# A Systems of Systems Preference-Based Multi-Objective Idealized Design Decision Support Tool

Connecting 'Capability' and 'Desirability' for Decision-Making by Applying and Integrating the Preferendus Methodology and Idealized Design at the Port of Rotterdam

Mater Thesis - Systems Engineering
Construction Management & Engineering

R.G.M. Grobben

Delft University of Technology

TUDelft

Port of Rotterdam

# A Systems of Systems Preference-Based Multi-Objective Idealized Design Decision Support Tool

## Connecting 'Capability' and 'Desirability' for Decision-Making by Applying and Integrating the Preferendus Methodology and Idealized Design at the Port of Rotterdam

by


R.G.M. Grobben

| Grobben |
| --- |
| Robbert |


| | |
| --- | --- |
| First Supervisor: | Dr.ir. R. Binnekamp |
| Second Supervisor: | Dr.ir. S. van Nederveen |
| Company Supervisor: | B. Madlener |
| Company Supervisor: | R. Wittenberg |
| Project Duration: | Aug, 2025 - Feb, 2026 |
| Faculty: | Faculty of Civil Engineering and Geosciences, Technical University Delft |


Cover: Canadarm 2 Robotic Arm Grapples SpaceX Dragon by NASA under CC BY-NC 2.0 (Modified)

Style: TU Delft Report Style, with modifications by Daan Zwaneveld

*”Thus the task is not so much to see what no one yet has seen, but to think what nobody yet has thought about that which everybody sees”*

*- Arthur Schopenhauer -*

# Preface

*This master's thesis is written in the domain of Systems Engineering at the Faculty of Civil Engineering and Geosciences at the TU Delft. This thesis aims to develop a decision support tool for the fleet renewal challenge at the Port of Rotterdam. The methodology employed is founded upon two distinct approaches that are taught in the Systems Engineering programme: the Preferendus Methodology and the Idealized Design methodology (both are explained in the report).*

*It could be argued that this master's thesis represents a reflection of my personal development during the period of my studies. This encompasses all extracurricular activities undertaken at the study and rowing association, in addition to the employment at construction company BAM. My professional journey started when I was a beginner in the Bachelor's programme in Civil Engineering. I was keen to undertake this programme as it is both technically oriented and it is at the core of society. Despite my desire to go to this study at the TU Delft, I had to obtain an extra secondary school diploma, as the first was not 'high' enough to go to the university. This process took an additional two years, but in retrospect, it was undoubtedly worthwhile. At the midpoint of my studies, I was eager to pursue a part-time role in the civil engineering sector, as I could already foresee my future in this field. Quite coincidentally, my part-time job led me to BAM, as during a work visit to a client's home I met someone who worked there. Sometimes luck is on your side. I can confidently state that my time working for BAM was a crucial factor in my decision to transition from civil engineering to construction management, with a particular emphasis on systems engineering. I came to the conclusion that I was better placed to adopt a more comprehensive approach, encompassing aspects beyond the purely technical. Thankfully, the Master's Track in Systems Engineering brought together both the technical and social aspects of design. The programming skills I acquired at BAM, and the system design perspective I gained during the master's track, are both reflected in this master's thesis as I have developed a tool. I am grateful for the opportunity to further refine my programming skills and gain valuable experience in the complex process of transforming a design assignment from a theoretical framework into a functional product.*

*The creation of the tool was challenging. It is important to understand that developing is very different from researching. I gained this insight during the course of my studies, and I must say that I really discovered this during the process of working on my thesis. It was a mentally challenging, yet highly informative process to differentiate between these divergent methodologies. Allow me to share three key learning points.*

*Firstly, I had to focus entirely on the fleet renewal issue. In my enthusiasm for the project, I decided to proceed with a very large-scale approach because I saw all kinds of possibilities. However, I discovered that it was necessary to begin with a very small scale, and that developing something 'small' is already a considerable challenge in itself.*

*Secondly, I discovered that I was able to delve deeply into the theoretical aspects of the subject. While I found it to be satisfactory, it did require a significant investment of time. Nevertheless, I found it very interesting to gain a better understanding of the underlying principles of the Preferendus methodology.*

*Finally, throughout the development process, I have noted that design involves various levels of abstraction, including problem analysis, tool design, mathematical formulation of the problem, interface design, workshop facilitation, and consideration of both the Port of Rotterdam and the university supervisors. Above all, it is essential to be able to articulate your ideas clearly in writing. This writing process presented a notable challenge. I always explain things in as much or as little detail as needed, but I think there is a balance to be found somewhere in between. The report should be concise yet informative. I would like to express my gratitude to my academic supervisors for their assistance in this process. I can confidently state that I gained significant learning from the overall experience, as they provided me with all the autonomy and consistently offered feedback that was 'spot on'.*

*R.G.M. Grobben*
*Delft, March 2026*

# Acknowledgement

I would like to express my gratitude to all those who provided assistance during the process of my master's thesis.

Firstly, I would like to express my gratitude to Ruud Binnekamp for offering courses on management, systems thinking, and design thinking that were both engaging and informative. I am grateful to him for my increased awareness of design and its true significance. I also found his coaching style during the supervision of my master's thesis to be beneficial. He provided me with sufficient autonomy to navigate my own path and face challenges independently. Above all, I found his coaching to be highly constructive, motivating, and inspiring.

Secondly, I would like to express my gratitude to Sander van Nederveen. His patience and willingness to listen were extremely valuable to me, helping me to maintain perspective during a challenging period of my graduation project. I would also like to express my sincere gratitude for his patience in explaining the design process and how to report on it repeatedly.

Thirdly, I would like to thank Bob Madlener, the supervisor of the Port of Rotterdam. His passion for his work and his vision were inspiring, and made working on my thesis a pleasure every day. Above all, I am extremely grateful for the opportunity he gave me to conduct my thesis research on his project.

Fourthly, I would like to express my gratitude to Robert Wittenberg for his invaluable guidance in the organisation of the Port of Rotterdam and for the insightful brainstorming sessions.

Furthermore, I would like to thank Frans van Gunsteren, who kindly helped me to refine my thoughts during the analysis phase. I would like to express my sincere gratitude for the invitation and hospitality at his home.

Finally, I would like to express my sincere gratitude to Hein Masselink and my father, Bart Grobben. Hein provided invaluable support at the most critical moments and was extremely helpful in the final stage of the process. As always, my father provided me with the courage and motivation by acting as one of my biggest supporters.

*R.G.M. Grobben*
*Delft, March 2026*

# Summary

By 2040, the Port of Rotterdam Authority (PoR) intends to replace its fleet with vessels that do not emit greenhouse gases and are modernised. Replacing the entire fleet also presents an opportunity to review and improve the operational processes and the equipment used. This is a complex challenge due to the following three factors: (1) the high number of stakeholders complicating the decision-making process, (2) risk aversion in modifying current business operations due to a lack of clarity regarding the impact of decisions, and (3) the challenge of determining what is feasible while also meeting the expectations of all stakeholders.

The PoR expressed a need and interest in becoming familiar with more scientifically based decision-making methods to help them achieve their ambitious goal. The method should facilitate improved decision-making for complex choices and should consider how the impact of different choices will be made visible, allowing users to explore various fleet combinations regarding the system performance.

Therefore, this master's thesis aims to develop a decision-support tool based on the Preferendus Methodology (from H. J. van Heukelum et al., 2024; Zhilyaev et al., 2022), a state-of-the-art approach specifically designed to bridge the gap between what is 'desirable' and what is 'feasible'. By doing this they tool facilitates the finding of the best 'fit for purpose' renewed fleet composition.

This Master's thesis demonstrates the successful development of a 'Preference Based Idealized Design' tool and methodology that integrates the Preferendus and Idealised Design methodologies. The tool and methodology are conceptually tested at the Port of Rotterdam for its Fleet Renewal Challenge. The tool facilitates the finding of a solution that is both 'desirable' and 'capable' by integrating multiple stakeholders' objectives and preferences into the modelled system. Additionally, the tool enables transparent collaborative decision-making and the integration of both technical and social aspects by incorporating stakeholder preferences.

Furthermore, the tool is developed with object-oriented-programming principles that ensure the maintainability and scalability of the tool. This makes it suitable for extensions and applications in other projects.

Additional research can be conducted by applying the Preference-Based Idealised Design tool and methodology to other projects. Ideally, this would be done with a project team that has fully adopted the methodology. It is particularly interesting to apply this tool and methodology to a project involving organisational issues, as the Idealized Design approach is designed for organisational redesign.

# Contents

# List of Figures

# List of Tables

# 1 Introduction

In January 2026, three key advisory bodies (Court of Audit[1], National Ombudsman[2], Council of State[3]) of the Dutch national government jointly issued a rare public statement. They warned that the government has a tendency to make unfulfillable promises, which is eroding public trust (Pieter Duisenberg et al., 2026). These institutions, which typically operate independently and behind the scenes, emphasised the urgent need for more realistic policymaking. Their unprecedented collaboration underscores the severity of their statement that the government must align its commitments with feasible objectives to restore confidence.

It can be argued that this act of making unfulfillable promises in policymaking is primarily driven by the desire to achieve a 'desired' outcome without giving full consideration to the 'feasibility' of that particular goal. The study by Ferreira et al. (2025) demonstrates that this phenomenon also has a parallel in the infrastructure sector. As illustrated in Figure 1.1, the authors' findings indicate that not all planned (and thus desired) offshore wind farms are feasible, as some fall outside the 'theoretical upper limit of offshore wind energy extraction'. They particularly mention the Dutch government's policies, as these show the 'largest mismatch' between policy (desirability) and 'aerodynamic limits' (feasibility).

This observation indicates that the successful execution of societal (mega) projects is a challenging endeavour. This is consistent with the conclusions of Flyvbjerg and Gardner (2022, p. 8) on mega-projects. They mention the so-called 'iron law of mega-projects', a concept identified as a significant challenge for mega-project management, wherein projects consistently are "over budget, over time, under benefits, over and over again". In this context, the 'under benefits' aspect is of particular interest, as it can be regarded as a failure to achieve the desired functionality; in other words, the project is not 'fit for purpose'.

Flyvbjerg and Gardner (2022, p. 9) explains the failure of mega projects by arguing that 'projects do not go wrong, they start wrong'. They highlight the tendency of individuals to 'prefer action over talking', suggesting that people would rather perform a task than debate which direction is right. Flyvbjerg and Gardner (2022, p. 25) illustrates how large-scale projects usually operate, using the example of the Pentagon, the headquarters of the United States' military: *'Purpose and goals are not carefully considered. Alternatives are not explored. Difficulties and risks are not investigated. Solutions are not found'*.

To address these pitfalls of mega-projects, Flyvbjerg and Gardner (2022, p. 17) simplifies the project lifecycle into two distinct phases of 'planning' and 'delivery', and provides the advice to 'think slowly' in the planning stage and 'act fast' in the delivery stage. The latter is made possible by careful preparation in the former stage.

One organisation that is implementing this strategy from Flyvbjerg and Gardner (2022), either consciously or unconsciously, is the Port of Rotterdam Authority with its Fleet Renewal Programme. While this project is not as large-scale as mega infrastructure projects worth several billion euros, it is nevertheless significant for the organisation. They are well aware of their ambitious goal (desirability) of making their fleet completely fossil fuel-free, but are also carefully considering the feasibility. They have

[1] NL: Algemene Rekenkamer
[2] NL: Nationale Ombudsman
[3] NL: Raad van State

expressed a need and interest in becoming familiar with more scientifically based methods to help them achieve their ambitious goal. Therefore, this master's thesis aims to develop a decision-support tool based on the Preferendus Methodology (from H. J. van Heukelum et al., 2024; Zhilyaev et al., 2022), a state-of-the-art approach specifically designed to bridge the gap between what is 'desirable' and what is 'feasible'.

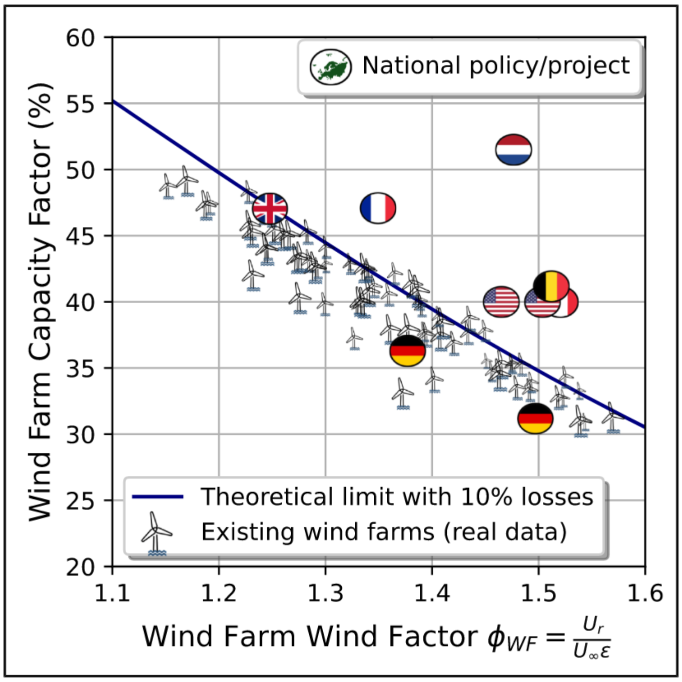



**Figure 1.1:** A theoretical upper limit for offshore wind energy extraction. The x-axis is defined by the 'Wind Farm Wind Factor', a measure of the maximum capacity factor that can be achieved for a given wind farm layout, given a specific set of location-related conditions. The y-axis is defined by the 'Wind Farm Capacity Factor', representing the ratio of the actual energy produced to the hypothetical maximum possible in a given period. Particularly, the Dutch government's policies show the 'largest mismatch' between the policy (desirability) and the 'aerodynamic limits' (feasibility). (Ferreira et al., 2025)

## 1.1. The Port of Rotterdam's Challenge of Renewing its Fleet.

The Port of Rotterdam Authority (PoR) is a private company, owned by the municipality of Rotterdam (70%) and the Dutch national government (30%). This organisation is responsible for the 'sustainable development, construction, management and operation' of the harbour region, as well as ensuring the 'safe', 'effective' and 'efficient' handling of cargo (Port of Rotterdam, n.d.-b).

Currently, the Port of Rotterdam has a fleet consisting of 16 vessels, 12 cars and approximately 160 personnel, which contribute to the port's responsibilities of "safe, smooth, sustainable, and secure handling of shipping" (Port of Rotterdam, n.d.-a). Although this is an oversimplification, for the ease of this introduction, it is useful to compare their services to firefighting and law enforcement. In synergy with their corresponding crews, the vessels have specialised tasks for which the ship is equipped, and the crew[4] is trained. Other internal stakeholders involved, besides the crew, are Asset Management (AM) and multiple coordination departments: Port Coordination Center[5], Traffic Management[6], Harbour Master Policy and Development[7]. Together, they play a pivotal role in the port's safety and security architecture, collaborating closely with external stakeholders such as local fire brigades and law enforcement agencies.

By 2040, the Port of Rotterdam (PoR) intends to replace its fleet with vessels that do not emit greenhouse gases and are modernised. Therefore, the objective of the Fleet Renewal Programme is to build "Tomorrow's Fit For Purpose Sustainable Fleet". For PoR, 'fit for purpose' means that the fleet is

[4] Ship and Environmental Safety Department (NL: Scheeps- en milieuveiligheid (SMV))
[5] NL: Haven Coördinatiecentrum (HCC)
[6] NL: Verkeersafhandeling (VA)
[7] NL: Havenmeester Beleid & Ontwikkeling

equipped to perform its tasks to the highest requirements, with the best possible performance. 'Sustainable' means that no greenhouse gas emissions are produced.

Replacing the entire fleet also presents an opportunity to review and improve the operational processes and the equipment used. This is a complex challenge due to the following three factors: (1) the high number of stakeholders complicating the decision-making process, (2) risk aversion in modifying current business operations due to a lack of clarity regarding the impact of decisions, and (3) the challenge of determining what is feasible while also meeting the expectations of all stakeholders.

## The Complexity Explained

To illustrate the complexity of the fleet renewal challenge, consider a fleet deployed in the largest harbour in Europe. The responsibility of this fleet lies in providing an agreed pump capacity (P) for firefighting operations within an agreed critical time-frame (T) at any location (X) within the harbour. This service is currently delivered through the deployment of a specific number (N) of incident response vessels, each equipped with the necessary pump systems. This can be expressed mathematically as shown in equation 1.1.

These parameters can be changed with the redesign of the entire fleet. This can be expressed mathematically as shown in equation 1.2. For instance, one can state that it is beneficial to lower the critical response time. However, the decision should be made on whether this is to be achieved by adding an extra ship, thereby reducing the responsible area coverage per vessel, or by having faster vessels. The first option would require the allocation of additional personnel and maintenance capacity. The latter option may require a larger battery pack (or other fuel tank), which impacts the vessel's design and raises questions about its feasibility due to the limitations of the size of the battery pack.

Please be aware that this is just one of the many tasks and decisions involved in the fleet renewal project. In fact, there are many tasks (see section 3.1) and associated relationships that need to be analysed. This further increases the complexity of the undertaking.

$$P_{\text{current agreed at X}} = p_{\text{current}} \times N_{\text{current}}(T_{\text{current agreed at X}}) \tag{1.1}$$

$$P_{\text{agreed at X}} = \sum_{i=1}^{n} p_i \times N_i(T_{\text{agreed at X}}) \tag{1.2}$$

| | | |
|---|---|---|
| $P_{\text{agreed at X}}$ | = | the total pump capacity agreed at any location X |
| $p_i$ | = | the pump capacity of the Incident Response Vessels of type $i$. |
| $N_i$ | = | the number of the Incident Response Vessels of type $i$, influenced by the critical response time $(T_{\text{agreed}})$. |
| $T_{\text{agreed at X}}$ | = | the agreed critical response time at any location X. It depends on the interplay between the number of operational vessels, the size of the area of responsibility and the agreed critical response time. |
| $X$ | = | any location X in the port where X can be changed due to updated agreements. |
| agreed | = | This is the currently agreed parameter that may be considered 'fixed' (unchangeable). |

## Additional Complexity by Societal Issues

The process of designing and constructing a new fleet is already challenging, due to the complex interplay of wishes and requirements within the organisation. Nevertheless, it is also important to consider societal key issues that are critical for the success of the fleet renewal project.

A relevant example of such a concern is that of electrical grid congestion (Madlener, 2025a), which impacts both the feasibility and the desirability of the project. The fundamental question that must be addressed is whether the necessary electricity is available (i.e. whether it is feasible) and whether it is desirable to be fully reliant on electricity. The latter is also of particular importance in the context of geopolitical tensions and resilience.

## 1.2. The Need for a decision-support tool to Solve the Challenge

The fleet renewal programme has the task to coordinate the replacement of the current fleet with new vessels, using a programmatic approach (as opposed to a project-oriented approach) and based on a company-wide vision of what the new fleet should look like (Madlener, 2025b).

The project team includes various experts and representatives from other departments. For instance, there is a technical expert for the construction of the ships, an expert in the field of Modular Functional Design (MFD), and a governance expert for the port authority's organisation. In addition, the project team includes representatives with operational experience regarding the ships and the associated tasks, as well as individuals from the asset management department and a representative from the Harbour Master[8].

The team's composition reflects the project team's observation that the challenge is twofold: technical and organisational, with an emphasis on 'change and adoption' (Madlener, 2025b). From this perspective, they are driven to maintain close contact with all stakeholders and incorporate their views into the decision-making process. In addition to face-to-face communication, they also use documentation, calculation tools and decision-making frameworks to streamline the information flow to facilitate decision-making.

Although the programme team is committed to providing insight into all relationships and considerations, they have expressed the need and interest for a more scientifically-based methodology to create a decision-support tool that integrates both technical and social aspects. The tool is expected to facilitate improved decision-making for complex choices by making trade-offs more transparent. In addition, the tool should consider how the impact of different choices will be made visible, allowing users to explore various fleet combinations, and provide insights into the following questions: in what ways will the new fleet facilitate the effective performance of their tasks, and which fleet composition best balances operational effectiveness, environmental goals, costs and other factors?

## 1.3. Development Statement

With the use of the NADI-framework[9] (van Boeijen et al., 2020), the development statement is formulated.

**Table 1.1:** The formulation of the 'Needs' with the help of the NADI-framework (van Boeijen et al., 2020). The 'solution' of the NADI-framework is changed to 'development statement'

| | |
|---|---|
| **Theme** | *The underlying structure of the experience: it is very challenging to create an entirely 'fit for purpose new fleet' based on an integrative and transparent informed decision.* |
| **Goal** | *Building Tomorrow's Fit For Purpose Sustainable Fleet* |
| **Scenario of Interaction** | *The programme team would like to interact with all the relationships between the factors they need to consider. These factors are both technical and social.* |
| **Development Statement** | *A decision-support tool is needed to facilitate improved decision-making for complex choices by making trade-offs more transparent and by integrating both technical and social aspects. In addition, the tool should consider how the impact of different choices will be made visible, allowing users to explore various fleet combinations, and provide insights into the following questions: in what ways will the new fleet facilitate the effective performance of their tasks, and which fleet composition best balances operational effectiveness, environmental goals, costs and other factors?* |

[8]This person, the Harbour Master, manages the Harbour Master's Division, which forms part of the Port of Rotterdam Authority. The Harbour Master and its departments are responsible for harbour safety and shipping on behalf of the Dutch government, performing duties under public law (Port of Rotterdam, n.d.-d).

[9]NADI = Needs & Aspirations for Design & Innovation

## 1.4. The Social-Technical Systems Perspective for Problem Solving

In order to construct a decision-support tool, it is first necessary to gain an understanding of the phenomenon that it is intended to address. As demonstrated in Figure 1.2, the fleet operations can be characterised as a system-of-systems phenomenon. The abstract value that should be created is ”safety”, which is delivered by the fleet of vessels. These vessels can be categorised into distinct types and personnel, each equipped with a pump system and other features.

To be more specific, the fleet operations can be seen as a multi-layered ’social-technical’ system. The vessels are not merely individual technical assets; on the contrary, they function within and contribute to a much larger social-technical network shaped by people, procedures, environmental conditions and strategic goals. As previously stated, the fleet operations are characterised by the involvement of multiple departments of the Port of Rotterdam. Collectively, they are responsible for the delivery of safety services to the harbour region (the service takers). Furthermore, the performance of these services is influenced by the expectations of both internal and external stakeholders. For instance, the fleet should be designed to provide fire-fighting services with a certain capacity, while also taking measures to minimise the impact on the environment. This is illustrated in Figure 1.3.

This social-technological systems perspective is important as the decision-support tool is expected to facilitate analysis with a focus on enhancing the overall system performance. For instance, it could be proposed that the system might be improved by delivering the currently agreed amount of pump capacity with more vessels, fewer vessels, or even with different kinds of equipment, such as drones. Alternatively, it could be proposed that the delivery of 1/4 of the pump capacity at any given location, 3 times faster, is potentially ’superior’ compared to the current operations.

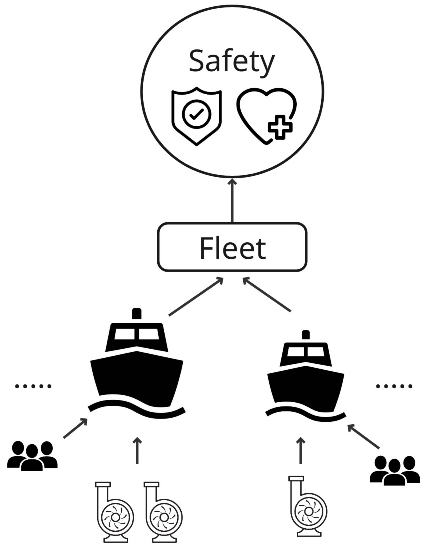



**Figure 1.2:** Example of systems of systems characteristic of the Fleet Renewal Challenge about safety and pump-capacity. Note, in addition to the crew of the vessels, other departments are also involved. For instance, in the maintenance and coordination of incident responses. *(own illustration)*

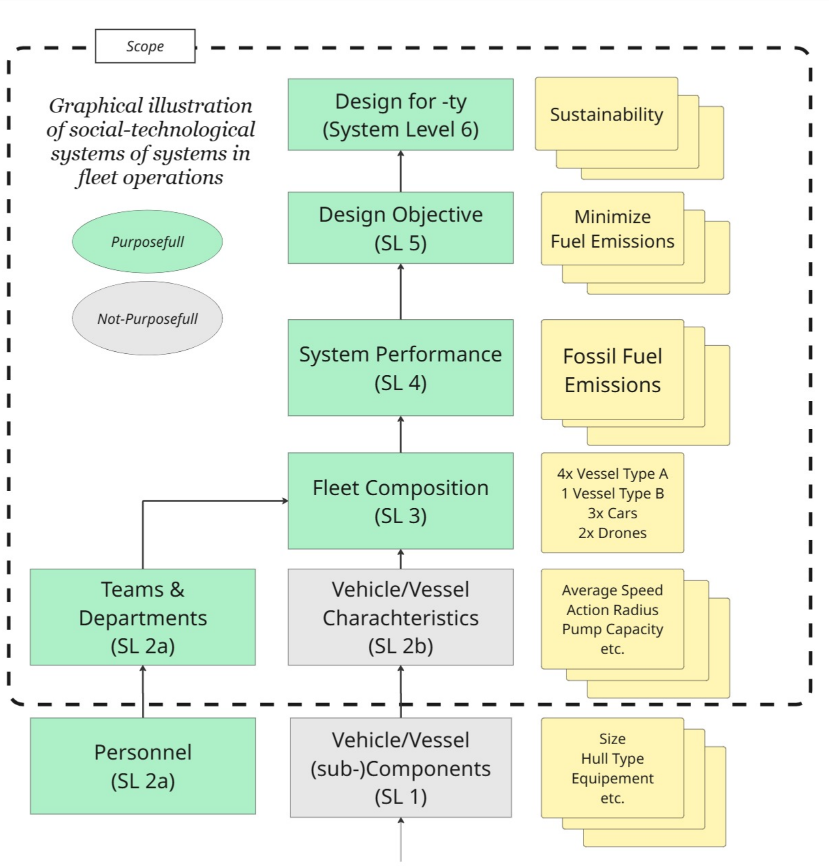



**Figure 1.3:** Graphical Illustration of Social-Technical Systems of Systems in Fleet Operations. The "design-for-ty" can be defined as the 'vague' attribute of fleet operations, while the "design objective" is the specific goal of minimising fossil fuel emissions. The "system's performance" is defined as the actual emissions of the fleet, which are determined by the "fleet composition" that exists due to the crew and the individual technical systems, etc.
The subsystems of the vessels, such as the electrical system or the floating-system (hull), are examples of technical and mechanical systems, following the characteristics as described by Wolfert (2023): *"integrate the parts"*, *"are causal"*, and *"neither the parts nor the whole are purposeful"*. In contrast, the workforce of the Port of Rotterdam, including the ship crews, is an example of a social system. Wolfert (2023) describes these systems as those that *"differentiate from the whole"*, are *"goal-oriented"*, and *"where both the parts and the whole are 'purposeful'". Together they form the social-technical system.. (own illustration)*

## 1.5. The Best Approach for Problem Solving: Dissolving by Idealized Design

As previously explained, the challenge of renewing the fleet has a significant impact on both the technical systems (i.e., vessels) and the social systems (i.a., business processes) at different system levels within the Port of Rotterdam. Together with the pursuit of enhancing system performance, it is essential to adopt a holistic approach, rather than considering each component in isolation. As Ackoff (2003) explains, design is the only approach that 'deals with the whole and moves to the parts'. Consequently, he emphasises that only design can bring a solution for a systems problem, which he refers to as 'a mess' or 'messes' for 'systems of problems'.

To clarify the argument for why design is the most effective approach, it is useful to consider Ackoff et al. (2007, p. 117) four ways of dealing with problems: 'Absolution', 'Resolution', 'Solution', and 'Dissolution'.

In the context of the Port of Rotterdam's fleet renewal challenge, the objective of establishing a "Tomorrow's Fit for Purpose Sustainable Fleet" necessitates a comprehensive approach that does not rely on 'absolution' and 'resolution'. Absolution is regarded as the act of maintaining the current state of operations without implementing any modifications (Ackoff et al., 2007). It is not possible to seek absolution in this case, as the current system is not future-proof (Madlener, 2025a). There are two approaches to resolution. The first approach entails the utilisation of prior experiences to address present challenges, whereas the secondary approach involves the elimination of the underlying cause (Ackoff et al., 2007). Both are not applicable, given the absence of prior experience with fossil fuel-free vessels and the perceived impracticality of removing the underlying cause. This is because the vessels are essential for ensuring safety in the harbour.

The remaining approaches of dealing with problems are 'solution' and 'dissolution', both applicable to solving the fleet renewal challenge. However, dissolution is regarded as a superior method in comparison to solution. Whereas the act of solving is merely an attempt to achieve the most favourable outcome, the act of dissolving is an approach that deals with problems by redesigning the system to improve the performance in the future by preventing the problems from occurring again (Ackoff et al., 2007). Once again, note the importance of 'design' in dissolving problems.

The Idealised Design methodology from Ackoff et al. (2007) emphasises the importance of design even further and is particularly relevant to the challenge of renewing the Port of Rotterdam's fleet. The Idealized Design Methodology has been developed for 'creating an organisation's future'. It is particularly relevant given that the Port of Rotterdam must adapt to fulfil its long-term public responsibilities (Madlener, 2025a). Consider, for example, the emergence of new technologies such as drones and artificial intelligence, and society's aspiration to reduce greenhouse gas emissions.

The methodology does not plan for the future by thinking about what one wants at that moment in the future. Instead, it is a process of formulating the desired organisational state at the present moment in time, and plans for the steps required to achieve that state in the future. By conducting this process iteratively, the organisation will achieve success in the 'unknown future'. Although the desired organisational state will also evolve over time, the organisation moves step by step to a more successful organisation (Ackoff et al., 2007).

## 1.6. 'Fitness for Purpose' in Design

The decision-support tool should help to determine the optimal composition of "Tomorrow's Fit For Purpose Sustainable Fleet". Therefore, it is important to explain what 'fit for purpose' means from both the perspective of the Port of Rotterdam and the theoretical perspective.

For the Port of Rotterdam (PoR), 'fit for purpose' means that the fleet is equipped to perform its tasks to the highest requirements, with the best possible performance. 'Sustainable' means that no greenhouse gas emissions are produced. The order is important and has been chosen on purpose. In this context, it is more important to make sure that the equipment works well, rather than that it is environmentally friendly (Madlener, 2025b). Although this formulation is important to the PoR, a holistic perspective on 'fit for purpose' would consider sustainability and task performance as both part of the overarching goal to find a solution that is "fit for purpose".

From a theoretical perspective, the concept of 'fitness for (common) purpose' is understood through the frameworks provided by van Gunteren et al. (2011) and Wolfert (2023).

'Fit for purpose' is defined as 'quality' by van Gunteren et al. (2011, p. 15). He identifies seven types of quality as can be seen in Figure 1.4. According to van Gunteren et al. (2011, p. 15), maximising 'fitness for purpose' in projects requires covering as much of the (circle of) 'non-realized quality' while minimising the (circles) 'excuse- and wasted quality'. In the context of the fleet renewal challenge, the minimisation of critical response time in comparison to the current situation can be considered part of the (not-yet) 'non-realised quality'. Conversely, the currently defined amount of firefighting foam may be excessively high and can be reduced. In this conceptual example, the latter may be regarded as part of 'excuse- or wasted quality'.

To extend the concept of 'fitness for purpose', Wolfert (2023, p. 174) explains that the 'fit' is found in the overlap of what is 'capable' (e.g. feasibility) and what is 'desirable'. According to him, this should be the aim of projects: bridging the gap between desirability and capability as can be seen in Figure 1.5. Desirability stems from social preferences, while capability is rooted in physics, mathematics, and current knowledge and technology (Wolfert, 2023). In the context of the fleet renewal challenge, the feasibility of diesel vessels is recognised, though their desirability is low. Conversely, the feasibility of fully electric vessels is uncertain, though their desirability is high.

To evolve from ’fitness for purpose’ to ’fitness for *common* purpose’ (a phrase from Wolfert, 2023), it is essential to heavily involve the perspectives of all stakeholders (clients, users, contractors, etc.) and consider their expectations and desires, which is referred to as ’stakeholder preferences’.

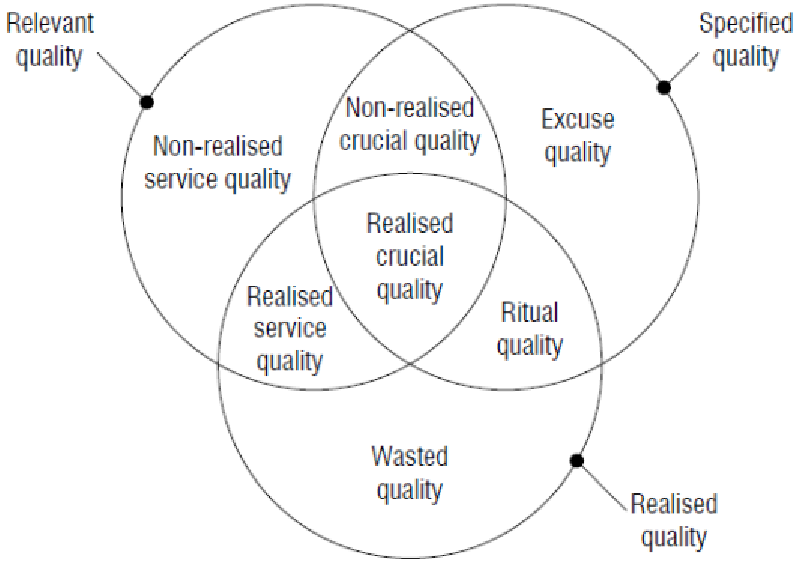



**Figure 1.4:** Classification of seven categories of quality. According to van Gunteren et al. (2011, p. 15), maximising ’fitness for purpose’ in projects requires covering as much of the ’non-realized quality’ while minimising the ’excuse- and wasted quality’. (van Gunteren et al., 2011))

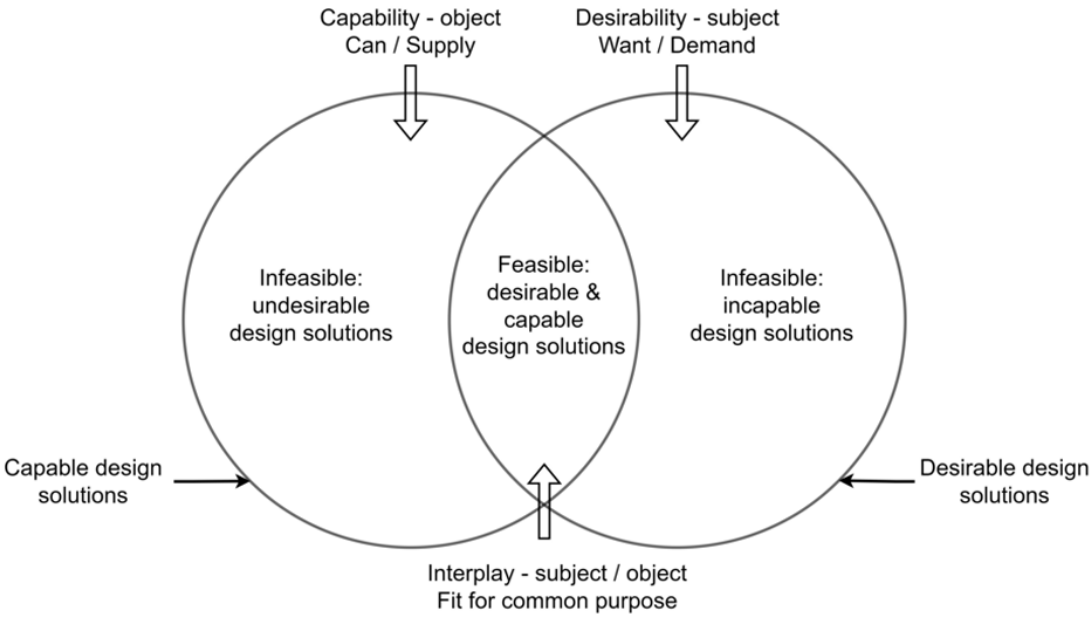



**Figure 1.5:** Socio-technical interplay between (un)desirability and (in)capability. ’Fitness for common purpose’ is both desriable as capable. (Wolfert, 2023)

## 1.7. State-of-the-art Decision-making: Preference Functional Modelling (PFM) and Preferendus Methodology

It is observed that the challenge of the fleet renewal project must be regarded as a systemic problem that requires a design-oriented approach to find the best 'fit for common purpose' fleet composition. However, the method by which (system-design) alternatives and choices are evaluated remains to be addressed.

Multi-Criteria Design Analysis (MCDA) and Multi-Objective Design Optimisation (MODO) are widespread methodologies employed within the engineering discipline for the evaluation (MCDA) and optimisation (MODO) of design alternatives and the selection of the best design (Wolfert, 2023).

MCDA is utilised for the evaluation of alternatives that have already been produced (a posteriori) in accordance with the multiple criteria defined. The evaluation of each alternative is conducted by assigning a score for each specified criterion. Each criterion is assigned a specific weight, thereby enabling the calculation of an overall aggregated score for each alternative, often done with a weighted sum (Wolfert, 2023).

MODO utilises an algorithm to search for the most 'optimal' design. This is frequently implemented with the assistance of computer power to explore the design space by generating a range of design alternatives. The algorithm uses 'objectives' that are weighted to guide the search process. For instance, an objective could be the maximisation of pump capacity for firefighting with a weight factor of 0.3, or the minimisation of critical response time with a weight factor of 0.7.

However, MCDA and MODO are frequently implemented incorrectly due to the following reasons:

(a) the lack of stakeholder involvement at the initiation and throughout the design process, leading to the chance of not identifying the 'optimal' design (H. van Heukelum et al., 2023);
(b) the misperception that all objectives can be translated to a metric other than preferences (e.g. money) (H. van Heukelum et al., 2023);
(c) mathematical errors regarding preference- measurement and aggregation found by Barzilai (2022)
(d) the misunderstanding that a design process can lead to multiple designs that are all equally preferred (for example, using the Pareto front), when in reality there is always one 'best' design chosen based on preferences (H. van Heukelum et al., 2023; Wolfert, 2023).

Two methods are developed to address the mistakes: the Preference Functional Modelling (PFM) from Barzilai (2022), and the Preferendus Methodology from H. J. van Heukelum et al. (2024). PFM is responsible for the correction of mathematical errors regarding preference- measurement and aggregation. This is useful for both MCDA and MODO. The Preferendus Methodology is developed for MODO purposes and is based on PFM. To be more specific, the Preferendus is an a A-priori Preference-Based Multi-Objective Multi-Stakeholder Optimisation. This approach allows for the integration of stakeholder preferences into the design process, ensuring that the final design aligns with what is 'desirable'. The integration of design performance functions ensures that the design is also 'feasible'. This is essential for finding a solution that is "fit for purpose", which has been defined earlier as a solution that is both desirable and feasible in terms of design.

## 1.8. Academic Contribution

The Port of Rotterdam expresses the need and interest for a decision-support tool to facilitate improved decision-making for complex choices by making trade-offs more transparent and by integrating both technical and social aspects. The Preferendus Methodology serves as the foundational framework for this tool, as it has previously demonstrated its value in incorporating stakeholder preferences while ensuring the feasibility of the project. The methodology ensures transparent and well-informed decision-making for complex projects by systematically integrating these preferences.

The development of the Preferendus, related to the Open Design Systems (Odesys) methodology (Wolfert, 2023), is based on former work. The first concept in the direction of the Preferendus is formulated in the paper of Zhilyaev et al. (2022). In this study, the authors have developed the first concepts of the Preferendus and have applied it to a 'real-life multi-store building design case'. Followed by this paper, the Preferendus is developed and first introduced in the work of Van Heukelum, Binnekamp and Wolfert (H. J. van Heukelum et al., 2024). This paper provides a demonstration of the value of the Preferendus Methodology by applying it to a 'railway level-crossing life-cycle design' and a 'floating wind turbine installation design'.

In later stages, the Preferendus is evaluated and implemented across a range of contexts: for off-shore projects (H. J. van Heukelum, 2022; H. J. van Heukelum et al., 2023), resolving on-shore wind-farm development (Teuber & Wolfert, 2024), in urban development (Pallandt, 2025; Raaphorst, 2024; van Eijck & Nannes, 2022), applied for quay walls assessment (Aulbers, 2023), and to enhance collaboration within a project team for developing a data centre (Mol & Schriever, 2024),

As outlined, the Preferendus Methodology has been employed in a variety of contexts for a range of purposes. However, the application of a systems-of-systems concept to this methodology, and its implementation in an existing operational organisation, in conjunction with the Idealized Design Methodology from Ackoff et al. (2007), such as a continuous fleet operation, remains unexplored. This master's thesis attempts to address this gap.

## 1.9. Structure and Reader Guide

This thesis is structured to provide an understanding of the decision-support tool developed for the Fleet Renewal Challenge at the Port of Rotterdam. The report is organised into six main chapters, followed by references and appendices.

- **Chapter 2: Theoretical Fundamentals** - The present chapter provides an exposition of the theoretical fundamentals of the two methodologies used. The Preferendus Methodology is outlined in sub-chapter 2.1, and the Idealised Design methodology is outlined in sub-chapter 2.2.

- **Chapter 3: Data Gathering** – Outlines the system analysis to introduce the stakeholders and the operational context of the fleet operations. In addition, the mathematical formulations are explained: design variables, design objectives, bounds, constraints and preference curves.

- **Chapter 4: Model Building** – Presents the development of the decision-support tool, including needs and requirements, conceptual model framework, process flow, and data flow.

- **Chapter 5: Analysis & Solution Selection** – To demonstrate the functionality of the tool, an analysis and solution selection process is conducted with the end goal of finding the best fleet composition.

- **Chapter 6: Discussion** – Reflections on the tool and methodology. This includes a reflection on the integration of methodologies, application to systems of systems problems, and alignment of desirability with capability. Moreover, the section outlines the reflections on the Preferendus Methodology of the project team from the Port of Rotterdam.

- **Chapter 7: Conclusion** – Providing a conclusion of the master thesis aims to develop a decision-making tool for the fleet renewal challenge at the Port of Rotterdam.

- **References** – List of all references used in this thesis.

- **Appendices** – Additional material and detailed information supporting the development of the decision-making tool for the fleet renewal challenge at the Port of Rotterdam.

# 2 Theoretical Fundamentals

This chapter provides an exposition of the theoretical fundamentals of the two methodologies used. The Preferendus Methodology is outlined in sub-chapter 2.1, and the Idealised Design methodology is outlined in sub-chapter 2.2.

## 2.1. Preferendus Methodology

The Preferendus Methodology is used as the foundation of the decision-support tool to facilitate decision making and the evaluation of design alternatives. This methodology, developed by H. J. van Heukelum et al. (2024) and first introduced by Zhilyaev et al. (2022), is an a-priori multi-objective design and decision support optimisation methodology that can be used for multi-stakeholder social-technical systems. For a more detailed explanation of multi-objective and multi-stakeholder analyses and optimisation, please refer to Wolfert (2023) and Technical University of Delft (2023).

The methodology uses Integrative Maximised Aggregated Preferences (IMAP) (H. van Heukelum et al., 2023) as an optimisation method based on Preference Functional Modelling (PFM) from Barzilai (2022), which accurately aggregates preferences. Therefore, the methodology accurately incorporates the different preferences of various stakeholders regarding their objectives within the system. The workflow of the Preferendus can be seen in Figure 2.2, and for a more detailed explanation, see Wolfert (2023) and H. J. van Heukelum et al. (2023).

### Conceptual Framework

The Preferendus mathematically connects the spheres of 'capability' and 'desirability'. This is done by having three types of functions within the mathematical model, besides the usual bounds and constraints (Wolfert, 2023):

| | | |
|---|---|---|
| 1. | Design Performance Functions | (Capability – Object) |
| 2. | Objective Functions | (Integration – Object & Subject) |
| 3. | Preference Functions | (Desirability – Subject) |

To illustrate the conceptual framework, imagine the deployment of incident response vessels in the largest harbour in Europe, the harbour of Rotterdam. A simplified overview of the objectives can be outlined as follows: minimising expenditure and minimising critical response time.

The safety authorities, constrained by limited financial resources, are driven to optimise the value they create, regardless of budgetary limitations. Consequently, this approach may also result in reduced expenditure if it is considered to be an optimal utilisation of resources. This is due to the fact that scarce and saved funds can also be allocated to other important matters.

The critical response time, in this example, is determined exclusively by the number of vessels. The increase in the number of vessels leads to a reduction in the size of the operational areas per vessel. Consequently, this results in a decrease in the maximum response distance, and therefore a decrease in the critical response time.

- **Design Variables**
  A multitude of parameters may be considered as design variables within the system. The Preferendus Methodology has been developed for the optimisation of these parameters. In this example, the design variables are the different vessel types, each of which has a predetermined capital expenditure value.

$$x_i \tag{2.1}$$

where $x_i$ = the number of vessels of type $i$

- **Design Performance Functions**
  Design performance functions represent the way the system works and its characteristics.

$$\text{capex}_{\text{vehicle},i} \tag{2.2}$$

*where it is dependent on size, quality, and functionalities (e.g., extinguishing capacity) and additional factors*

$$\text{Length One Sector} = \text{Total Length Harbour} / \sum_{i=1}^{n} x_i \tag{2.3}$$

- **Design Objective Functions**
  The Objective Functions integrate the spheres of ”capability” and ”desirability”. These functions are constructed on the basis of the design performance functions and calculate a single metric for each objective. Specifically, in the context of computer coding, the objective function facilitates the integration of the preference function, thereby enabling the synthesis of the ’capability/feasibility’ from the design performance functions with the ’desirability’ formulated with the preference functions.

$$\text{CAPEX} = \sum_{i=1}^{n} x_i \cdot \text{capex}_{\text{vehicle},i} \tag{2.4}$$

$$\text{Critical Response Time} = \frac{\text{Length One Sector}}{\text{Critical Maximum Speed}} \tag{2.5}$$

Critical Maximum Speed = the minimum maximum speed of all vessels deployed

- **Preference Functions**
  Preference Functions provide a subjective evaluation of the defined objective functions. Objective functions can be regarded as the neutral calculation of a metric, whereby the preference function provides the subjective assessment. To illustrate this point, the preference function can be used to indicate whether a significant financial expenditure is deemed acceptable or undesirable. It should be noted that multiple preference functions can be generated, one for each stakeholder, that correspond to one objective.

  Creating a preference curve can be done by specifying a best alternative, a worst alternative, and an alternative in between, see (Zhilyaev et al., 2022). These alternatives get the scores of 100 and 0, respectively, and any number in between 100 and 0. Note that 0 (least preferred) and 100 (most preferred) are arbitrary, and any other scale can be taken (see the work of Barzilai (2022)). See Figure 2.1 below for an example of preference curves.

