical form.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing it as a black box module(s) would be beneficial, because the technical solution consists advanced components, interacting with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, total replacement of the system, because of malfunctioning is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.31. Echo Sweep System (k_{31})

The hydrographic echo sounder sweep system is specifically designed for the use in canals, rivers and other shallow bodies of water. Its precise depth and bottom detection capabilities provide detailed bottom imagery. [31]

l_1 *This part is **strongly** influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **some** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. Although, a planned change is not unthinkable. During the midlife upgrade of the vessel, the function carrier may be replaced by one that is better in terms of performance.

l_6 *This function can have the same physical form in **none** of the product variants.*
The same systems may be installed on every ship type as long as every ship types fulfils

its function and performs as desired.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance of the equipment this system consists is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
The equipment this system consists of is advanced technology. Therefore, deliverance of this equipment as a black box module by a specialist would cost less than designing and producing yourself. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, total replacement of the system, because of malfunctioning is not expected.

l_{11} *It is possible that **most** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel could be necessary as the current functionality of the concept is improved in terms of performance in the future. However, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.32. Echo Sounder (k_{32})

Multi-beam echo sounders have become the accepted technology used to survey the ocean floor. Unlike the single-beam echo sounder, the multiple-beam system can plot dozens or even hundreds of points in a line perpendicular to the heading of the vessel. The multi-beam echo sounder offers the advantage of mapping large areas of the ocean floor from the ship. The system is also more cost-efficient because the array of echo sounder transducers and signal processing electronics moves the echo-sounder beam across the ocean bed, covering a large area with each sweep. [1]

l_1 *This part is **strongly** influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types.

Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **some** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. Although, a planned change is not unthinkable. During the midlife upgrade of the vessel, the function carrier may be replaced by one that is better in terms of performance.

l_6 *This function can have the same physical form in **some** of the product variants.*
The same systems may be installed on every ship type as long as every ship types fulfils its function and performs as desired.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance of the equipment this system consists is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
The equipment this system consists of is advanced technology. Therefore, deliverance of this equipment as a black box module by a specialist would cost less than designing and producing yourself. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, total replacement of the system, because of malfunctioning is not expected.

l_{11} *It is possible that **most** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel could be necessary as the current functionality of the concept is improved in terms of performance in the future. However, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.33. Magnetometer (k_{33})

A magnetometer measure variation in the earth's magnetic field. Surveys are used specifically for object detection or alternatively for wide area geological analysis in order to assist in the interpretation of sub-seabed structure and morphology. [2]

l_1 *This part is **strongly** influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **some** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. Although, a planned change is not unthinkable. During the midlife upgrade of the vessel, the function carrier may be replaced by one that is better in terms of performance.

l_6 *This function can have the same physical form in **none** of the product variants.*
The same systems may be installed on every ship type as long as every ship types fulfils its function and performs as desired.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance of the equipment this system consists is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
The equipment this system consists of is advanced technology. Therefore, deliverance of this equipment as a black box module by a specialist would cost less than designing and producing yourself. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, total replacement of the system, because of malfunctioning is not expected.

l_{11} ***Most** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel could be necessary as the current functionality of the concept is improved in terms of performance in the future. However, an eventual

enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.34. Side Scan Sonar (k_{34})

Side scan sonar is a specialised sonar system for searching and detecting objects on the seafloor. Like other sonars, a side scan transmits sound energy and analyses the return signal (i.e., echo) that bounces off the seafloor or other objects. Side scan sonar typically consists of three basic components: a towfish, a transmission cable and the topside processing unit. [43]

l_1 *This part is **strongly** influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **some** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. Although, a planned change is not unthinkable. During the midlife upgrade of the vessel, the function carrier may be replaced by one that is better in terms of performance.

l_6 *This function can have the same physical form in **none** of the product variants.*
The same systems may be installed on every ship type as long as every ship types fulfils its function and performs as desired.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance of the equipment this system consists is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*

The equipment this system consists of is advanced technology. Therefore, deliverance of this equipment as a black box module by a specialist would cost less than designing and producing yourself. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, total replacement of the system, because of malfunctioning is not expected.