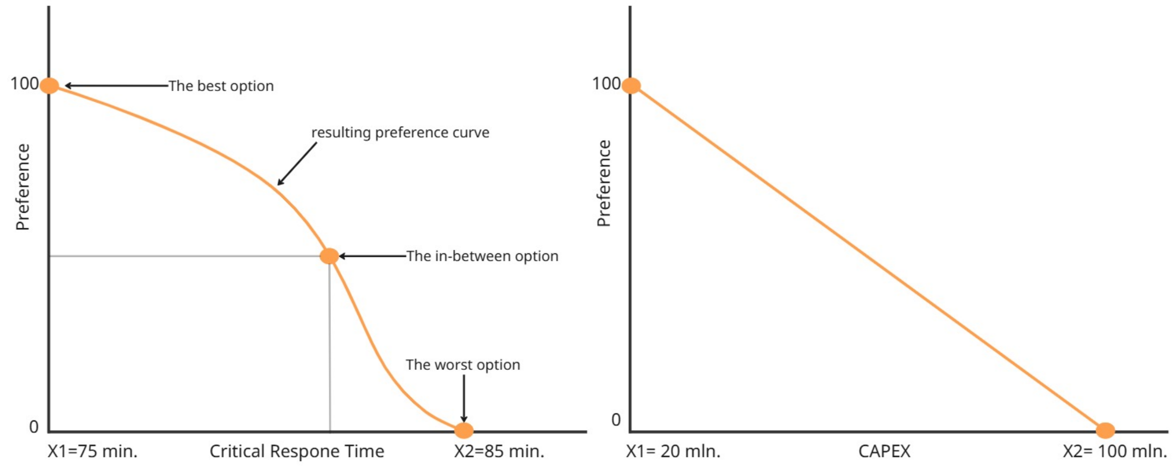



**Figure 2.1:** Example preference curves critical-response-time and CAPEX. A preference curve can be done by specifying a best alternative, a worst alternative, and an alternative in between, see (Zhilyaev et al., 2022). These alternatives get the scores of 100 and 0, respectively, and any number in between 100 and 0. Note that 0 (least preferred) and 100 (most preferred) are arbitrary, and any other scale can be taken (see the work of Barzilai (2022)). *(own illustration but based on the work of Zhilyaev et al. (2022)*)

### Practical Example

Although this master's thesis employs the Preferendus Methodology, thereby demonstrating its functionality, a worthwhile example is the research of Teuber and Wolfert (2024), about a wind farm design. Their web-based 'Odesys dynamic toolbox' is of particular interest in this regard, as it allows the user to easily experiment with the tool themselves. The authors' findings revealed that in a wide range of configurations, no viable solutions were identified. In summary, it was determined that the construction of the wind farm was not a viable proposition; its construction should be avoided. This was because the required wind speed was 'impossible' (Teuber & Wolfert, 2024).

### Methodology Step by Step

The steps of the Preferendus Methodology are explained below and are based on Zhilyaev et al. (2022).

1. **Define the Design Problem:** by formulating the design variables, objectives, bounds, and hard constraints.
2. **Finding the minima and maxima of the objective functions:** to explore the solution space. This can be done by Single Objective Design optimisation (SODO's), wherein a single objective is given full weight, while the remaining objectives are set to zero.
3. **Defining Preferences:** by drawing preference curves. This can be done by specifying a best alternative, a worst alternative, and an alternative in between (see Zhilyaev et al. (2022)). These alternatives get the scores of 100 and 0, respectively, and any number in between 100 and 0. Note that 0 (least preferred) and 100 (most preferred) are arbitrary, and any other scale can be taken.
4. **Specifying Weights:** by giving a weight for each objective. The total weight of all the scores should be 1.
5. **Setting Up the optimisation Problem:** by creating a model that includes all the defined design variables, objectives, bounds, hard constraints, preferences, and weights. Zhilyaev et al. (2022) has done this in Matlab (The MathWorks Inc., 2025), this master's thesis uses Python (Python Software Foundation, 2026).
6. **Generating the Initial Population:** by running the Genetic Algorithm (GA), the initial population is generated with randomly generated members. These members include a random number for each design variable within the given bounds. Each unique member represented a unique design alternative.

7. **Preference Aggregation and Evaluation:** by using the Integrative Maximisation of Aggregated Preferences (IMAP) method (H. J. van Heukelum et al., 2024) that is based on the PFM-theory of Barzilai (2022). Each member is assigned an aggregate preference score, and all members are evaluated based on this score. The feasibility of the members is also evaluated according to the constraints. Note, the score of every alternative is relative to all the alternatives (scoring).
8. **Selecting the Best Individual:** the member that has the highest preference score and is feasible is selected and is considered as the optimal design solution
9. **Result Verification:** by evaluating the resulting solution by the stakeholders. In the case that the stakeholders express dissatisfaction with the result, they have the option of making adjustments to their preferences, weights, objectives, and constraints. Thereafter, they shall repeat the preceding steps. Should the stakeholders be satisfied with the proposed optimal design solution, the final design will be adopted.

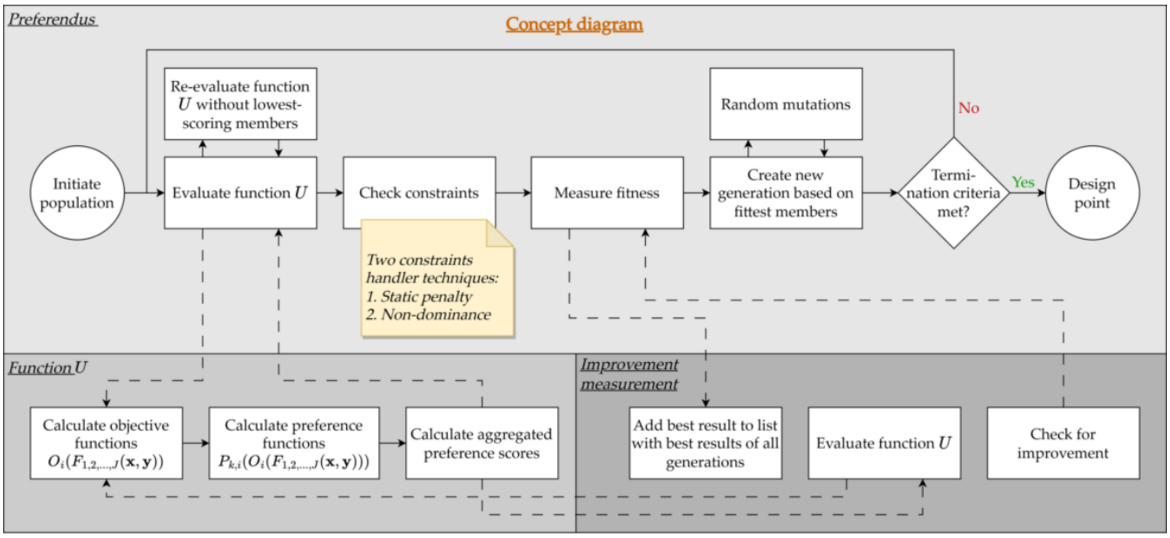



**Figure 2.2:** The workflow of the Preferendus, presented as concept diagram (Wolfert, 2023)

## 2.2. Idealized Design Methodology

The Preferendus Methodology, as explained in the previous section, is integrated with the Idealized Design Methodology, from Ackoff et al. (2007), in terms of the sequence of steps in the process. The Idealized Design Methodology has been developed for 'creating an organisation's future'. It is particularly relevant given that the Port of Rotterdam must adapt to fulfil its long-term public responsibilities (Madlener, 2025a). Consider, for example, the emergence of new technologies such as drones and artificial intelligence, and society's aspiration to reduce greenhouse gas emissions.

The methodology does not plan for the future by thinking about what one wants at that moment in the future. Instead, it is a process of formulating the desired organisational state at the present moment in time, and plans for the steps required to achieve that state in the future. By conducting this process iteratively, the organisation will achieve success in the 'unknown future'. Although the desired organisational state will also evolve over time, the organisation moves step by step to a more successful organisation. See Figure 2.3 for the graphical representation.

The following steps are defined in Idealized Design from Ackoff et al. (2007, p. 6) and separated into two phases of Idealization and Realization:

### Idealization

In the 'Idealised Design' phase, the organisation determines the desired state for the company, in comparison to its current state. This approach differs from the strategic planning process, which involves formulating future predictions to determine the desired state of an organisation in the future. Instead, the ideal state should be considered in relation to the present context.

1. ***Formulating the Mess***
   In order to establish a defined ideal state of the organisation, it is first necessary to ascertain the threats and opportunities currently facing it. The combination of these threats and opportunities, in addition to their interactions, has been described by Ackoff et al. (2007) as 'a mess'. According to Ackoff et al. (2007, p. 6), this formulation of the 'mess' is aimed at determining *'how the organization would eventually destroy itself if it were to continue doing what it is doing currently'*.

   Formulating the mess is conducted in four steps:

   - ***Prepare a system analysis*** – Description about how the current organization functions.
   - ***Prepare an obstruction analysis*** – Formulating the parts of the organisation that are 'obstructing' or resistant to change.
   - ***Prepare reference projections*** – Formulate a future projection for the organisation if it does not change. This analysis provides a framework for understanding how the organisation might face destruction if it does not modify its current strategy and working practices.
   - ***Prepare a presentation of the mess*** – Integrate all the previous steps into one presentation that makes clear what the future self-destroying scenario would be.

2. ***Ends Planning***
   This stage involves the determination of the desired current state of the organisation, without consideration of any current limitations. This state is referred to as the 'Idealized Design'. Following this, the 'gap' can be determined between the ideal design and the organisation as it is currently. Please note that the ideal design should prevent the self-destruction of the organisation formulated in the previous stage of 'formulating the mess'.

### Realization

3. ***Means Planning***
   In this step, the organisation should formulate a plan to approximate the ideal design as closely as possible, as defined in the preceding step of 'ends planning'.

4. ***Resource Planning***
   The implementation of idealised designs should incorporate the consideration of available resources. Determine which resource (human, financial, technical, etc.) should be allocated to which task and at what time, and formulate a plan to address shortages of resources.

5. ***Design of Implementation***
   The creation of a detailed schedule and the allocation of resources to the tasks to be

carried out should be undertaken at this stage.

– From Ackoff et al. (2007, p. 6) –

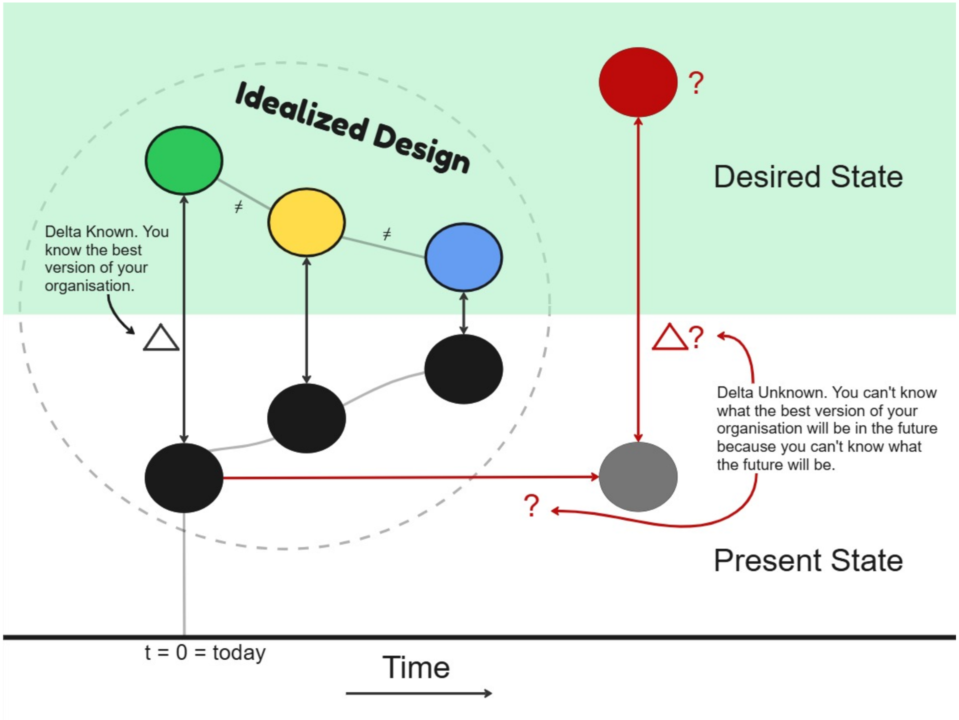



**Figure 2.3:** Visual Representation of Idealized Design (Ackoff et al., 2007). It is a process of formulating the desired organisational state at the present moment in time, and plans for the steps required to achieve that state in the future. By conducting this process iteratively, the organisation will achieve success in the 'unknown future'. Although the desired organisational state will also evolve over time, the organisation moves step by step to a more successful organisation. This is different from thinking about the ideal organisation in relation to the unknown future. *(own illustration)*

# 3
# Data Gathering

The Port of Rotterdam expressed a need and interest in becoming familiar with more scientifically based decision-making methods to help them achieve their ambitious goal. Therefore, this master's thesis aims to develop a decision-support tool. By doing this they tool should facilitate the finding of the best 'fit for purpose' renewed fleet composition. This chapter describes the analysis of the operational context and the mathematical model used for modelling the fleet-renewal challenge.

The first main section provides an analysis of the current situation with regard to the stakeholders, tasks, and resources involved in fleet operations at the Port of Rotterdam (see section 3.1). Furthermore, it evaluates the key societal issues that are critical for the success of the fleet renewal project. Section 3.3 outlines the "design for -ty" objectives employed, which represent the stakeholders' interests. These objectives are related to the design variables, which are optimized (chapter 3.2). The bounds and constraint functions can be located in chapters 3.4 and 3.5, respectively. The final section of the text presents the preference curves.

## 3.1. System Analysis

This section provides an analysis of the current situation with regard to the stakeholders, tasks, and resources involved in fleet operations at the Port of Rotterdam. Furthermore, it evaluates the key societal issues that are critical for the success of the fleet renewal project.

### Context Fleet Operations: Stakeholders, Tasks and Resources

This section provides an overview of the current situation regarding the stakeholders, tasks and resources of the fleet operations at the Port of Rotterdam. In terms of organisations, the system boundaries have been set between the Port of Rotterdam's internal and external stakeholders. Due to limited time and resources, this master's thesis does not take external stakeholders into account. A comprehensive analysis of the stakeholders can be found in Appendix A, and the organisational system boundaries, set between the internal and external stakeholders, are visualised in Figure A.1.

**Harbour Master Department**

The Harbour Master Department, led by the Harbour Master itself, plays a pivotal role in keeping the port 'safe, smooth, clean and secure' (Port of Rotterdam, n.d.-a). This department of the Port of Rotterdam Authority functions as an independent entity (under public law), and has the following sub-departments: Port Coordination Centre (HCC) [1], Traffic Management [2], Harbour master policy and development [3] and Ship and environmental safety [4]. All are related to the fleet operations, and their responsibilities are defined as:

- Safe and efficient management of maritime traffic,

[1] NL: Haven Coördinatiecentrum (HCC)
[2] NL: Verkeersafhandeling (VA)
[3] NL: Havenmeester Beleid & Ontwikkeling
[4] NL: Scheeps- en milieuveiligheid (SMV)

- Enforcing regulations
- Providing (first) incident response services,
- Coordinating emergency situations (e.g. fires and accidents)
- Protecting the environment

**Asset Management**
The Asset Management (AM) department, under the supervision of the Chief Operating Officer of the executive board, is responsible for the management of the port's physical assets throughout their lifecycle. This includes maintenance, upgrades, and strategic planning for the port's infrastructure and equipment. A sub-department of AM has been designated to manage the fleet and is named "AM Fleet" (Port of Rotterdam, 2025). The Fleet Renewal Programme is of significant importance to AM-fleet due to their expertise in the maintenance of the current fleet and their involvement in the management of the future fleet.

**Finance, Procurement and Innovation**
The Fleet Renewal Programme is a major innovative program, one of the largest in terms of budget, timelines, and stakeholders involved. Therefore, the finance, procurement, and innovation departments, supervised by the Chief Financial Officer (CFO) of the executive board, are also important (internal) stakeholders.

**Incident Response & Law Enforcement - Tasks and Resources of Fleet Operations**
The fleet of the Port of Rotterdam currently consists of 16 ships, 12 cars and approximately 160 personnel. While the port also operates two surveying vessels and one tour boat, these fall outside the scope of this thesis. See Figure B.2 for an overview of the vessels.

The crew is trained, and the vessels are equipped for their specialised tasks. These tasks are incident response (red-tasks; e.g. firefighting) and patrols & enforcement (blue-tasks; e.g. inspections). In addition to its specialisation, all ships have general tasks (green-tasks; e.g. search and rescue) they must perform. See Figure B.1 for the overview of tasks (also named fleet services).

Although the current service level provides a clear baseline for ongoing operations, the new fleet is scheduled to be deployed in 2030 and will remain operational for a considerable period thereafter. The issue is whether the current tasks will remain unchanged or be subject to modification. Furthermore, the question arises of whether it is possible to predict these changes and adjust the new fleet accordingly.

**Law Enforcement (Blue-Tasks)**
Law enforcement is carried out by Special Investigation Officers (BOAs [5]), whose duties include:

- Providing requested and unrequested advice based on legislation and procedures regarding hazardous and harmful substances;
- Conducting security inspections for ships and terminals;
- Detecting economic crimes related to unfair competition.
- Supervision and policing during events.

Law enforcement operations are subdivided into two components: shore-based inspections, conducted by vehicle at onshore and near-shore locations, and water-based inspections, carried out by vessel at locations on the water or near the shoreline.

**Incident Response (Red-Tasks)**
Incident response operations are conducted exclusively on water by Incident Response Vessels (IBVs[6]) and their dedicated crews. These specialised teams are trained for operations in hazardous areas and have the following responsibilities:

- Providing water and fire-fighting foam to the fire brigade in the event of incidents occurring along or on the water.
- Providing water to terminal fire extinguishing systems. These are large quantities of water under

[5] NL: Buitengewoon Opsporings Ambtenaar (BOA)
[6] NL: Incident Bestrijdings Vaartuig

high pressure.
- Source mitigation[7] of a fire or hazardous substances.
- Deploying (oil) containment barriers in unsafe areas.

**General Tasks (Green-Tasks)**
Besides the specialised tasks, both teams also have general tasks:
- The provision of first incident response services in safe areas, including: first aid, containing water pollution, creating a safe nautical situation, deploying water pumps for rescue operations, and bringing other vessels to safety by pushing or towing them.
- Search and Rescue (SAR).
- Providing information to the users and guests of the harbour area.
- Supervision of port activities to ensure compliance with the law.
- Inspecting damaged infrastructure.
- Supervision and policing during events. In collaboration with the fire brigade, police, ambulance service, Rijkswaterstaat, and military police.
- Transportation of persons (emergency workers and colleagues) and equipment.
- Assisting other safety agencies in the nautical management area. These include the police, fire brigade (including diving teams) and ambulance services.
- Remove objects from the water
- Collection and sharing of information. In collaboration with the Port Coordination Centre, traffic control centres, the camera network, drones and other resources.
- Physical traffic control in the event of failure of the Traffic Centres (TCH, VCR).
- Physical escorting of large seagoing vessels is carried out by a vessel while sailing. The crew of the vessel assists the traffic control centres in monitoring the surroundings and communicating with other shipping traffic.
- The recovery and transport of dead bodies.
- Deploying (oil) containment barriers in safe areas.

### Societal Key Issues
It is already very challenging to come up with an entirely new fleet and make an informed decision based on all stakeholder preferences while considering social-technical feasibility. This is due to the large number of factors and relationships within a socio-technical domain, where both the organisation and the technologies must be ready for change.

However, in addition to social-technical feasibility, it is also important to consider the societal key issues that are very risky for the success of the Fleet Renewal Programme. This section outlines these key issues.

**Shortage of (skilled) Workforce (organisation issue)**
Forecasts suggest that a shortage of workers and this will not change in the future (Volkerink et al., 2024). The main drivers for this issue are an ageing population and fewer graduates entering the labour market (Madlener, 2025a). Currently, the situation is acceptable; however, in the future, there will be fewer (skilled) workers. Potential solution directions may include lowering service level expectations, seeking synergies with other agencies and organizations and ensuring fewer staff are required by making smart use of other semi-autonomous resources.

**Electrical Grid Congestion (resource issue)**
The increasing demand for electricity resulting from sustainability measures is causing shortages on the electricity grid, with significant economic and social consequences. Grid congestion is a major problem in the Port of Rotterdam, meaning that expanding electrical grid capacity does not seem possible until after 2030. This could delay the implementation of electric-driven vehicles. The main drivers for this issue are the energy transition and workforce shortages (Madlener, 2025a; TenneT, 2025). Currently, the situation is urgent, but in the future, it is possible but uncertain. Potential solution directions may include designing a fleet that is resilient to grid congestion, obtaining political guarantees for assured capacity, and avoiding the use of electric vehicles.

[7] NL: Bronbestrijding

**New and More Hazardous Substances (safety issue)**
New and more dangerous substances are appearing in the port area. These substances arrive as cargo and are used on board as energy carriers for ships, making them especially dangerous during bunkering. The Port of Rotterdam Authority must adapt the way they conduct inspections and responds to incidents to cope with this new situation. The main driver for this issue is the energy transition (Madlener, 2025a). Currently, the port deals with substances like kerosene, benzene, LNG, and LPG. In the future, these substances will be extended by ammonia, batteries, hydrogen, and methanol. Potential solution directions may include adjusting harbour legislation, training crew, and using new technologies to keep the crew and surroundings safe.

**Increasing Undermining (safety and security issue)** Various threats on the horizon could lead to different types of unauthorised hostile activity in the port, including criminal activities, terrorist attacks, and extreme activist activities aimed at disrupting the harbour operations. These activities are associated with hybrid warfare (espionage, sabotage, disinformation, and cyber-attacks). The main drivers for this issue are increasing drug-related crime, increasing geopolitical tensions, and increasing political and societal tensions (Madlener, 2025a). Currently, the situation is urgent, and it is expected to become even more urgent in the future. Potential solution directions may include increasing patrols and employing additional technologies like cameras and drone surveillance.

**Less Oil Industry and Differentiated Feedstock Chemical Industry (economic issue)** The chemical and oil industries are well represented in the harbour of Rotterdam. However, it is expected that the oil industry will shrink, while the chemical industry will remain stable. The chemical industry is shifting towards using other materials like biomass and recycled materials instead of oil. The main driver for this issue is the energy transition and higher energy prices (BNR Webredeactie, 2025; Lakens & de Jongh, 2025; LyondellBasell, 2025; Port of Rotterdam, n.d.-c; UPM, 2025). Currently, the port has an oil and oil-based chemical industry, but in the future, this remains uncertain.

**Unpredictable and More Severe Weather Conditions (operational issue)** Storms become heavier, and ships grow larger. The risk of ships breaking loose (drifting) increases. During a storm, we can rely less and less on tugboats because there are too few of them. The main driver for this issue is climate change (Madlener, 2025a). Currently, the situation is manageable, but in the future, the expectation will be more and larger ships drifting in severe weather conditions. Potential solution directions may include having more and better equipment for dealing with drifting vessels.

## 3.2. Design Variables

The design variables are the number of different types of vessels, cars, and other vehicles, represented as $x_i$.

## 3.3. Design Objectives

In this section, the objectives are outlined to test the model. In order to formulate the objectives of the stakeholders with regard to the fleet renewal challenge, and consequently design the new fleet composition, the 'design for -TY' framework is utilised. The design for -ty objectives represents the interests of the various stakeholders. For instance, 'Affordability-TY' is the 'vague need' of the project leader that the design should be affordable.

The stakeholder interests linked to the 'design for -ty principles' are shown in Figures J.2 and J.3. As can be seen, the 'design for -ty' objectives are considered as the 'highest abstract level' and can contain several sub-objectives.

These 'vague needs', formulated by the 'design for -ty' objectives, are used to define the objectives that need to be addressed for the fleet renewal challenge. The objective 'Safety & Security' reflects the tasks and therefore the purpose of the fleet. These tasks are already explained and can be seen in Figure B.1. Note that these tasks are the current, 'Present Mode' services the fleet needs to provide. However, this set of tasks may be defined differently in 'Future Mode', with more or fewer tasks or a different understanding of the task.

It is important to acknowledge that these objectives do not fully capture address the complexity of the issue. However, the principal objective of this thesis project was not to provide a complete representation of the problem into the model, but rather to develop a tool that would facilitate the finding of the solution.

---

**Affordability**

Renewing an entire fleet is a large investment. The Port of Rotterdam must carefully consider the initial purchase costs and operational expenses.

- *Minimizing Capital Expenditures (CAPEX)*

$$\text{MIN} \quad \text{CAPEX} = \sum_{i=1}^{n} x_i \cdot \text{capex}_{\text{vehicle},i} \tag{3.1}$$

where:
  - $x_i$ is the number of vehicles of type $i$ ($x_i \geq 0$).
  - $\text{capex}_{\text{vehicle},i}$ is the capital expenditure per unit for vehicle type $i$.

- *Minimizing Operational Expenditures (OPEX)*

$$\text{MIN} \quad \text{OPEX} = \sum_{i=1}^{n} y_i \cdot \text{opex}_{\text{vehicle},i} \tag{3.2}$$

where:
  - $x_i$ is the number of vehicles of type $i$ ($x_i \geq 0$).
  - $\text{opex}_{\text{vehicle},i}$ is the operational expenditure per unit for vehicle type $i$.

---

**Sustainability**

The transition to a zero-emission fleet is an essential step in reducing the carbon footprint in the operational phase. However, it is also fair to consider emissions from the construction of the new fleet.

- *Minimizing Carbon Footprint Investment (construction, transportation, etc.)*

$$\text{MIN} \quad \text{CFI} = \sum_{i=1}^{n} x_i \cdot \text{cfi}_i \tag{3.3}$$

where:
  - $x_i$ is the number of vehicles of type $i$ ($x_i \geq 0$).
  - $\text{cfi}_i$ is the carbon footprint of the investment for vehicle type $i$.

- *Minimizing Carbon Footprint Operations*
  - (See K.1 for overview calculation structure)

$$\text{MIN} \quad \text{CFO} = \sum_{i=1}^{n} v_{\textbf{avg-i}} \cdot \text{OpH}_i \cdot \text{E}_i \tag{3.4}$$

where:
  - $v_{\textbf{avg -i}}$ is the average speed of vehicle type $i$
  - $\text{OpH}_i$ is the operational hours vehicle type $i$.
  - $\text{E}_i$ is the average carbon emissions per km vehicle type $i$.

---

**Maintainability**
In the context of fleet management, the maintenance and repair of a fleet with a reduced number of components is beneficial. The maintenance is therefore related to the complexity of maintenance. For now, this is represented as the different vessel types in the fleet.

- *Minimizing Complexity*

$$\text{MIN} \quad \text{Complexity} = \sum_i \begin{cases} 1 & \text{if } x_i > 1, \\ 0 & \text{otherwise.} \end{cases} \tag{3.5}$$

where:
  - $x_i$ is the number of vehicles of type $i$ ($x_i \geq 0$).

---

**Safety & Security**
The objective 'Safety & Security' reflects the tasks and therefore the purpose of the fleet. These tasks are already explained and can be seen in Figure B.1. Note that these tasks are the current, 'Present Mode' services the fleet needs to provide. However, this set of tasks may be defined differently in the future ('Future Mode'), with more or fewer tasks or a different understanding of the task.

- *Maximizing Number of Barge Inspections (NL: Binnevaart Inspecties)*
  - In order to ensure that barge operators comply with the established regulations, inspections are routinely conducted.
  - (See K.2 for overview calculation structure)

$$\text{MAX} \quad \text{Numb Barges Inspections} = \text{Total Vessels} \cdot \text{InspH} \cdot \text{OpT} \tag{3.6}$$

Assumptions:
  - InspH is calculated based on the average of 350 inspections per month (30 days) with 3 operational vessels working 12 hours per day:

$$\text{InspH} = \frac{350}{30 \cdot 3 \cdot 12} = 0.32 \tag{3.7}$$

where:
  - InspH is the average number of inspections per hour done by one car.
  - OpT is the total operational time of the cars.
  - Total Vessels is the total number of patrol vessels available..

- *Maximizing Number of Inspections Seafarers (NL: Zeevaart Inspecties)*
  - In order to ensure that seafarer operators comply with the established regulations, inspections are routinely conducted.
  - (See K.3 for overview calculation structure)

$$\text{MAX} \quad \text{Numb Seafarers Inspections} = \text{Total Cars} \cdot \text{InspH} \cdot \text{OpT} \tag{3.8}$$

Assumptions:
  - InspH is calculated based on the average of 250 inspections per month (30 days) with 5 operational cars working 8 hours per day:

$$\text{InspH} = \frac{250}{30 \cdot 5 \cdot 8} = 0.21 \tag{3.9}$$

where:
  - Total Cars is the total number of cars available.

- *Maximizing Patrol Distance*
  - Physical presence in the port contributes to port safety. This is represented by the distance at which vessels sail.

$$\text{MAX} \quad \text{Patrol Distance} = \text{Average Patrol Speed} \cdot \text{OpT} \tag{3.10}$$

where:
  - Average Patrol Speed is the average speed at which patrols are conducted.

- *Maximizing Availability Capacity Coverage Incident Response*
  - It is important that the incident response vessels (red-tasks) are available on a 24/7 basis. For instance, in the event of an incident occurring during the battery recharge period for one vessel, there should be another vessel available to continue operations. This objective represents 'availability'.
  - (See K.5 for overview calculation structure)

$$\text{MAX} \quad \text{Ratio Capacity Coverage Incident Response} = \frac{\text{Total Operational Hours Fleet}}{\text{Required Operational Total Time}} \tag{3.11}$$

where:
  - Total Operational Hours Fleet is the total operational hours of the fleet.
  - Required Operational Total Time is the total required operational time.

Assumptions:
  - It is assumed that every incident response vessel should be operational 24/7. When they are recharging or refuelling, there should be a stand-in vessel to fill the gap during this time.
  - A ratio of 1 indicates precisely the right capacity. A ratio above 1 indicates overcapacity, while a ratio below 1 indicates undercapacity.

- *Maximizing Availability Long Term Deployment in Incident Response*
  - In the event of an incident that lasts a long time (24/7 for one week, for example), a specified number of vessels must be continuously operational on site. In the event of downtime due to battery recharging, this must be compensated for by another vessel.
  - (See K.6 for overview calculation structure)

$$\text{MAX} \quad \text{Ratio Avai. Long Term Depl. in Incidents} = \frac{\text{Total Operational Hours Fleet}}{\text{Required Operational Total Time}} \tag{3.12}$$

where:
  - Total Operational Hours Fleet is the total operational hours of the fleet during an incident response.
  - Required Operational Total Time is the required operational time for incident response (24/7 for one week).

Assumptions:
  - At least two Incident Response Vessels are required for incident response.
  - The required operational time is one full week (24/7), which equals 168 hours.
  - The time needed to sail to an incident and return to the home base is assumed to be 25 minutes each way.
  - If the number of Incident Patrol Vessels is less than 2, the ratio is penalized to 0.01.
  - The operational time is calculated considering the time needed to sail to the incident and back.

- *Minimizing Critical Initial Response Time*

- It is important that the vessels arrive at their designated location within the port within a specified time frame for incidents.

$$\text{MIN} \quad \text{Critical Response Time} = \frac{\text{Length One Sector}}{\text{Critical Maximum Speed}} \tag{3.13}$$

where:
- Length One Sector is the distance of one sector that needs to be covered, calculated as $\frac{\text{Total Port Length}}{\text{Number of Incident Response Vessels}}$.
- Critical Maximum Speed is the minimum maximum speed among all incident response vessels.

Assumptions:
- This function determines the critical initial response time for the first vessel required to approach the location of an incident.
- The total port length is assumed to be 42 km.
- The response time is calculated based on the distance of one sector and the minimum maximum speed of the vessels.

---

**Societal Key-Issues**

- *Minimizing Electricity Dependency*
  The net congestion is calculated based on the ratio of electricity-dependent kilometres to the total kilometres in operations by all vessels within a certain time frame.

$$\text{MIN} \quad \text{Electricity Dependency Ratio} = \sum_i \begin{cases} \frac{\text{Total Operational Distance Electricity}}{\text{Total Operational Distance}} & \text{if } X > 1, \\ 0 & \text{otherwise.} \end{cases} \tag{3.14}$$

where:
- $X$ is the total quantity of vessels.
- Total Operational Distance Electricity is the action radius of the fleet based on electricity.
- Total Operational Distance is the total action radius of the fleet.

- *Minimising the Risk of Shortage (Skilled) Workforce*

  The key-issue of the shortage of (skilled) personnel can also be modelled. For instance, one can determine the required skill-set for each vehicle type and couple this to a ratio like the net congestion. However, the Human-Resources (HR) part is not taken into consideration in this master's thesis project and therefore left out. As an alternative, the parameter of the available crew members can be adjusted to simulate, for instance, a shortage of workforce (for the effect of this feculence see, for example, the constraint function 3.15 and the objective functions)

---

## 3.4. Bounds

The optimisation model should be enabled to operate with maximum freedom so that the solution space can be investigated in its full potential. In consideration of the present fleet's composition, which is approximately 15 ships, the upper limit for each vehicle has been set at 30. This decision has been made on the basis that a configuration exceeding 30 vehicles is deemed to be unrealistic and will cause slow convergence of the algorithm. It is impossible for a negative vehicle number to exist in reality; therefore, the bounds of all vehicles ($x_i$) are set between 0 and 100 for each vehicle.

## 3.5. Constraints

A constraint is added that ensures the number of incident response vessels is lower than or equal to the capacity of the crew members who have received special training for incident response services (e.g., fire-fighting). Although human resources are embedded in the objective functions, this constraint provides faster convergence of the algorithm. There is no explicit restriction on the number of law enforcement vessels, as no additional training is required for this purpose. Consequently, all crew members are permitted to sail.

The inequality constraint function is defined as:

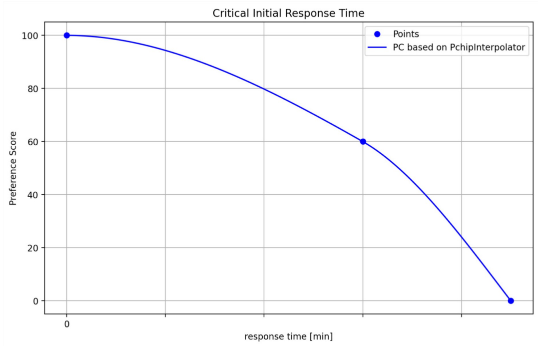
$$N_{\text{Incident response vessels}} \times R_{\text{number crew}} \leq C_{\text{incident response}} \tag{3.15}$$

where:

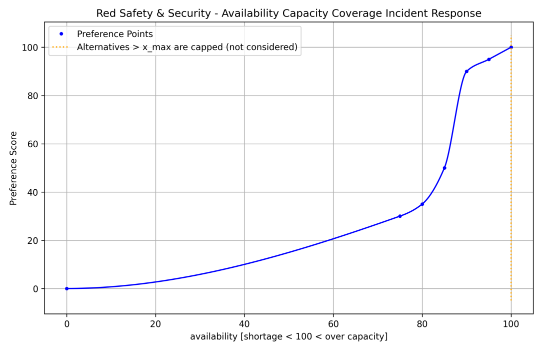
- $N_{\text{Incident response vessels}}$ = the number of incident response vessels
- $R_{\text{number crew}}$ = the minimum required number of crew members for each incident response vessel
- $C_{\text{incident response}}$ = the capacity crew members incident response vessels. This is calculated based on the total number of crew members required to ensure the continuous operations of the vessels on a 24-hour, 7-day basis. This means that, for example, 1 ship requires approximately X crew members to be operational 24/7, taking into account the utilisation rate.

## 3.6. Preference Curves

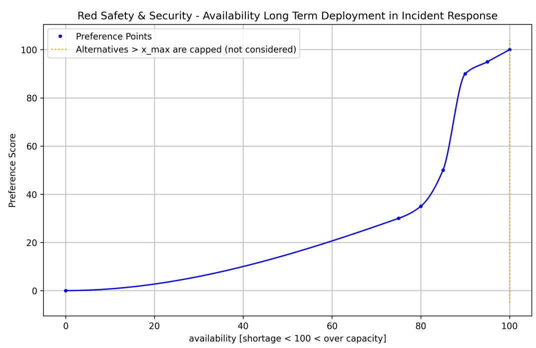
The subsequent illustrations are the preference curves that were utilised in the analysis and optimisation processes. For enlarged figures, see appendix L.2




**(a)** Preference Curve Critical Initial Response Time as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)

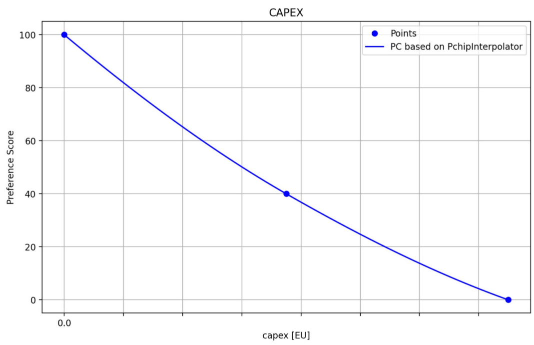



**(b)** Preference Curve Availability Capacity Coverage Incident Response as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)

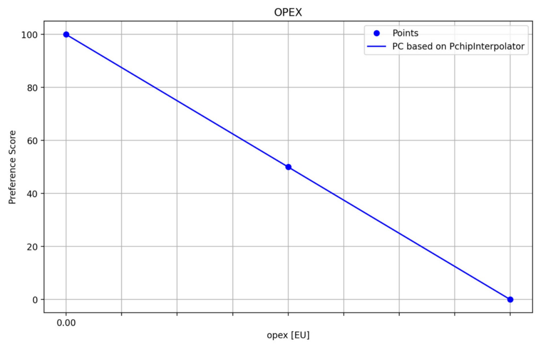



**(c)** Preference Curve Availability Long Term Deployment in Incident Response as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)

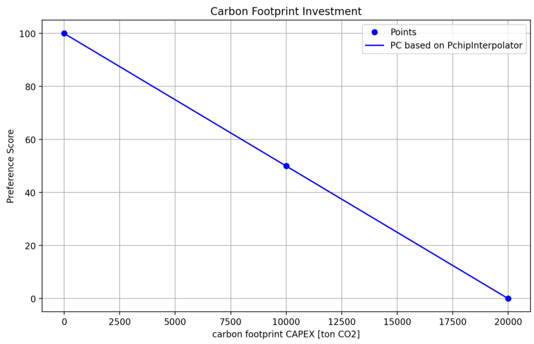
**Figure 3.1:** Preference Curves for Red Tasks Safety & Security. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axis.



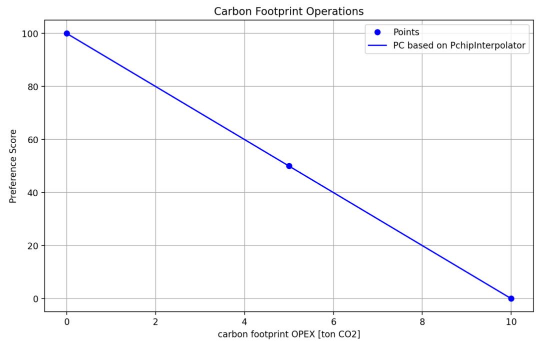

**(a)** Preference Curve CAPEX as sub-objectives from 'Affordability' (design for -ty objective)



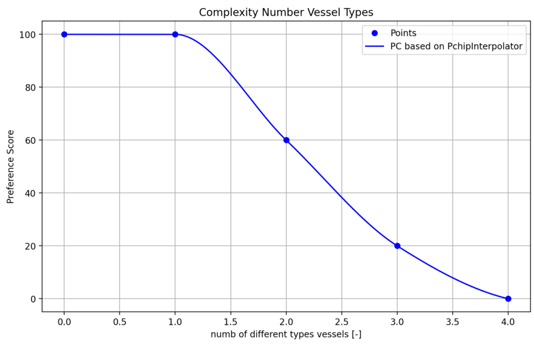

**(b)** Preference Curve OPEX as sub-objectives from 'Affordability' (design for -ty objective)



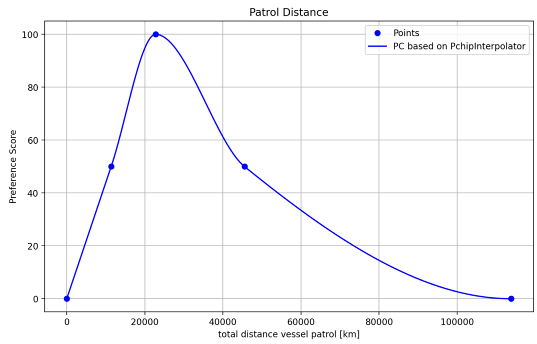

**(c)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)



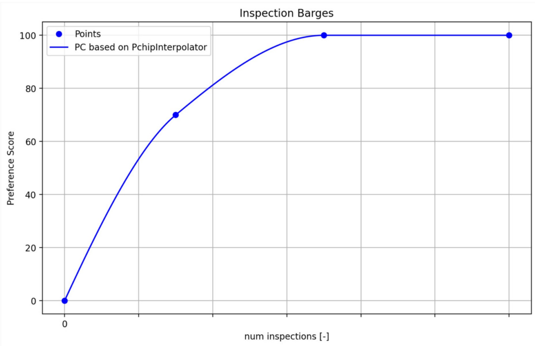

**(d)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)



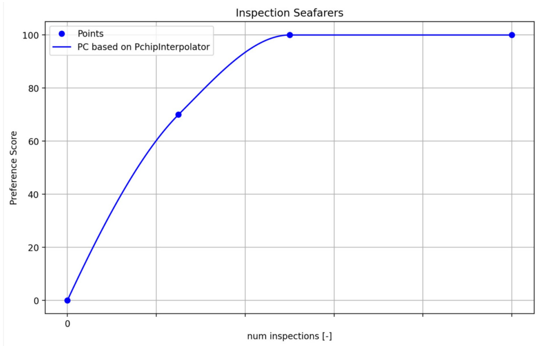

**(e)** Preference Curve Complexity Number of Vessel Types as objective from 'Maintainability' (design for -ty objective)




**(f)** Preference Curve Patrol Distance as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)




**(g)** Preference Curve Inspection Barges as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)




**(h)** Preference Curve Inspection Barges as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)

**Figure 3.2:** Preference Curves for Affordability, Sustainability, Maintainability and Blue Tasks Safety & Security. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axis.

# 4 Model Building

The Port of Rotterdam expressed a need and interest in becoming familiar with more scientifically based decision-making methods to help them achieve their ambitious goal. Therefore, this master's thesis aims to develop a decision-support tool. By doing this they tool should facilitate the finding of the best 'fit for purpose' renewed fleet composition.

This chapter describes the construction of the decision-support tool. These include the needs and requirements set out in section 4.1, the conceptual model framework outlined in Chapter 4.2, and the process flow of the usage of Preferendus Based Idealized Design in chapter 4.3, which is used for applying the decision-support tool. Moreover, the reader is directed to Chapters 4.5 and 4.6 for detailed explanations of the tool's code architecture and the enhancements made to the Preferendus algorithm, respectively.

## 4.1. Needs & Requirements

The fleet renewal challenge is regarded as a complex socio-technological system. The challenge roots in the complex interplay of various factors, including: stakeholder preferences, technical requirements, and desired objectives. The decision-support tool should interconnect all of these factors and, consequently, map their relations. The Table 4.1 below provides the overview of the needs and the corresponding requirements. An verification/evalulation of the requirements can be found in appendix G.

**Table 4.1:** Needs and Requirements for the Fleet Renewal decision-support tool

| **Need** | **Requirement** |
|---|---|
| **Transparent** | • An interface that is understandable and provides feedback on the taken actions.<br>• Preference curves (Preferendus Methodology) to make stakeholder wishes and desires (= preference) transparent.<br>• The usage of weight factors to prioritise design objectives. |
| **Interactive** | • An interface that is as friendly as possible in the interaction with the users. |

*Continued on next page*

**Table 4.1 — Continued**

| Need | Requirement |
|---|---|
| **Integration of social and technical aspects** | • Preference curves (Preferendus Methodology). To properly integrate design objectives with different metrics (e.g., money in comparison with fossil fuel emissions) and to properly integrate the preferences of the different stakeholders.<br>• Proper preference calculations (Preferendus Methodology). Based on the work of Barzilai about PFM. |
| **The tool should be designed for complex systems** | • The tool should be designed with the principles of Object-Oriented Programming (OOP). This socio-technical system of fleet operations is a systems of systems problem. Working with objects is beneficial to make the code understandable, maintainable, and extendable. It is also easier for the model-interface integration.<br>• To make the Preferendus Genetic Algorithm (GA) workable with OOP, the PFM-calculations need to be locally automated and integrated into the GA. |
| **How the solution should be found (social-need)** | • Collaborating with internal and external stakeholders to create economic societal value.<br>• Be adaptable to respond effectively to geopolitical tensions and rapid technological advances<br>• Apply systems-of-systems thinking to investigate the solution space and address the systems-of-systems complexity of fleet operations. |
| **What the solution should include (technical-need)** | • Synergies to improve the safety and security of the harbour region, despite the key-issues, by enhancing collaboration among the various internal and external stakeholders.<br>• The company-wide vision to create and implement a new fleet that creates value for all stakeholders.<br>• Sustainable practices to create the most sustainable port and fleet.<br>• Modern equipment and workflows to be a leading port with the latest technologies, equipment and workflows to ensure modernisation.<br>• Technical resources as enabler for service delivery.<br>• Human resources as enabler for service delivery.<br>• Current tasks as design requirements and baseline.<br>• Future tasks, making sure ”Tomorrow’s Fit for Purpose Sustainable Fleet”.<br>• Service-level-expectations of the stakeholders as an influential determinant of defining task performance.<br>• Preference of all Stakeholders to create a widely supported solution. |

## 4.2. Conceptual Model Framework

The schematic overview of Figure 4.1 represents a conceptual model framework for the fleet renewal decision-support tool. It includes the following aspects: stakeholders' preferences, service level expectations, design for -ty objectives[1], defined tasks, the available resources, and the key-issues. The 'system' has been differentiated between Present Mode and Future Mode. The Present Mode is the current situation, and the Future Mode is the future situation where the fleet composition is feasible and aligned with the desired service levels and is aligned with social-technological feasibility. This is referred to as a solution that 'fits for common purpose' that reflects the 'synthesis' of what is 'desirable' with what is 'capable'.

See Appendix E for the detailed description of the object-oriented programming modules.

[1]'Design for -ty Objectives' are the different design perspectives of the stakeholders, e.g., Affordability. More about this in section 3.3)

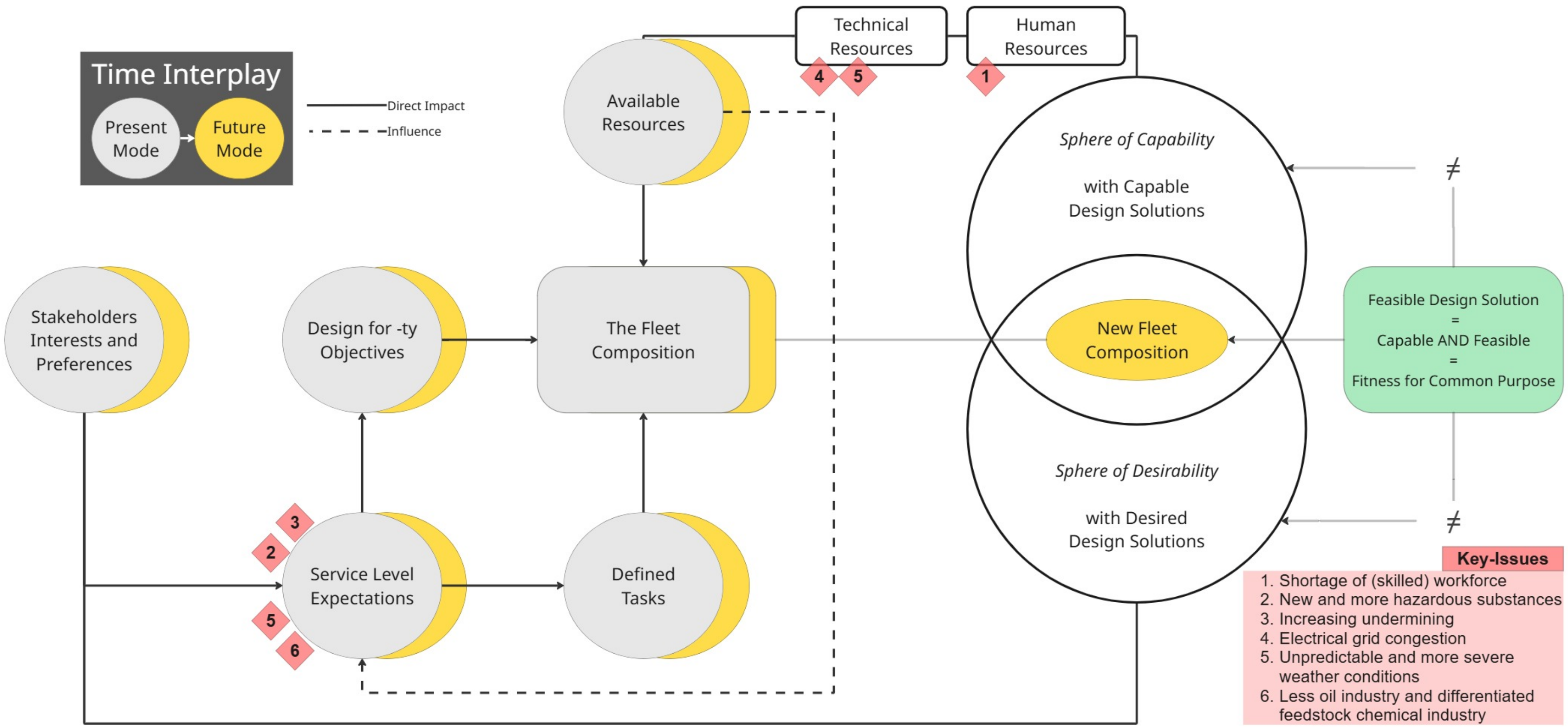



**Figure 4.1:** Conceptual model framework for fleet renewal decision-support tool. It includes the following aspects: stakeholders' preferences, service level expectations, design for -ty objectives. The 'system' has been differentiated between Present Mode and Future Mode. The Present Mode is the current situation, and the Future Mode is the future situation where the fleet composition is feasible and aligned with the desired service levels and is aligned with social-technological feasibility. This is referred to as a solution that 'fits for common purpose' that reflects the 'synthesis' of what is 'desirable' with what is 'capable'. *(own illustration)*

## 4.3. Process Flow Preferendus Based Idealized Design

The decision-support tool is used by following an integrated process flow of the Idealized Design methodology and the Preferendus Methodology, as outlined below and visualized in Figure 4.2. The Idealized Design is used as the basis. See section 2.2 for the description of the Idealized Design and section 2.1 for the Preferendus Methodology. Note, an important part of the process is the system analysis and the continuous reflection after each step.

In instances where the step in the process flow is based on Idealised Design, this is indicated with ”(ID)”. Similarly, if the step is based on the Preferendus Methodology, this is indicated with ”(PM)”.

**Idealization (ID)**

1. **Formulating the Mess (ID) | Design the Design Problem (PM)**

   - ***Prepare a system analysis*** *(ID)* - is the input of 'Ends Planning'
   - ***Prepare an obstruction analysis*** *(ID)* - is the input for the 'Means Planing'.
   - ***Prepare reference projections*** *(ID)* - is the input of the 'Means Planning' and 'Ends Planning'.
   - ***Prepare a presentation of the mess*** *(ID)* - is the input of the 'Ends Planning'.

   These findings are used to create the computer model.

---

2. **Ends Planning (ID)**
   Based on the analysis of 'Formulating the Mess', the 'ideal' design is configured by the use of the Preferendus Methodology. For this, it is required to the following steps:

   - ***Define Preferences*** *(PM).*
   - ***Specifying Weights for each (Idealized) objective*** (PM).
   - ***Run optimization to determine the ideal design*** (PM).

   Check if the result is satisfying. If that is the case, proceed to the 'Realization' stage. If not, repeat the previous steps from 'Formulating the mess'.

---

**Realization (ID)**

3. **Means Planning (ID)**
   Based on the analysis of 'Formulating the Mess' and especially the 'obstruction analysis', the 'means planning' is conducted. The risks and obstructions are formulated as key-issue objectives and modelled. Thereafter, the following steps are followed:

   - ***Define Preferences*** *(PM).*

   - ***Specifying Weights for each (Realization) objective*** *(PM)*. The weights of the Idealized objectives and the Realization objectives remain the same.

   - ***Run optimization to determine the design based on the Idealization and Realization*** *(PM)*.

   Check if the result is satisfying. If that is the case, proceed to the next stages of 'Resource Planning', 'Design of Implementation', and 'Design of Controls'. If not, the ideal-design is not reachable. Repeat the previous steps from 'Formulating the mess' until the gap between the 'Ideal Design' and the 'Real Design' is considered as satisfied.

---

4. *Resource Planning - out of scope.*
5. *Design of Implementation - out of scope*

6. *Design of Controls - out of scope*

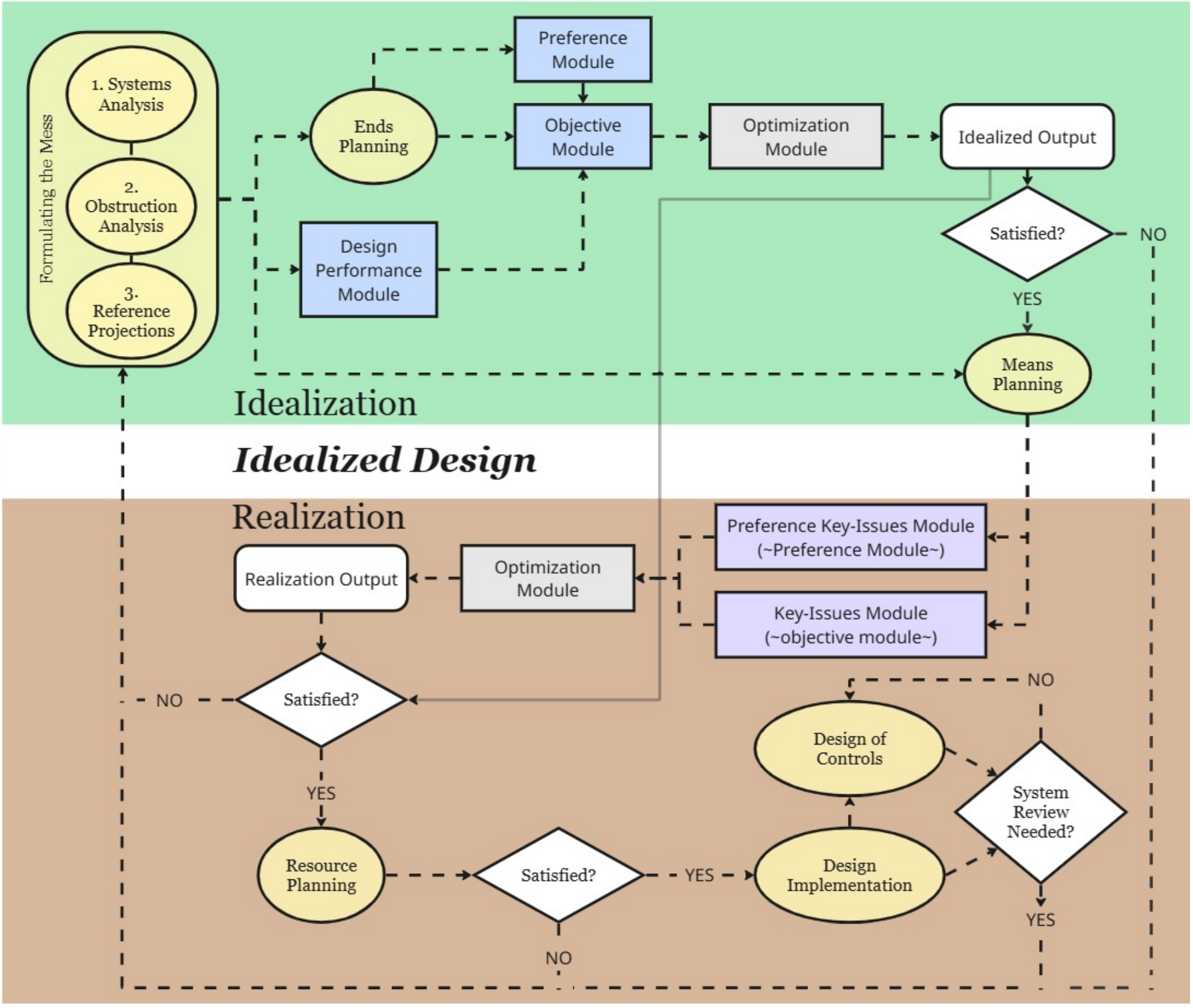



**Figure 4.2:** Process Flow A-priori Preference Based Idealized Design. *(own illustration)*

## 4.4. Data Flow

The fleet renewal challenge is regarded as a complex socio-technological systems challenge, as previously outlined. Therefore, the Preferendus Algorithm, from H. J. van Heukelum et al. (2024), is made compatible with an 'Object-Oriented System of System' extension (see the modules explained in section E). This extension is created to integrate and facilitate the system's calculations (vessel type 1 + vessel type 2 + car type 1 = Fleet Composition 1 → System Performance). The figure 4.3 shows the position of these modules within the Preferendus workflow.

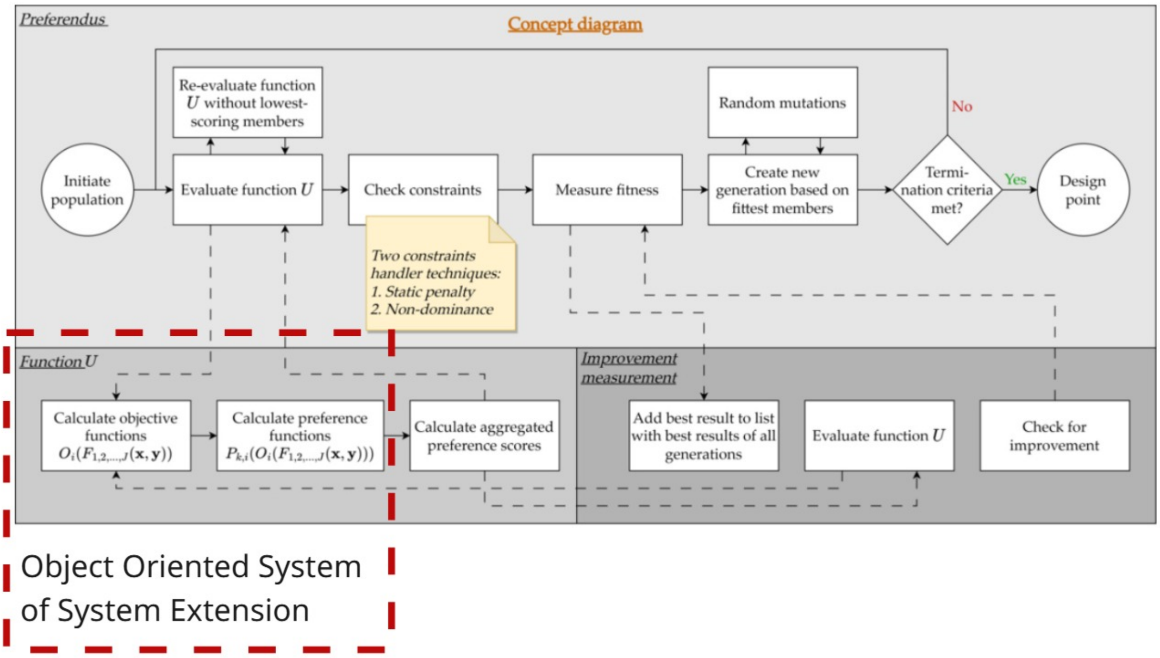



**Figure 4.3:** The workflow of the Preferendus, presented as a concept diagram (Wolfert, 2023). Additionally, the position of the extensions created by this master's thesis is presented.

The Figure 4.4 provides a graphical visualization of the data flow of the 'Object Oriented System of System' extension and the 'Idealized Design Preferendus' module.

First, the 'design variables' are randomly generated for each alternative and stored in a design-variables-matrix. Each row in the matrix is considered as a design alternative (fleet), where each design variable represents the quantity of that corresponding vessel/car type. Based on this information, the 'VehicleMix' is created and represents the fleet consisting of a certain amount of different vessels and cars (this can be extended in further research, for example, with drones).

The 'VehicleMix' is equipped with standard design performance functions based on its fleet-characteristics. Together with the other design performance functions (PortGeographics, HumanResources), the metric of an objective function can be calculated (the objective value). Based on the preference function and the objective value, the preference score can be determined. This score is stored in a preference matrix, where each row represents the corresponding alternative of the previously mentioned design-variables-matrix. This is done for each objective for both the Idealization- and the Realization objectives.

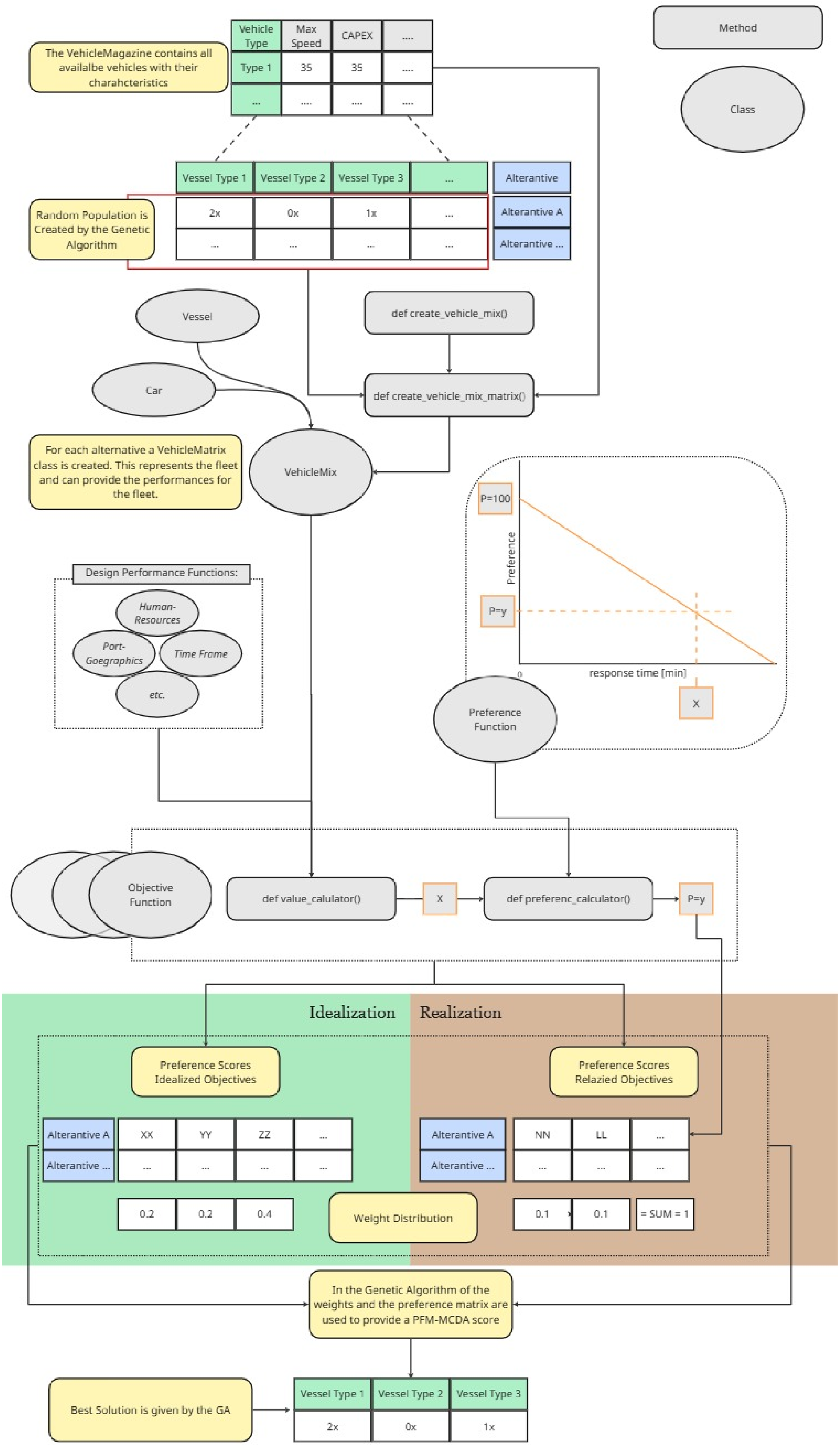



**Figure 4.4:** Graphical Representation of the Data Flow with Optimization *(own illustration)*

## 4.5. Code Architecture Decision-Making-Tool

As previously outlined, the fleet renewal challenge is regarded as a complex socio-technological systems challenge. It is therefore essential to ensure that the tool can be easily expanded as the project progresses and additional system layers are incorporated. Furthermore, it is beneficial if the tool is designed in such a manner that it can be utilised to analyse other matters within the scope of the fleet renewal programme or other relevant questions in relation to fleet operations. Therefore, the tool should comply with the need of "utility[2]". In order to guarantee this, the tool must be both maintainable and expandable, while also being clearly readable from a computer coding perspective. Another benefit is that the tool can be used by other projects interested in using the Preferendus Methodology.

**Objected-Oriented Programming Principles**

Object-Oriented Programming (OOP) has been demonstrated to be effective in meeting these criteria for utility. According to Saide (2024, p. 1), OOP *"leverages principles such as encapsulation, inheritance, and polymorphism to enhance flexibility, scalability, and modularity in software systems"*.

The term 'encapsulation' is used to describe the functionality that prevents data within the objects from being modified or read by unintended purposes. This is beneficial, as this prevents errors (Amos & Python, n.d.; GeeksforGeeks, 2025; Stemmler, 2022).

The 'inheritance' functionality establishes a connection between all individual 'vessel' objects and the parent object of the same type (Amos & Python, n.d.; GeeksforGeeks, 2025; Stemmler, 2022). The property of action-radius is common to all these vessels. However, with "inheritance" functionality, this property only needs to be specified for the parent object, i.e. "Vessel", rather than for each ship type separately. The rationale behind this phenomenon is that the various ship types automatically inherit the action-radius functionality. However, it should be noted that the data employed in the calculation of the range is defined at the sub-object level. Inheritance is therefore important for 'code reuse' and 'simplifying maintenance' (Saide, 2024).

'Polymorphism' is a characteristic that enables a single interface to be utilised for a wide range of objects, without the necessity of full knowledge of the working of the other objects, as long as the behaviour of the objects remains the same (Amos & Python, n.d.; GeeksforGeeks, 2025; Stemmler, 2022).

The functionalities of encapsulation, inheritance and polymorphism in conjunction facilitate the concept of 'abstraction'. Abstraction can be defined as the functionality of hiding the inner workings of an object, thereby exposing only the functionality that is considered essential. This facilitates simple communication between objects (Amos & Python, n.d.; GeeksforGeeks, 2025; Stemmler, 2022).

**Coding Language**

The Python programming language is relatively easy to use and capable of handling OOP-coding (Amos & Python, n.d.; GeeksforGeeks, 2025; Stemmler, 2022). Therefore, the tool is created using the Python programming language.

**The Tool that is Created**

The fleet renewal decision-support tool is created based on object-oriented programming principles and contains several modules. Appendix E provides an overview of the code structure of the tool.

## 4.6. Preferendus Algorithm Extension and Improvements

This chapter outlines the extensions and enhancements made to the Preferendus Genetic Algorithm (GA) and the Integrative Minimisation of Aggregated Preferences (IMAP), originally developed by H. J. van Heukelum et al. (2024) and first concepts developed by Zhilyaev et al. (2022). The text addresses the key limitations in elite selection and diversity calculation. It also introduces an object-oriented programming approach and a locally deployed PFM module to enhance functionality and the robustness of the software.

**Extension - PFM-algorithm Deployed Locally as PFM-module**

The Preferendus of H. J. van Heukelum et al. (2024) employs the Multi-Criteria-Decision-Analysis method of Barzilai (Barzilai, 2022) based on his Preference-Functional-Modelling algorithm, utilising

[2] NL: bruikbaarheid

preferences to find the best alternative. For further information about the MCDA, please see ScientificMetrics (2002, 2025) and Wolfert (2023). Van H. J. van Heukelum et al. (2024) made use of the Scientific Metrics server to apply the PFM-algorithm.

Although the server is adequate for relatively simple problems, the connection is lost when the calculations are more substantial, as is the case in this master's thesis. Consequently, a Python class has been developed to facilitate these calculations without the necessity for an external server. This approach offers the additional benefit of understanding the mathematical operations involved by the author. The functionality of the developed class is verified with the use of the ChoiceRobot (ScientificMetrics, 2002) and with the test data of H. J. van Heukelum et al. (2024).

The developed PFM-module can be found on GitHub: LINK.

**Improving the functionality and robustness by object-oriented programming principles**

The Preferendus of van H. J. van Heukelum et al. (2024) is modified to a more object-oriented programming style by separating the code into methods and functions. A significant advantage of this approach is that it enables the development of unit tests, thereby ensuring the correct functionality of the code.

**Preferendus Algorithm Improvements - Issues Resolved**

During the analysis of the code of the Preferendus of H. J. van Heukelum et al. (2024), certain issues were identified and subsequently resolved. For a comprehensive overview, please refer to appendix D.

*Selecting Elites for Next Population Genetic Algorithm (GA)*

The initial algorithm of H. J. van Heukelum et al. (2024) had two issues with selecting the elites (see code listing D.1):

1. **Incorrect elite selection**: The algorithm identifies the highest scores as elites. This is incorrect for a minimization algorithm where the goal is to find the lowest scores.

2. **Alternative loss with identical scores**: The algorithm only saves the first population member that matches a unique score, and does not save the other members with the same score. This can lead to the loss of potentially valuable alternatives because two different alternatives can have the same score. For instance, alternative A with x1=2 and x2=5 can have the same score as alternative B with x1=10 and x2=1.

An improved elites method addresses these issues by (see code listing D.2):

- **Correct elite selection**: Selecting the elites based on the lowest scores, which is in line with the minimization algorithm.

- **Preserving all alternatives**: Saving all different alternatives that have the same score by checking if the selected population member has already been saved, ensuring no valuable alternatives are lost.

- **Only unique populations:** The code makes sure that all elites are unique populations.

*Diversity Calculation for Populations in Genetic Algorithm (GA)*

The initial algorithm of H. J. van Heukelum et al. (2024) for calculating the diversity had two issues (see code listing D.3):

1. **Diversity confusion**: H. J. van Heukelum et al. (2024) calculates the diversity over the full matrix. For example, with apples and chairs ([apple, chair]), the diversity of [[1, 2], [2, 3]] is calculated as 3. These indices (design-variables) do not represent the same 'object'. In other words, 2 chairs and 2 apples can not be compared with each other, and therefore, the diversity should be 4. For example, ([apple, chairs]) [[1, 2], [3, 4]] has the same diversity as [[2, 2], [3, 3]]. Therefore, the diversity of the full matrix has no meaning.

2. **Intuitive scale**: A higher diversity-number means lower diversity, which is counterintuitive.

An improved diversity calculation method addresses these issues by (see code listing D.4):

- **Comprehensive population diversity**: Calculating diversity for the entire population to provide an overall measure of variance of numbers within the dataset.
- **Variable-specific analysis**: Calculating diversity for each variable separately to offer a more nuanced understanding of the data.
- **Intuitive scaling**: Employing a more intuitive scaling system where a higher number indicates higher diversity, making interpretation and analysis more straightforward.
- **Detailed uniqueness quantification**: Calculating the number of unique values per variable separately to provide an additional parameter next to diversity.

# 5
# Analysis & Solution Selection

This chapter is a demonstration of the decision support tool that has been specially created for the Port of Rotterdam Fleet Renewal Challenge. This is achieved by employing a process that integrates the Preferendus- and Idealized Design Methodologies (see section 4.3). To demonstrate the functionality of the tool, an analysis and solution selection process based on a study from the Port of Rotterdam. They have a study conducted that compares the different fleet compositions. This study is utilised to illustrate the functionality of the tool and to compare the optimisation outcomes.

The study, which was conducted by the Port of Rotterdam, made a comparison between the different fleet compositions. Six alternatives have been developed, each of which makes a clear distinction between the 'red-' and 'blue-' tasks (see Figure B.1). Red-tasks can be seen as the fire-fighting department, and the blue-tasks can be seen as the law enforcement department. Therefore, the tool is tested with these alternatives, and the results are represented as red tasks, blue tasks, and combined tasks (both red- and blue-tasks). The purpose of the combined tasks is to demonstrate the synergies that the model can provide.

The scope of this section is limited to the consideration of the combined tasks when applying the Preferendus Methodology in conjunction with the Idealised Design Methodology, which are integrated into one process (see Section 4.3). Please refer to the Appendix L for all the figures and tables of the results for blue, red, and combined tasks.

In instances where the step in the process flow is based on Idealised Design, this is indicated with "(ID)". Similarly, if the step is based on the Preferendus Methodology, this is indicated with "(PM)".

---

Note, this master's thesis has the objective of developing a decision-support tool and not for the pursuit of a solution to the fleet renewal challenge. Therefore, the modelled system should be considered as a simplified abstraction of reality. Consequently, one should be cautious when using the outcomes of the analysis.

## Idealization (ID)

### 1. Formulating the Mess (ID) | Design the Design Problem (PM)

- ***Prepare a system analysis*** – is formulated in Section 3.1 and includes the tasks, resources and stakeholders. This is the input of the 'Ends Planning' and Design Performance Module.

- ***Prepare an obstruction analysis*** – is formulated in Section 3.1 and includes the societal key-issues. This is the input for the 'Means Planning'.

- ***Prepare reference projections*** – is formulated in Figure C.1 and describes the future scenarios regarding the interplay between tasks, resources, and societal key-issues. The figure provides an insightful analysis of the problem of staff shortages due to ageing and the need to sail fossil-free to combat climate change.

- ***Prepare a presentation of the mess*** - is not specifically formulated in this master thesis, as it involves a presentation of all the findings. However, you can see the previous sub-steps as the presentation of the mess.

These findings are used to create the computer model. See chapter 3.3 for the (mathematical) formulations.

## 2. Ends Planning (ID)

Based on the analysis of 'Formulating the Mess', the 'ideal' design is configured by the use of the Preferendus Methodology. For this, it is required to the following steps:

- ***Define Preferences*** *(PM)* – See the preference curves in Section 3.6.

- ***Specifying Weights for each (Idealized) objective*** *(PM)* – See Table 5.1 below.

**Table 5.1:** Weight Distribution Idealization Optimization Combined Tasks

| Objective | Weight | Sub-Objective | Sub-Weight | Optimization-Weight |
|---|---|---|---|---|
| Affordability | 18.421 | OPEX | 50.00 | 0.092 |
| | | CAPEX | 50.00 | 0.092 |
| Sustainability | 18.421 | Carbon Footprint Investment (construction) | 50.00 | 0.092 |
| | | Carbon Footprint Operations | 50.00 | 0.092 |
| Maintainability | 5.263 | Minimize Complexity Number Vessel Types | 100.00 | 0.053 |
| Red Tasks Safety & Security | 28.947 | Maximizing Availability Capacity Coverage Incident Response | 33.33 | 0.097 |
| | | Maximizing Availability Long Term Deployment in Incident Response | 33.33 | 0.097 |
| | | Minimizing Critical Initial Response Time | 33.33 | 0.097 |
| Blue Tasks Safety & Security | 28.947 | Maximizing Number of Barge Inspections | 33.33 | 0.097 |
| | | Maximizing Number of Inspections Seafarers | 33.33 | 0.097 |
| | | Maximizing Patrol Distance | 33.33 | 0.097 |

- ***Run optimization to determine the ideal design*** *(PM)* – See Table 5.2.

**Table 5.2:** An overview table of the **aggregated** performance of the different fleet compositions when both blue and red tasks are considered. Keep in mind that PFM scores are compared to other scores. If X scores close to Y, it is because Z scores very differently. For more information about Preference-Functional-Modelling see Barzilai (2022)

| Alternative | A1 | A2 | B1 | B2 | B3 | B4 | Baseline | Optimization |
|---|---|---|---|---|---|---|---|---|
| **PFM score** | 29.34 | 46.19 | 14.83 | 15.18 | 30.03 | 0.0 | 28.60 | 100.0 |

- ***Check if the result is satisfying***. – This result of 3 'IBV-AWS' vessels for the combined tasks is considered as the 'ideal' design (See table L.1). This corresponds to the optimisation result. Alternative A1 and A2 have also 3 'IBV-AWS' vessels, but include additional vessels for law-enforcement purposes. However, the optimization provides only 3 vessels that are used for both the incident response and law-enforcement services.

# Realization (ID)

## 3. Means Planning (ID)

Based on the analysis of 'formulating the mess' and especially based on the 'obstruction' analysis, the 'means planning' is conducted. The risks and obstructions are formulated as key-issue objectives and modelled. See the mathematical formulation chapter 3.3. For demonstration purposes, only the key-issue of Net Congestion is used.

The following steps are followed:

- ***Define Preferences*** *(PM)* – See below the preference curve of Net Congestion in section L.14. The preference scores for the fleet composition alternatives are also presented.

- ***Specifying Weights for each (Idealized) objective*** *(PM)* – The Net-Congestion objective is added, and therefore the weight distribution for optimization is also changed. See Table 5.3 below. Note, the weight of the Net-Congestion is very low compared to the other objectives.

**Table 5.3:** Weight Distribution Realization Optimization Combined Tasks

| Objective | Sub-Objective | Optimization-Weight |
|---|---|---|
| Affordability | OPEX | 0.0875 |
| | CAPEX | 0.0875 |
| Sustainability | Carbon Footprint Investment (construction) | 0.0875 |
| | Carbon Footprint Operations | 0.0875 |
| Maintainability | Minimize Complexity Number Vessel Types | 0.05 |
| Red Tasks Safety & Security | Maximizing Availability Capacity Coverage Incident Response | 0.0917 |
| | Maximizing Availability Long Term Deployment in Incident Response | 0.0917 |
| | Minimizing Critical Initial Response Time | 0.0917 |
| Blue Tasks Safety & Security | Maximizing Number of Barge Inspections | 0.0917 |
| | Maximizing Number of Inspections Seafarers | 0.0917 |
| | Maximizing Patrol Distance | 0.0917 |
| Societal Key Issues | Net Congestion | 0.05 |

- ***Run optimization to determine the design based on the Idealization and Realization*** *(PM)*

**Table 5.4:** An overview table of the **aggregated** performance of the different fleet compositions when both blue and red tasks are considered in the Realization (including Net Congestion). Keep in mind that PFM scores are compared to other scores. If X scores close to Y, it is because Z scores very differently. For more information about Preference-Functional-Modelling see Barzilai (2022)

| Alternative | A1 | A2 | B1 | B2 | B3 | B4 | Baseline | Optimization Idealization | Optimization Realization |
|---|---|---|---|---|---|---|---|---|---|
| ***PFM score Idealization*** | *29.34* | *46.19* | *14.83* | *15.18* | *30.03* | *0.0* | *28.60* | *100.0* | - |
| **PFM score Realization** | 31.47 | 45.04 | 16.99 | 16.36 | 30.80 | 0.0 | 38.47 | 89.89 | 100.00 |

- ***Check if the result is satisfying - solution selection***.

  ***Purchase vessels that are not solely dependent on electricity***
  The result of the realisation, including the objective 'net congestion', is three fossil-fuel-powered IBV-vessels that are currently in use. It is important to note that, despite its relatively low weight, the objective net congestion is nevertheless influential. The solution that is provided by realisation

is independent of electricity. By contrast, the ideal design is composed of three fully electrical vessels. Although it seems that the PFM-score of 'ideal design' is relatively close to the 'realisation design', this is misleading. When interpreting PFM scores, it is important to consider that these scores are relative to each other. In other words, if the score of alternative X is found to be closely aligned with that of Y, is this because Z scores very differently. In conclusion, the findings of the analysis indicate that it would be advisable to procure new vessels that are not dependent on electricity. If the development of electric ships is still considered, it is essential to ensure the reliability of the supply side.

***Identify synergies between the blue- and red- departments***

The optimisation process resulted in three vessels, contrasting with the predefined alternatives, which involved a greater number of vessels, see Table L.1. This is likely a consequence of the mathematical model's omission of the maintenance period, during which vessels are planned or unplanned out of service. Moreover, it should be noted that this model does not encompass all tasks. Nevertheless, the recommendation is to identify synergies between the blue- and red-departments. The optimisation of fleet operations, in tandem with the identification of opportunities, is expected to facilitate the adaptation-capabilities to the projected future. For instance, the optimisation of work processes has the potential to achieve the same level of output with a reduced number of personnel. This approach may assist in addressing the current shortage of skilled workers. To conclude, it should be noted that the identification of synergies can be facilitated by utilising the decision-support tool that has been specifically developed for the fleet renewal challenge in this master's thesis, and which has been employed in this analysis.

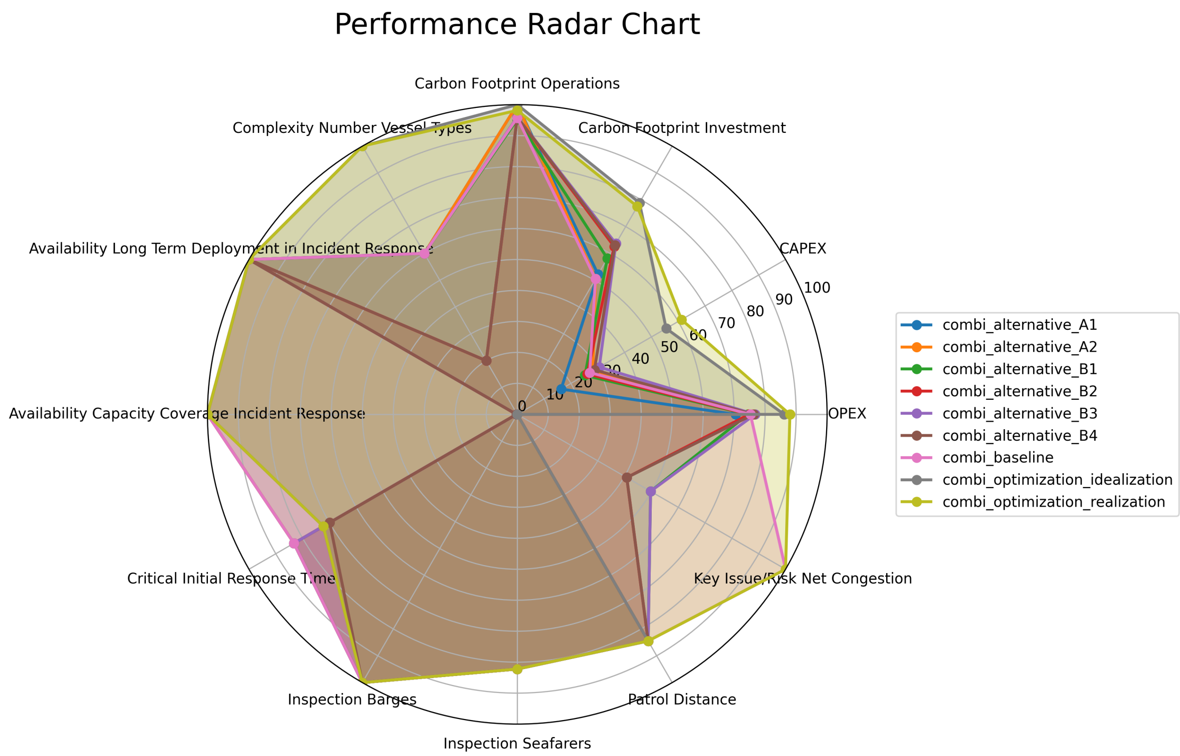



**Figure 5.1:** An overview of the performance of the different fleet compositions when only the red tasks are considered for the realization (with net congestion) after the idealization. The performance is indicated by PFM-scores. Keep in mind that PFM scores are compared to other scores. If X scores close to Y, it is because Z scores very differently. For more information about Preference-Functional-Modelling see Barzilai (2022)

# 6 Discussion

The following structure is employed in this chapter. Firstly, an evaluation of the decision-support tool is conducted, and recommendations are subsequently provided. Secondly, the chapter explores how the Preferendus Methodology can be used to improve the system. In the final section, the reflections of the Port of Rotterdam with regard to the methodology of the Preferendus are outlined.

## 6.1. Decision-Support Tool Reflections & Recommendations

This section outlines the evaluation of the Preference-Based Idealized Design decision-support tool and methodology, and the process of this master's thesis.

### Integration of the Preferendus Methodology with Idealized Design

The integration of the Preferendus Methodology and the Idealized Design methodology is successful. However, the verification and validation can be seen as a conceptual and therefore more research is needed. Additionally, this thesis considers human resources as constants, while Idealized Design is even more interesting when this is considered as variables. It is recommended to conduct a case study with an organization that incorporates both technical aspects and human resources.

Although this thesis already shows the implementation of Idealized Design, it is considered important to investigate whether an objective should be considered as ideal or real as it is used in different stages of the process. For instance, the objective 'costs' is categorised as idealised because it is a design characteristic. The motivation may be a preference for the ideal design to have limited operational costs. In contrast, temporary budget constraints can be categorised as a realisation objective. A clearer example is electrical net-congestion. This key issue/risk is real but uncertain and temporary. It has a significant impact on the realization of the design and can determine a design that is not in the direction of the ideal design, or can even exclude the realization of the ideal design.

### Preferendus Algorithm applied to Systems of Systems Problems

The results show that the tool is capable of connecting vessel and fleet characteristics with overall system performance. This is done by the systems of systems perspective, where the fleet is created by its 'unique' vessels and vehicles. The different vessels' characteristics together determine the fleet-performance and therefore the system's performance of the fleet.

This master's thesis was only able to incorporate vessels and cars. Conceptually, this is considered adequate. However, it would be interesting to incorporate more Fleet sub-systems, for example, the integration of the human resources, drones, etc.

Additionally, the tool only connects the system-level of vehicles/vessels with the fleet based on the user input of the vessel characteristics. It is possible, in principle, to extend this with additional design variables from the vessels. For instance, the battery size, the dimensions of the hull, the pump's capacity, etc. In this case, three system-levels are coupled: subsystem-vessel, vessel-system, and fleet-system.

### Best Fit for Common Purpose Fleet Configuration by aligning Desirability with Capability

The Preferendus Methodology has previously been demonstrated to be capable of identifying the 'best fit for purpose' solution in other contexts (Aulbers, 2023; Mol & Schriever, 2024; Pallandt, 2025; Raaphorst, 2024; Teuber & Wolfert, 2024; van Eijck & Nannes, 2022; H. J. van Heukelum, 2022; H. J. van Heukelum et al., 2023). This is also the case for this master's thesis, as it can be considered as an additional case study that serves to demonstrate the usefulness of the Preferendus Methodology. The additional value of this master's thesis is the application to an operational asset management organization like the Port of Rotterdam. The results (section 5) demonstrate the capability of the tool to find the 'best fit for common purpose' solution. The solution generated by optimisation may be more aligned with 'desirability' and is also 'capable', compared to the predefined alternatives. This is achieved by first defining the ideal design through idealisation, resulting in 3 fully electric vehicles. The design is then determined based on realisation, resulting in 3 fully-diesel vehicles.

However, the concept of a 'common purpose' is not fully explored in this thesis. Although the Preferendus Methodology has already proven itself conceptually in this area, the environment of fleet operations at the Port of Rotterdam is of particular interest for conducting further research on this topic with a case study. Unfortunately, this was not examined in its full potential due to the lack of time and the primary focus on the creation of a decision-support tool. In order to further explore the concept of 'common purpose', it is recommended that the developed tool and methodology would be applied with more internal and external stakeholders in relation to the Port of Rotterdam.

### Adaptable and Flexible Tool

In the early developmental stages of the tool, implementing object-oriented programming (OOP) principles required a significant effort. However, as the project progresses, it has shown evidence of flexibility and scalability, primarily due to the fact that the objects are only required to be created once. Due to the concept of inheritance, new objects are easily created.

The integration of the tool with an interface facilitates the deployment of applications based on the Preferendus Methodology by other practitioners. It would be interesting to create an open-source library that can be shared with everyone who is interested.

Although the author has developed its coding skills professionally, through side-projects and self-study, it is important to note that the author of the thesis has not studied computer science. Especially, the author had never previously created an application, including both the tool and the interface. Due to the author's lack of prior professional experience, it is reasonable to assume that a significant number of enhancements can be made regarding the tool. Specifically, the interface is operating at a rather slow speed. Perhaps a more appropriate solution could be found in an alternative library to StreamLit.

### Improvement of the Mathematical Model

The mathematical model can be further enhanced by making several expansions and adjustments.

Firstly, it is possible to expand the objective of carbon footprint in operations and construction by incorporating additional sustainable parameters. For instance, additional objectives in line with the Nations' Sustainability Goals, including environmental impact and the total life cycle of the vessels.

Secondly, the model has the capacity to establish links between different tasks and the personnel with the necessary skills. This approach facilitates the identification of opportunities and synergies to enhance the effective utilisation of personnel.

Thirdly, the objective of Maintainability-Complexity can be given a more detailed definition in order to take into account the number of modules and different suppliers, in addition to vessel types. This expansion ensures a more precise representation of maintenance requirements and workload.

Fourthly, the model differentiates between Barge Inspections and Seafarers Inspections, with the former conducted exclusively by ships and the latter exclusively by cars. It is recommended that the model be adapted to ensure that both inspections are feasible, regardless of the chosen mode of transport. This approach also facilitates the optimisation of the system and the identification of synergies between the currently distinct departments.

Finally, the model may be expanded to incorporate a broader range of security metrics in addition to the number of inspections that are operationally feasible.

## 6.2. Improving the System Using the Preferendus Methodology

This section presents a further reflection on the application of the Preferendus Methodology for the enhancement of system performance. For a detailed explanation, see appendix I.

### Evaluating Alternatives Within the Indicated Preference Curves

The Preferendus Method utilises an algorithm to evaluate the various design alternatives based on Preference Functional Modelling (PFM) (Barzilai, 2022). PFM is an evaluation technique in which the score of one alternative is relative to the other alternatives. For instance, if X scores close to Y, it is because Z scores very differently. Further information regarding Preference-Functional-Modelling can be found in Barzilai (2022).

The PFM evaluation is conducted by the Preferendus Methodology, on the basis of the preference scores for all the different objectives. For the purpose of illustration, consider the preference curve of the objective initial response time, as demonstrated in Figure 6.1.

When the X-value (initial response time) falls outside the defined range, H. J. van Heukelum et al. (2024) caps the scores to the extremes of the preference score at $x_{min}$ or $x_{max}$. This application can be characterized as *'inside the preference box'*:

If the preference values are outside the limits of 0 or 100, the preference scores are set to the lower (0) or upper limit (100). This can be called as 'capping'.

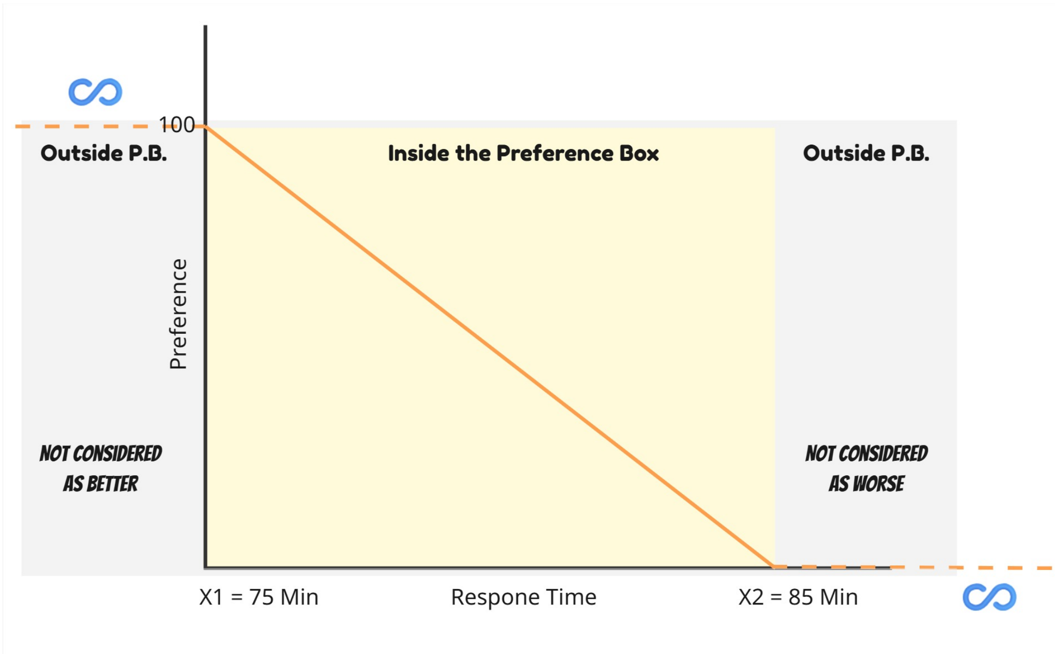



**Figure 6.1:** Inside the Preference Box Demonstration Figure *(made with Miro (Miro, 2025))*

This approach is not considered beneficial when the objective is to enhance the system. The algorithm is unable to identify an enhanced system design when it is unable to determine whether an alternative score exceeds 100 or falls below 0, due to the restriction of scores at the upper and lower limits. For instance, 120 is set to 100, and -150 is set to 0. This process is known as 'capping', with 120 representing the maximum limit of 100.

### Difference between 'Capping' and Constraints

To clarify, it is important to note that setting an alternative from, for instance, 120 to 100 (named as 'capping') is not the same as setting a constraint. When constraints are employed, design alternatives with a lower preference rating $x_{min}$ or higher than $x_{max}$ will not be evaluated. However, when 'capping' is used, these alternatives will be evaluated, but the preference rating will be indicated as '0' or '100', and the model is unaware that an alternative is less preferred by the stakeholders.

**Options to deal with Inside-Outside the Preference Box:**

- **No capping, no constraints**: *(highly preferred option)*
  All alternatives are evaluated. If needed by extrapolation. Alternatives and preferences are evaluated Inside- and Outside the Preference-Box.

- **In the case of capping**:
  All alternatives are evaluated by extrapolation. Alternatives are evaluated Inside- and Outside the Preference-Box and preferences are capped to the edges of the preference-box. This means that the model evaluates alternatives outside the preference box but is unable to determine whether an alternative is worse or better than the alternatives defined within the preference box.

$$\text{Design alternatives } i \text{ with } x_i < x_{\text{min}} \rightarrow \text{evaluated but given } P = P(x_{\text{min}})$$
$$\text{Design alternatives } i \text{ with } x_i > x_{\text{max}} \rightarrow \text{evaluated but given } P = P(x_{\text{max}})$$

- **In the case of constraints**:
  All the alternatives outside the preference-box are not evaluated. Only alternatives inside the preference are evaluated by the model.

$$\text{Design alternatives } i \text{ with } x_i < x_{\text{min}} \rightarrow \text{not evaluated}$$
$$\text{Design alternatives } i \text{ with } x_i > x_{\text{max}} \rightarrow \text{not evaluated}$$

### Evaluating Alternatives Beyond the Indicated Preference Curves

In order to address the implications of only evaluating alternatives within the preference curves, known as 'inside the preference box', it is considered preferable to extrapolate beyond the defined range of x-values in order to generate the preference value. This method is called *'outside the preference box'*. However, this raises complications because it is not known how the extrapolation should be done. In the case of a straight line, it is straightforward to use that slope for extrapolation, as demonstrated in Figure 6.2. However, when the preference curve has a specific form, it is debatable whether one can use the slopes at the extremes.

### Guidelines for System Improvements

In order to enhance the system as a whole, it is essential to evaluate design alternatives beyond the defined preferences. However, it is important to consider the validity of extrapolation in the context of the preference curves related to the objectives. To address the issue of uncertainty surrounding the validity of the extrapolation, the following guidelines should be followed:

1. Do not restrict extrapolation for the sake of the pursuit to discover design alternatives to improve the system as a whole.

2. Consider the ethical implications of the objectives. If important, consider using constraints.

3. Discover if extrapolation is 'valid' based on the end-slopes of the preference curve. If so, leave it. If not, ask the stakeholder to define its preference to a broader extent.