l_{11} ***Most** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel could be necessary as the current functionality of the concept is improved in terms of performance in the future. However, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.35. ROV (k_{35})

A remotely operated underwater vehicle (ROV) is a tethered underwater mobile device. ROVs are unoccupied, usually highly manoeuvrable, and operated by a crew either aboard a vessel/floating platform or on proximate land. They are linked to a host ship by a neutrally buoyant tether. They are used to assist with hydrographic survey, i.e., the location and positioning of subsea structures, and also for inspection work for example pipeline surveys, jacket inspections and marine hull inspection of vessels. [63]

l_1 *This part is **strongly** influenced by varying requirements.*
There is only one ship type of the potential product family that requires a ROV.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **some** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept is not likely to happen, as this would increase the capital expenditures and would not add much value. Although, a planned change is not unthinkable. During the midlife upgrade of the vessel, the function carrier may be replaced by one that is better in terms of performance.

l_6 *This function can have the same physical form in **none** of the product variants.*
As the function carrier will be used for one ship type, there will be a single physical form.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance of the equipment this system consists is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing the function carriers as a black box module would be beneficial, because the technical solution consists advanced components and/or interact with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, total replacement of the system, because of malfunctioning is not expected.

l_{11} *It is possible that **most** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel could be necessary as the current functionality of the concept is improved in terms of performance in the future. However, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.36. Hydrographic Processing System (k_{36})

The hydrographic survey systems need to be operated and the acquired hydrographic data from the different systems, needs to be processed. Furthermore, the operator has to be able to use the data in such a way it can make predictions or find more information. Also, the seafarer must be able to control the settings of the systems, so that the system can be operated as efficiently as possible. The rooms a hydrographic survey vessel uses for this are the hydrographic processing room and a plotter room.

l_1 *This part is **strongly** influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of the function carriers is to be functional for the user. Fashion and trends, in terms of hardware, do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the function carriers will be designed as standardised products. Then, the displaying of data, the possibility to plot and to input data, may be influenced by trends, in terms of software. However, this does not really effect the physical concept.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The working principle of the subfunction carriers, in terms of hardware, are pretty conservative and are not likely to change in the short term. The computers that process and analyse the data are likely to become better, but this part of the potential module is easy to replace. Furthermore, these modules can be used over several ship types. For the long term, the processing system will be outdated.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
This technical solution is required during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditure. However, a replacement of the function carrier that processes the data, by one that is better in terms of performance, could be interesting.

l_6 *This function can have the same physical form in **none** of the product variants.*
As the function carrier will be used for one ship type, there will be a single physical form.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance of the equipment this system consists is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment. However, in this case is DSNS the client.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing the function carriers as a black box module would be beneficial, because the technical solution consists advanced components and/or interact with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, total replacement of the system, because of malfunctioning is not expected.

l_{11} *It is possible that **most** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel could be necessary as the current functionality of the concept is improved in terms of performance in the future. However, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable

anymore. However, the materials can be used for other purposes.

B.6.37. Anti-Roll Tank (k_{37})

Anti-roll tanks are tanks that are fitted onto a ship in order to improve her response to roll motion. The baffles that are fitted in the anti-roll tanks are intended to slow the rate of water transfer from the port side of the tank to the starboard side. The tank is designed in such a way that a large amount of water is trapped on the higher side of the vessel. This is intended to have an effect opposite of that of the free surface effect. [62]

l_1 *This part is **fairly** influenced by varying requirements.*
There are only two ship type within the potential product family that require an anti-roll tank.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are **some** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept is not likely to happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **some** of the product variants.*
As the function carrier will be used for two ship types, a single physical form may not be efficient, as the rolling movement of the ships can differ from each other. Hence, different capacities may be required per ship type.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As two ship types require the same function carrier, the production process could become leaner if some of these function carriers would be modularised to a certain extent. Hence, robotics in manufacturing could be a cost saver. Also, this system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance of the equipment this system consists is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately, the client can be informed about the performance capabilities of the equipment. However, in this case is DSNS the client.