4. As a facilitator, you may ask whether the preference points outside the preference box should be considered. Beyond the two extremes of the x-points, it could be the case that these preferences can be capped on the extremes. Note that this differs from constraints! Because if you define the design alternatives beyond the extremes of the x-points as invalid (through constraints), these design alternatives are not considered at all. If it is not defined as a constraint but capped at the extremes, the design alternatives beyond the extremes of the x-points are considered, but the model scores it as the extremes of the preferences (p=0 or p=100).

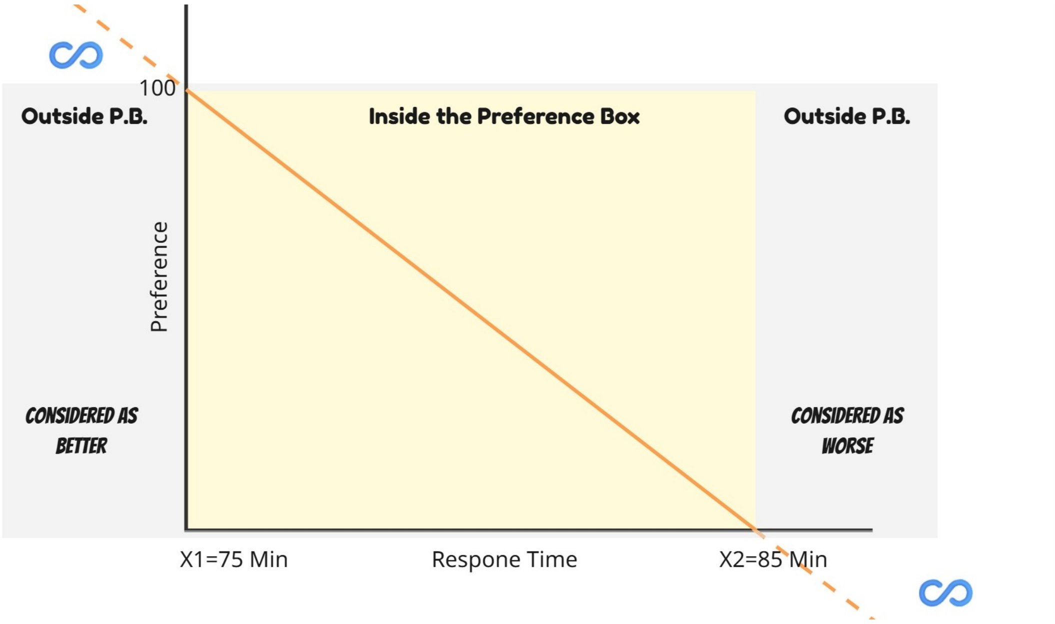



**Figure 6.2:** Extrapolation Outside the Preference Box Demonstration Figure *(made with Miro (Miro, 2025))*

## 6.3. Reflections Port of Rotterdam regarding the Preferendus Methodology

This section provides a reflection on the application of the Preferendus Methodology at the Port of Rotterdam, with a particular emphasis on its strategic value. It also offers recommendations for future collaborative design.

### Preferendus Methodology for Strategic Decision Making

At the start of the master's thesis project, the Port of Rotterdam's main supervisor outlined the objective of the present study, as the development of a tool that will facilitate a comparison of different resource mixes. This model should integrate objective factors (such as cost) as well as subjective, human-driven factors. The daily supervisor further emphasised a pivotal aspect: the necessity for the tool to analyse whether the selection of vehicles guarantees the presence of the crew and vessels at their designated locations and times, equipped with the required equipment.

Both the main supervisor and the daily supervisor have confirmed that these objectives are achieved by the creation of the tool. Additionally, by presenting the product and the methodology to the programme team, they were very enthusiastic and saw the potential in it. In addition, the technical expert and Harbour Authority Advisor mentioned the following:

*"I see that this is very interesting because it gives you a better understanding of the different relationships".*

- Paraphrased Technical Expert -

*"I see possibilities with the Harbour Authority to better grasp what 'safety' is. Now we have metrics that determine how 'safe' the harbour is. With your method, we can discuss this more precisely by integrating these metrics into your model. In this way, these safety-metrics are more coupled to the (fleet-)operations. Moreover, we can then determine and motivate (with this model) a decision like: if we do 20 fewer inspections per month, we have more time to spend on other safety-improving-activities"*

- Paraphrased Harbour Authority Advisor -

In this view, these phenomena are related to the capabilities of the social-technical system of fleet operations and the related performances that it can provide. Incorporating these factors into a modelled 'system' creates the opportunity to make strategic decisions based on a systems-of-systems approach. For further clarification regarding this potential, related to the tool created in this master's thesis, please refer to appendix H.

### Preferendus Methodology to Achieve Success = Quality x Adoption

The main supervisor has observed that the tool makes a significant contribution to two pivotal factors for success: quality and acceptance (success = quality × acceptance).

The quality of a solution is defined as the ability to identify a practical solution that fulfils its intended purpose, in other words: 'fit for common purpose'. This is even more the case when the tool can provide an understanding of the most significant and differentiating factors, or 'leverage points[1]', within the solution space.

The concept of acceptance, or more precisely, 'adoption' as defined by the main supervisor, is facilitated within the Preferendus Methodology. This process involves the generation of insights with stakeholders through the incorporation of their opinions and preferences into the model, thereby enhancing acceptance. This can be considered a form of collaborative design, whereby the model facilitates the design process of the stakeholders.

### Collaborative Design with The Industry to Ensure Fitness for Common Purpose

During the course of a meeting with the project team, the following risk was mentioned: In the event of an overly specific definition of the requirements, the potential exists for a situation in which no contractors/yards will apply for the tender. In such circumstances, it is also not possible to achieve 'fitness for purpose'.

In this particular context, the model developed by the author utilising the Preferendus Methodology has the potential to offer a solution. The game can be 'played' together with the yards/contractors and the PoR as a client by using the Preferred Methodology. During the iterative design process, it is possible to determine the impact on the service level (that the fleet can provide) by modelling the design decisions of the yards/contractors.

One can state that this is the most 'ideal' form of 'fitness-for-common-purpose' where together (yards/contractors and the client) with systems thinking, the preferred solution is defined, given the circumstances and resources that are available with both the PoR and the market. In this way, the solution is both 'capable' and 'desirable'.

### Preferendus Methodology to Investigate the Cost of Complexity

During the master's thesis project at the Port of Rotterdam (PoR), the fleet renewal programme team hired an external consultant to analyse and forecast the 'cost of complexity' of the different fleet composition alternatives. For instance, while fixed battery packages are more advanced in terms of development and usage compared to swappable battery packages, they present several other challenges. The former option results in lower vessel availability compared to the latter due to the recharge time. Furthermore, the implementation of a fixed battery is affected by net-congestion issues. This is due to the need for increased peak energy demands during the process of recharging in a short time frame. Furthermore, the required land-side infrastructure differs significantly between these two battery package options, adding another layer of complexity to the decision-making.

This was a particularly interesting aspect for this master's thesis, as the PoR supervisors noted the significant overlap with the tool developed in this thesis. This addresses the need and the potential of preference-based decision support tools, such as the tool developed in this master's thesis.

[1]Maedows (1999) explains 'Leverage Points' as "places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big change in everything".

# 7 Conclusion

The objective of this thesis was to develop a decision-support tool for the Port of Rotterdam's fleet renewal programme, to facilitate improved decision-making for complex choices. In addition, the tool should consider how the impact of different choices will be made visible, allowing users to explore various fleet combinations regarding the system performance.

This Master's thesis demonstrates the successful development of a 'Preference Based Idealized Design' tool and methodology that integrates the Preferendus and Idealised Design methodologies. The tool and methodology are conceptually tested at the Port of Rotterdam for their Fleet Renewal Challenge. The tool facilitates the finding of a solution that is both 'desirable' and 'capable' by integrating multiple stakeholders' objectives and preferences into the modelled system. Additionally, by incorporating stakeholder preferences, the tool facilitates transparent collaborative decision-making and the integration of both technical and social aspects.

Furthermore, the tool is developed with object-oriented-programming principles that ensure the maintainability and scalability of the tool. This makes it suitable for extensions and applications at other projects.

Additional research can be conducted by applying the Preference-Based Idealised Design tool and methodology to other projects. Ideally, this would be done with a project team that has fully adopted the methodology. It is particularly interesting to apply this tool and methodology to a project involving organisational issues, as the Idealized Design approach is designed for organisational redesign.

# References


Ackoff, R. L. (2003). Systems thinking speech by dr. russell ackoff. Retrieved December 17, 2025, from https://www.youtube.com/watch?v=EbLh7rZ3rhU

Ackoff, R., Magidson, J., & Addison, H. (2007). R.L. Ackoff, J. Magidson, H.J. Addison, Idealized Design – Creating An Organization's Future, Wharton School Publishing, PA, USA (2006), ISBN: 0-13-196363-5. *European Journal of Operational Research*, *183*(1), 479–481. https://doi.org/10.1016/j.ejor.2006.11.005

Amos, D., & Python, R. (n.d.). Object-Oriented Programming (OOP) in Python – Real Python. Retrieved December 25, 2025, from https://realpython.com/python3-object-oriented-programming/

Aulbers, J. (2023). Preference-Based Decision Support for Quay Wall Assessment. Retrieved December 23, 2025, from https://repository.tudelft.nl/record/uuid:953dea20-a3d5-4ffb-9afc-3abed411c617

Baker, C., Rainald62, reptilicus, cjohnson318, 23pointsNorth, Puntaier, R., Aklelka, michael.orchard, Guillaume, P., Sanders, D., & StackOverflow. (2022). Python - Bézier curve fitting with SciPy - Stack Overflow. Retrieved December 30, 2025, from https://stackoverflow.com/questions/12643079/b%C3%A9zier-curve-fitting-with-scipy

Barzilai, J. (2022). *Pure Economics*. The Ingram Book Company. Retrieved December 22, 2025, from https://books.friesenpress.com/store/title/119734000235137024/Jonathan-Barzilai-Pure-Economics

Binnekamp, R. (2010). Preference-Based Design in Architecture. Retrieved November 1, 2025, from https://www.researchgate.net/publication/43796818_Preference-Based_Design_in_Architecture

BNR Webredeactie. (2025). *Haven Rotterdam waarschuwt voor de-industrialisatie: 'Wat we in 50 jaar hebben opgebouwd, verdwijnt in 5 tot 10 jaar'*. Retrieved December 16, 2025, from https://www.bnr.nl/nieuws/economie/10587901/haven-rotterdam-waarschuwt-voor-de-industrialisatie-wat-we-in-50-jaar-hebben-opgebouwd-verdwijnt-in-5-tot-10-jaar

Ferreira, C. S., Larsen, G. C., & Sørensen, J. N. (2025). A theoretical upper limit for offshore wind energy extraction [Publisher: Elsevier]. *Cell Reports Sustainability*, *0*(0). https://doi.org/10.1016/j.crsus.2025.100573

Flyvbjerg, B., & Gardner, D. (2022, September). *How Big Things Get Done: The Surprising Factors that Determine the Fate of Every Project from Home Renovations to Space Exploration, and Everything in Between. Penguin Random House 2023*.

GeeksforGeeks. (2025). Understanding Encapsulation, Inheritance, Polymorphism, Abstraction in OOPs. Retrieved January 22, 2026, from https://www.geeksforgeeks.org/java/understanding-encapsulation-inheritance-polymorphism-abstraction-in-oops/

Gezamenlijke-Brandweer. (2025). Gezamenlijke Brandweer. Retrieved December 16, 2025, from https://www.gezamenlijke-brandweer.nl/

Informs. (2026). Operations Research Analytics. Retrieved January 23, 2026, from https://www.informs.org/Explore/Operations-Research-Analytics

Kustwacht, N. (n.d.). Wij zijn de Kustwacht. Retrieved December 16, 2025, from https://kustwacht.nl/

Lakens, P., & de Jongh, H. (2025, June). Rotterdam vreest verdere fabriekssluitingen na val kabinet. Retrieved December 16, 2025, from https://fd.nl/bedrijfsleven/1558531/rotterdam-vreest-verdere-fabriekssluitingen-na-val-kabinet

LyondellBasell. (2025, March). LyondellBasell and Covestro announce permanent closure of PO11 unit at Maasvlakte. Retrieved December 16, 2025, from https://www.lyondellbasell.com/en/who-we-are/updates-events/corporate--financial-news/lyondellbasell-and-covestro-announce-permanent-closure-of-po11-unit-at-maasvlakte/

Madlener, B. (2025a, April). Bijlage B, Programmaplan - Programma Vloot Vernieuwing en Verduurzaming.

Madlener, B. (2025b, April). Programmaplan - Programma Vloot Vernieuwing en Verduurzaming.

Maedows, D. (1999). Leverage Points: Places to Intervene in a System. Retrieved January 6, 2026, from https://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/

Ministerie van Defensie. (2019, September). *Taken marechaussee*. Koninklijke Marechaussee. Retrieved December 16, 2025, from https://www.defensie.nl/organisatie/marechaussee/taken

Miro, M. (2025). Over Miro | Maak kennis met het team | Onze missie - Miro | De werkomgeving voor innovatie. Retrieved December 16, 2025, from https://miro.com/nl/about/

Mol, B., & Schriever, D. (2024). Design of a Digital Interactive Collaboration Facilitator in a Datacenter Development Context. Retrieved December 22, 2025, from https://repository.tudelft.nl/record/uuid:eff5d735-57f2-4ce9-98e3-2c5354d7e6da

Nederlandse Douane. (n.d.). Werk van de Douane | Over de Douane. Retrieved December 16, 2025, from https://www.overdedouane.nl/werk-douane

Operational Research Society. (n.d.). Optimising Tomorrow: Insights into Operational Research. Retrieved January 23, 2026, from https://www.theorsociety.com/ORS/ORS/About-OR/About-OR.aspx

Pallandt, F. (2025). A Data-Driven Decision Support Tool for a priori Multi-Objective Optimization of Building Portfolio Assets. Retrieved December 23, 2025, from https://repository.tudelft.nl/record/uuid:7b79c975-fc7d-4325-b084-452ab01c9195

Pieter Duisenberg, Reinier van Zutphen, & Thom de Graaf. (2026, January). Naar een realistische overheid. https://www.rekenkamer.nl/documenten/2026/01/14/naar-een-realistische-overheid

Politie, N. (n.d.). Wat doet de politie op het water? Retrieved December 16, 2025, from https://www.politie.nl/informatie/wat-doet-de-politie-op-het-water.html

Port of Rotterdam. (n.d.-a). (Rijks-) Havenmeester | Port of Rotterdam. Retrieved December 16, 2025, from https://portofrotterdam.sharepoint.com/sites/thuisweb-afdelingen/SitePages/Rijks-Havenmeester.aspx

Port of Rotterdam. (n.d.-b). About the Port Authority | Port of Rotterdam. Retrieved December 15, 2025, from https://www.portofrotterdam.com/en/about-port-authority

Port of Rotterdam. (n.d.-c). Announcement of closure of LyondellBasell/Covestro (Maasvlakte) and Tronox (Botlek) chemical plants 'tough day for the port' | Port of Rotterdam. Retrieved December 16, 2025, from https://www.portofrotterdam.com/en/news-and-press-releases/announcement-closure-lyondellbasellcovestro-maasvlakte-and-tronox-botlek

Port of Rotterdam. (n.d.-d). Harbour Master | Port of Rotterdam. Retrieved January 22, 2026, from https://www.portofrotterdam.com/en/about-port-authority/our-organisation/harbour-master

Port of Rotterdam. (n.d.-e). Purpose. Retrieved December 15, 2025, from https://portofrotterdam.sharepoint.com/sites/thuisweb-programmas-Purpose

Port of Rotterdam. (2025, November). Asset Management. https://portofrotterdam.sharepoint.com/sites/thuisweb-afdelingen/SitePages/Asset-Management.aspx

Python Software Foundation. (2026). *Python 3* (Version 3.x). https://www.python.org/

Raaphorst, T. (2024). Raising the acceptance for a preference-based design methodology in the context of urban development. Retrieved December 22, 2025, from https://repository.tudelft.nl/record/uuid:199fec66-490c-4d05-9d27-ac2f69dadad4

Roozenburg, N., & Eekels, J. (2016). *Productontwerpen, structuur en methoden* (2nd ed.). Boom Uitgevers Amsterdam.

Saide, M. (2024, July). Understanding Object-Oriented Development: Concepts, Benefits, and Inheritance in Modern Software Engineering by Mamudo Saide :: SSRN. Retrieved December 25, 2025, from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4881346

ScientificMetrics. (2002). ChoiceRobot. Retrieved December 26, 2025, from https://choicerobot.com/ChoiceWeb/Welcome.php

ScientificMetrics. (2025, December). Scientific Metrics: Home. Retrieved December 26, 2025, from https://scientificmetrics.com/

Scipy. (2025). Pchip_interpolate — SciPy v1.16.2 Manual. Retrieved December 30, 2025, from https://docs.scipy.org/doc/scipy/reference/generated/scipy.interpolate.pchip_interpolate.html

Stemmler, K. (2022, June). 4 Principles of Object-Oriented Programming | Khalil Stemmler. Retrieved December 25, 2025, from https://khalilstemmler.com/articles/object-oriented/programming/4-principles/

Streamlit. (2021, January). Streamlit • A faster way to build and share data apps. Retrieved January 4, 2026, from https://streamlit.io/

Technical University of Delft. (2023). System Engineering Design — TeachBook TU Delft. Retrieved January 13, 2026, from https://teachbooks.io/systems-engineering-design/main/chapters/chapter_1.html

TenneT. (2025). Congestieonderzoek Haven Rotterdam. Retrieved December 16, 2025, from https://tennet-drupal.s3.eu-central-1.amazonaws.com/default/2025-10/Congestieonderzoek%20Haven%20van%20Rotterdam%20herijking%20oktober%202025.pdf

Teuber, L. G., & Wolfert, A. R. M. (2024, November). Confronting Conflicts to Yes: Untangling Wicked Problems with Open Design Systems [arXiv:2409.10549 [cs]]. https://doi.org/10.48550/arXiv.2409.10549

The MathWorks Inc. (2025). Matlab. https://www.mathworks.com

UPM. (2025, June). UPM sharpens its focus on biofuels growth strategy and plans to discontinue the Rotterdam Biofuels Refinery project. Retrieved December 16, 2025, from https://www.upm.com/news-and-stories/releases/2025/05/upm-sharpens-its-focus-on-biofuels-growth-strategy-and-plans-to-discontinue-the-rotterdam-biofuels-refinery-project/

van Boeijen, A. G., Daalhuizen, J., & Zijlstra, J. (2020). *Delft Design Guide: Perspectives, models, approaches, methods*. BIS Publishers.

van Eijck, S., & Nannes, R. (2022). Preference based decision support system for Waelpolder. Retrieved December 23, 2025, from https://repository.tudelft.nl/record/uuid:36146902-4c0c-4d50-8643-59c067008978

van Gunteren, L. A., Binnekamp, R., & Barzilai, J. (2013). *Quality in Design and Execution of Engineering Practice*. IOS Press.

van Gunteren, L. A., Ruud, B., & de Graaf, R. P. (2011). *Stakeholder-Oriented Project Management | Tools and Concepts*. IOS Press.

van Heukelum, H. J. (2022). Preference and Performance Based Design; Decision Systems in Offshore; Dredging Engineering. Retrieved December 22, 2025, from https://repository.tudelft.nl/record/uuid:6e91cd0c-fc51-4b85-a897-70dac35c8c88

van Heukelum, H. J., Binnekamp, R., & Wolfert, A. R. (2024). Socio-technical systems integration and design: A multi-objective optimisation method based on integrative preference maximisation. *Structure and Infrastructure Engineering*. https://doi.org/10.1080/15732479.2023.2297891

van Heukelum, H. J., Steenbrink, A., Colomés, O., Binnekamp, R., & Wolfert, A. R. M. (2023). Preference-based service life design of floating wind structures. Retrieved December 22, 2025, from https://repository.tudelft.nl/record/uuid:4ba63e20-bb66-4865-bc43-0c6b2897acac

van Heukelum, H., Binnekamp, R., & Wolfert, R. (2023, April). *Human preference and asset performance systems design integration*. https://doi.org/10.48550/arXiv.2304.07168

Veiligheids-Regio-Rotterdam-Rijnmond. (n.d.). Veiligheids Regio Rotterdam-Rijnmond. Retrieved December 16, 2025, from https://vr-rr.nl/over/

Verein-Deutscher-Ingenieure. (1986). VDI 2221 - Systematic approach to the desing of technical systems and products. Retrieved December 23, 2025, from https://www.dinmedia.de/en/technical-rule/vdi-2221/1892472

Volkerink, M., Van Moock, F., & Van Rooij, M. (2024). Arbeidsmarktkrapte het nieuwe normaal? | De Nederlandsche Bank N.V. Retrieved December 16, 2025, from https://www.dnb.nl/media/tlzp2ktq/dnb-analyse-arbeidsmarktkrapte-het-nieuwe-normaal.pdf

Wolfert, A. R. M. ( (2023, August). *Open Design Systems*. TU Delft OPEN Books. https://doi.org/10.59490/mt.78

Zhilyaev, D., Binnekamp, R., & Wolfert, A. M. R. (2022). Best Fit for Common Purpose: A Multi-Stakeholder Design Optimization Methodology for Construction Management [Publisher: Multidisciplinary Digital Publishing Institute]. *Buildings*, *12*(5), 527. https://doi.org/10.3390/buildings12050527

# A
# Stakeholders

The fleet of the Port of Rotterdam plays an important role in the safety architecture of the Rotterdam harbour area. This section provides an overview of the most critical stakeholders involved.

## Port of Rotterdam Authority

The Port of Rotterdam Authority is a private company, owned by the municipality of Rotterdam (70%) and the Dutch national government (30%). The organisation has approximately 1400 employees and fulfils two core tasks (Port of Rotterdam, n.d.-b):

1. The sustainable development, construction, management and operation of the port and industrial area in Rotterdam.
2. The promotion of the safe, effective and efficient handling of shipping in the port of Rotterdam and the offshore approaches to the port

This master's thesis employs systems engineering principles to establish a connection between ”vague” goals and 'preferences' (sphere of desirability) and tangible metrics (sphere of capability) to facilitate design/business decisions. Consequently, it is worthwhile to explore the strategic framework of the PoR:

**Table A.1:** Strategic Framework Port of Rotterdam Authority (Port of Rotterdam, n.d.-e). *The Business Strategy 2025–2029 can be found on their website*

| | | |
|---|---|---|
| **Purpose** | *Connecting the world. Building tomorrow's sustainable port.* | |
| **Mission** | *We create economic and societal value by working with customers and stakeholders to achieve sustainable growth in the world-class port.* | |
| **Vision** | *We are the developer of a leading, safe, efficient and sustainable port where our customers can do business successfully.* | |
| **Core-values** | ***Focus:*** | *We set priorities, make decisive choices and finish what we start.* |
| | ***Respect:*** | *We respect each other, our environment, and the earth.* |
| | ***Resilient:*** | *We are resilient, recover quickly, and are ready for the future.* |
| | ***Connection:*** | *We work together with and for our customers, other stakeholders, and each other.* |
| **Objective Fleet Renewal Programme** | *Building Tomorrow's Fit for Purpose Sustainable Fleet* | |

## Fleet Renewal Programme

Based on the renewed purpose of the Port of Rotterdam in 2023 and the fact that the current incident response vessels are reaching the end of their operational life between 2030 and 2040, the Fleet Renewal Programme has been initiated by the departments of Asset Management and the Harbour Master Department [1]. The programme's task is to coordinate the replacement of the current fleet with new vessels, using a programmatic approach (as opposed to a project-oriented approach) and based on a company-wide vision of what the new fleet should look like (Madlener, 2025b).

Replacing the entire fleet presents an opportunity to review and modernise operational processes and equipment, and to make the fleet as sustainable as possible. Therefore, the objective of the Fleet Renewal Programme is to build ”Tomorrow's Fit For Purpose Sustainable Fleet”. The term 'fit for purpose' means that the fleet is equipped to perform its tasks to the highest requirements, with the best possible performance. 'Sustainable' means that no greenhouse gas emissions are produced. The order is important and has been chosen on purpose. In this context, it is more important to make sure that the equipment works well, rather than that it is environmentally friendly. Although this formulation was important to the PoR, a holistic perspective on 'fit for purpose' would consider sustainability and task performance as both part of the overarching goal that is ”fit for purpose”.

The Fleet Renewal Challenge is already of considerable complexity, with a lot of stakeholders involved. However, the present time frame is characterised by intensified geopolitical tensions and a rapid pace of technological developments and innovations. This contributes to the complexity of the task (Madlener, 2025b).

## Internal Stakeholders

### Harbour Master Department

The Harbour Master Department, led by the Harbour Master itself, plays a pivotal role in keeping the port 'safe, smooth, clean and secure' (Port of Rotterdam, n.d.-a). This department of the Port of Rotterdam Authority functions as an independent entity (under public law), and has the following sub-departments: Port Coordination Centre (HCC) [2], Traffic Management [3], Harbour master policy and development [4] and Ship and environmental safety [5]. All are related to the fleet operations, and their responsibilities are defined as:

- Safe and efficient management of maritime traffic,
- Enforcing regulations
- Providing (first) incident response services,
- Coordinating emergency situations (e.g. fires and accidents)
- Protecting the environment

### Asset Management

The Asset Management (AM) department, under the supervision of the Chief Operating Officer of the executive board, is responsible for the management of the port's physical assets throughout their lifecycle. This includes maintenance, upgrades, and strategic planning for the port's infrastructure and equipment. A sub-department of AM has been designated to manage the fleet and is named ”AM Fleet” (Port of Rotterdam, 2025). The Fleet Renewal Programme is of significant importance to AM-fleet due to their expertise in the maintenance of the current fleet and their involvement in the management of the future fleet.

### Finance, Procurement and Innovation

The Fleet Renewal Programme is a major innovative program, one of the largest in terms of budget, timelines, and stakeholders involved. Therefore, the finance, procurement, and innovation departments, supervised by the Chief Financial Officer (CFO) of the executive board, are also important (internal) stakeholders.

[1]NL: Divise Havenmeester Rotterdam (DHMR)
[2]NL: Haven Coördinatiecentrum (HCC)
[3]NL: Verkeersafhandeling (VA)
[4]NL: Havenmeester Beleid & Ontwikkeling
[5]NL: Scheeps- en milieuveiligheid (SMV)

## Safety Architecture; Inter-Organisational Partnerships

The Port of Rotterdam Authority collaborates closely with other public safety agencies and organisations, as outlined in the following sub-sections.

### Rotterdam-Rijnmond Safety Region

The Harbour Authority works closely with the Rotterdam-Rijnmond Safety Region for coordinating the incident response and law enforcement. The Rotterdam-Rijnmond Safety Region (VRR) [6] is a governmental organisation that executes critical public safety functions on behalf of thirteen municipalities. Emergency response, crisis management, risk reduction, fire and ambulance services, and medical aid are all included in its duties. All thirteen mayors make up the VRR's governing board, and is chaired by the mayor of Rotterdam (Veiligheids-Regio-Rotterdam-Rijnmond, n.d.). To provide a perspective on the size of the VRR, it has the highest population density of the 25 safety regions in the Netherlands and includes Rotterdam-The Hague Airport and the Port of Rotterdam.

### Joint- & Local Fire Brigade

As Europe's largest port, Rotterdam hosts a large petrochemical industry. Therefore, the necessity for two fire brigades: (1) the Joint Fire Brigade for the industrial area and (2) the Local Fire Brigade for both Rotterdam city and the safety region as a whole.

The Joint Fire Brigade[7] is a partnership between companies in Rotterdam's port and industrial area, and the Municipality of Rotterdam. The brigade fulfils a dual mandate: providing dedicated industrial fire protection to port and industrial facilities, and also delivering municipal fire services to both the port's operational areas and adjacent residential communities (Gezamenlijke-Brandweer, 2025). The Joint Fire Brigade has specialised tasks, including:

- Rescuing people in hard-to-reach places.
- Deploying (oil) containment barriers in safe areas.
- Firefighting on Vessels.
- Cold-cutting fire suppression for inaccessible compartments (named: Cobra System).
- Chemical-hazard response and decontamination.

### Police, Customs and Military Police

The Port of Rotterdam Authority collaborates with multiple law enforcement agencies, including the seaport police, customs, and the military police, to ensure safety and security within the harbour. The Dutch National Police operates a specialised maritime unit conducting patrols and enforcement in the Port of Rotterdam (Politie, n.d.). The Royal Marechaussee (military police) is responsible for safeguarding the European external border. This includes airports, seaports, and coastal areas (Ministerie van Defensie, 2019). Dutch Customs, in turn, oversees the supervision and inspection of goods through the harbour to ensure compliance with trade and security regulations (Nederlandse Douane, n.d.).

### Coast Guard and Navy

While the Port of Rotterdam Authority and its direct partners hold primary responsibility for safety and security within the port, the harbour's connection to the North Sea introduces additional governance layers. This involves the Dutch Coast Guard and the Royal Dutch Navy. Given escalating geopolitical tensions, their collaboration with the port may be of greater significance in the future.

The Dutch Coast Guard shares overlapping responsibilities with the Port Authority in law enforcement and incident response, though its jurisdiction extends to the wider North Sea region. Its fleet comprises specialised assets for maritime safety, environmental protection, and fisheries control (Kustwacht, n.d.). From the perspective of overlapping responsibilities, it would be interesting to investigate the potential for collaboration between the Coast Guard and the Port of Rotterdam in order to pursue synergies in terms of equipment, personnel and business processes.

[6] NL: Veiligheidsregio Rotterdam Rijnmond
[7] NL: Gezamelijke Brandweer (GB)

# Graphical Overview of Stakeholders with the set Organisational-System-Boundary (scope).

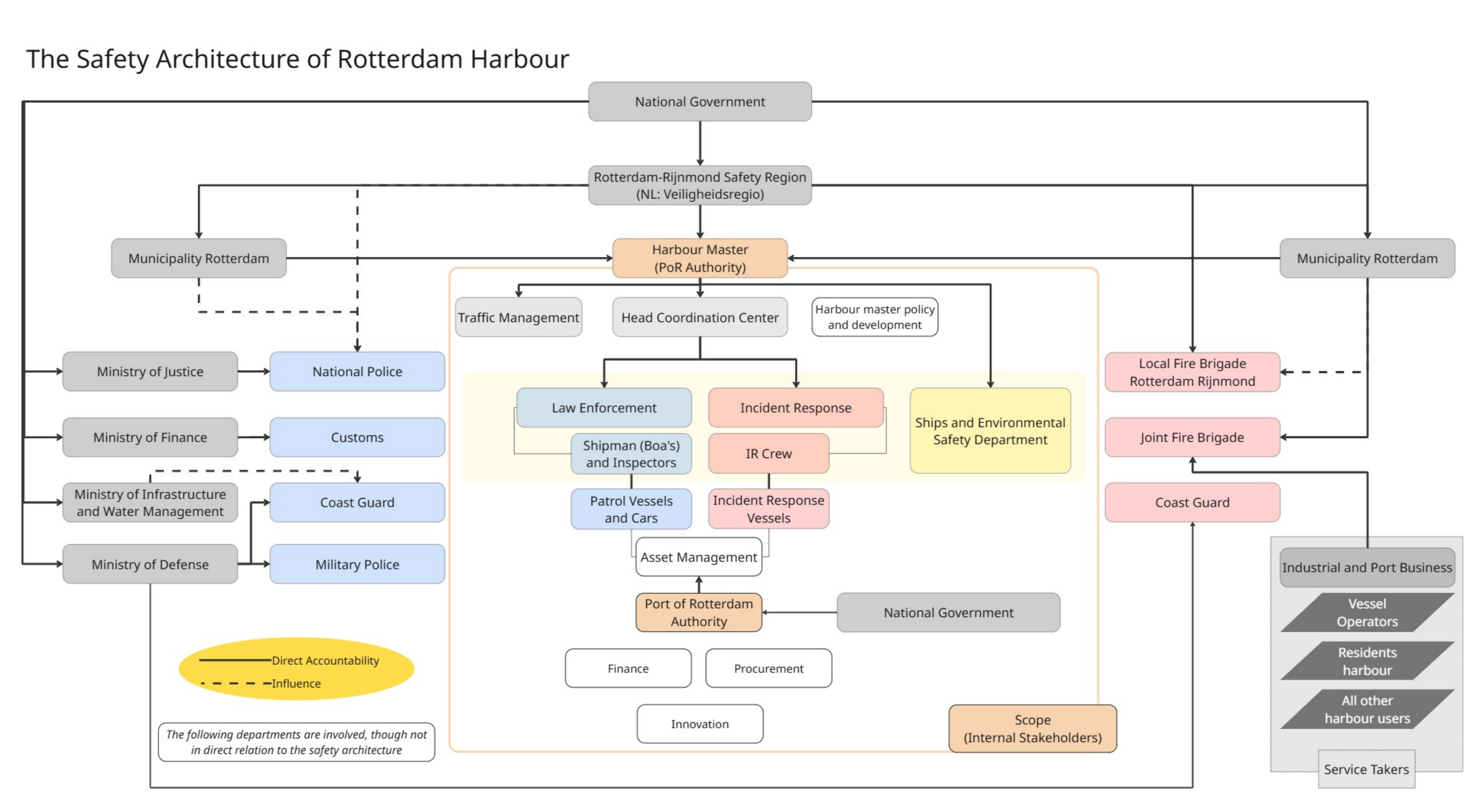



**Figure A.1:** Stakeholders of the Safety Architecture of Rotterdam Harbour and the most critical stakeholders, *(own illustration)*

# B

# Graphical Overview Tasks and Resources

**The Port of Rotterdam Authority Responsabilities:**

- Safe and efficient management of maritime traffic,
- Enforcing regulations
- Providing (first) incident response services,
- Coordinating emergency situations (e.g. fires and accidents)
- Protecting the environment

**Incident Response**

Tasks (red):

- Providing water and fire-fighting foam to the fire brigade in the event of incidents occurring along or on the water.
- Providing water to terminal fire extinguishing systems. These are large quantities of water under high pressure.
- Source mitigation 7 of a fire or hazardous substances.
- Deploying (oil) containment barriers in unsafe areas.

7x Incident Response Vessel (4x in operation, 3x reserve)
90x Crew members (ship-master)

**Law Enforcement (Patrol and Inspections)**

Tasks (blue):

- Providing requested and unrequested advice based on legislation and procedures regarding hazardous and harmful substances;
- Conducting security inspections for ships and terminals;
- Detecting economic crimes related to unfair competition.
- Supervision and policing during events

5x Patrol Vessels (3x in operation, 2x reserve)
1x RHIB (Rigid-hulled inflatable boat)
50x Crew members (ship-master)

12x Cars
35x Crew members (inspectors)

**General**

Tasks (green):

- The provision of first incident response services in safe areas, including: first aid, containing water pollution, creating a safe nautical situation, deploying water pumps for rescue operations, and bringing other vessels to safety by pushing or towing them.
- Search and Rescue (SAR).
- Providing information to the users and guest of the harbour area.
- Supervision of port activities to ensure compliance with the law.
- Inspecting damaged infrastructure.
- Supervision and policing during events. In collaboration with the fire brigade, police, ambulance service, Rijkswaterstaat, and military police.
- Transportation of persons (emergency workers and colleagues) and equipment.
- Assisting other safety agency in the nautical management area. These include the police, fire brigade (including diving teams) and ambulance services.
- Remove objects from the water
- Collection and sharing of information. In collaboration with the Port Coordination Centre, traffic control centres, the camera network, drones and other resources.
- Physical traffic control in the event of failure of the Traffic Centres (TCH, VCR).
- Physical escorting of large seagoing vessels is carried out by a vessel while sailing. The crew of the vessel assists the traffic control centres in monitoring the surroundings and communicating with other shipping traffic.
- The recovery and transport of dead bodies.
- Deploying (oil) containment barriers in safe areas.

**Figure B.1:** Overview of the fleet-tasks / services that the fleet provides, *(own illustration)*


**Figure B.2:** Overview of the current fleet (Madlener, 2025b)

# C

# Future Scenarios - Interplay Tasks, Resources and Societal Key Issues

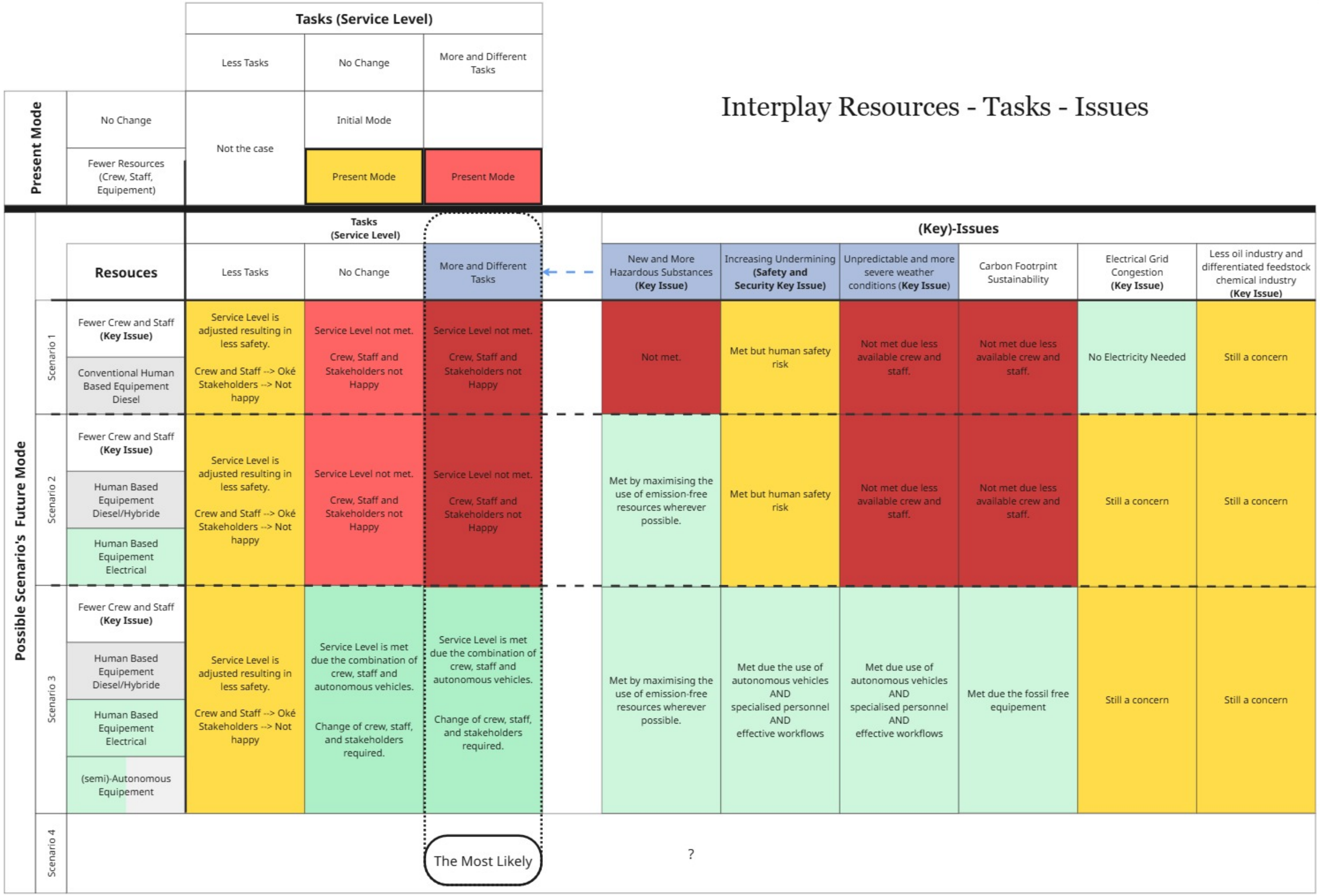



**Figure C.1:** Visualization of the interplay between resources, tasks, and key issues and what the possible scenarios are. One scenario has been left blank to emphasise that a solution can still be found that is better than the current forecasts. *(own illustration)*

# D

# Improvements Preferendus Genetic Algorithm (GA) and Integrative Maximisation of Aggregated Preferences (IMAP)

This appendix outlines the enhancements made to the Preferendus algorithm, originally developed by H. J. van Heukelum et al. (2024).

## Selecting Elites for Next Population

The initial algorithm of H. J. van Heukelum et al. (2024) had two issues with selecting the elites (see code listing D.1):

1. **Incorrect elite selection**: The algorithm identifies the highest scores as elites. This is incorrect for a minimization algorithm where the goal is to find the lowest scores.
2. **Alternative loss with identical scores**: The algorithm only saves the first population member that matches a unique score, and do not save the other members with the same score. This can lead to the loss of potentially valuable alternatives because two different alternatives can have the same score. For instance, alternative A with x1=2 and x2=5 can have the same score as alternative B with x1=10 and x2=1.

**Listing D.1:** Initial Elites Selection

```

# determine the part that is elite
unique_scores = np.unique(scores_feasible)
n_elite = int(self.elitism_percentage * len(unique_scores)) - int(
                                      self.elitism_percentage * len(unique_scores)) % 2

children = list()
if n_elite != 0:
    elites = unique_scores[-1 * n_elite:]
    for score in elites:
        for i, p in enumerate(pop):
            if scores_feasible[i] == score:
                children.append(p.copy())
                break

Works as:
# Sample population: each individual is represented by a list of parameters
pop = [
    [1, 2, 3],
    [4, 5, 6],
    [7, 8, 9],
    [10, 11, 12],
```

```
        [13, 14, 15],
        [16, 17, 18],
        [19, 20, 21],
        [22, 23, 24],
        [25, 26, 27],
        [28, 29, 30]
    ]

    # Sample scores corresponding to the population
    scores_feasible = np.array([10, 20, 20, 30, 40, 40, 50, 60, 70, 80])

    # Define the elitism percentage (e.g., 20%)
    elitism_percentage = 0.4

    # Find unique scores
    unique_scores = np.unique(scores_feasible)
    print("Unique␣scores:", unique_scores)  --> [10 20 30 40 50 60 80]

    # Calculate the number of elite scores
    n_elite = int(elitism_percentage * len(unique_scores)) - int(elitism_percentage * len(
        unique_scores)) % 2
    print("Number␣of␣elite␣scores:", n_elite)  --> 2

    # Get the elite scores (the top n_elite scores)
    elite_scores = unique_scores[-n_elite:] if n_elite > 0 else []
    print("Elite␣scores:", elite_scores) --> [60, 80]

    # Create a list of children based on the elite scores
    children = list()
    if n_elite != 0:
        elites = unique_scores[-1 * n_elite:]
        for score in elites:
            for i, p in enumerate(pop):
                if scores_feasible[i] == score:
                    children.append(p.copy())
                    break

    print("Children␣based␣on␣elite␣scores:", children) --> [[22, 23, 24], [25, 26, 27]]
```

An improved elites method addresses these issues by (see code listing D.2):

- **Correct elite selection**: Selecting the elites based on the lowest scores, which is in line with the minimization algorithm.
- **Preserving all alternatives**: Saving all different alternatives that have the same score by checking if the selected population member has already been saved, ensuring no valuable alternatives are lost.
- **Only unique populations:** The code makes sure that all elites are unique populations.

**Listing D.2:** Improved Elites Selection

```

def calculate_n_elites(population_size: int, elitism_percentage: float) -> int:
    correct_to_even_if_needed = int(elitism_percentage * population_size) % 2
    n_elite = int(elitism_percentage * population_size) - correct_to_even_if_needed
    return n_elite


def select_elites(
        population: List[Union[List[Union[float, int]], List[List[Union[float, int]]]]],
        scores: List[float],
        n_elite: int,
        correct_to_even: bool = False,
) -> List[Union[List[Union[float, int]], List[List[Union[float, int]]]]]:
    children = []
    seen = set()

    if n_elite != 0:
        # Sort scores to determine elites
        final_scores_sorted = np.sort(scores)
        elites_scores = final_scores_sorted[:n_elite]
        rest_scores = final_scores_sorted[n_elite:]
```

```
        for score in elites_scores:
            indices = [index for index, s in enumerate(scores) if s == score]
            for index in indices:
                if len(children) < n_elite:
                    # Convert individual to tuple for checking in the set
                    if isinstance(population[index][0], list):
                        # For three-dimensional lists
                        individual_tuple = tuple(tuple(inner) for inner in population[index])
                    else:
                        # For two-dimensional lists
                        individual_tuple = tuple(population[index])

                    if individual_tuple not in seen:
                        seen.add(individual_tuple)
                        children.append(population[index].copy())
                else:
                    break
            if len(children) >= n_elite:
                break

        delta_shortage = n_elite - len(children)
        if delta_shortage > 0:
            for score in rest_scores:
                indices_rest_scores = [index for index, s in enumerate(scores) if s == score]
                for index in indices_rest_scores:
                    if len(children) < n_elite:
                        if isinstance(population[index][0], list):
                            individual_tuple = tuple(tuple(inner) for inner in population[
                                index])
                        else:
                            individual_tuple = tuple(population[index])

                        if individual_tuple not in seen:
                            seen.add(individual_tuple)
                            children.append(population[index].copy())
                    else:
                        break
                if len(children) >= n_elite:
                    break

    # Note: when it is necessary to return an even number of elites. The last child is erased
        .
    if len(children) % 2 > 0 and correct_to_even:
        return children[:-1]
    return children
```

## Diversity

The initial algorithm of H. J. van Heukelum et al. (2024) calculates the diversity over the full population as follows (see code listing D.3):

*Example population with 2 alternatives (rows) and 3 design variables (columns):*

$$\begin{bmatrix} 2 & 5 & 3 \\ 4 & 2 & 8 \end{bmatrix}$$

**Listing D.3:** Initial diversity calculation function

```

decoded_population =    [
                            [2, 5, 3],
                            [4, 2, 8]
                        ]

The diversity calculation in code:
# check diversity:
check_div = round(np.max(np.unique(decoded_population, return_counts=True)[1]) /
                  (len(pop) * len(pop[0])), 3)
```

```

This code works as:
    1. unique values = [2, 3, 4, 5, 8]
    2. counts = [2, 1, 1, 1, 1]
    3. max_counts = 2
    4. tota_variables = 2 (alternatives) * 3 (design variables) = 6
    5. diversity = 2/3
```

Two issues with this approach (see code listing D.4):

1. **Diversity confusion**: H. J. van Heukelum et al. (2024) calculates the diversity over the full matrix. For example with apples and chairs ([apple, chair]), the diversity of [[1, 2], [2, 3]] is calculated as 3.
   These indices (design-variables) do not represent the same 'object'. In other word, 2 chairs and 2 apples can not compared with each other and therefore the diversity should be 4. For example, ([apple, chairs]) [[1, 2], [3, 4]] has the same diversity as [[2, 2], [3, 3]].
   Therefore, the diversity of the full matrix has no meaning.
2. **Intuitive scale**: A higher diversity-number means lower diversity, which is counter-intuitive.

An improved diversity calculation method addresses these issues by (see code listing D.4):

- **Comprehensive population diversity**: Calculating diversity for the entire population to provide an overall measure of variance within the dataset.
- **Variable-specific analysis**: Calculating diversity for each variable separately to offer a more nuanced understanding of the data.
- **Intuitive scaling**: Employing a more intuitive scaling system where a higher number indicates higher diversity, making interpretation and analysis more straightforward.
- **Detailed uniqueness quantification**: Calculating the number of unique values per variable separately to provide an additional parameter next to diversity.

**Listing D.4:** Improved diversity calculation function

```

def check_diversity(population: np.ndarray) -> Tuple[float, List[float], List[float]]:
    # Calculate the total number of values in the population
    number_values_in_population = len(population) * len(population[0])
    # Calculate the diversity of the entire population
    unique_values, counts = np.unique(population, return_counts=True)
    numb_unique_values = len(unique_values)
    # Diversity of 0 means low-diversity. 1 means high diversity
    if numb_unique_values == 1:
        div_full_population = 0
    else:
        div_full_population = round(numb_unique_values / number_values_in_population, 3)

    # Calculate the diversity per variable
    diversity_per_variable = []
    numb_unique_values_per_variable = []
    if len(population) == 1:
        diversity_per_variable = [1] * len(population[0])
        numb_unique_values_per_variable = [1] * len(population[0])
        return div_full_population, diversity_per_variable, numb_unique_values_per_variable

    for design_index in range(len(population[0])):  # Loop over each variable (column)
        # Measure the diversity for this variable
        all_values_design_variable_i = population[:, design_index]
        total_numb_values = len(all_values_design_variable_i)
        dv_unique_values, dv_counts = np.unique(all_values_design_variable_i, return_counts=
            True)
        dv_number_unique_values = len(dv_unique_values)
        if dv_number_unique_values == 1:
            dv_diversity = 0
        else:
            dv_diversity = round((dv_number_unique_values / total_numb_values), 3)
        diversity_per_variable.append(dv_diversity)
        numb_unique_values_per_variable.append(dv_number_unique_values)

    return div_full_population, diversity_per_variable, numb_unique_values_per_variable

```

```
decoded_population =    [
                            [2, 5, 3],
                            [4, 2, 8],
                            [4, 9, 7]
                        ]

The diversity calculation in code:
# check diversity:
check_div = check_diversity(diversity)

This code works as:
    1. unique values full population  = [2, 3, 4, 5, 7, 8, 9]
    2. counts = [2, 1, 2, 1, 1, 1]
    3. length_counts = 6
    4. tota_variables = 9
    5. diversity full population = 6/9 (relatively high)

    6. same procedure for every variable seperately
    7. diversity per variables    = [2/3, 1, 1]
    9. number of unique variables = [  2, 3, 3]
```

## Generation of Initial Population and Boolean Values

In the initial code, the random generated value for the boolean were able to get the number '2' while it should only be 0 or 1 (see code listing D.5). This is corrected by aplying *"np.random.randint(0, 1 + 1)"* instead of *"randint(0, 2)"*.

**Listing D.5:** Initial Population Generator

```

def _initiate_population(self):
       r_count = 0
       pop = list([0] * self.n_pop)
       for p in range(len(pop)):
           solo = list([0] * len(self.bounds))
           for i in range(len(solo)):
               if self.approach[i] == 'int':
                   solo[i] = randint(self.bounds[i][0], self.bounds[i][1] + 1)
                   r_count += 1
               elif self.approach[i] == 'bool':
                   # randint(0, 2) genereert 0, 1 en 2. maar je wilt 0 of 1.
                   solo[i] = randint(0, 2)
                   r_count += 1
               else:
                   solo[i] = randint(0, 2, self.n_bits).tolist()
                   r_count += self.n_bits
           pop[p] = solo.copy()
       return pop, r_count
```

## Tournament Algorithm Selection Parents

The tournament selection algorithm within the parents-selection-method has been enhanced to improve the balance between exploration and convergence in the genetic algorithm. The key changes and their implications are discussed below.

### Initial Approach

Initially, the algorithm selected parents based on half of the population size. This approach had the following characteristics:

- **Fast Convergence**: The algorithm can tend fast convergence, because the best parents were frequently selected.
- **Limited Exploration**: Rapid convergence reduced genetic diversity in the population, potentially leading to suboptimal solutions.

### Modified Approach

The algorithm has been modified to use an adjustable tournament size $k$. This was already noted in the description by H. J. van Heukelum et al. (2024) but not implemented. this offers several advantages:

- **Controlled Selection Pressure**: The selection pressure can be precisely controlled by adjusting $k$. A higher $k$ increases the likelihood of selecting better parents, while a lower $k$ introduces more randomness and exploration.
- **Flexibility**: The algorithm is more adaptable and can be tuned for different optimization problems by adjusting $k$.

The default value of $k$ is set to $\frac{1}{3}$ of the population size. This value provides a balanced approach, ensuring reasonable convergence speed while maintaining sufficient exploration.

**Implementation**

The implementation of the tournament selection algorithm is shown in Listing D.6. The algorithm operates as follows:

1. A random individual is selected from the population.
2. A tournament is held among $k$ randomly selected individuals from the population.
3. The individual with the best score (lowest score in a minimization problem) among the $k$ individuals is selected as the parent.

**Listing D.6:** Tournament Selection Algorithm

```
def _selection(pop, scores, k=3):
    # first random selection
    selection_ix = randint(len(pop))
    for ix in randint(0, len(pop), k):  # k - 1):
        # check if better (e.g. perform a tournament)
        if scores[ix] < scores[selection_ix]:
            selection_ix = ix
    return pop[selection_ix]
```

# E

# Object Oriented Preferendus Modules - Building Blocks

To model and optimise the complex socio-technical system of fleet renewal at the Port of Rotterdam, this graduation project implements an object-oriented programming (OOP) architecture based on the Preferendus proposed by Van Heukelum et al. (2024). The tool-architecture consists of five core modules:

- The **Design Performance Module** provides the technical foundation for vehicle capabilities
- The **Objective Module** manages the optimization objectives and their relationships
- The **Preference Module** handles stakeholder preferences and value functions
- The **Optimization Module** implements the solution algorithms
- The **Naming Module** establishes consistent terminology based on 'design for -ty' principles
- The **Data Storage and Alternative Comparison Module** manges the data and fleet configuration comparisons.

See Figure E.4 for a detailed visualization of the tool and its modules.

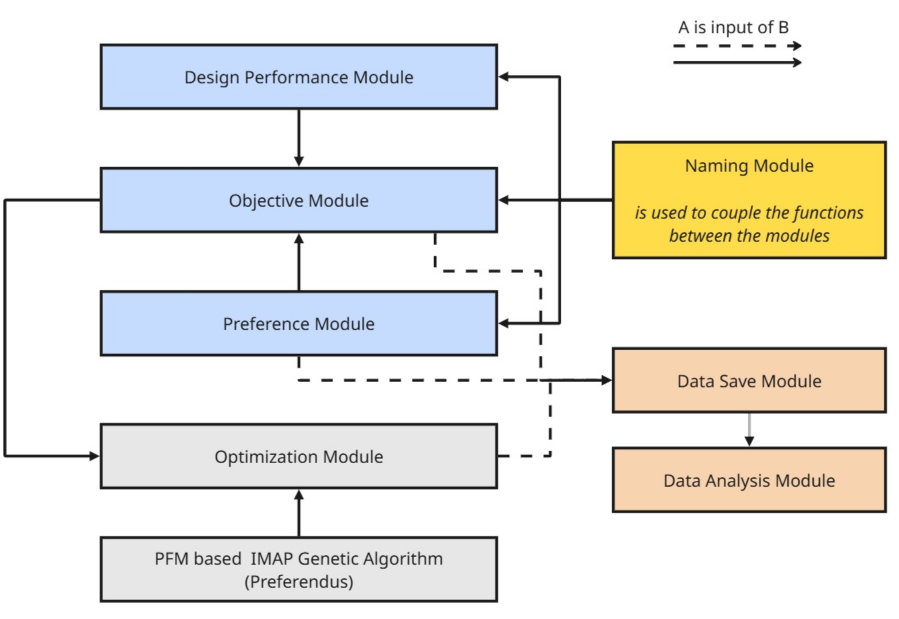



**Figure E.1:** Basic Graphical Overview of OOP Building Blocks *(own illustration)*

# Objective Module

The objective module is designed to manage and optimize multiple objectives. This module is organized around several classes that work together to represent, manage, and optimize objectives according to the 'design for -ty' principles:

**ObjectiveABC Class**
The ObjectiveABC class is an abstract class that is used to create objectives for optimisation. The function standardises the calculation of values and preferences.

**ObjectiveForOptimizationABC Class**
The ObjectiveForOptimizationABC class serves as an abstract base class that encapsulates the following: main objective name aligned with 'design for -ty' principles, sub-objective name, objective class, tetra weight, normalized weight, and overall optimization weight.

**DesignForTyMainObjective Class**
The DesignForTyMainObjective class organizes related objectives according to the 'design for -ty' methodology. This abstract class manages a collection of sub-objectives as ObjectiveForOptimizationABC instances and saves the weight for the main objective. For instance, the 'design For -ty' objective 'Affordability' is defined with the sub-objectives 'CAPEX' and 'OPEX'.

**ContainerObjectivesForOptimization Class**
The ObjectivesContainerABC abstract base class facilitates the managing of main objectives as ObjectiveForOptimizationABC instances. It includes weight normalization and validation procedures, optimization weight calculation capabilities, and data export functionalities to pandas DataFrame and dictionary formats.

*Creating the Weight Distribution*
This module calculates the optimization weight for each objective based on user input (see section F). A specialized method was developed to assist users in determining appropriate weight distributions. This is particularly valuable when comparing objectives that may be difficult to evaluate directly. For instance, 'Min CAPEX' versus 'Min Response Time'. This method uses the mathematical formula blow that involves a two-step process and three principles:

Two steps:
1. The users evaluate the importance of the main 'Design for -ty' objectives
2. Then, users evaluate the relative importance of sub-objectives within each 'design for -ty' objective.

Three Principles:
1. Evaluation is conducted on the same scale (for instance, between 0 and 100).
2. Evaluation is conducted on the same abstract levels.
3. If an objective is excluded, exclude the objective from the weight calculation. The score '0' does not mean that it is excluded. It is just an arbitrary number on the one-dimensional affine space. Only the differences between points provide the information (when within the same framework)

The following formula is used to determine the weight for optimization:

$$w_{\text{normalized}} = \left( \frac{b + w}{(\sum w) + b \times n} \right) \times 100 \tag{E.1}$$

- $w_{\text{normalized}}$ is the normalized weight objective.
- $b$ is the baseline value (10 in this case) and is used to make '0' values possible.
- $w$ is the original weight of the objective set by the user.
- $\sum w$ is the sum of the objectives weights.
- $n$ the number of objectives evaluated.

**ContainerObjectivesForOptimization Class**

The ContainerObjectivesForOptimization class is utilised to prepare the objectives for the optimisation module.

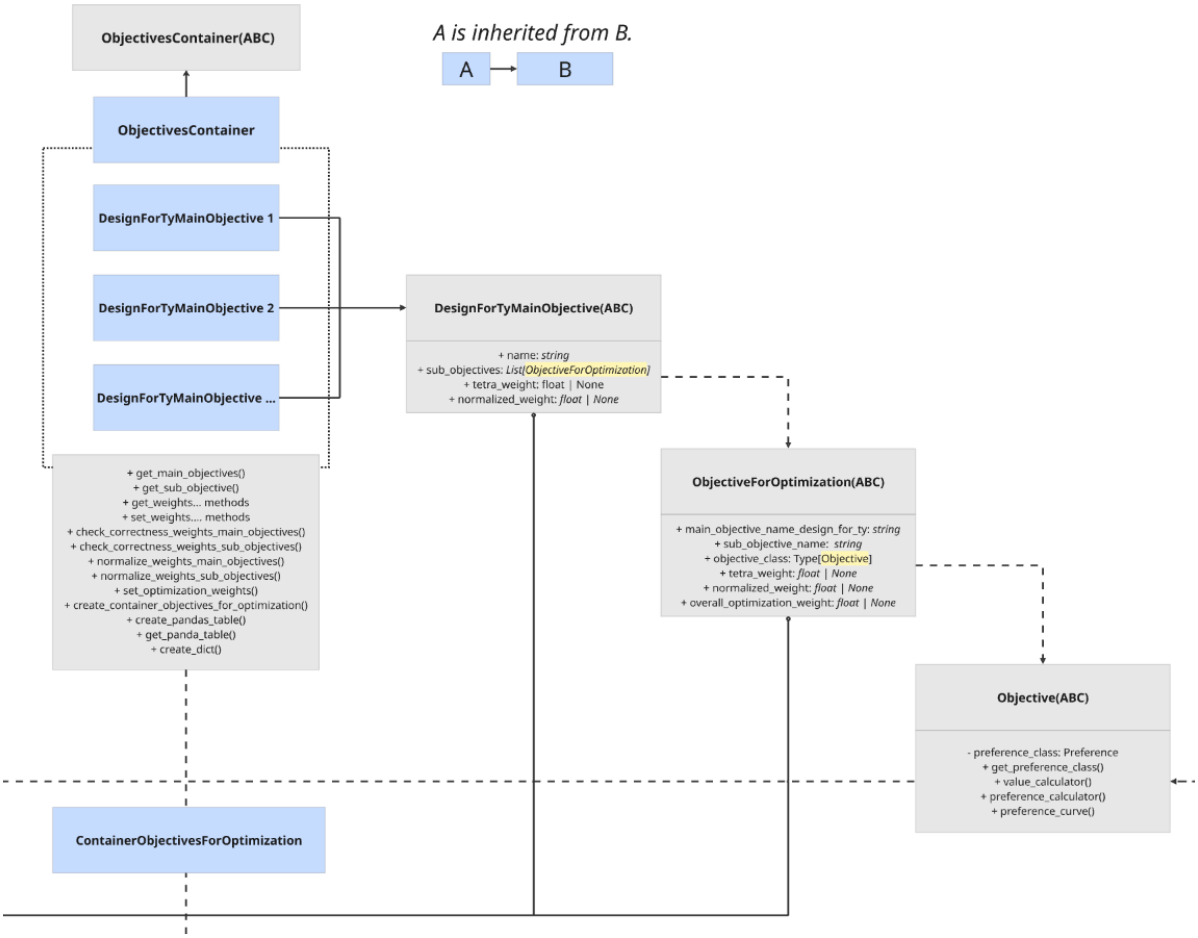



**Figure E.2:** Graphical Overview Objective Module *(own illustration)*

# Preference Module

**Preference Class**
The Preference class is an base-class, meaning it can be used to create dozens of preference curves with the same capabilities imbedded in the base-class. The Preference class is designed to store the x-values and the corresponding p-values (preferences). Additionally, the user has the option to *'cap alternatives'* (see section I.1) that fall below or above the defined x-values.

Binnekamp (2010) preferred the usage for Bezier curves over Lagrange-Polynomials and Cubic-Splines. Lagrange-Polynomials and Cubic-Splines have the tendency to return unwanted negative values, and therefore Bézier curves are preferred (Binnekamp, 2010). However, H. J. van Heukelum et al. (2024) employed monotonic cubic splines through the pchip_interpolate method offered by the Python SciPy package (Scipy, 2025).

This thesis introduces the possibility of creating a Bezier curve that is created using x- and preference points, in conjunction with the number of control points. The code for the Bezier curves was derived from Baker et al. (2022) and has been integrated into the Preference class. The preference curve can be created by either utilizing the PchipInterpolator (PchipInterpolator — SciPY V1.16.2 Manual, n.d.) or the Bézier curve. Unfortunately, the scope of this thesis did not allow for a comprehensive investigation into the advantages and disadvantages, as well as the implications, of utilizing the PchipInterpolator or the Bezier-fitting method. Further research is recommended.

The Preference Class integrates the 'capping' and 'constraint' functionality related to the preference curves. These concepts are explained in I.1.

**PreferencesContainer Class**
The PreferencesContainer is a dataclass that manages multiple instances of preference curve subclasses. This container facilitates centralized access, dynamic updates, and systematic retrieval of preference parameters.

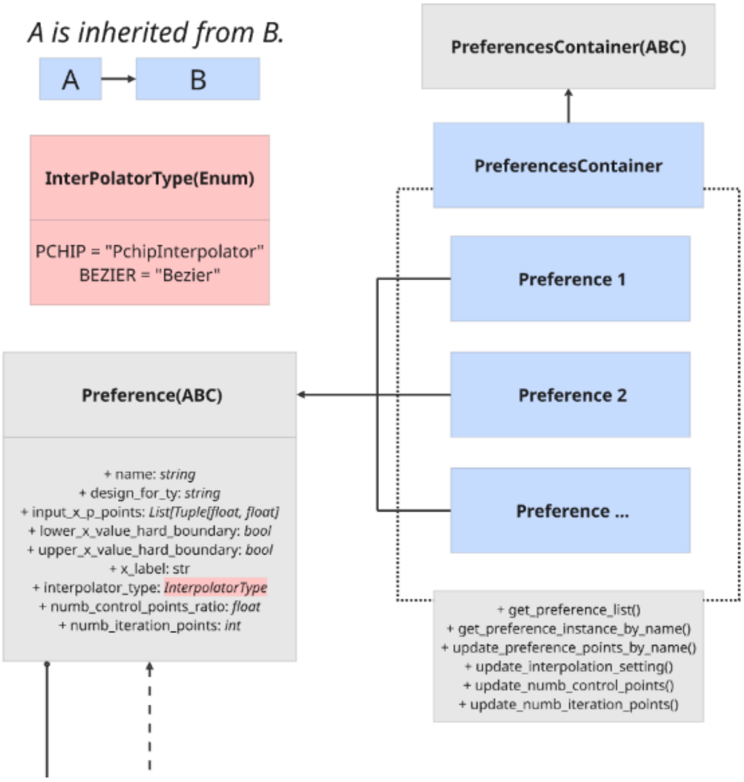



**Figure E.3:** Graphical Overview Preference Module *(own illustration)*

# Optimization Module

The optimization module facilitates the solving of a multi-objective optimization problem within the decision support system. The SolverABC class provides an abstract base class for the creation of the project-specific-solver. The SolverABC class include:

- Integration with the objective container and constraints
- Abstract methods for initial guess generation
- Abstract methods for defining optimization bounds
- Abstract methods for objective aggregation
- Concrete implementation of the solver execution process

# Naming Module

The naming module manages the main objectives and their corresponding sub-objectives within the decision support system. This module is designed to maintain consistency in terminology and facilitate easy access to objective names throughout the code.

- The DesignForTyABC class functions as an abstract dataclass that manages the 'design for -ty' names for the objectives.
- The MainAndSubObjectivesABC class is used to organise sub-objectives under their respective main objectives.
- The NamingObjectivesContainerABC class manages all the defined main- and sub-objective names

## Design Performance Module

The design performance module provides the technical foundation for the decision support system. This module is different from the others because it does not include pre-defined helper classes. This is fully project-specific and supports the project-specific objective functions.

For this project, the following design performance classes are created:

- The **Car class** and **Vessel class** represent the vehicles with their specific operational and financial characteristics.
- The **VehicleMagazine class** serves as a catalogue of all available vehicle types (both vessels and cars), while the **VehicleMix class** represents specific fleet configurations by combining quantities of each vehicle type. The vehicle-mix also includes design performance functions that are characterized by the fleet-composition.
- The **VehicleMagazine class** is to serve as a catalogue of the optional vehicles (design variables) from which the optimization can select.
- The **HumanResources class** complements the technical vehicle models by incorporating the human factors into fleet operations. The human resources model provides constraints for the optimization process by determining, for instance, the maximum achievable operational capacity based on available personnel and work patterns.
- The **PortGeographics class** defines the spatial dimensions of the operational area, and the **TimeFrame class** establishes the time-specific boundaries for calculations

## Idealized Design Preferendus Module

he Idealized Design Module is a class and an extension of the Preferendus. It manages the integration of the Idealization objectives with the Realization objectives and can activate the Preferendus algorithm.

The scaling is based on the 'Realization Threshold' and is done according the following algorithm:

$$f_{\text{ideal}} = 1 - r$$

$$f_{\text{real}} = r$$

$$w'_{\text{ideal},i} = f_{\text{ideal}} \cdot w_{\text{ideal},i} \quad \textit{for all } i$$

$$w'_{\text{real},j} = f_{\text{real}} \cdot w_{\text{real},j} \quad \textit{for all } j$$

$$w_{\text{integrated}} = [w'_{\text{ideal},1}, \ldots, w'_{\text{ideal},n}] + [w'_{\text{real},1}, \ldots, w'_{\text{real},m}]$$

Thus, the integrated weights $w_{\text{integrated}}$ are obtained by concatenating the scaled idealization and realization weights based on the Realization Threshold ($0 \leq r \leq 1$). The $w_{\text{ideal}}$ is the list of idealization weights, and $w_{\text{real}}$ is the list of realization weights. The weight distributions can be determined with the method explained in section E.

## Data Storage and Alternative Comparison Module

The data Storage and alternative comparison module provides functionalities for storing results and comparing different fleet configurations.

- The **DataStorage Class** has the functionality to capture the interface configurations and save the data in a directory.
- The **AlternativeComparison Class** has the functionality to analyze the different fleet compositions. It checks on beforehand if the comparison is valid, meaning that the weight distributions and the preference curves are the same. The comparison is based on the Preference Functional Modelling from Barzilai (2022) and uses the PFM-module. The class has the functionality to create a comparison table and to create a radar chart for comparison.

## AI System Analysis Module

The object-oriented Preferendus tool can be used for very complex systems. However, it is still good if the user can see how the different parts of the system are connected. The design performance functions and the objective functions show how the system works. This means that the tool contains a lot of information about the working of the system. The user can use an AI to analyse this information.

The ’System Analysis’ module has been created for this reason. For example, the user can ask the AI how the ’initial response time’ is created.

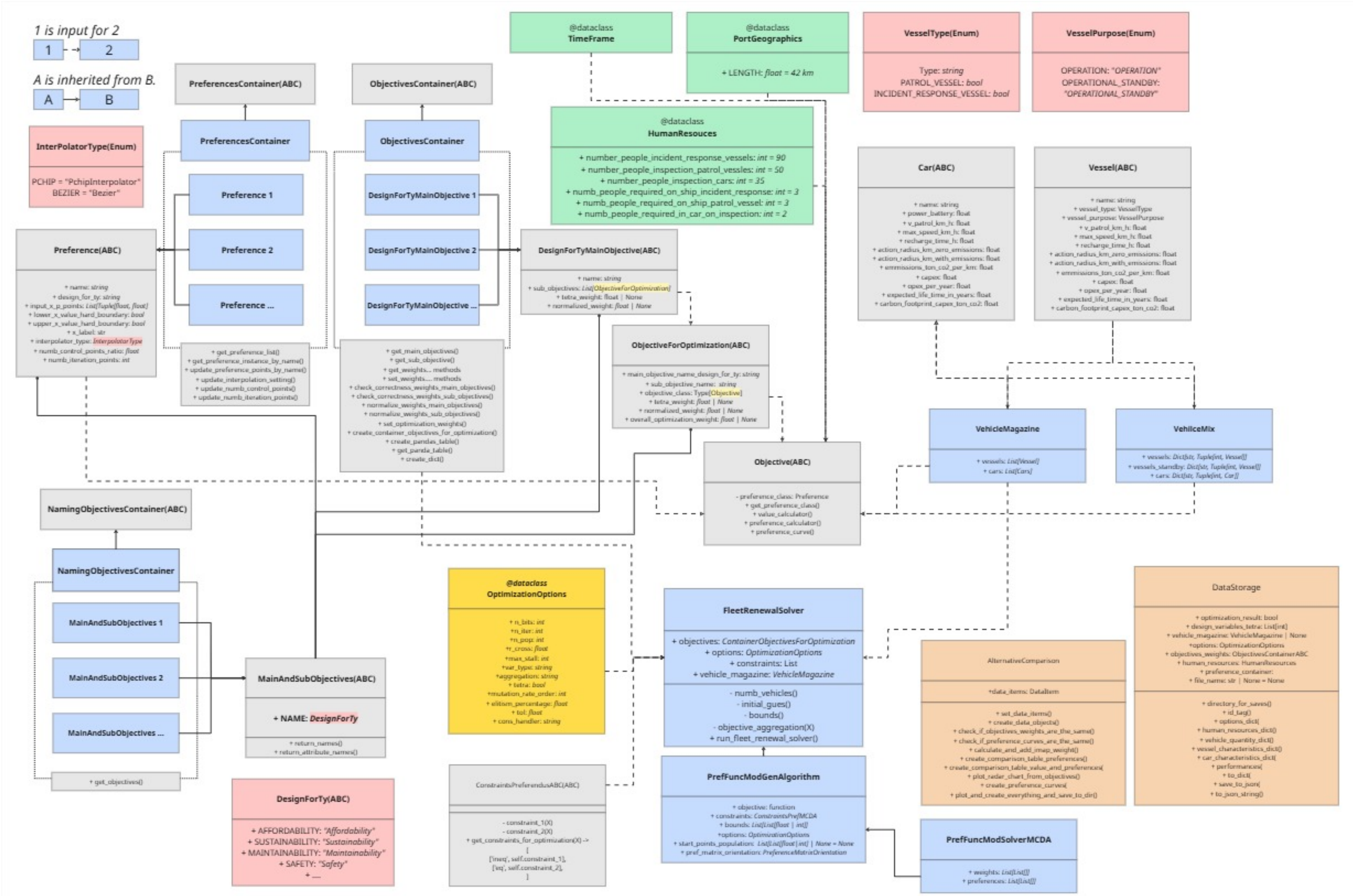



**Figure E.4:** Overview OOP-Python Based Application *(own illustration)*

# F
# Interface

The interface has been developed with distinct pages, each representing a step of the decision-support tool as can be read in section 4.3. The interface is created with the open source Streamlit package (Streamlit, 2021).

## Objectives Selection And Weights Distribution

Inspired by the Tetra software (ScientificMetrics, 2002, 2025) the importance of the objectives are determined by relative distances on a scale between 0 and 100. If an objective should be considered, it should be 'turned-off'. As explained in section E the weight distribution for optimization is determined according equation E.1.

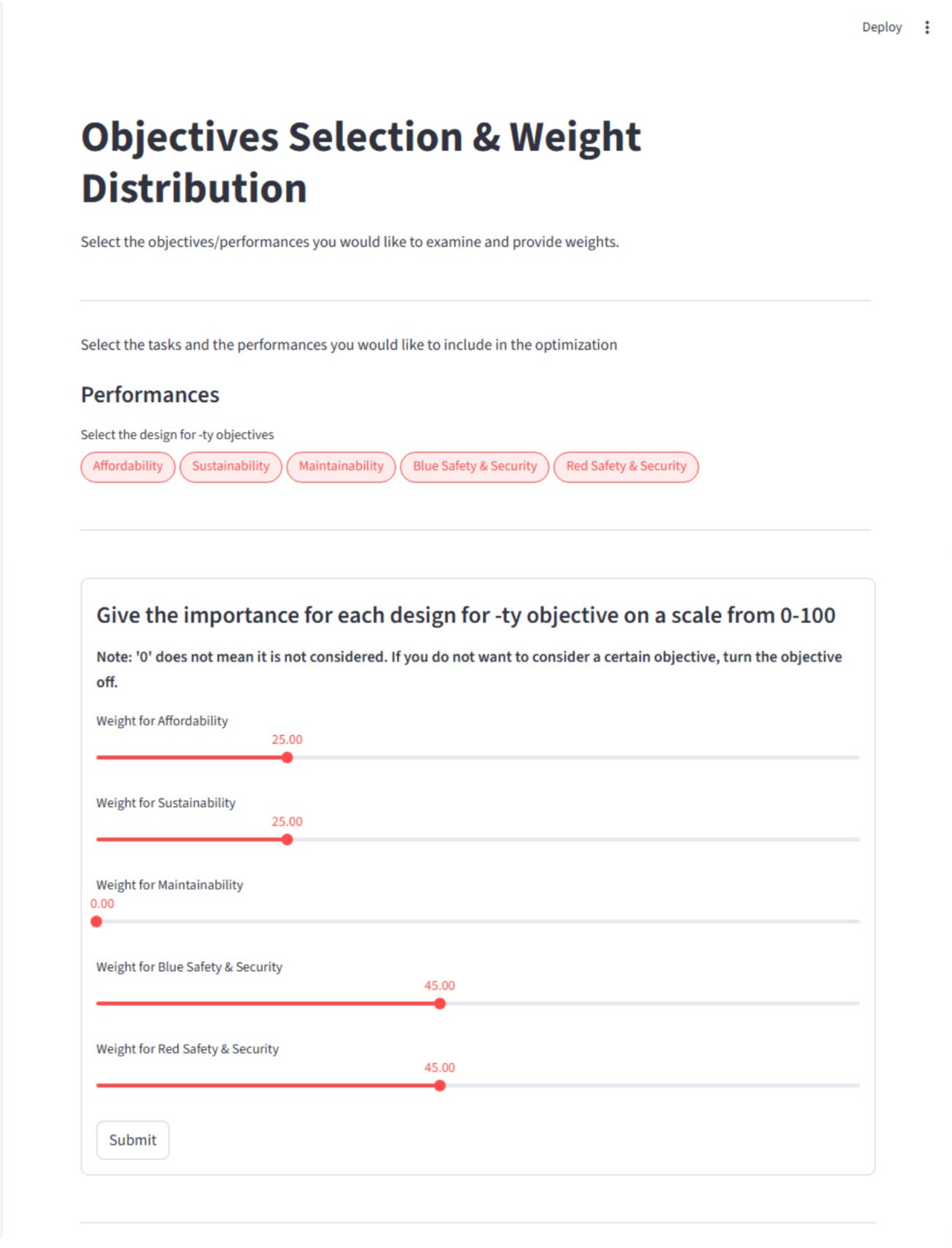



**Figure F.1:** Interface Objective Selection and Weight Distribution


## Overview Objectives and Weights

The column 'Optimization Weights' shows the normalized weights used for optimization

| | Objective | Weight | Sub-Objective | Sub-Weight | Optimization Weight |
|---|---|---|---|---|---|
| 0 | Affordability | 18.421 | | | |
| 1 | | | Opex | 50.000 | 0.092 |
| 2 | | | Capex | 50.000 | 0.092 |
| 3 | Sustainability | 18.421 | | | |
| 4 | | | Carbon Footprint Capex | 50.000 | 0.092 |
| 5 | | | Carbon Footprint Opex | 50.000 | 0.092 |
| 6 | Maintainability | 5.263 | | | |
| 7 | | | Minimize Complexity Number Vessel Types | 100.000 | 0.053 |
| 8 | Redsafetyandsecurity | 28.947 | | | |
| 9 | | | Average Incident Coverage Over Time | 0.000 | 0.000 |
| 10 | | | Average Capacity Coverage | 0.000 | 0.000 |
| 11 | | | Initial Response Time | 0.000 | 0.000 |
| 12 | Bluesafetyandsecurity | 28.947 | | | |
| 13 | | | Inspection Barges | 33.333 | 0.097 |
| 14 | | | Inspection Seafarers | 33.333 | 0.097 |
| 15 | | | Patrol | 33.333 | 0.097 |

**Figure F.2:** Interface Objective Selection and Weight Distribution

# Preference Curves

The preference curve can be drawn with the interface by providing x- and preference-points. All the functionalities of the Preference Class are integrated which are explained in E and I.1.


**Figure F.3:** Interface Preference Curves

## Resources as Boundary Conditions

This page allows users to modify the boundary conditions for optimization, specifically the time frame under consideration and human resources parameters. It should be noted that the human resources aspect of the Fleet Renewal Challenge falls outside the scope of this master's thesis. Consequently, human resources parameters are not fully integrated as design variables but are instead considered as boundary conditions for the optimization process. However, future work could explore making human resources a design variable to investigate optimal organizational structures through system optimization.

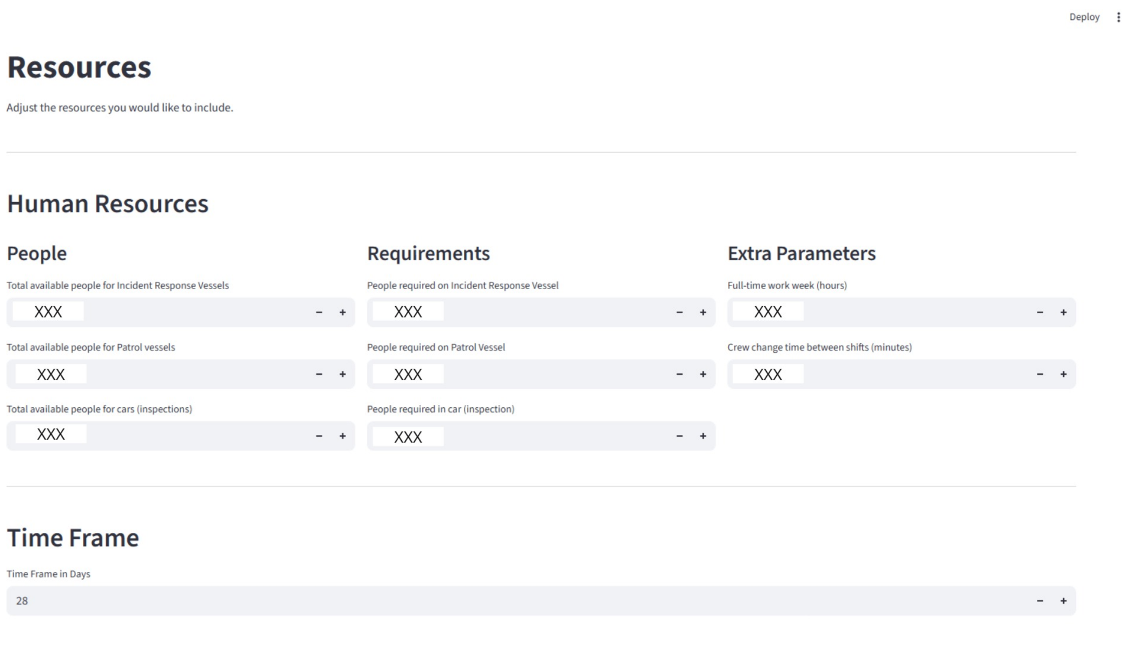



**Figure F.4:** Interface Resources as Boundary Conditions

## Resources as Design Variables

This page facilitates the selection of resources for consideration in the optimisation process. At this stage, the focus is on vessels and cars. However, the potential for expansion into other vehicle types and equipment, such as drones, is a possibility for future research. The interface also facilitates the creation of new vehicles by the user.

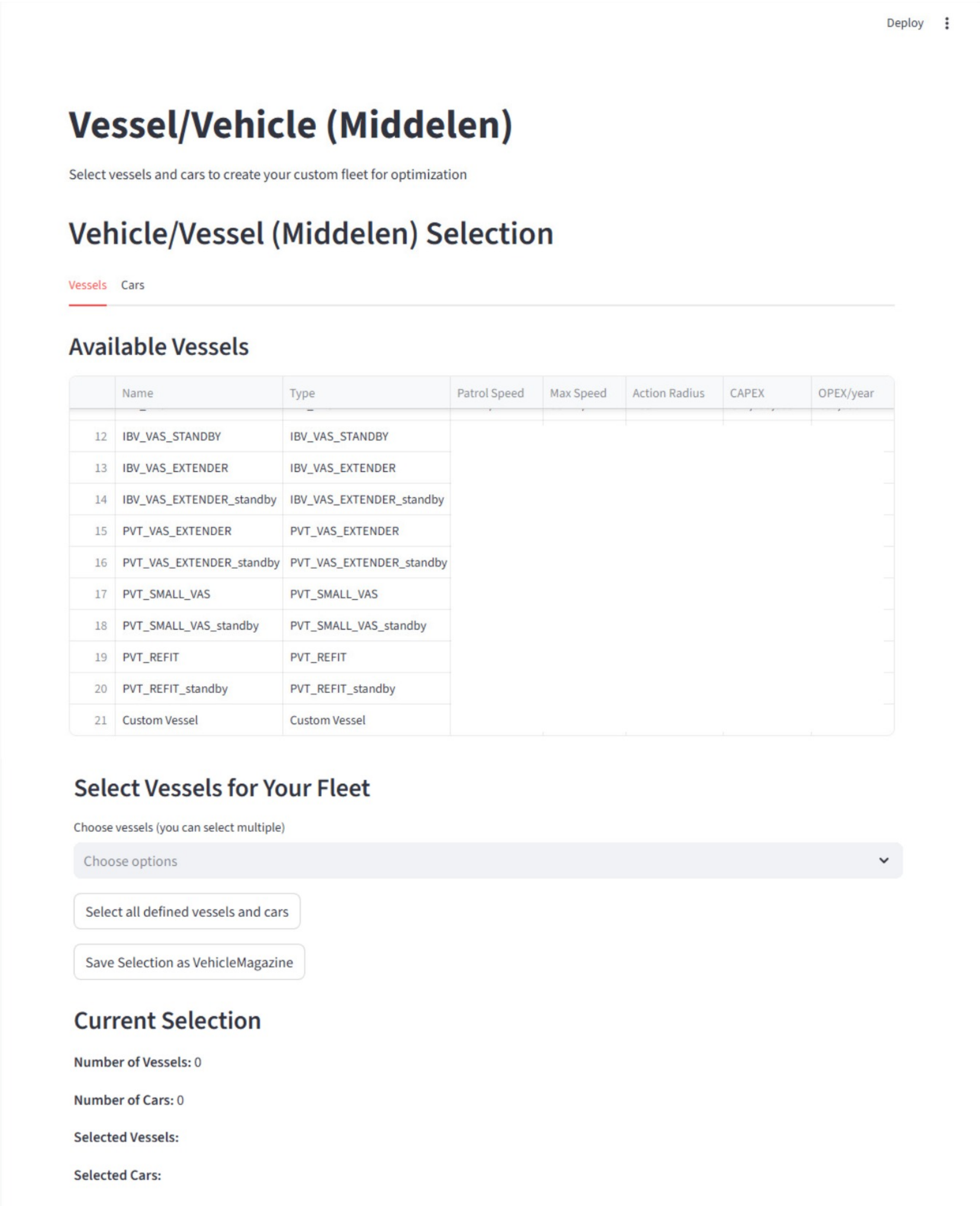



**Figure F.5:** Interface Resources as Design Variables

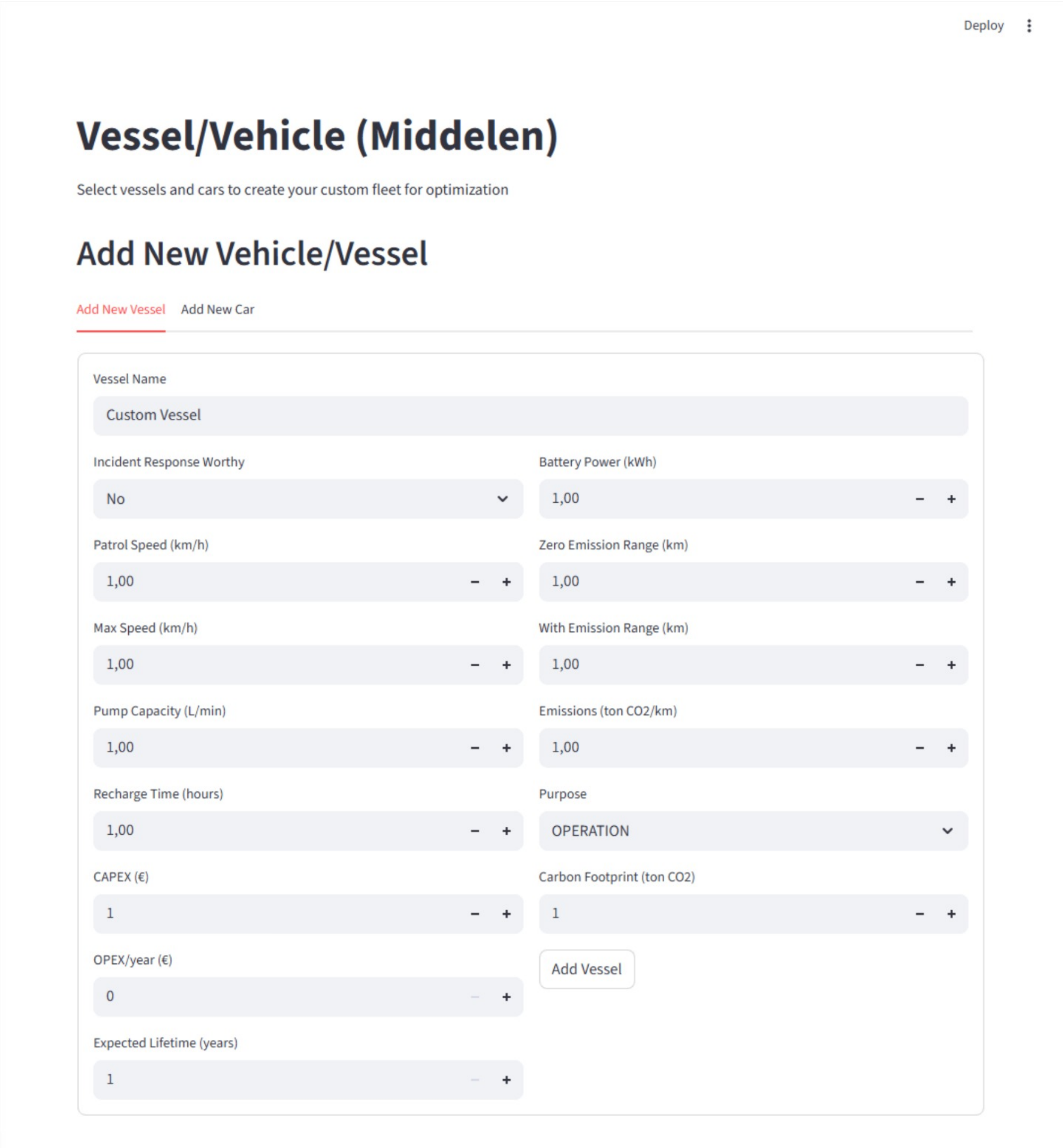



**Figure F.6:** Interface Resources as Design Variables add Vehicle

# Solver; Preferendus Genetic Algorithm

This page provides the possibility to adjust the optimization parameters of the Preferendus Genetic Algorithm and run the algorithm.


**Figure F.7:** Interface Options Preferendus Genetic Algorithm

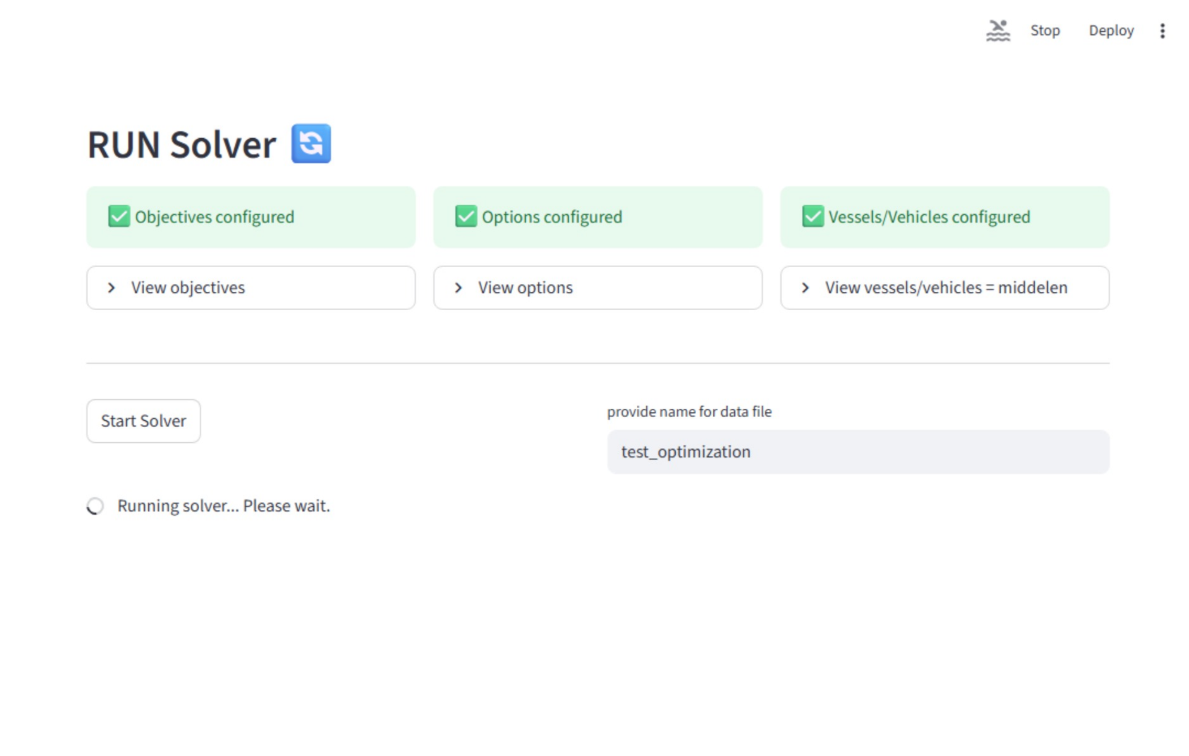
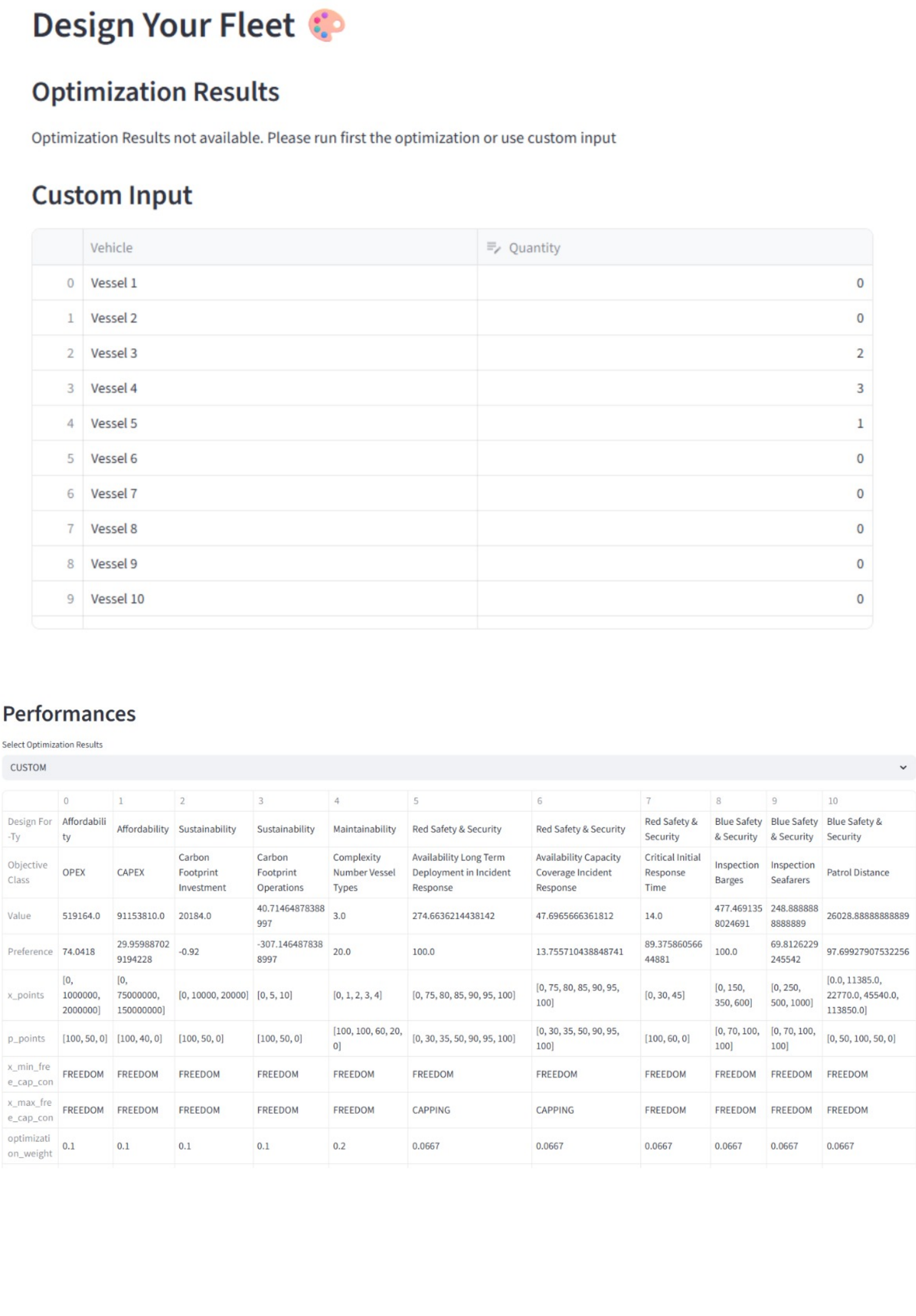



**Figure F.8:** Interface Run Solver Preferendus Genetic Algorithm

# Design Your Fleet

This page provides the possibility to design your own fleet and see the impact on the objectives.