l_9 *There are **some** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c)*

The manufacturing and development capacity can be balanced.
Designing the function carriers as a black box module would be beneficial, because the technical solution consists advanced components and/or interact with each other. If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that* ***none*** *of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, total replacement of the system, because of malfunctioning is not expected.

l_{11} ***None*** *of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.38. Cargo Handling System (k_{38})

The vessel has access, handling systems and/or equipment to efficiently transfer solid cargo [48].

l_1 *This part is* ***fairly*** *influenced by varying requirements.*
The capacity of the technical solution is mainly depend on the required maximum weight to be carried. This is difference per ship type.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, this system will have most likely one neutral standard design.

l_3 *There are* ***no*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is* ***no*** *risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology, causing a technology push, is not expected. Moreover, such a change would increase the capital expenditures.

l_5 *There are* ***no*** *reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept is not likely to happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in* ***some*** *of the product variants.*
The physical form of the function carriers may be different between ship types, because of the difference in required capacities and capabilities.

l_7 *There are* ***medium*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group.*

(c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.
As all ships require the same function carrier, the production process could become leaner if this function carrier would be modularised to a certain extent. Hence, robotics in manufacturing could be a cost saver. Also, this system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment. However, in this case is DSNS the client.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.39. Hold/Deck (k_{39})

The cargo hold or deck provides volume and carrying capacity to transport cargo. The cargo hold's and deck's arrangement has enough usable volume/area and accessibility for cargo that is either directly lifted by the main cargo cranes or a crane on shore. [48]

l_1 *This part is **fairly** influenced by varying requirements.*
The variable that may cause varying requirements among the ship types are the volume, area, dimensions and carrying capacity. As the requirements between the ship types are not the same, multiple variants may be desired. Although, the function carriers of the subfunctions may be carried over.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, the function carriers will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The hold/deck is a relatively simple concept. Its technical solutions are not expected to change. As mentioned before, some function carriers for the subfunctions could be common per ship type. Hence, the chance these function carrier will be carried over also increase.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*

Because the current concepts match the desired functionalities, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology causing a technology push is not expected. Also, such a change would have increase the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
Another priority of the facilities is that it fulfils its functionality during the whole lifetime of the ship. Therefore, a change in one of the concepts will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **some** of the product variants.*
The ship types requiring the same cargo capacities, may also have the same physical form. However, some ship types are installed with mission specific equipment that have to be taken into account. This can effect the arrangement and thus the physical form.

l_7 *There are **no** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
For the ship types requiring the same building blocks, a shorter production process could be possible. Hence, robotics in manufacturing may be a cost saver.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
This system does not need to be built out of modules in order to be tested. Separately testing of building blocks or standardised components already suffice.

l_9 *There are **no** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
This part is relatively big and designing it as a black box module is not possible. Moreover, designing it as a black box the function should be integrated with (an)other function(s).

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.40. Cargo Securement (k_{40})

Equipment or tools to secure cargo. To secure cargo, the equipment should resist forces in order to forestall movement of the cargo.

l_1 *This part is **not** influenced by varying requirements.*
The requirements between function carriers for the type of cargo may vary. However, if the function is subdivided into several functions, the variation in requirements can become less. Therefore, at a certain function level, function carriers can be standardised and used for the whole product family.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*

The priority of the cargo securement is to be functional for the user. Fashion and trends do not play a big role in this. Also, the capital expenditures must be minimised. Therefore, most likely the securement will have one neutral standard design.

l_3 *There are **strong** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
As this technology is simple and may be used on several places on the ship it is beneficial to create modules. (Naturally, this is done already. Think of securing TUE's, such securement exists already.)