## Design Your Fleet

### Optimization Results

Optimization Results not available. Please run first the optimization or use custom input

### Custom Input

| | Vehicle | Quantity |
|---|---|---|
| 0 | Vessel 1 | 0 |
| 1 | Vessel 2 | 0 |
| 2 | Vessel 3 | 2 |
| 3 | Vessel 4 | 3 |
| 4 | Vessel 5 | 1 |
| 5 | Vessel 6 | 0 |
| 6 | Vessel 7 | 0 |
| 7 | Vessel 8 | 0 |
| 8 | Vessel 9 | 0 |
| 9 | Vessel 10 | 0 |

### Performances

Select Optimization Results

CUSTOM

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Design For -Ty | Affordability | Affordability | Sustainability | Sustainability | Maintainability | Red Safety & Security | Red Safety & Security | Red Safety & Security | Blue Safety & Security | Blue Safety & Security | Blue Safety & Security |
| Objective Class | OPEX | CAPEX | Carbon Footprint Investment | Carbon Footprint Operations | Complexity Number Vessel Types | Availability Long Term Deployment in Incident Response | Availability Capacity Coverage Incident Response | Critical Initial Response Time | Inspection Barges | Inspection Seafarers | Patrol Distance |
| Value | 519164.0 | 91153810.0 | 20184.0 | 40.71464878388997 | 3.0 | 274.6636214438142 | 47.6965666361812 | 14.0 | 477.4691358024691 | 248.8888888888889 | 26028.88888888889 |
| Preference | 74.0418 | 29.959887029194228 | -0.92 | -307.1464878388997 | 20.0 | 100.0 | 13.755710438848741 | 89.37586056644881 | 100.0 | 69.8126229245542 | 97.69927907532256 |
| x_points | [0, 1000000, 2000000] | [0, 75000000, 150000000] | [0, 10000, 20000] | [0, 5, 10] | [0, 1, 2, 3, 4] | [0, 75, 80, 85, 90, 95, 100] | [0, 75, 80, 85, 90, 95, 100] | [0, 30, 45] | [0, 150, 350, 600] | [0, 250, 500, 1000] | [0.0, 11385.0, 22770.0, 45540.0, 113850.0] |
| p_points | [100, 50, 0] | [100, 40, 0] | [100, 50, 0] | [100, 50, 0] | [100, 100, 60, 20, 0] | [0, 30, 35, 50, 90, 95, 100] | [0, 30, 35, 50, 90, 95, 100] | [100, 60, 0] | [0, 70, 100, 100] | [0, 70, 100, 100] | [0, 50, 100, 50, 0] |
| x_min_free_cap_con | FREEDOM | FREEDOM | FREEDOM | FREEDOM | FREEDOM | FREEDOM | FREEDOM | FREEDOM | FREEDOM | FREEDOM | FREEDOM |
| x_max_free_cap_con | FREEDOM | FREEDOM | FREEDOM | FREEDOM | FREEDOM | CAPPING | CAPPING | FREEDOM | FREEDOM | FREEDOM | FREEDOM |
| optimization_weight | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.0667 | 0.0667 | 0.0667 | 0.0667 | 0.0667 | 0.0667 |

**Figure F.9:** Interface Design Your Fleet

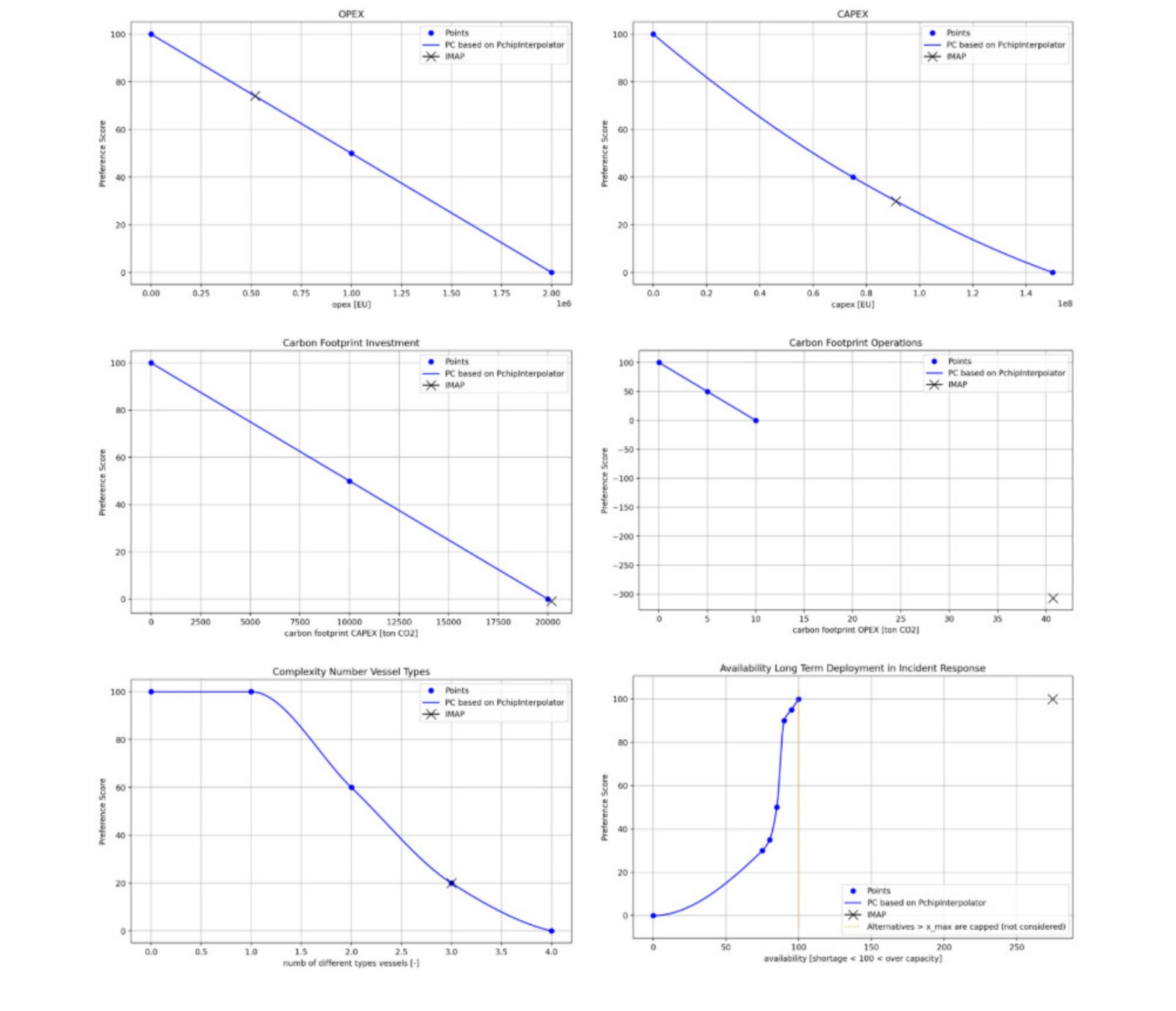



**Figure F.10:** Interface Design Your Fleet

## Performance Analysis

This page provides the analysis of different fleet compositions.

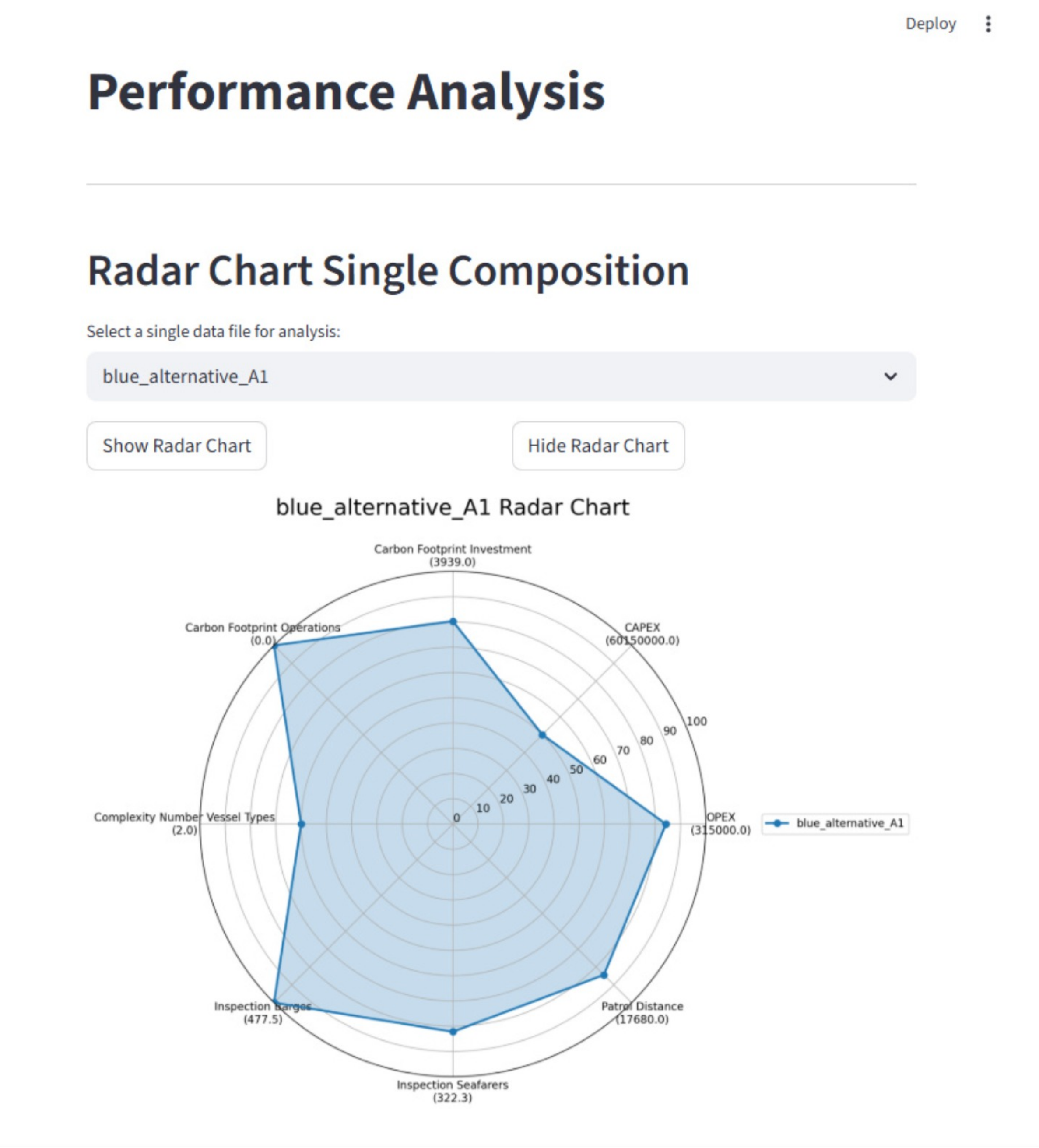



**Figure F.11:** Performance Analysis Radar Chart Single Fleet Composition

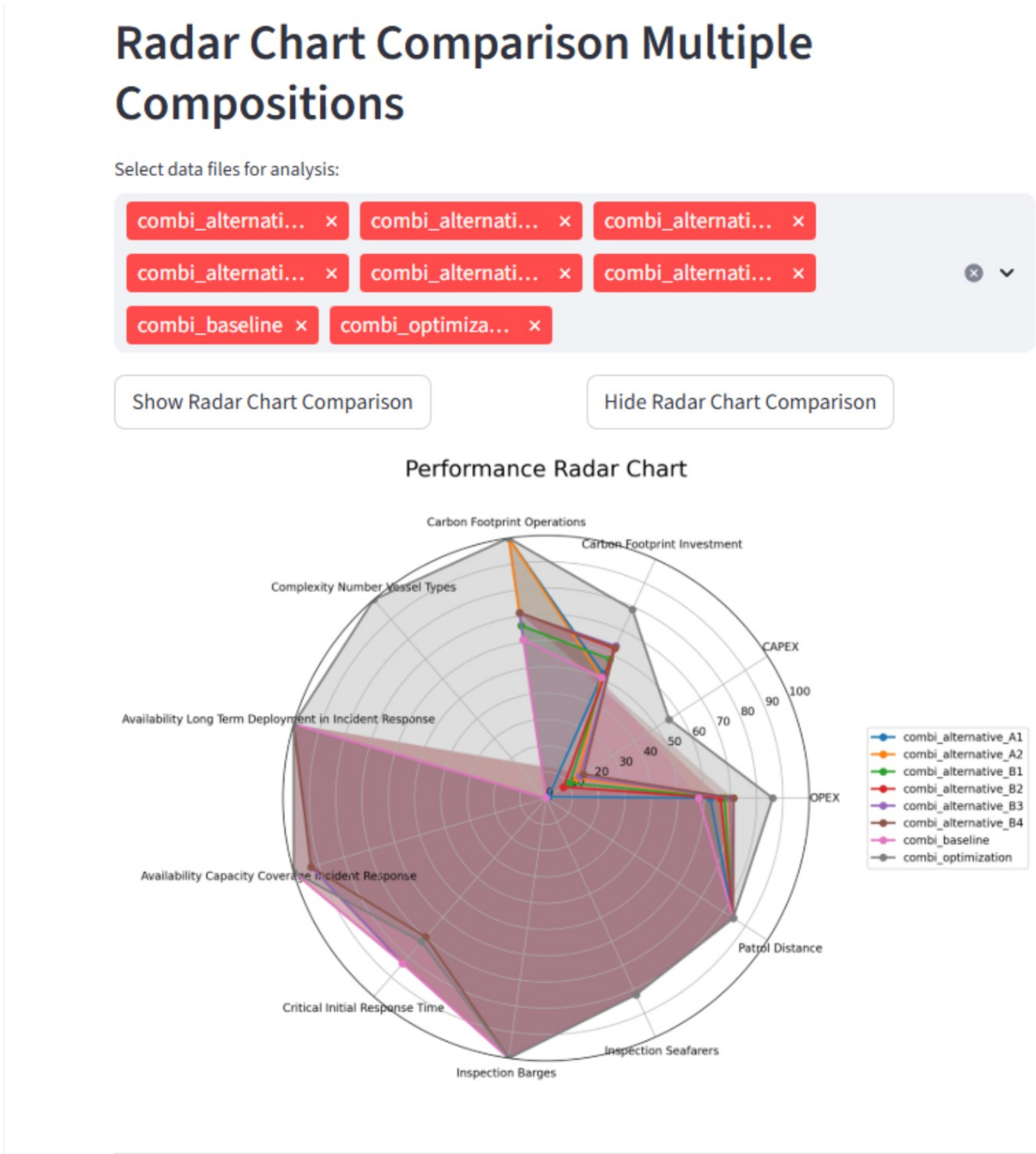



**Figure F.12:** Performance Analysis Radar Chart Multiple Fleet Compositions

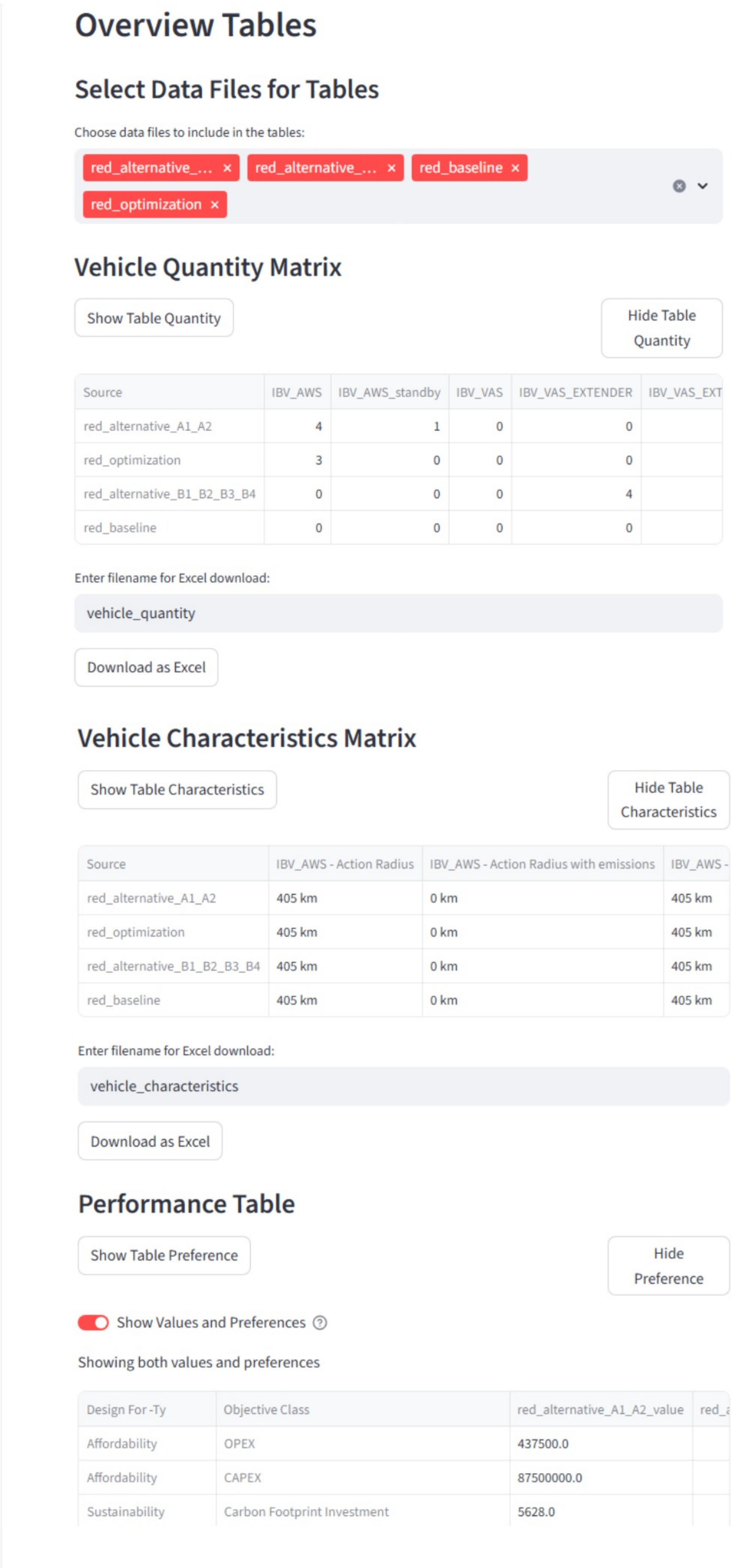



**Figure F.13:** Performance Analysis Performance Tables

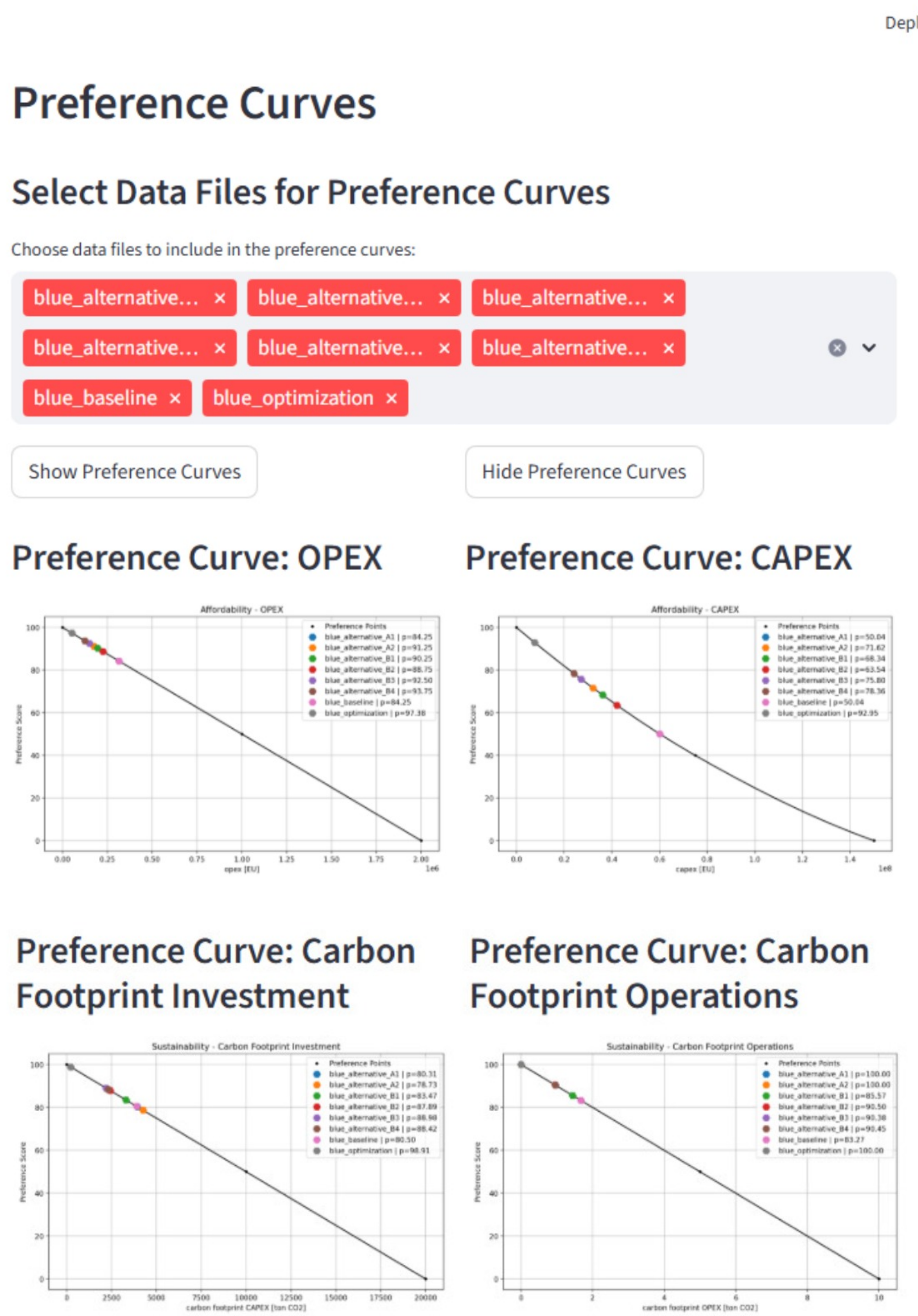



**Figure F.14:** Performance Analysis Preference Curves with Multiple Fleet Performances

# G
# Verification

This chapter provides a more detailed exposition of the verification process. In the course of the graduation project and the development of the preference-based idealised design decision support tool, the basic design cycle (van Boeijen et al., 2020) is applied. At each stage of the process, a thorough evaluation of the functionality was conducted. The process was iterative in nature. The tool's testing was primarily conducted by the developer. A workshop was also conducted with the Port of Rotterdam's supervisory team. The observations made during this workshop contributed to the verification process. The following section provides a concise evaluation of each need and requirement.

## Transparant

**Need: The tool should be transparent.**

- **An interface that is understandable and provides feedback on the taken actions.**

  The interface is understandable to users familiar with the project and the Preferendus Methodology. It would be beneficial to provide the tool with more comprehensive explanations. This is particularly the case when the utilisation of the tool is expected to be more widespread.

- **Preference curves (Preferendus Methodology) to make stakeholders wishes and desires (=preference) transparent.**

  The use of preference curves in decision-making processes has shown a contribution to the value of transparenty, by providing a visual representation of stakeholders' preferences. Furthermore, the gradient of the curves provides insights into the stakeholders' priorities. The tool has been developed with a preference module incorporating both PchipInterpolate and Bézier curves. It is also possible to utilise the functionality associated as 'capping' and 'constraints' (see section I.1).

- **The usage of weight factors to prioritise design objectives**

  The weight factors have been integrated into the interface, and users have the option to modify them. In addition, a specialised methodology has been developed for the purpose of evaluating objectives at that same 'abstract level'. For example, the evaluation of affordability, maintainability and safety and security are evaluated at and considered as on one abstract level. A further abstract level in the hierarchy is that of evaluating capital expenditure (CAPEX) and operating expenditure (OPEX). This level is one abstract level lower than that of affordability (see section E).

## Interactive

**Need: The tool should be interactive.**

- **An interface that is as friendly as possible in the interaction with the users**

  The interface is interactive and provides feedback with all significant actions. The present interface would benefit from enhancement to ensure its operation is smoother, faster and less prone to user errors.

## Social-Technical Aspects

**Need: Integration of social and technical factors.**

- **Preference curves (Preferendus Methodology). To properly integrate design objectives with different metrics (e.g., money in comparison with fossil fuel emissions) and to properly integrate the preferences of the different stakeholders.**

  This is achieved by establishing a connection between preference curves and objectives, which are defined in terms of both financial metrics and other key performance indicators, such as critical response time and the number of inspections.

- **Proper preference calculations (Preferendus Methodology). Based on the work of Barzilai about PFM.**

  The success of this requirement is facilitated by the creation of a special Python module to perform the calculations based on Preference Functional Modelling of Barzilai (Barzilai, 2022). The verification is executed by the use of the data of the H. van Heukelum et al. (2023) and ChoiceRobot of ScientificMetrics (2002). In addition, the examples of Technical University of Delft (2023) are used to verify the outcome.

## Complex Systems

**The tool should be designed for complex systems.**

- **Need: The tool should be designed with the principles of Object-Oriented Programming (OOP). This socio-technical system of fleet operations is a systems of systems problem. Working with objects is beneficial to make the code understandable, maintainable, and extendable. It is also easier for the model-interface integration.**

  In the early developmental stages of the tool, implementing object-oriented programming (OOP) principles required a significant effort. However, as the project progresses, it has shown evidence of flexibility and scalability, primarily due to the fact that the objects are only required to be created once. Due to the concept of inheritance, new objects are easily created.

  The integration of the tool with an interface facilitates the deployment of applications based on the Preferendus Methodology by other practitioners. It would be interesting to create an open-source library that can be shared with everyone who is interested.

  Although the author has developed its coding skills professionally, through side-projects and self-study, it is important to note that the author of the thesis has not studied computer science. Especially, the author had never previously created an application, including both the tool and the interface. Due to the author's lack of prior professional experience, it is reasonable to assume that a significant number of enhancements can be made regarding the tool. Specifically, the interface is operating at a rather slow speed. Perhaps a more appropriate solution could be found in an alternative library to StreamLit.

- **To make the Preferendus Genetic Algorithm (GA) workable with OOP, the PFM-calculations need to be locally automated and integrated into the GA.**

  The success of this requirement is facilitated by the integrating the creation of a special Python

Preference Functional Modeling module of Barzilai (Barzilai, 2022) in the Preferendus Algorithm of H. J. van Heukelum (2022). Moreover, the Preferendus algorithm has been rewritten in a more object-oriented style, a change which has been shown to enhance maintainability and robustness. The verification is executed by the use of the data of the H. van Heukelum et al. (2023) and ChoiceRobot of ScientificMetrics (2002). In addition, the examples of Technical University of Delft (2023) are used to verify the outcome.

## How the Solution Should be Found

**Need: requirements about how the solution should be found, facilitated by the tool (social-need).**

- **Collaborating with internal and external stakeholders to create economic societal value.**

  The tool is developed with the Preferendus Methodology, aimed to find an 'fit for common purpose' solution for the fleet renewal challenge. The Preferendus Methodology has previously been demonstrated to be capable of identifying the 'best fit for purpose' solution in other contexts (Aulbers, 2023; Mol & Schriever, 2024; Pallandt, 2025; Raaphorst, 2024; Teuber & Wolfert, 2024; van Eijck & Nannes, 2022; H. J. van Heukelum, 2022; H. J. van Heukelum et al., 2023). This is also the case for this master's thesis, as it can be considered as an additional case study that serves to demonstrate the usefulness of the Preferendus Methodology.

  However, the concept of a 'common purpose' is not fully explored in this thesis. The scope of this master's thesis project was confined to the internal stakeholders, and this could have been conducted with greater precision. Nevertheless, this was not a possibility due to the time constraints. The tool itself is capable of integrating all the preferences (preference curves and weights of the objectives) of the stakeholders. It is recommended that the development of an additional functionality be initiated, namely the integration of preference curves from multiple stakeholders, alongside the creation of a separate interface for each stakeholder.

- **Be adaptable to respond effectively to geopolitical tensions and rapid technological advances**

  The exploration of this topic was constrained by the limited time available. The tool has the capacity to incorporate objectives related to geopolitical tensions and rapid technological advances.

- **Apply systems-of-systems thinking to investigate the solution space and address the systems-of-systems complexity of fleet operations.**

  This requirement is succesfull as the tool is capable to provide systems-of-systems calculations by the use of Objected-Oriented-Programming (OOP).

## What the Solution Should Include

**Need: requirements about what the solution should include (technical-need)**

- **Synergies to improve the safety and security of the harbour region, despite the key-issues, by enhancing collaboration among the various internal and external stakeholders.**
- **The company-wide vision to create and implement a new fleet that creates value for all stakeholders.**
- **Sustainable practices to create the most sustainable port and fleet.**
- **Modern equipment and workflows to be a leading port with the latest technologies, equipment and workflows to ensure modernisation.**
- **Technical resources as enabler for service delivery.**
- **Human resources as enabler for service delivery.**
- **Current tasks as design requirements and baseline.**
- **Future tasks, making sure "Tomorrow's Fit for Purpose Sustainable Fleet".**

- **Service-level-expectations of the stakeholders as an influential determinant of defining task performance.**
- **Preference of all Stakeholders to create a widely supported solution.**

These requirements are based on the the preliminary analysis of the fleet renewal challenge, and are factors which influence the outcome of the composition of the new fleet. It has been demonstrated that the tool possesses the capacity to fulfil all the aforementioned requirements. However, it is important to acknowledge that the verification tests remain predominantly conceptual in nature. It is recommended that further research would be conducted with this tool, with the primary focus of the finding of a solution for the fleet renewal challenge. This study should use the tool to explore and integrate all these factors and requirements. This study should not focus on the improvement or development of the tool as that is too time-consuming.

# H
# Computer Modelling for Design and Operational Research

For the creation of this master's thesis and also for analysing the Port of Rotterdam's Fleet Renewal challenge, design thinking is applied.

In an ideal scenario, design is a thought process that works towards a situation where the 'abstraction' of what is 'desirable' is concretised into something (the product) that is both 'capable' and 'desirable', resulting in 'fitness for purpose' (van Gunteren et al., 2011, 2013; Wolfert, 2023). This can be undertaken by an individual, a small group, or the entire organisation, and even society at large. In the event of multiple users or stakeholders being involved in the product's usage or being affected by it, the term 'fitness for common purpose' is applicable.

The design process can take various forms, is not a 'linear process' but 'iterative', has multiple levels of abstraction, and involves 'diverging' and 'converging'. As the process continues, more information will be gathered. The latter can be conceptualised by imagining a rolling snowball, with the size of the snowball representing the available information, that increases with each cycle. Another aspect of design is the need to make design choices that have implications on the solution space and, therefore, the final design. Figure H.1 is a useful illustration of the diverging and converging characteristics in Design, and the role of design decisions.

It's hard to keep track of all the design decisions. In the last decades, this was usually based on documents. In this context, it is hard to repeat the design process quickly. With better software and more computing power, it is possible to redo the design process over and over again. This can be done by recording the design process by translating the design choices into a computer programming language. By recording design choices, the tool can redo the design process over and over again. This creates the possibility of reflection on the design choices. If this is done using an iterative approach, alongside the knowledge gained over time, the system can be improved based on the first design choice up to the last design choice.

This master's thesis aims to create a tool that facilitates the design process and can be seen as a form of Operational Research[1] (OR). Although this is already beneficial for the design process, the tool can also be used for operational research at later stages. Once the new fleet has been designed and purchased, the tool can essentially be seen as a digital replica of the fleet. During use, the tool can therefore be used to support decision-making.

[1]Operational research (OR) and analytics focus on solving complex management problems by combining scientific principles, empirical evidence, and analytical methods. This enables organisations to make informed decisions and optimise business operations (Informs, 2026; Operational Research Society, n.d.)

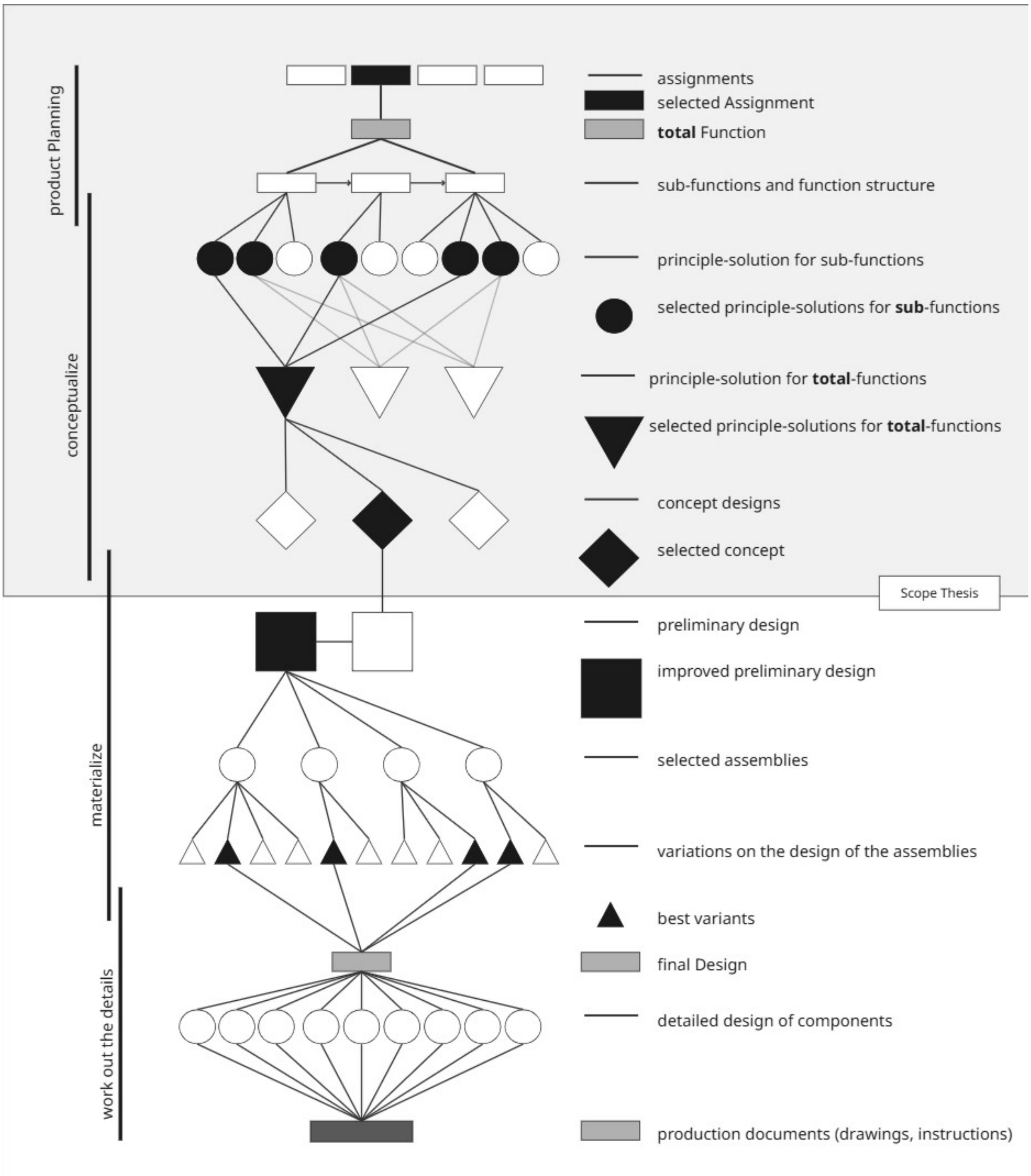



**Figure H.1:** Design Process of Converging and Diverging (*re-illustrated and reproduced in full from Verein-Deutscher-Ingenieure (1986), which appeared in Roozenburg and Eekels (2016, p. 123)*)

# I

# Preferendus Methodology, Thoughts and Reflections

## I.1. Inside- & Outside the Preference Box (Or trap?)

While introducing the Bézier curve, it is discovered that Bézier-curves does not provide values outside the bounds of the defined x-points. That gave food for thought and raised the question: how can the preference value be determined outside the bounds?

---

### Inside the Preference Box

The implemented solution of H. J. van Heukelum et al. (2024) is examined. This solution can be characterized as *'inside the preference box'*:

If the preference values are outside the limits of 0 or 100, the preference scores are set to the lower (0) or upper limit (100).

In Code:

**Listing I.1:** Inside the Preference Box Code

```

def mask_p(p):
    mask1 = p > 100
    mask2 = p < 0
    p[mask1] = 100
    p[mask2] = 0
    return p
```

In the context of the Port of Rotterdam, the current response time requirement for incident response vessels is within X1 and X2 minutes, for any location within the harbour. For illustration purposes, the arbitrary numbers 75 and 85 will be employed. The following preference curve could be drawn:

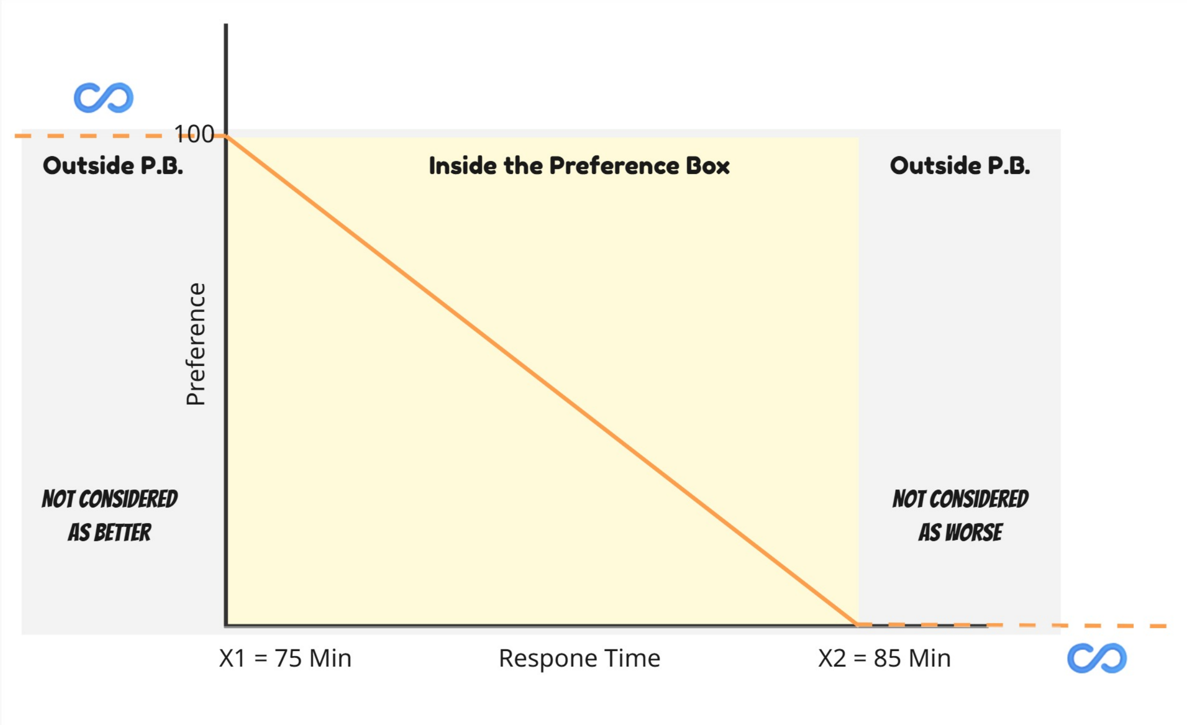



**Figure I.1:** Inside the Preference Box Demonstration Figure *(made with Miro (Miro, 2025))*

When implementing the solution H. J. van Heukelum et al. (2024), the Preferendus Algorithm considers the design-alternatives which are lower than 75 minutes ( $X1 < 75$) equal to the solution that is 75 minutes ($X1 = 75$) (by assigning the preference = 100). In math-notation: If $X \leq 75$ —> $P = P(X = 75)$.

Is this useful, and is this not a 'trap' that keeps the system sub-optimal within the known (preference) box? Would it not be beneficial to 'know' that a lower response time is possible with a certain design alternative? How can the system ever evaluate to an improved system if our assumptions, based on the present mode and characterised as 'inside the preference box', determine our perception of how the future mode should be designed?

---

## Beyond the Box - Beyond the Initial Perception

In this phenomenon, it is important to recognise that the preference curves are a reflection of the thought process of stakeholders, which is based on their perception of reality and the functioning of the social-technical system. Nevertheless, perception is not reality itself, but rather a construct based on reality.

The following exercise by Ackoff et al. (2007, p. 14) will help to make this point. Most people are finding it hard to find the solution. But when people are encouraged to think in new ways by drawing outside the 'lines', "the solution is relatively easy" (Ackoff et al., 2007).

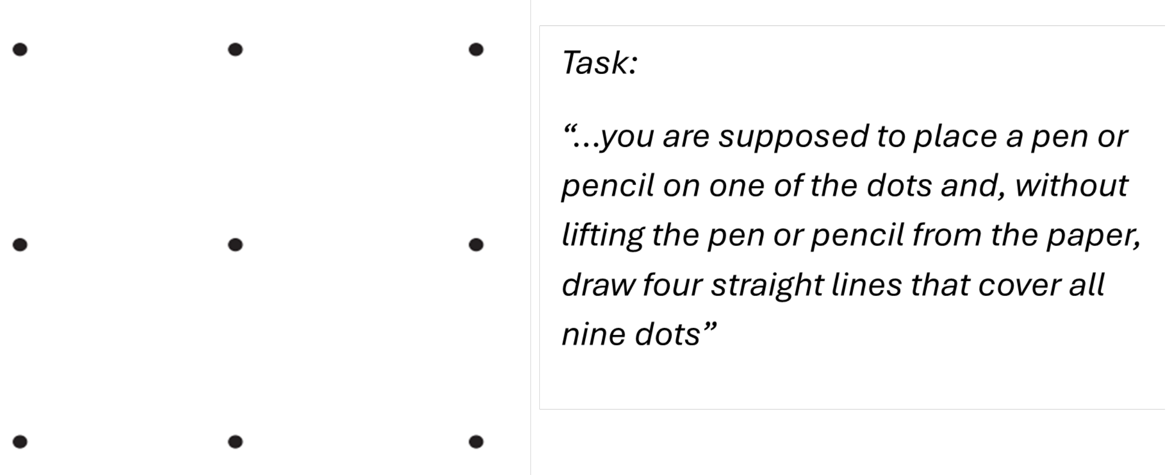



**Figure I.2:** Exercise from Ackoff et al. (2007, p. 14) to demonstrate the ”inside and outside the preference box”

The following quote of Arthur Schopenhauer is also an argument against the ‘inside the preference box’-method:

*“Thus the task is not so much to see what no one yet has seen,*
*but to think what nobody yet has thought about that which everybody sees.”*

- Arthur Schopenhauer -

Computer (mathematical) models can be perceived as a manifestation of the creators’ thought processes. In the context of highly complex systems, creators are constrained in their ability to consider a large number of factors. However, a (computer) model can help with considering all the factors. Designed by the creators, the model reflects their thinking process, serving as a mirror for reflection. The model does not provide information that the creators ‘have not yet seen’. If there were any information, it would already be modelled. Nevertheless, the model can ‘think’ what nobody yet has thought about that which everybody sees” by providing a design alternative that is feasible but beyond what ‘everyone has seen’. Although this can be accomplished using the ”inside the preference box” method, it is even more the case with the ”outside the preference box” method.

The following questions can be asked based on these findings: What if the ’best’ solution lies outside the defined preferences, as described as ’outside the preference box’? How should preferences be scored when they fall outside the bounds of the defined x-points?

---

## Beyond the Box; Extrapolation Outside the Preference Box

The PchipInterpolator (PchipInterpolator — SciPY V1.16.2 Manual, n.d.) can extrapolate the line with the slope of the last intervals. Extrapolation could be considered as ”valid” in the scenario where a preferred line is defined as a single straight line and therefore a constant slope. The following proposed solution is therefore put forward for consideration:

Extrapolate the preference curve when the value is out of the bounds of the defined x-values.

To explore this possibility, three paragraphs follow below: (1) Validity of the concept, (2) Validity of the practice, (3) Reflection.

1. **Validity of the concept**
   In the preference curve below, extrapolation can be seen. The slope of the last segments is used (in this case, it is the same) for the extrapolation. In practice, a preference value > ‘100’ or <

'0' is possible. It is important to note that these preference numbers are arbitrary, and only the scale differences between at least three alternatives are important. For instance, the numerical sequence 20-50-80 denotes equivalent preference scores to that of 100-180-260 for the three distinct alternatives, A, B and C, respectively. For the sake of convenience, the scale between 0 and 100 is utilised, as this is generally understood to be equivalent to percentages, with 100 representing 'full' satisfaction and 0 representing no satisfaction.

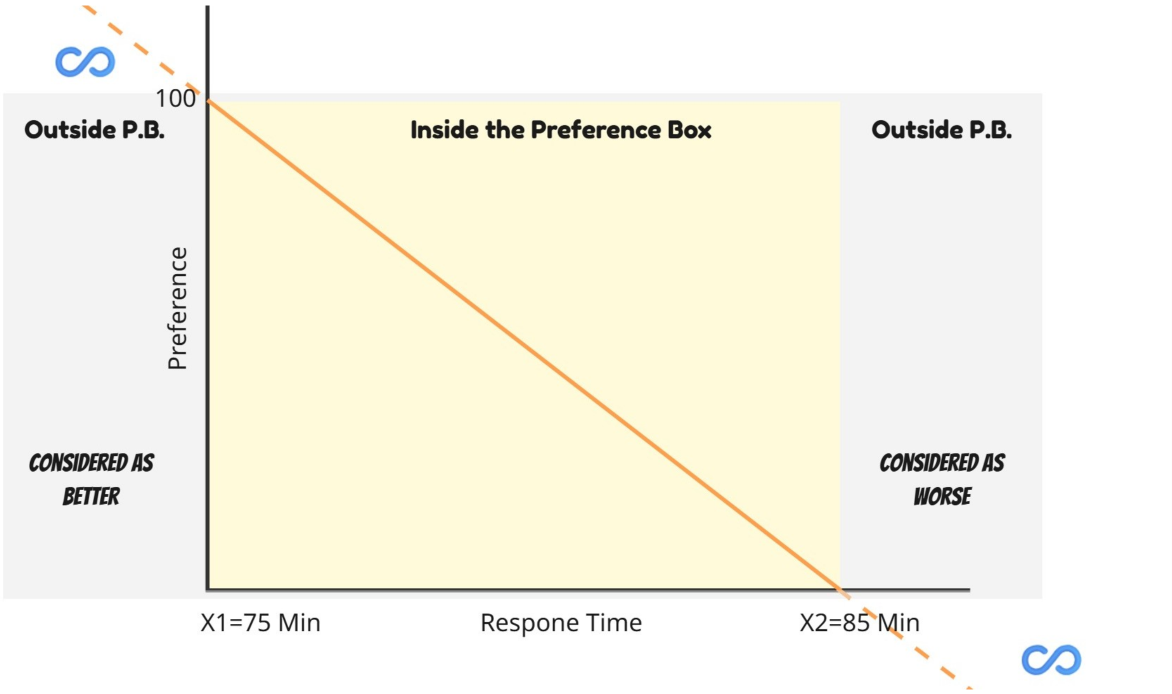



**Figure I.3:** Extrapolation Outside the Preference Box Demonstration Figure *(made with Miro (Miro, 2025))*

From a social-cycle perspective, it could be argued that when 'the game is played', the preferences can be adjusted during the play. With the first design iteration, the initial start point is set with 75 minutes corresponding to a preference score of 100 (indicative of complete satisfaction). In the second iteration, the stakeholder(s) may adjust their preference score to align with the scenario wherein 65 minutes is equivalent to a preference score of 100 (representing complete satisfaction).

From the perspective of the mathematical formulation developed by Barzilai (Barzilai, 2022), the validity of these calculations is determined not by the specific number, but rather by his notion that the scale difference between at least three alternatives in an one-dimensional affine space is the determining factor. In short, the 'arbitrary' number is of no importance; the scale-difference is. For instance, the numeral '260' is equivalent to '80' and '60', provided that the scale remains constant between the other points (see the table below). From this standpoint, it could be argued that extrapolation is an acceptable practice because 65 minutes with a preference score of 200 can be the same as a preference of 100. Both can represent the highest preferred score. Although this thesis has studied this subject extensively, the author is not a mathematician. Further research is therefore recommended.

2. **Validity of the Practice**
   In the above example of 'response-time', the preference curve is a straight line and therefore the slope is constant. Extrapolation with this slope can be seen as valid. But what if the preference curve is not straightforward?
   It is a theoretical possibility for a preference curve to be of any shape. For instance, consider the preference curve for 'project duration'. The duration of a project is influenced by a number of factors. For example, the project scope, the quality of the work, the approval of permits, weather

**Table I.1:** Example of equal scoring of alternatives with different values but same scaling. It is important to note that these preference numbers are arbitrary, and only the scale differences between at least three alternatives are important. For instance, the numerical sequence 20-50-80 denotes equivalent preference scores to that of 100-180-260 for the three distinct alternatives, A, B and C, respectively.

| | Alternative A | Alternative B | Alternative C |
|---|---|---|---|
| Scores | 20 | 50 | 80 |
| | 100 | 180 | 260 |
| | 0 | 30 | 60 |
| | -30 | 0 | 30 |
| | -100 | -180 | -260 |
| Normalized | -1.2247 | 0 | 1.2247 |
| | -1.2247 | 0 | 1.2247 |
| | -1.2247 | 0 | 1.2247 |
| | -1.2247 | 0 | 1.2247 |
| | -1.2247 | 0 | 1.2247 |

**Table I.2:** Example of equal scoring of response-time with different values but same scaling. It is important to note that these preference numbers are arbitrary, and only the scale differences between at least three alternatives are important. For instance, the numerical sequence 20-50-80 denotes equivalent preference scores to that of 100-180-260 for the three distinct alternatives, A, B and C, respectively.

| | Alternative A | Alternative B | Alternative C |
|---|---|---|---|
| Response time | 65 min | 75 min | 85 min |
| Preference Score | 200 | 100 | 0 |
| Preference Score | 100 | 50 | 0 |
| Preference Score | 100 | 0 | -100 |

conditions, the availability of materials, the workforce, project complexity, logistics, and so forth. It is possible to calculate an estimate of the average duration of a project and assign that value to the maximum preference setting (p = 100). It is then stated that a reduction in project duration has a negative impact on quality and is therefore less desirable. The stakeholder may also choose to incorporate the relationship between project duration and project scope. It is reasonable for the stakeholders to consider two project scopes, categorised as either 'small' or 'big', and it is not feasible to take aascope in between these two discrete scopes. For instance, consider the process of constructing an underground parking garage. In the given scenario, the construction of a parking garage is undertaken with one or two levels, not one and a half. The following preference curve could be drawn (see below).

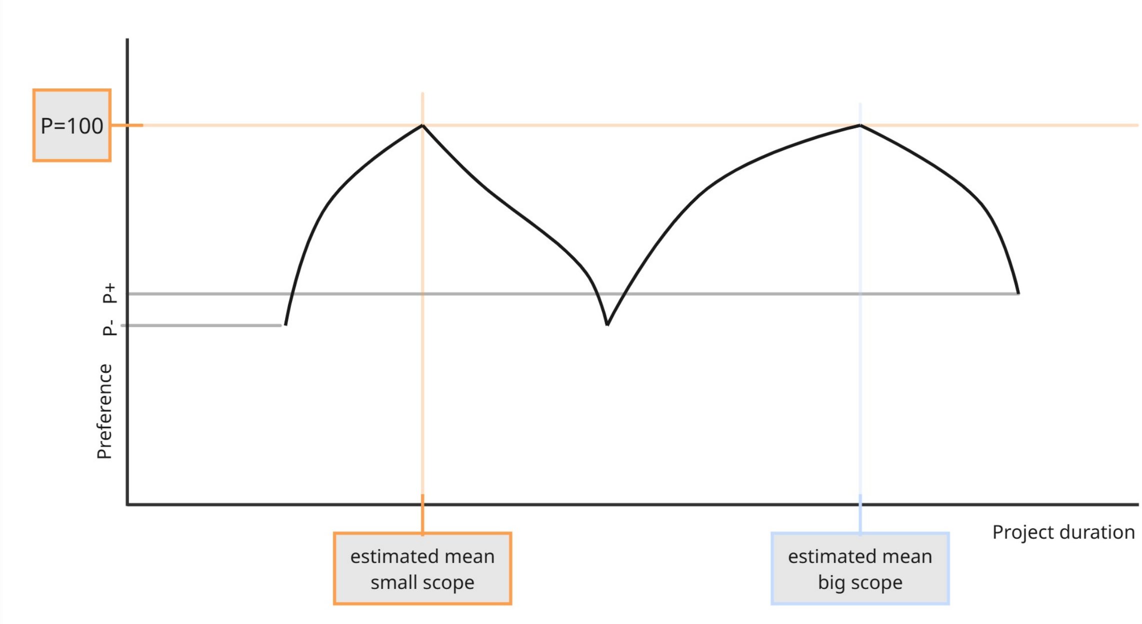



**Figure I.4:** Example ”No-Pure” Preference Curve Project Duration *(made with Miro (Miro, 2025))*

In this case, extrapolation is difficult to consider because the stakeholder incorporates a lot of factors in its preference. This thesis states that these kinds of preference curves are not ‘pure’ and should not be used. More about this can be read in section I.2.

One potential solution to this issue would be to consult with the relevant stakeholders to ascertain whether extrapolation is acceptable in this context.

If extrapolation is preferred, the preferences that are located outside of the designated preference box can be limited to the upper or lower extremes of the preference curve. In this particular case, for the duration of the project, this means that preferences are set to ’P-’ or ’P+’ (this phenomenon is named as ’capping’).

It is important to note that capping of preference values beyond the defined extremes of the preference curve is not the same as setting constraints. In the context of ’capping’, design alternatives that fall outside the bounds of the extremes are still considered, while these design alternatives are not considered when using constraints.

In the event that ’capping’ or setting ’constraints’ are both unsatisfactory, the facilitator may request a more detailed definition of the preference curve from the participant, including any sections that have not yet been defined. A more effective approach would be to request that stakeholders define multiple objectives, rather than combining them into a single one.

**Options to deal with Inside-Outside the Preference Box:**

- **No capping, no constraints**: *(highly preferred option)*
  All alternatives are evaluated. If needed by extrapolation. Alternatives and preferences are evaluated Inside- and Outside the Preference-Box.

- **In the case of capping**:
  All alternatives are evaluated by extrapolation. Alternatives are evaluated Inside- and Outside the Preference-Box and preferences are capped to the edges of the preference-box. This means that the model evaluates alternatives outside the preference box but is unable to determine whether an alternative is worse or better than the alternatives defined within the preference box.

$$\text{Design alternatives } i \text{ with } x_i < x_{\text{min}} \rightarrow \text{evaluated but given } P = P(x_{\text{min}})$$
$$\text{Design alternatives } i \text{ with } x_i > x_{\text{max}} \rightarrow \text{evaluated but given } P = P(x_{\text{max}})$$

- **In the case of constraints**:
  All the alternatives outside the preference-box are not evaluated. Only alternatives inside the preference are evaluated by the model.

$$\text{Design alternatives } i \text{ with } x_i < x_{\text{min}} \rightarrow \text{not evaluated}$$
$$\text{Design alternatives } i \text{ with } x_i > x_{\text{max}} \rightarrow \text{not evaluated}$$

3. **Reflection**
The Preferendus Methodology works with preferences that correspond to the utility theory. To calculate with preferences in a proper way, the Preferendus Algorithm makes use of the Preference Function Modelling (PFM) of Barzilai (2022).

*A: inside-the-preference-box*
When using the 'inside-the-preference-box' method, it could be seen as a way of keeping all stakeholders satisfied, whereby the social-technical system is designed based on the principle of achieving the highest overall aggregated preference without violating anyone's preference box. This can be seen as alternative A in the table below. In this case, constraints must be added to eliminate design alternatives that fall outside the preference box. When using the 'capping' method, alternatives outside the preference box will be evaluated and indicated by the capped preference value of '0' or '100', even if the extrapolated preference would be, for example, +10,000 or -10.000.

*B: inside-outside-the-preference-box*
As design participants, the stakeholders can agree that it is not possible to violate anyone's lowest preference and allow others to become more satisfied than initially indicated. This can be named as 'inside-outside-the-preference box' and can be seen as alternative B in the table below. In this case, they should add constraints to the locations of the lowest preferences and not 'cap' it. When constraints are employed, design alternatives with a lower preference rating will not be evaluated. However, when 'caping' is used, these alternatives will be evaluated, but the preference rating will be indicated as '0', and the model does not know that an alternative is less preferred by the stakeholders.

*C: outside-the-preference-box*
The stakeholders have the option of employing the 'outside-the-preference-box' method. This can be seen as alternative C in the table below. This approach enables the identification of an alternative that lies outside the defined preferences and is superior to the alternatives within the defined preference box.

**Table I.3:** Aggregated Preference Scores for Alternatives

| Alternatives | Objectives (equal weights) | | | Aggregated Preference | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | Not Normalized | Normalized |
| A | 100 | 100 | 100 | 16.6765 | 58.26 |
| B | 0 | 100 | 250 | 16.6667 | 52.75 |
| C | -50 | 100 | 300 | 16.5727 | 0.0 |
| C* | -50 | 100 | 350 | 16.7508 | 100.0 |

*Reflection of System Improvement*
When the goal of the design objective is to create an improved system as a whole, one cannot

solely focus on improving the separate parts (Ackoff et al., 2007). In this light, the use of the "inside-the-preference-box" method with capping or/and with constraints is not contributing to the goal of improving the system as a whole. While extrapolation will, and is enabled by, the 'outside the preference box' method. This can be seen as alternative C in table I.3 above.
*Reflection of Ethics*
Whether or not it is ethical depends on the meaning of the objective and the stakeholders' perspectives. For example, if the objective is to consider only technical aspects, extrapolation will be acceptable, whereas if the objective is related to humans, animals or the natural environment, extrapolation could have ethical implications. Although it is interesting to explore ethical theories and their implications, this is outside the scope of the thesis and is recommended for further research.

---

### Proposed Guidelines Inside- & Outside the Preference Box

The preceding findings demonstrate the importance of being aware of the implications that the preference function configuration has on the final automated design produced by the Preferendus algorithm. To address these implications, the following advice has been formulated and must be implemented in the social cycle (the social process relating to the stakeholders):

1. Do not restrict extrapolation for the sake of the pursuit to discover design alternatives to improve the system as a whole.
2. Consider the ethical implications of the objectives. If important, consider using constraints.
3. Discover if extrapolation is 'valid' based on the end-slopes of the preference curve. If so, leave it. If not, ask the stakeholder to define its preference to a broader extent.
4. As a facilitator, you may ask whether the preference points outside the preference box should be considered. Beyond the two extremes of the x-points, it could be the case that these preferences can be capped on the extremes. Note that this differs from constraints! Because if you define the design alternatives beyond the extremes of the x-points as invalid (through constraints), these design alternatives are not considered at all. If it is not defined as a constraint but capped at the extremes, the design alternatives beyond the extremes of the x-points are considered, but the model scores it as the extremes of the preferences (p=0 or p=100).

## I.2. The consequence of no 'pure' objectives

Mol and Schriever (2024, p. 17) stated a criterion of the Social Cycle as:

> "Stakeholders should understand what their preference represents with respect to the **outcomes**".

This is considered impossible in very complex systems. One cannot overlook the impact of a criterion in a complex system. Moreover, it is important to define the preference-curves as 'pure' as possible. The social cycle criterion is defined as:

> "Stakeholders should understand what their preference represents with respect to the **objective**".

---

### Explaination

The duration of a project depends on several things. For instance: project scope, quality of the work, approval of permits, weather conditions, availability of materials, the workforce, project complexity, logistics, etc.

Drawing the preference curve of the objective "Project Duration", it is very difficult to take into account the impact of all those factors. One can try to estimate an average project-duration and set that to maximum preference (p=100). And then state that a lower project duration impacts quality and is therefore less preferred. (See figure I.5). But what about a higher project duration? And, what if those elements change while modelling? The estimation is wrong (unless the estimation is dynamically integrated in the model). This makes it very complex.

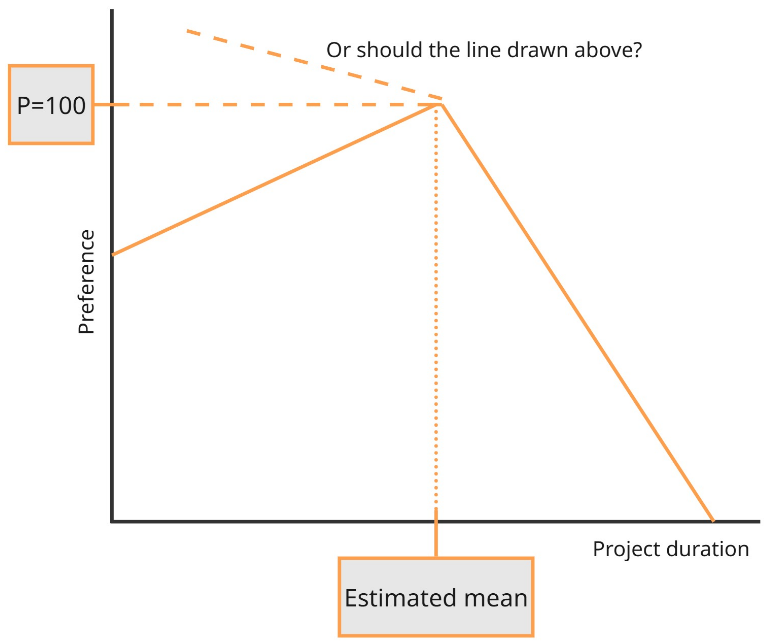



**Figure I.5:** Example graphic of a 'no-pure' objective. *(made with Miro (Miro, 2025))*

Drawing the preference curve of the objective "Project Duration" in the *'purest'* way (see figure I.6). It is possible to state that the objective is to minimise the project duration in a linear way. And one can add extra objectives for the other criteria, like 'quality'. A project duration cannot be lower than 'zero', the preference is at that point maximum (P=100). The least preferred defined project duration could be, for example, the 'max allowed' preferred project duration.

## Reflection based on the Workshop

During the validation workshop with the Fleet Renewal Program team at the Port of Rotterdam, a difference in perspective emerged concerning the challenge of drawing the preference curves, with either the impact on outcomes in mind or rather focusing solely on the objective. In other words, the aforementioned concept emerged during this workshop.

The curve below (figure I.7) was created by user A when drawing the preference curve for capital expenditure costs. User A considered "zero cost" to be undesirable because financial expenditure is a prerequisite for the creation of new vessels. User B, who was in the same workshop, was perplexed by this reasoning because this user was more aligned with his objective of minimising expenses without considering the impact on other objectives (figure I.8). It is evident that user A's perspective aligns more closely with the line of thought proposed by Mol and Schriever (2024), while user B's viewpoint is more aligned with the perspective outlined in the thesis named as a 'pure' objective.

Reflecting on this, this thesis thinks that the approach of Mol and Schriever (2024) is more applicable to less complex modelled systems and/or near the end-phase of the design. This is due to the fact that the solution space is already narrowed down. By contrast, the 'pure-objectives' are more applicable in more complex modelled systems and/or in earlier design phases where the solution space is very broad and its implications on the design are not clear.

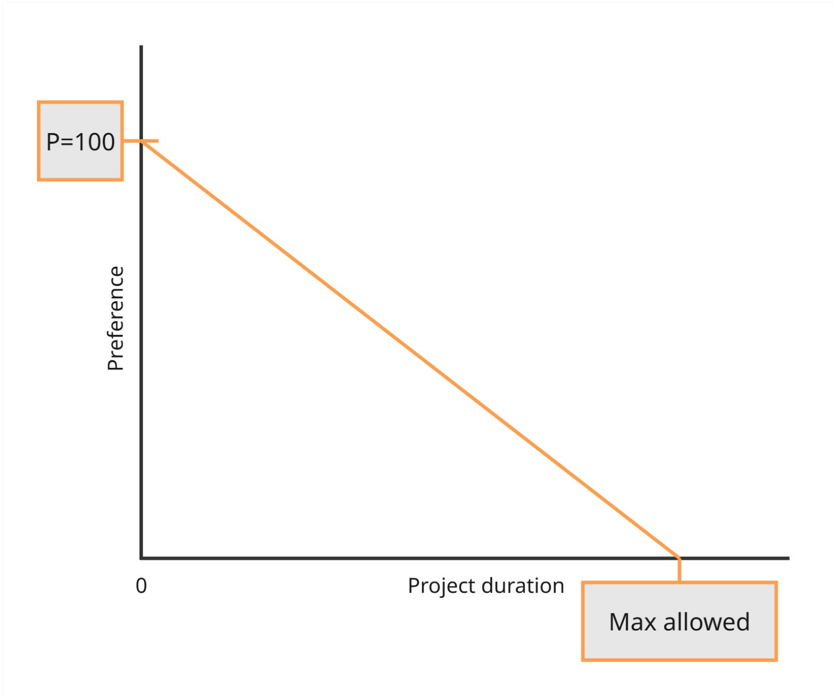



**Figure I.6:** Example graphic of a 'pure' objective. *(made with Miro (Miro, 2025))*

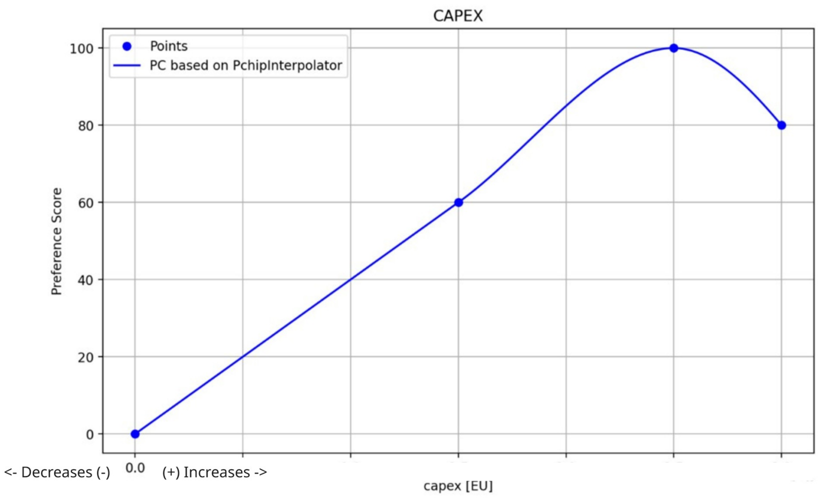



**Figure I.7:** Workshop graphic of a 'no pure' objective.

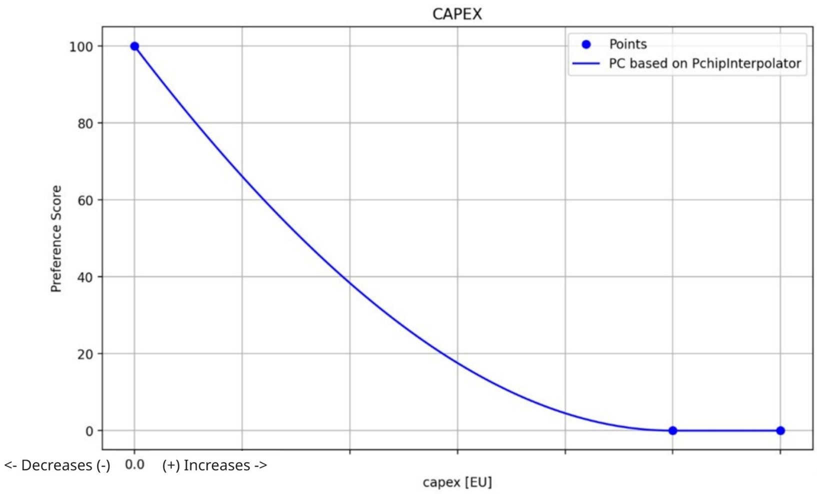



**Figure I.8:** Workshop graphic of a ’pure’ objective.

# J

# Design for '-ty' Framework

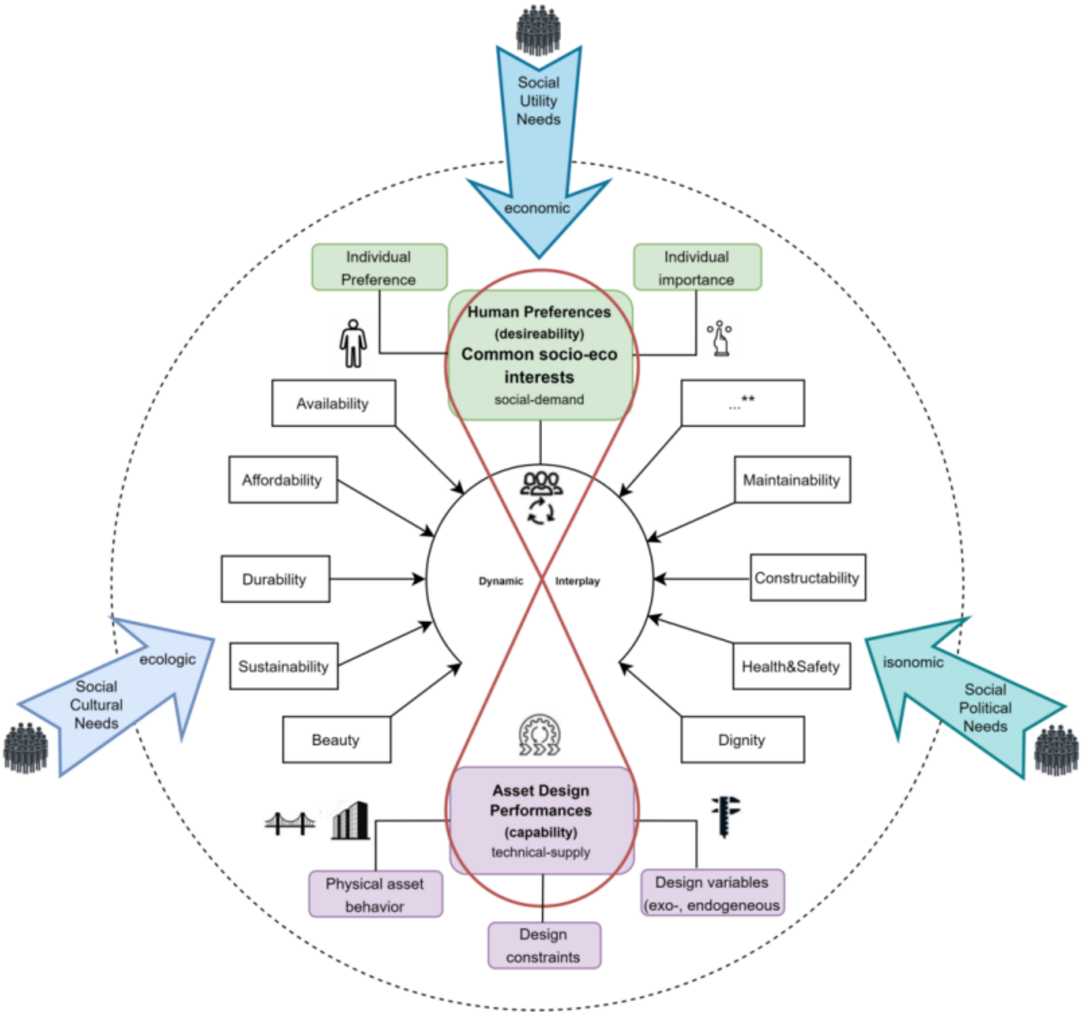



**Figure J.1:** Common socio-eco interests diagram, a participatory design tY framework, derived from societal and organizational needs/wishes/requirements. The design tY values, to be translated into preference-, objective-, and performance functions and/or constraints (not limitative). ...** Adaptability, Capacity, Comfortability, Connectivity, Creativity, Distributivity, Flexibility, Fraternity, Immunity, Integrability, Integrity, Invest-propensity, Liberty, Liveability, Operatorability, Profitability, Reliability, Resistivity, Reconfigurability, Predictability, Recyclability, Security, Solidarity, Supportability, Simplicity, Servicability, Scarcity, Transportability, Testability, and Vulnerability. (Wolfert, 2023)

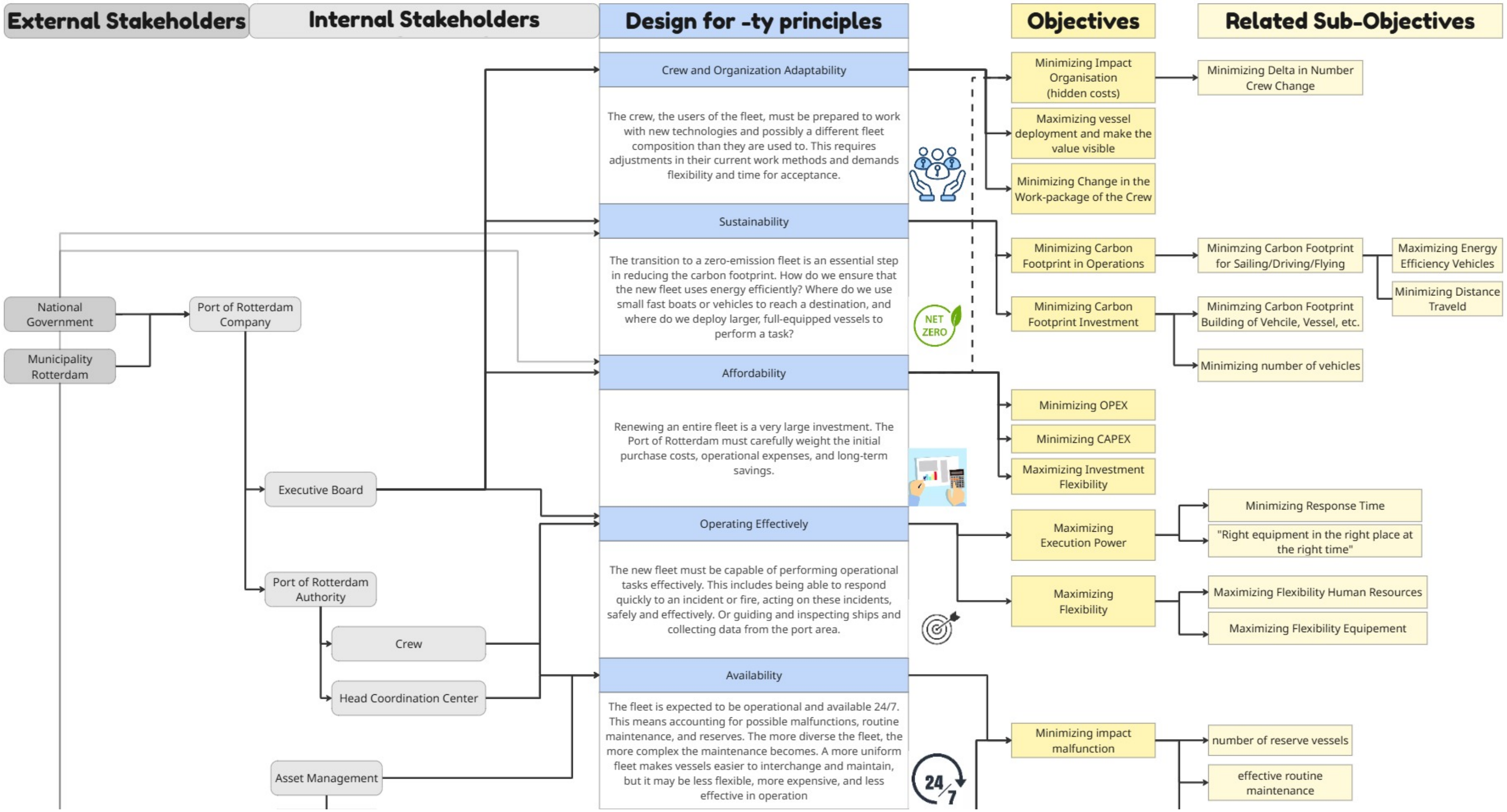



**Figure J.2:** Overview Design For -Ty Objectives and sub-objectives *(own illustration)*

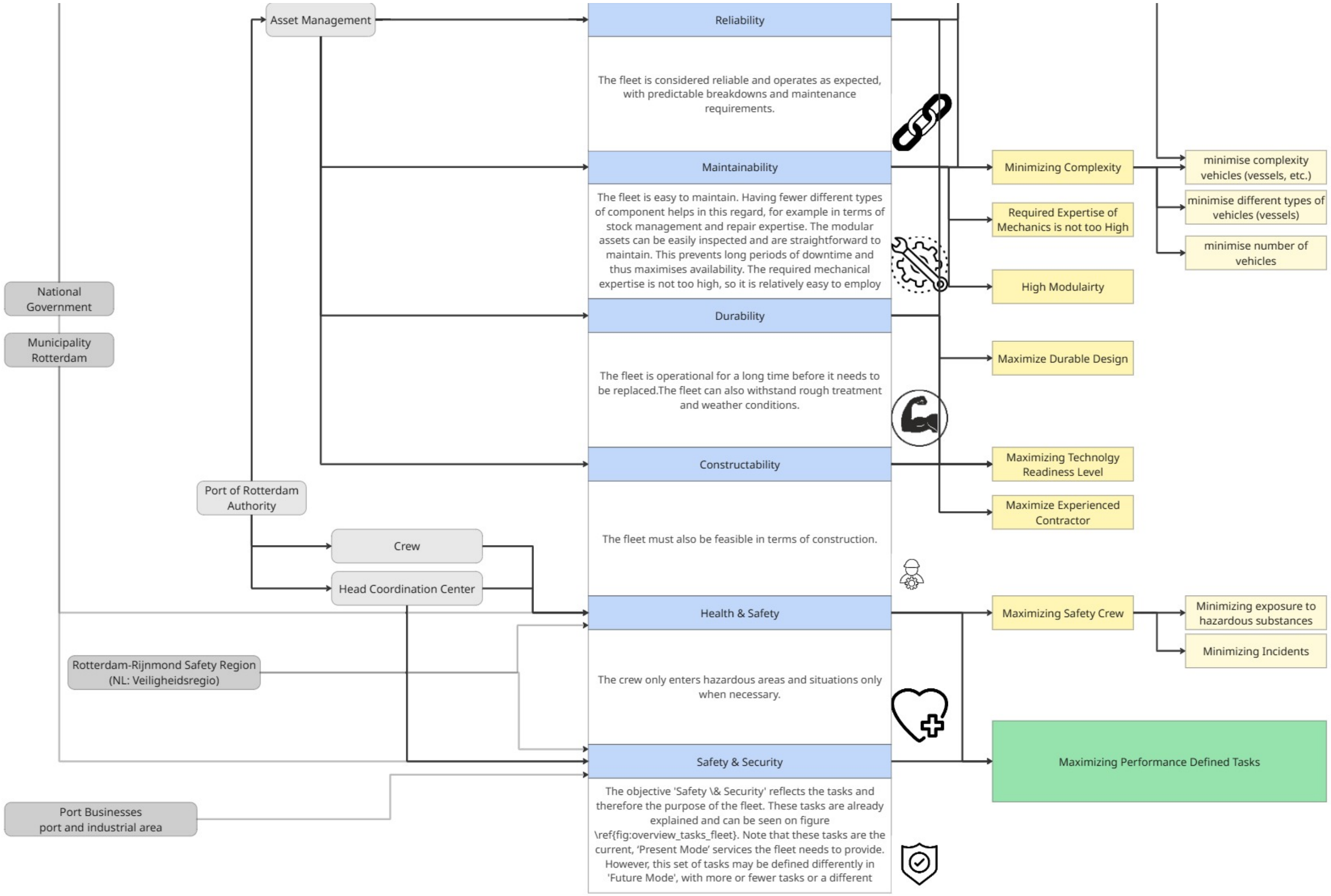



**Figure J.3:** Overview Design For -Ty Objectives and sub-objectives *(own illustration)*

# K

# Graphical Visualization Objectives

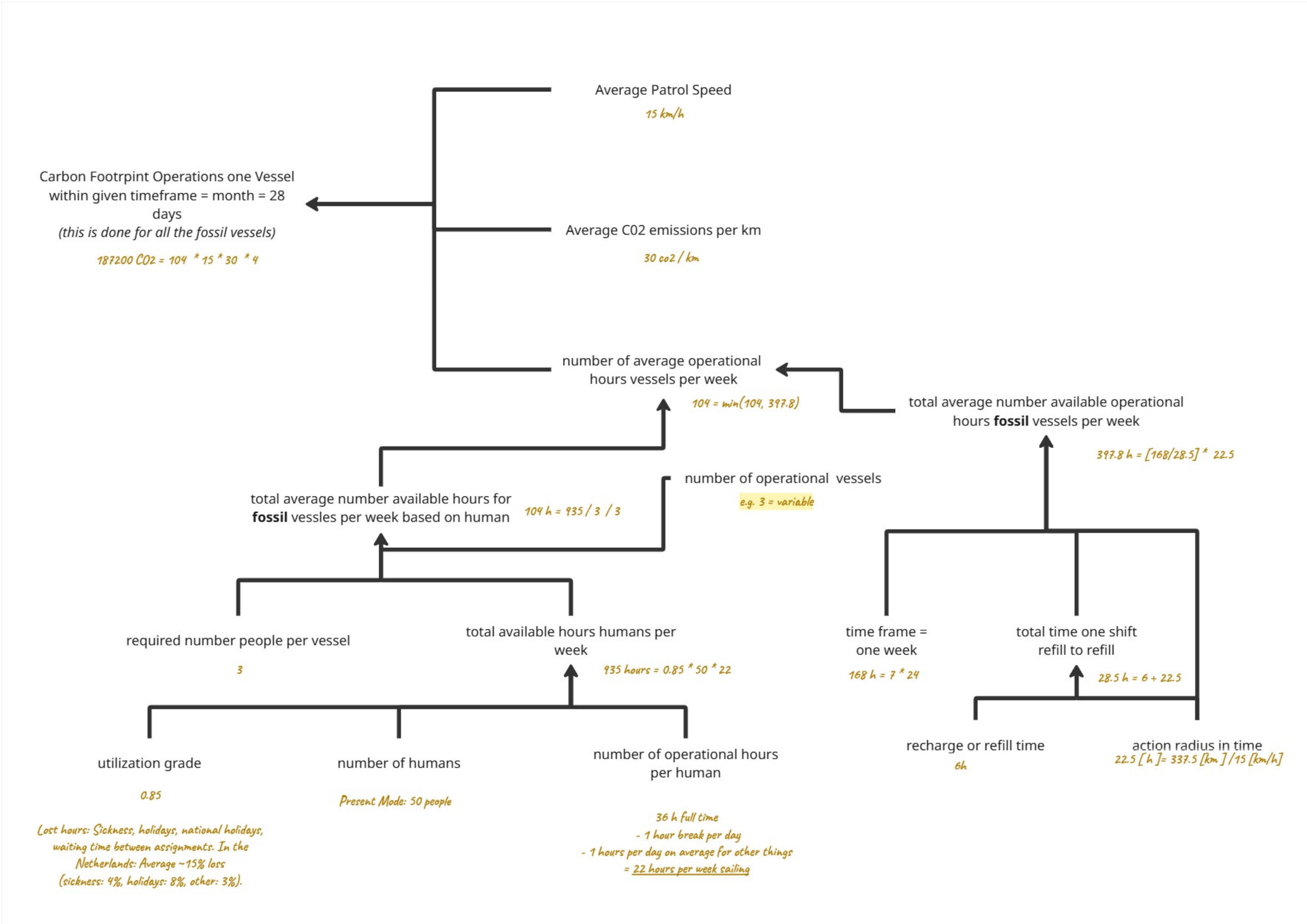



**Figure K.1:** Overview Calculation Structure Carbon Footprpint Operations *(own illustration)*

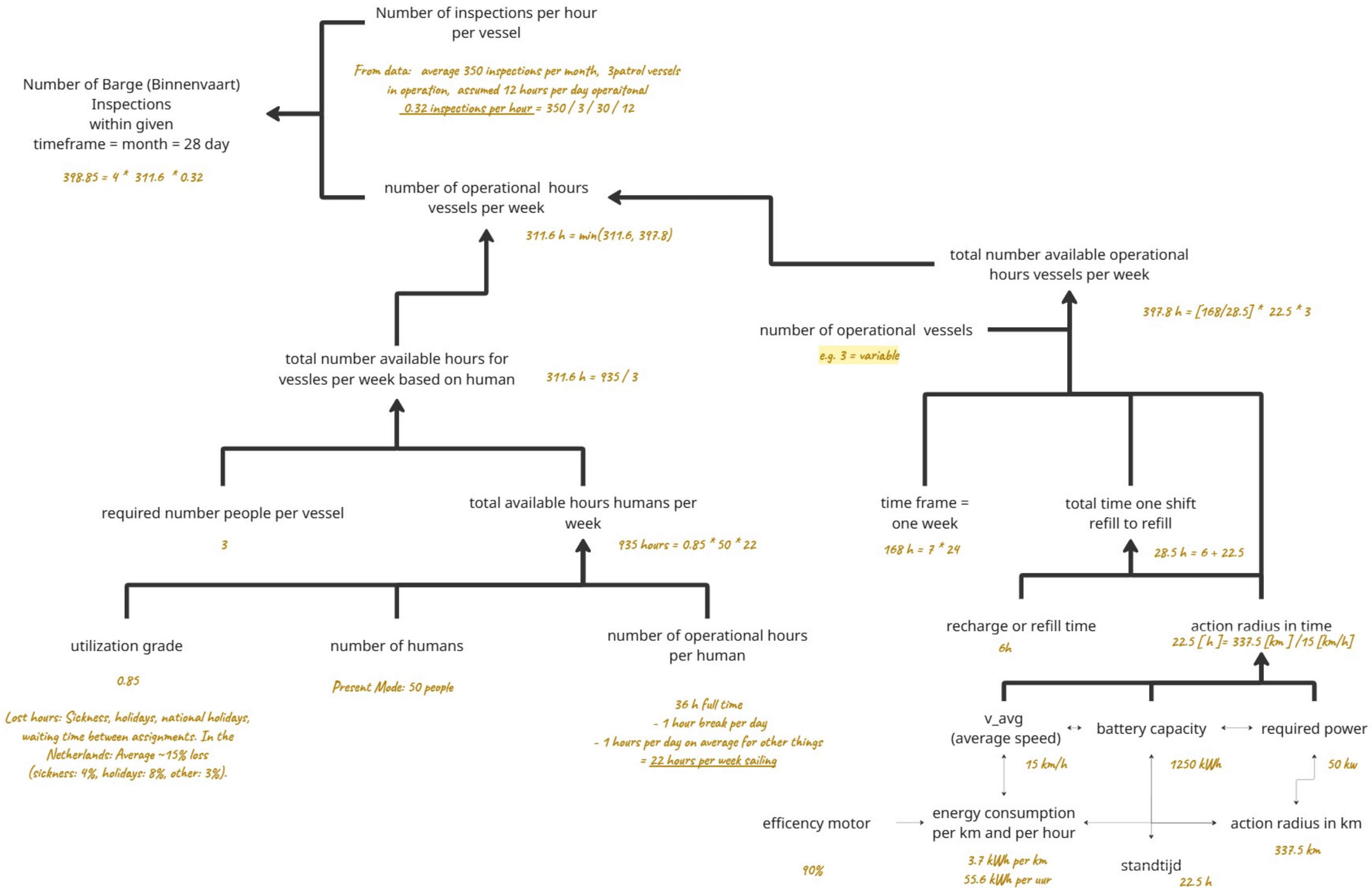



**Figure K.2:** Overview Calculation Structure Barge Inspections (NL: Binnevaart Inspecties) *(own illustration)*

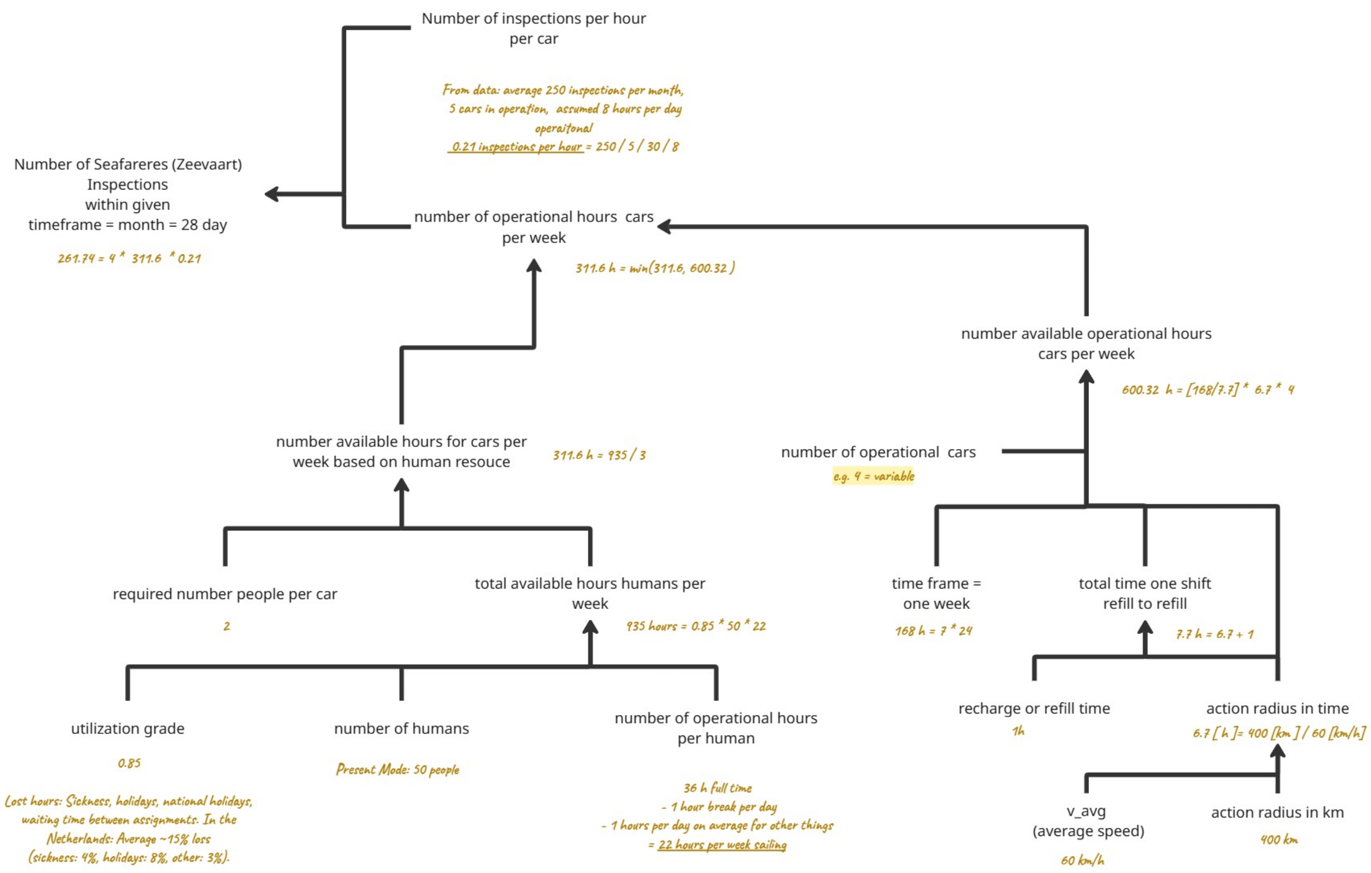



**Figure K.3:** Overview Calculation Structure Seafarer Inspections (NL: Zeevaart Inspecties) *(own illustration)*

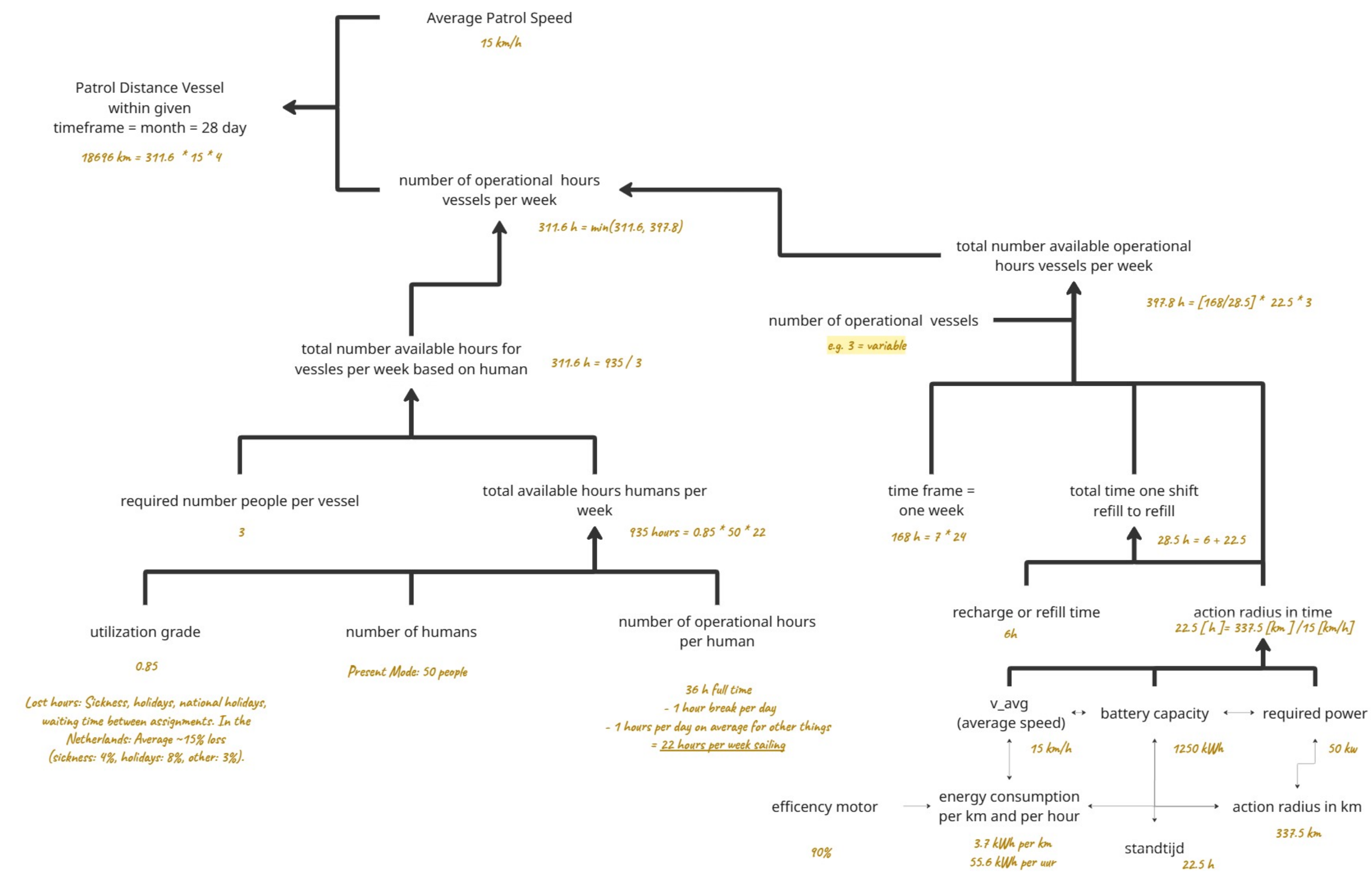



**Figure K.4:** Overview Calculation Structure Patrol Distance *(own illustration)*

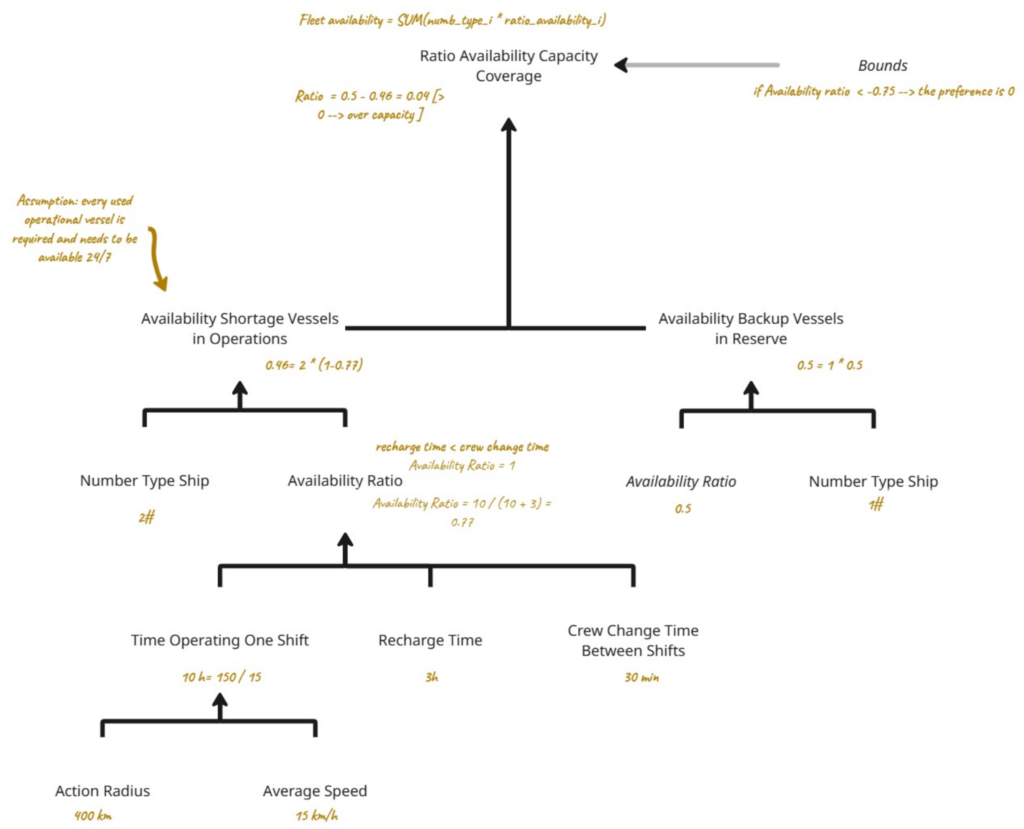



**Figure K.5:** Overview Calculation Structure Ratio Availability Capacity Coverage Incident Response *(own illustration)*