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
The cargo securement does not require a technological shift during the lifetime as the current technologies match the desired functionality and the TRL is of a high standard. Also, the current technologies comply to regulations during the lifetime of the ship. Moreover, a replacement would have a negative influence to the capital expenditures and would not be realistic.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
The cargo securement does not require development during the lifetime as the current technologies match the desired functionality and the TRL is of a high standard. Also, the current technologies comply to regulations during the lifetime of the ship. Moreover, a replacement would have a negative influence to the capital expenditures and would not be realistic.

l_6 *This function can have the same physical form in **most** of the product variants.*
The physical form for most of the function carriers can be the same for the different ship types, because multiple function carriers can be used to secure the cargo.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
As all ships require the same function carriers, the production process could become leaner if this function carrier would be modularised to a certain extent. Hence, robotics in manufacturing could be a cost saver. Also, this system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
If a specialist could deliver this as black boxes, logistics costs could be reduced. In other words, the manufacturing and development capacity can be balanced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to*

recycle by designing it as a module.
At the end of the lifetime, the functionalities of the system are not expected to be reliable anymore. However, the materials can be used for other purposes.

B.6.41. Torpedo Handling System (k_{41})

A special trench that can lift the torpedo onto the aft deck.

l_1 *This part is **strongly** influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, the function carriers will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology during the lifetime of the vessel, causing a technology push, is not expected. Moreover, such a change would have a negative influence to the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **none** of the product variants.*
As the function carrier will be used for one ship type, there will be a single physical form.

l_7 *There are **strong** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
This system does not need to be built out of modules in order to be tested. Separately testing of building blocks or standardised components already suffice.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some equipment as a black box module would be beneficial, as they have to comply to strict regulations and its construction is precise. If a specialist could deliver this, the logistics costs could be reduced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of

the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities the system consist are expected not to be used again as each equipment must comply to strict regulations. However, the materials can be used for other purposes.

B.6.42. Maintenance Street (k_{42})

The maintenance street consists of a disassembling room, an assembling room, workshops, elevator lifts and a torpedo room. This is for handling, storing and maintaining torpedoes.

l_1 *This part is **strongly** influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, the function carriers will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology during the lifetime of the vessel, causing a technology push, is not expected. Moreover, such a change would have a negative influence to the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **none** of the product variants.*
As the function carrier will be used for one ship type, there will be a single physical form.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **some** reasons why this part should be a separate module because its function can be tested separately.*
The performance and reliability of some parts of this system is important. Normally, a client opts for a certain equipment because of its performance and price. By testing it separately the client can be informed about the performance capabilities and its reliability of the equipment.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some equipment as a black box module would be beneficial, as they have to comply to strict regulations and its construction is precise. If a specialist could deliver

this, the logistics costs could be reduced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***None** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities the system consist are expected not to be used again as each equipment must comply to strict regulations. However, the materials can be used for other purposes.

B.6.43. Communication System (k_{43})

An underwater telephone enables the crew to communicate with submerged submarines.

l_1 *This part is **strongly** influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is **not** influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, the function carriers will have most likely one neutral standard design.

l_3 *There are **no** reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is **no** risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology during the lifetime of the vessel, causing a technology push, is not expected. Moreover, such a change would have a negative influence to the capital expenditures.

l_5 *There are **no** reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in **none** of the product variants.*
As the function carrier will be used for one ship type, there will be a single physical form.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
This system does not need to be built out of modules in order to be tested. Separately testing of building blocks or standardised components already suffice.

l_9 *There are **strong** reasons that this part should be a separate module because: (a) There*

are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.
Designing some equipment as a black box module would be beneficial, as they have to comply to strict regulations and its construction is precise. If a specialist could deliver this, the logistics costs could be reduced.

l_{10} *It is possible that* ***none*** *of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***None*** *of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel are unnecessary as the current functionality of the concept is already providing sufficient performance. Also, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities the system consist are expected not to be used again as each equipment must comply to strict regulations. However, the materials can be used for other purposes.

B.6.44. Passive Sonar (k_{44})

A passive sonar can follow the launched torpedoes. Hence, this can prevent torpedoes from being lost.

l_1 *This part is* ***strongly*** *influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, the function carriers will have most likely one neutral standard design.

l_3 *There are* ***no*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is* ***no*** *risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology during the lifetime of the vessel, causing a technology push, is not expected. Moreover, such a change would have a negative influence to the capital expenditures.

l_5 *There are* ***no*** *reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in* ***none*** *of the product variants.*
As the function carrier will be used for one ship type, there will be a single physical form.

l_7 *There are* ***strong*** *reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are* ***no*** *reasons why this part should be a separate module because its function can be tested separately.*
This system does not need to be built out of modules in order to be tested. Separately testing of building blocks or standardised components already suffice.

l_9 *There are* ***strong*** *reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some equipment as a black box module would be beneficial, as they have to comply to strict regulations and its construction is precise. If a specialist could deliver this, the logistics costs could be reduced.

l_{10} *It is possible that* ***none*** *of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***Most*** *of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel could be necessary as the current functionality of the concept is improved in terms of performance in the future. However, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None*** *of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities the system consist are expected not to be used again as each equipment must comply to strict regulations. However, the materials can be used for other purposes.

B.6.45. Training Bridge (k_{45})

To educate maritime students an additional bridge provides more educational possibilities.

l_1 *This part is* ***strongly*** *influenced by varying requirements.*
Only one ship types of the potential product family requires this technical solution.

l_2 *This part is* ***not*** *influenced by trends and fashion in such a way that form and/or colour has to be altered or should be tied to a trademark.*
The priority of this system is to be functional for the user while being cost efficient. Fashion and trends do not play a big role in this. Therefore, the function carriers will have most likely one neutral standard design.

l_3 *There are* ***no*** *reasons that this technical solution should be a separate module because the new design can be carried over to coming product generations.*
The technology is not likely to change. However, the specific capabilities and capacities may not necessary meet the (performance) requirements for any future ship types. Consequently, this could reduce the chance to be carried over.

l_4 *There is* ***no*** *risk that this part will go through a technology shift during the product lifecycle.*
Because the technology matches the desired functionality, the TRL is of high standard and regulations are not likely to change, an unexpected change within technology during the lifetime of the vessel, causing a technology push, is not expected. Moreover, such a change would have a negative influence to the capital expenditures.

l_5 *There are* ***no*** *reasons why this part should be a separate module since it is the carrier of attributes that will be changed according a product plan.*
One performance requirement of this technical solution is it that it fulfils its functionality during the whole lifetime of the ship. A planned change of the concept will not happen, as this would increase the capital expenditures and would not add much value.

l_6 *This function can have the same physical form in* ***none*** *of the product variants.*
As the function carrier will be used for one ship type, there will be a single physical form.

l_7 *There are **medium** reasons why this part should be a separate module because: (a) A specific or specialised process is needed. (b) It has a suitable work content for a group. (c) A pedagogical assembly can be formed. (d) The lead time will differ extraordinary.*
This system is a suitable work content for a group.

l_8 *There are **no** reasons why this part should be a separate module because its function can be tested separately.*
This system does not need to be built out of modules in order to be tested. Separately testing of building blocks or standardised components already suffice.

l_9 *There are **medium** reasons that this part should be a separate module because: (a) There are specialists that can deliver it as a black box. (b) The logistics cost can be reduced. (c) The manufacturing and development capacity can be balanced.*
Designing some equipment as a black box module would be beneficial, as they have to comply to strict regulations and its construction is precise. If a specialist could deliver this, the logistics costs could be reduced.

l_{10} *It is possible that **none** of the service repairs will be easier if this part is easy detachable.*
Some parts of the system may require maintenance where detachability of this part would provide an advantage. To achieve this, the main function should be divided into multiple subfunctions. However, replacement of the system is not expected.

l_{11} ***Some** of the future upgrading can be simplified if this part is easy to change.*
Upgrades during the lifetime of the vessel could be necessary as the current functionality of the concept is improved in terms of performance in the future. However, an eventual enhancement would mean an increase of the capital expenditures.

l_{12} ***None** of the highly polluting material or easy recyclable material in this part is easier to recycle by designing it as a module.*
At the end of the lifetime, the functionalities the system consist are expected not to be used again as each equipment must comply to strict regulations. However, the materials can be used for other purposes.