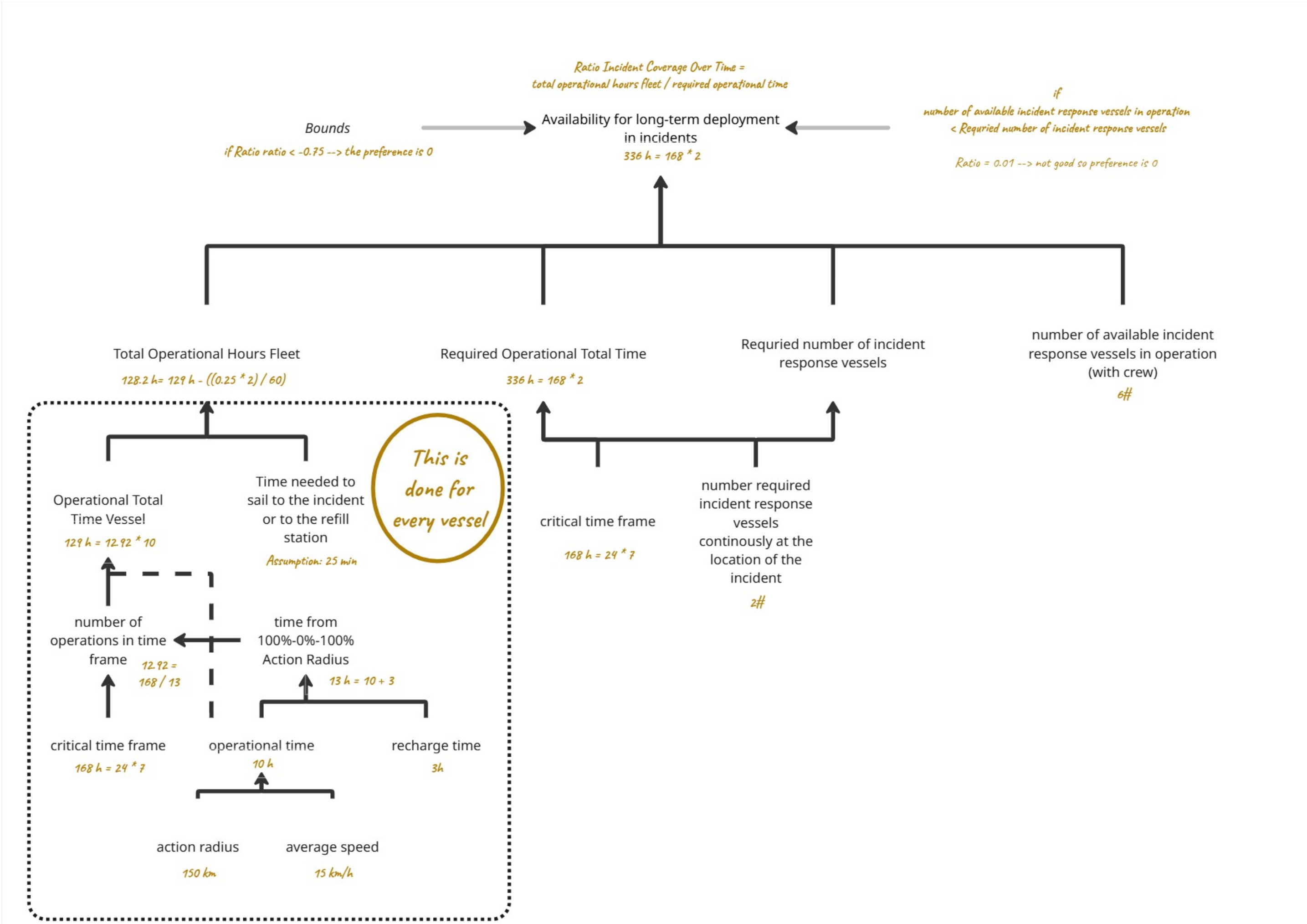



**Figure K.6:** Overview Calculation Structure Availability Ratio Long Term Deployment in Incidents *(own illustration)*

# L

# Verification by Comparison of Alternatives

## L.1. Fleet Compositions of Alternatives and Optimisation-results

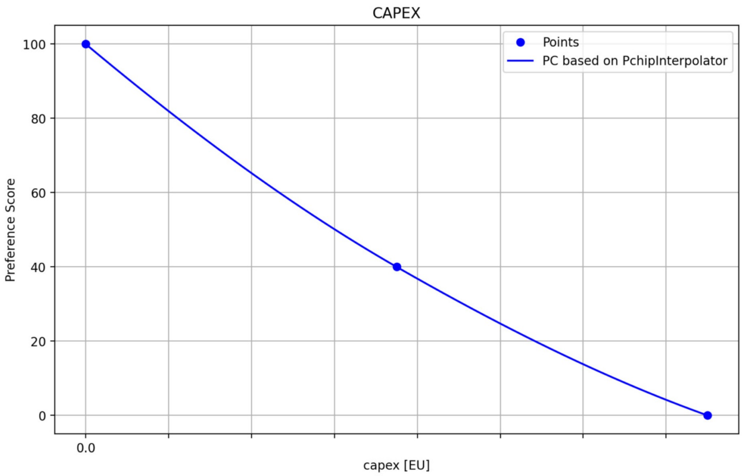
Table L.1 presents the vessels selected for each design configuration, according to the fleet composition. In addition to the vessels, each alternative employs three electric cars. The optimization process considered all these vessel types (and electric cars), and the results are also displayed in the same table.

To facilitate comparison across alternatives, the number of crew allocated to both blue and red tasks remains constant for all alternatives and optimization scenarios. In addition, the ’reserve’ vessels are not taken into consideration.

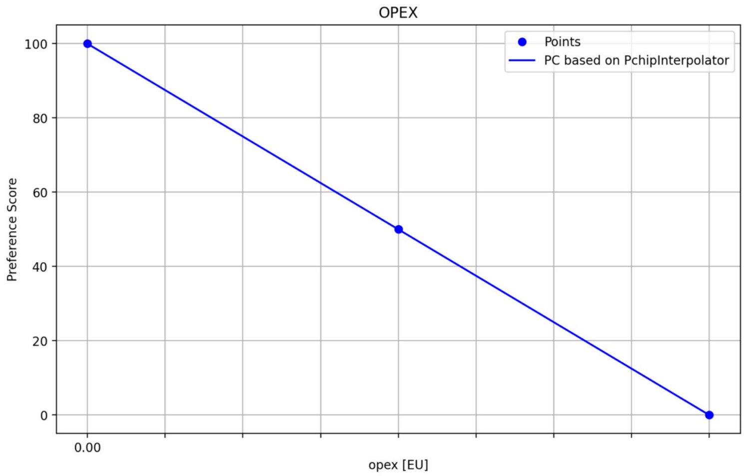
**Table L.1:** This table presents the vessels in each alternative configuration and optimisation-results. The Port of Rotterdam has not yet initiated the tender process, therefore the table does not contain the taken values. Instead, the table illustrates the differences between the vessels by the numbers and corresponding colours. For instance, with the characteristic ’capex’, the vessel ”IBV-current’ and the vessel ’PVT-hull IBV-AWS” have the same capex value.
In addition to the vessels, each alternative employs three electric cars. The ’reserve’ vessels are not taken into consideration.
The optimization process considered all these vessel types (and electric cars) and the results are also displayed in the same table. To facilitate comparison across alternatives, the number of crew allocated to both blue and red tasks remain constant for all alternatives and optimization scenarios.

| **Vessel** | **IBV - Current** | **PVT - Current** | **IBV - AWS** | **PVT - hull IBV - AWS** | **PVT - VAS** | **IBV - VAS** | **IBV - VAS + Extender** | **PVT - VAS + Extender** | **PVT - Small - VAS** | **PVT - Refit** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Incident Response Worthy** | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| **Patrol Speed [km/h]** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Top Speed [km/h]** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 |
| **Pump-Capacity (L/min)** | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| **Recharge Time (Hours)** | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| **CAPEX (EU)** | 1 | 2 | 3 | 1 | 4 | 5 | 6 | 7 | 8 | 9 |
| **OPEX (EU/year)** | 1 | 2 | 3 | 1 | 4 | 5 | 6 | 7 | 8 | 9 |
| **Zero-emissoin range (km) [Patrol speed]** | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 |
| **Emission range (km) [Patrol speed]** | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 4 | 4 |
| **Emissions Operation [ton CO2/km]** | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 2 | 2 |
| **Carbon Footrpint Investment (ton CO2e)** | 1 | 2 | 3 | 4 | 5 | 6 | 6 | 7 | 8 | 9 |
| | | | | | | | | | | |
| Alternative A1 | | | 4 (+1 reserve) | 3 (+1 reserve) | | | | | | |
| Alternative A2 | | | 4 (+1 reserve) | | 3 (+1 reserve) | | | | | |
| Alternative B1 | | | | | | | 4 (+1 reserve) | 3 (+ 1 reserve) | | |
| Alternative B2 | | | | | | | 4 (+1 reserve) | 2 (+ 1 reserve) | 3 (+ 3 reserve) | |
| Alternative B3 | | | | | | | 4 (+1 reserve) | 2 (+ 1 reserve) | | |
| Alternative B4 | | | | | | | 4 (+1 reserve) | 2 | | 1 (+ 1 reserve) |
| Baseline | 4 (+3 reserve) | 3 (+2 reserve) | | | | | | | | |
| Idealized Optimization Blue Tasks | | | | | | | | | 3 | |
| Idealized Optimization Red Tasks | | | 3 | | | | | | | |
| Idealized Optimization Blue + Red Tasks | | | 3 | | | | | | | |
| Realized Optimization Combined Tasks | 3 | | | | | | | | | |

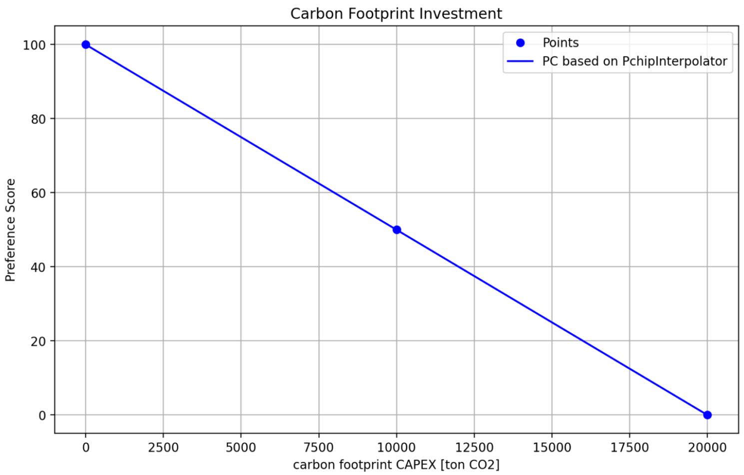
## L.2. Preference curves for verification by comparison of alternatives



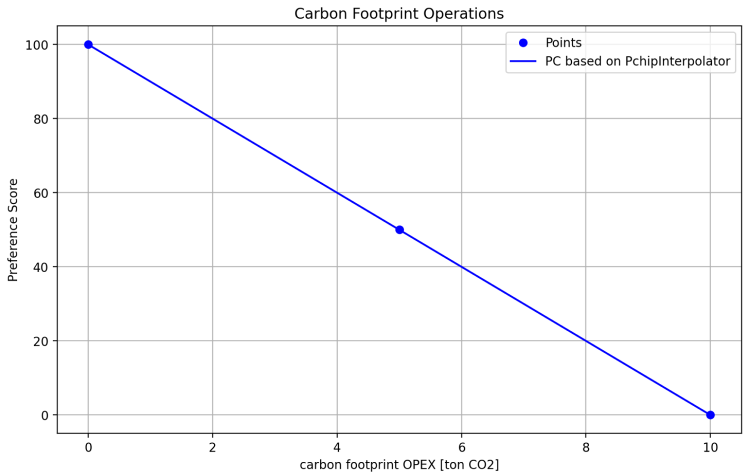

**(a)** Preference Curve CAPEX as sub-objectives from 'Affordability' (design for -ty objective)




**(b)** Preference Curve OPEX as sub-objectives from 'Affordability' (design for -ty objective)

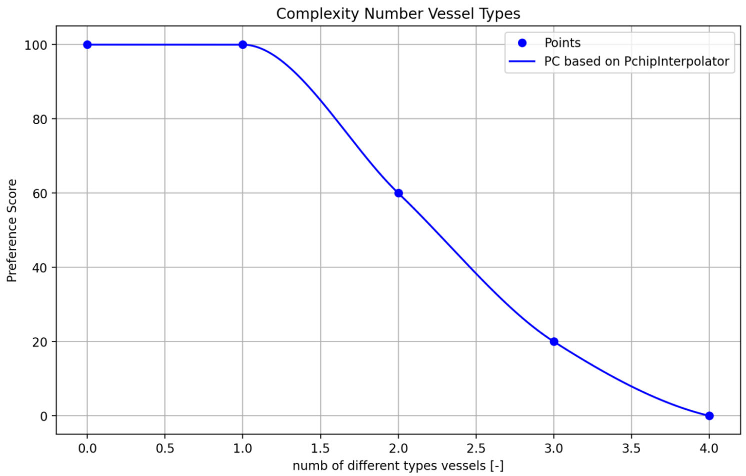



**(c)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)

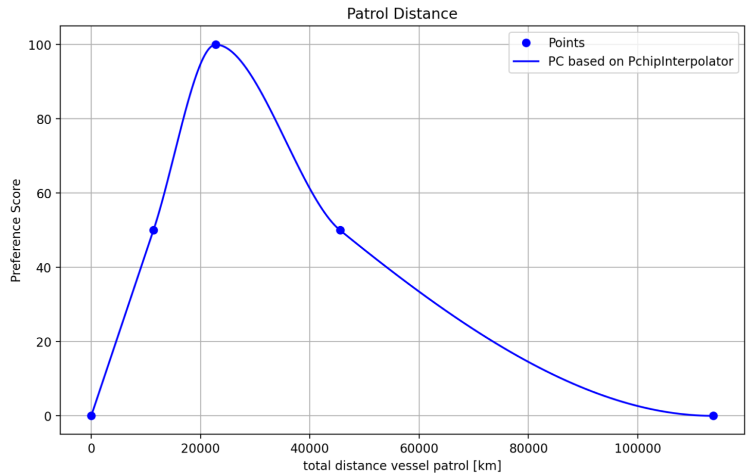



**(d)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)

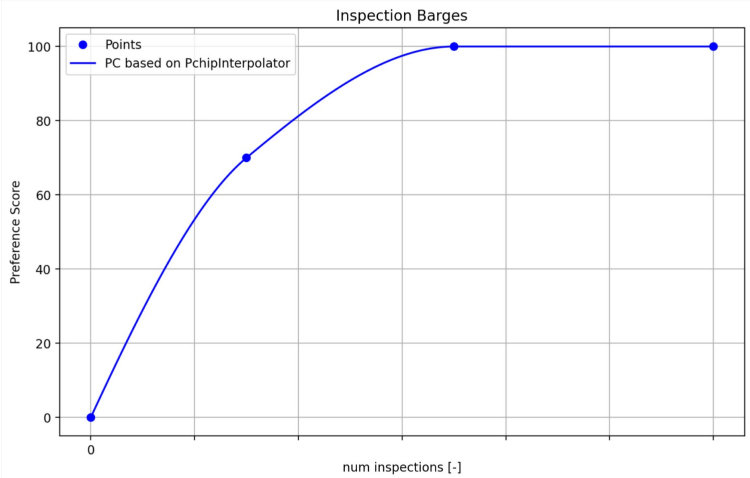
**Figure L.1:** Preference Curves for Affordability and Sustainability. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.



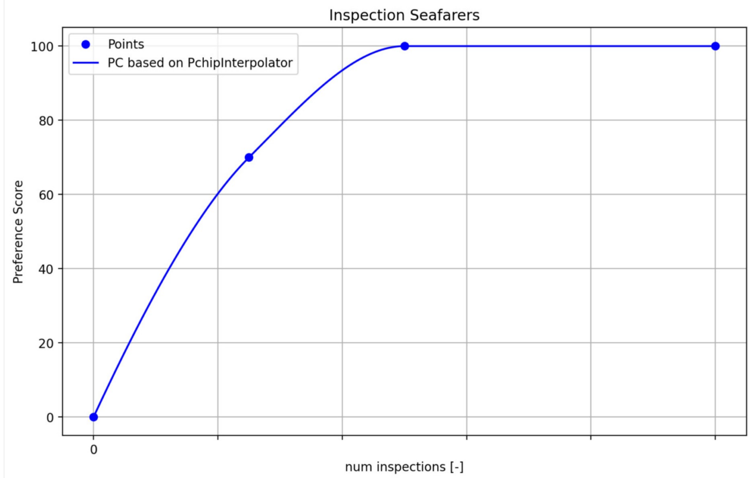

**(a)** Preference Curve Complexity Number of Vessel Types as objective from 'Maintainability' (design for -ty objective)




**(b)** Preference Curve Patrol Distance as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)

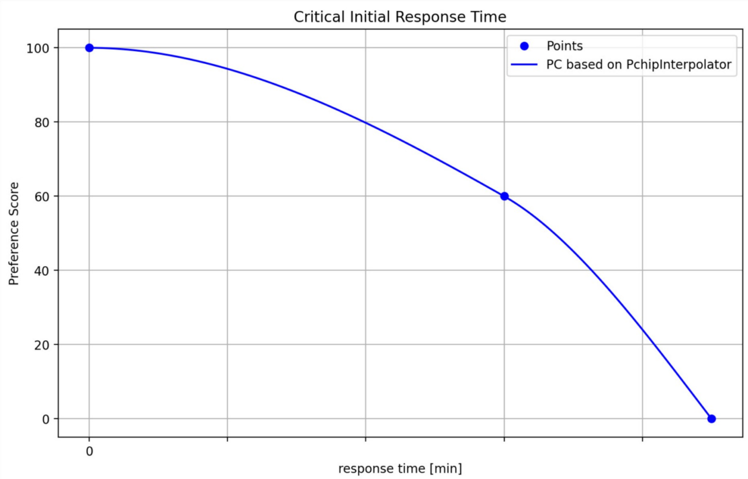



**(c)** Preference Curve Inspection Barges as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)

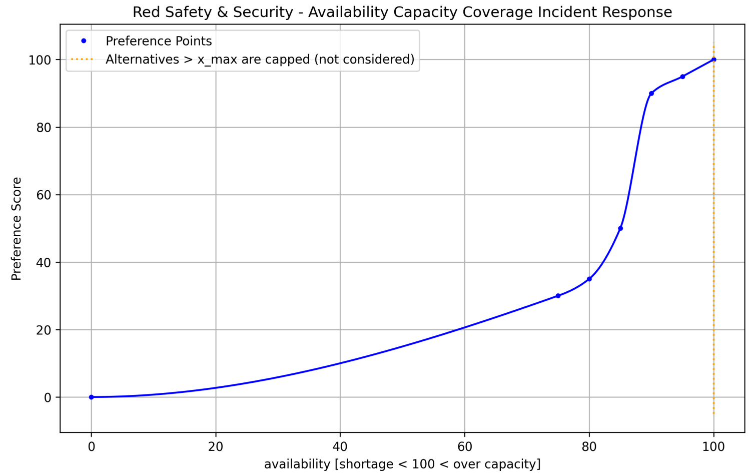



**(d)** Preference Curve Inspection Barges as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)

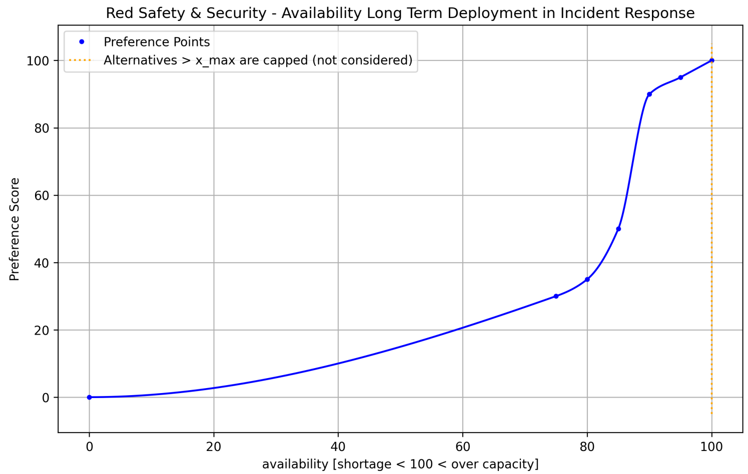
**Figure L.2:** Preference Curves for Maintainability and Blue Tasks Safety & Security. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.




**(a)** Preference Curve Critical Initial Response Time as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)




**(b)** Preference Curve Availability Capacity Coverage Incident Response as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)




**(c)** Preference Curve Availability Long Term Deployment in Incident Response as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)

**Figure L.3:** Preference Curves for Red Tasks Safety & Security. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.

## L.3. Results blue-tasks for verification tool by comparison of alternatives

**Table L.2:** Weight Distribution Optimization Blue Tasks

| Objective | Weight | Sub-Objective | Sub-Weight | Optimization-Weight |
|---|---|---|---|---|
| Affordability | 18.421 | OPEX | 50.00 | 0.092 |
| | | CAPEX | 50.00 | 0.092 |
| Sustainability | 18.421 | Carbon Footprint Investment (construction) | 50.00 | 0.092 |
| | | Carbon Footprint Operations | 50.00 | 0.092 |
| Maintainability | 5.263 | Minimize Complexity Number Vessel Types | 100.00 | 0.053 |
| Red Tasks Safety & Security | 0.0 | Maximizing Availability Capacity Coverage Incident Response | 33.33 | 0.193 |
| | | Maximizing Availability Long Term Deployment in Incident Response | 33.33 | 0.193 |
| | | Minimizing Critical Initial Response Time | 33.33 | 0.193 |
| Blue Tasks Safety & Security | 57.89 | Maximizing Number of Barge Inspections | 33.33 | 0.0 |
| | | Maximizing Number of Inspections Seafarers | 33.33 | 0.0 |
| | | Maximizing Patrol Distance | 33.33 | 0.0 |

**Table L.3:** An overview table of the **aggregated** performance of the different fleet compositions when only blue tasks are considered. Keep in mind that PFM scores are compared to other scores. If X scores close to Y, it is because Z scores very differently. For more information about Preference-Functional-Modelling see Barzilai (2022)

| **Alternative** | A1 | A2 | B1 | B2 | B3 | B4 | Baseline | Optimization |
|---|---|---|---|---|---|---|---|---|
| **PFM score** | 13.62 | 44.80 | 24.75 | 29.23 | 0.0 | 38.11 | 8.41 | 100.0 |

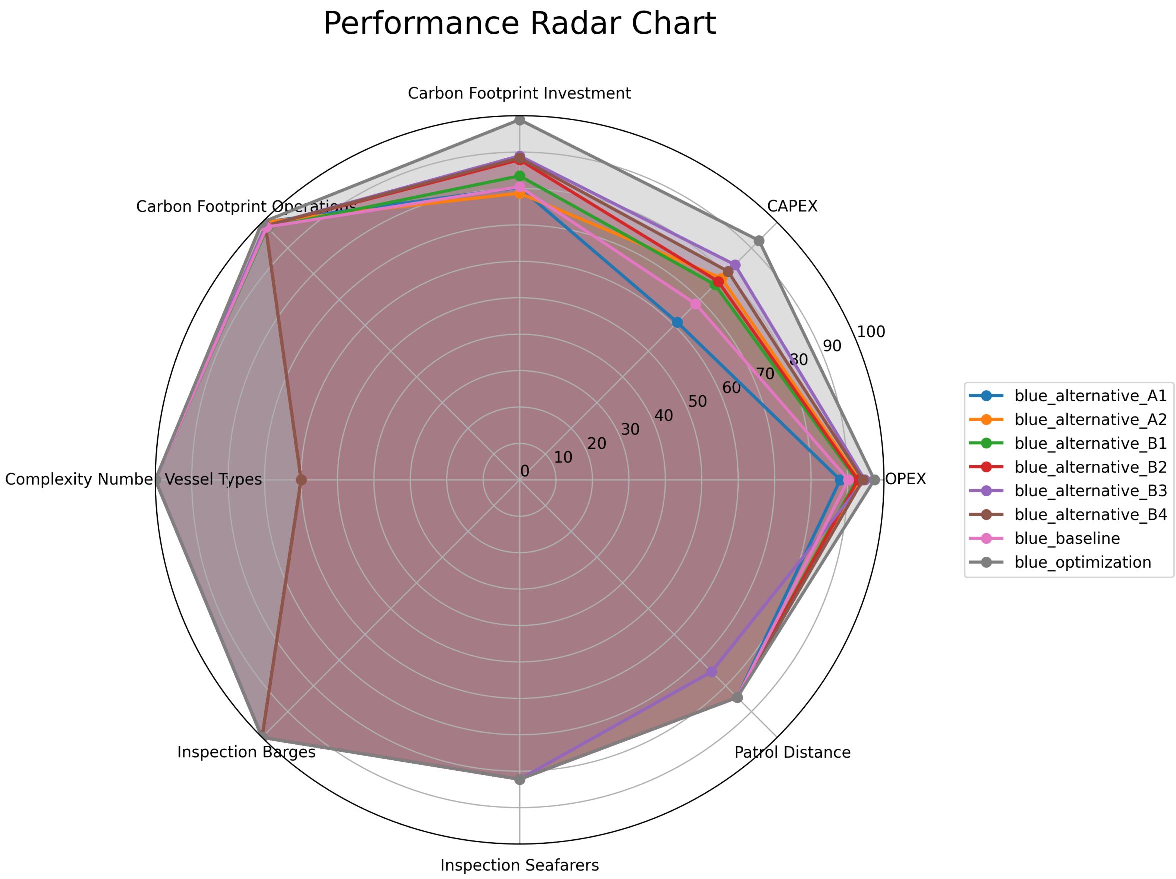
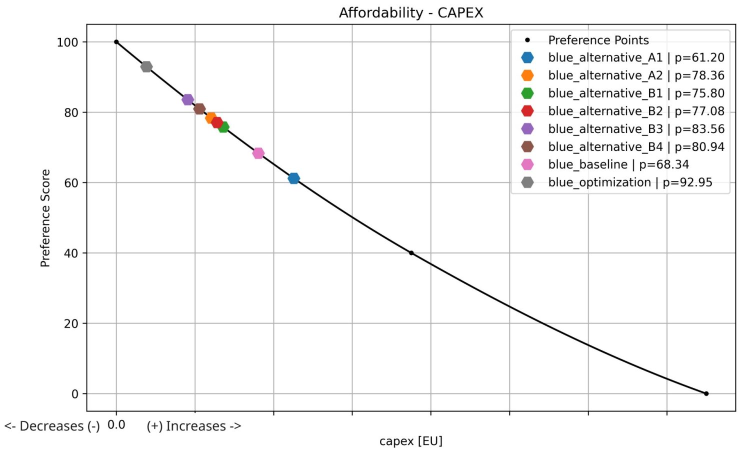
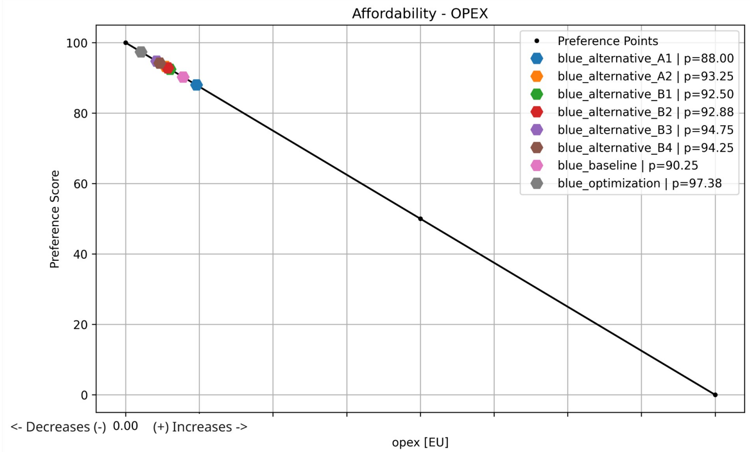


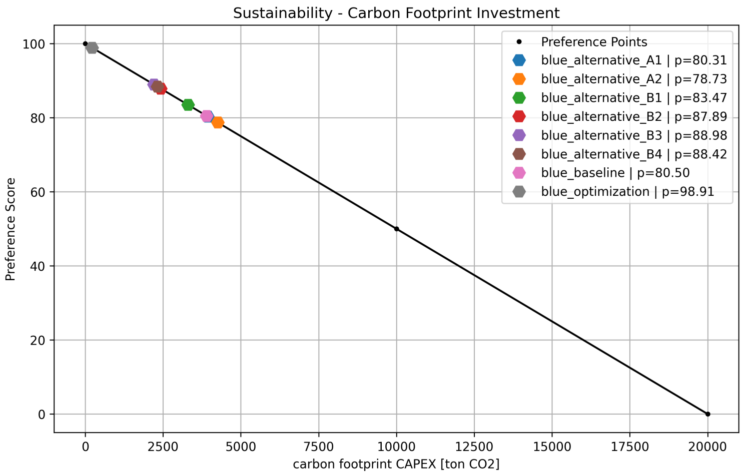

**Figure L.4:** An overview of the performance of the different fleet compositions when only the blue tasks are considered.



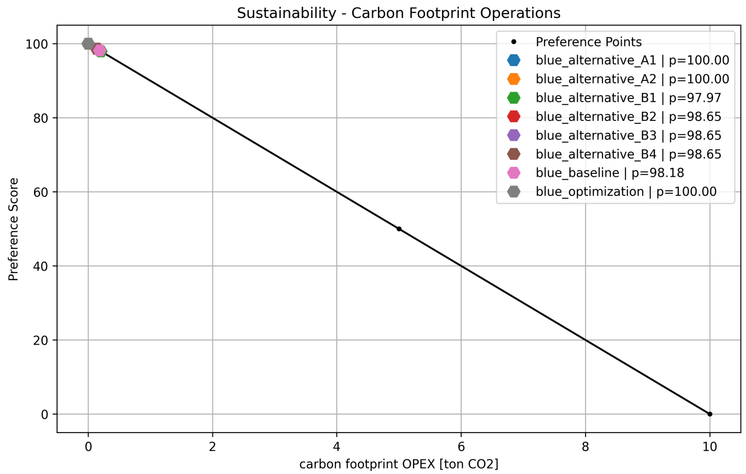

**(a)** Preference Curve CAPEX as sub-objectives from 'Affordability' (design for -ty objective)




**(b)** Preference Curve OPEX as sub-objectives from 'Affordability' (design for -ty objective)

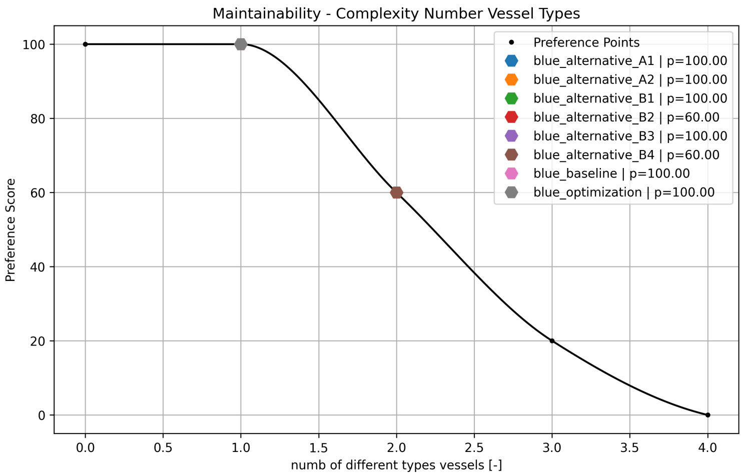



**(c)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)

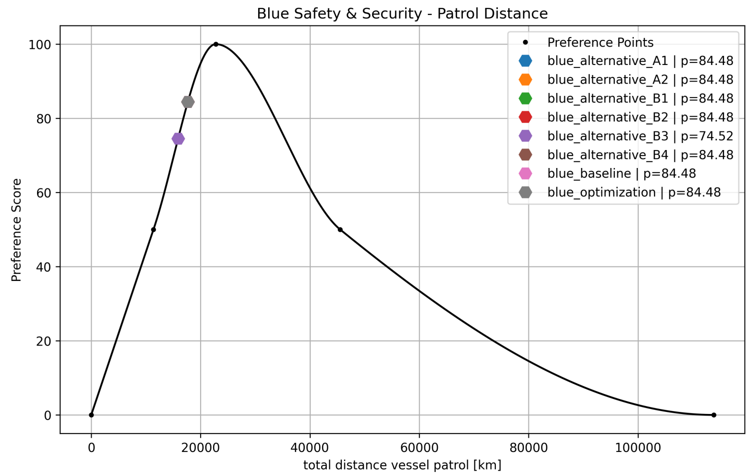



**(d)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)

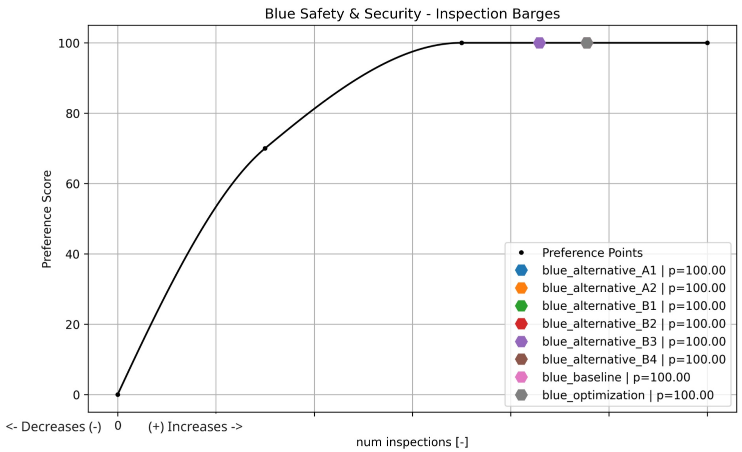
**Figure L.5:** Preference Curves for Affordability and Sustainability. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.



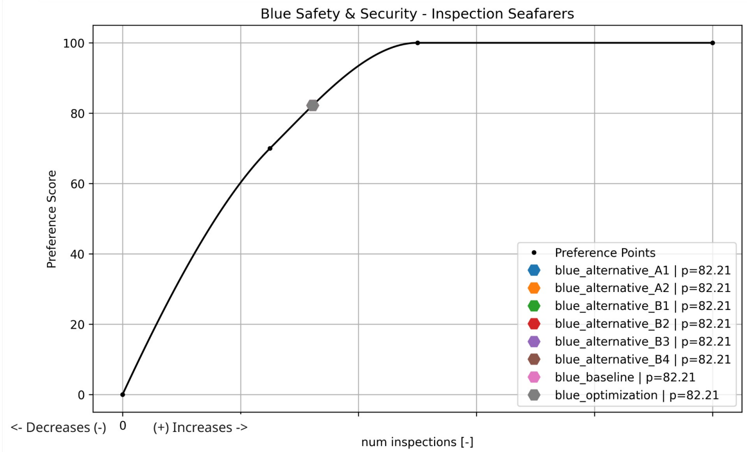

**(a)** Preference Curve Complexity Number of Vessel Types as objective from 'Maintainability' (design for -ty objective)




**(b)** Preference Curve Patrol Distance as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)




**(c)** Preference Curve Inspection Barges as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)




**(d)** Preference Curve Inspection Barges as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)

**Figure L.6:** Preference Curves for Maintainability and Blue Tasks Safety & Security. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.

**Table L.4:** An overview table of the preference scores of the different fleet compositions when only blue tasks are considered. Note that only with PFM-aggregation are the scores rescaled to the range [0, 100].

| Design For -Ty | Objective Class | A1 | A2 | B1 | B2 | B3 | B4 | Baseline | Optimisation |
|---|---|---|---|---|---|---|---|---|---|
| Affordability | OPEX | 88.0 | 93.25 | 92.5 | 92.875 | 94.75 | 94.25 | 90.25 | 97.375 |
| Affordability | CAPEX | 61.20 | 78.36 | 75.80 | 77.08 | 83.56 | 80.94 | 68.34 | 92.95 |
| Sustainability | Carbon Footprint Investment | 80.305 | 78.73 | 83.47 | 87.885 | 88.98 | 88.42 | 80.5 | 98.91 |
| Sustainability | Carbon Footprint Operations | 100.0 | 100.0 | 97.97 | 98.65 | 98.65 | 98.65 | 98.18 | 100.0 |
| Maintainability | Complexity Number Vessel Types | 100.0 | 100.0 | 100.0 | 60.0 | 100.0 | 60.0 | 100.0 | 100.0 |
| Blue Safety & Security | Inspection Barges | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Blue Safety & Security | Inspection Seafarers | 82.21 | 82.21 | 82.21 | 82.21 | 82.21 | 82.21 | 82.21 | 82.21 |
| Blue Safety & Security | Patrol Distance | 84.48 | 84.48 | 84.48 | 84.48 | 74.52 | 84.48 | 84.48 | 84.48 |
| PFM SCORE | | 13.62 | 44.80 | 24.75 | 29.23 | 0.0 | 38.11 | 8.41 | 100.0 |

## L.4. Results red-tasks for verification tool by comparison of alternatives

**Table L.5:** Weight Distribution Optimization Red Tasks

| Objective | Weight | Sub-Objective | Sub-Weight | Optimization-Weight |
|---|---|---|---|---|
| Affordability | 18.421 | OPEX | 50.00 | 0.092 |
| | | CAPEX | 50.00 | 0.092 |
| Sustainability | 18.421 | Carbon Footprint Investment (construction) | 50.00 | 0.092 |
| | | Carbon Footprint Operations | 50.00 | 0.092 |
| Maintainability | 5.263 | Minimize Complexity Number Vessel Types | 100.00 | 0.053 |
| Red Tasks Safety & Security | 57.89 | Maximizing Availability Capacity Coverage Incident Response | 33.33 | 0.0 |
| | | Maximizing Availability Long Term Deployment in Incident Response | 33.33 | 0.0 |
| | | Minimizing Critical Initial Response Time | 33.33 | 0.0 |
| Blue Tasks Safety & Security | 0.0 | Maximizing Number of Barge Inspections | 33.33 | 0.193 |
| | | Maximizing Number of Inspections Seafarers | 33.33 | 0.193 |
| | | Maximizing Patrol Distance | 33.33 | 0.193 |

**Table L.6:** An overview table of the **aggregated** performance of the different fleet compositions when only red tasks are considered. Keep in mind that PFM scores are compared to other scores. If X scores close to Y, it is because Z scores very differently. For more information about Preference-Functional-Modelling see Barzilai (2022)

| **Alternative** | A1 | A2 | B1 | B2 | B3 | B4 | Baseline | Optimization |
|---|---|---|---|---|---|---|---|---|
| **PFM score** | 79.26 | | 0.0 | | | | 80.17 | 100 |

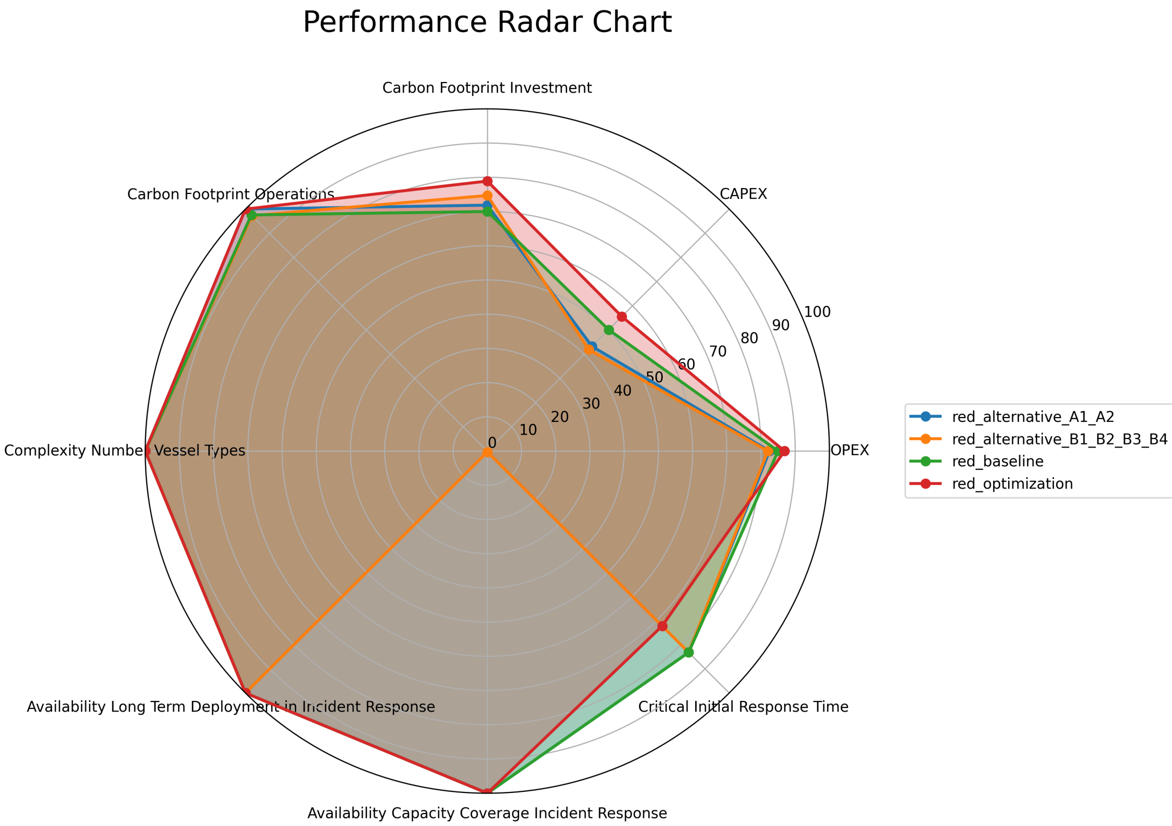
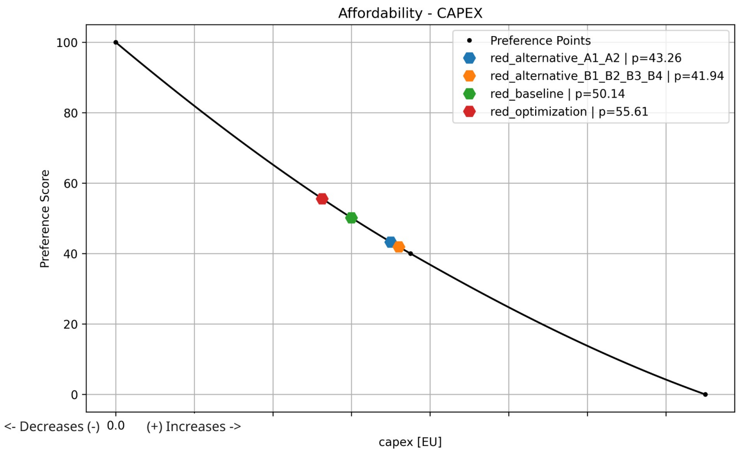
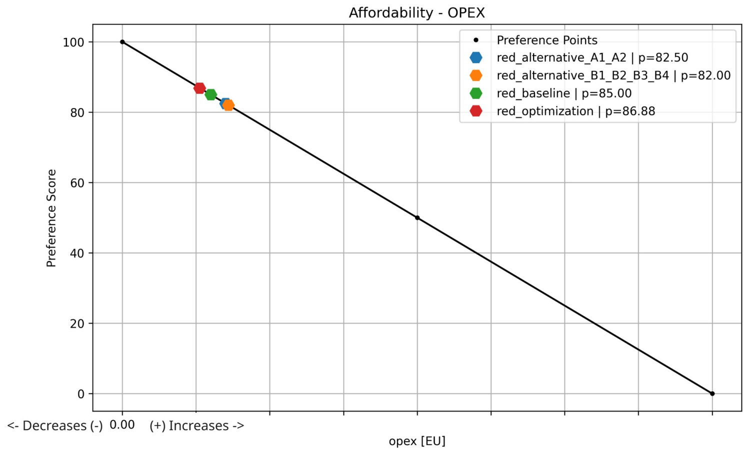


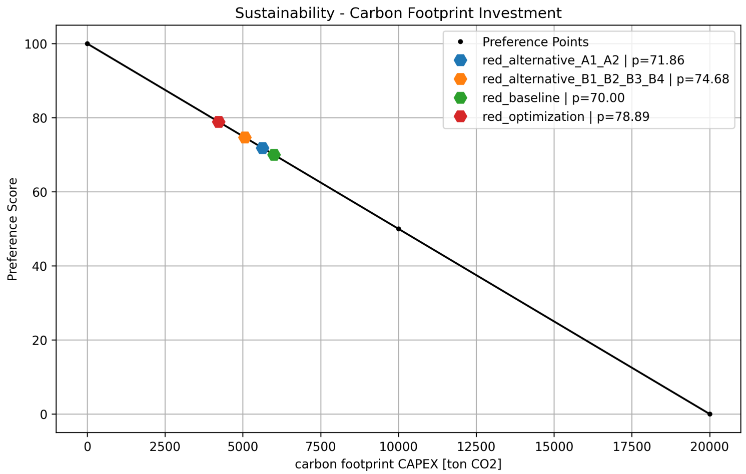

**Figure L.7:** An overview of the performance of the different fleet compositions when only the red tasks are considered.



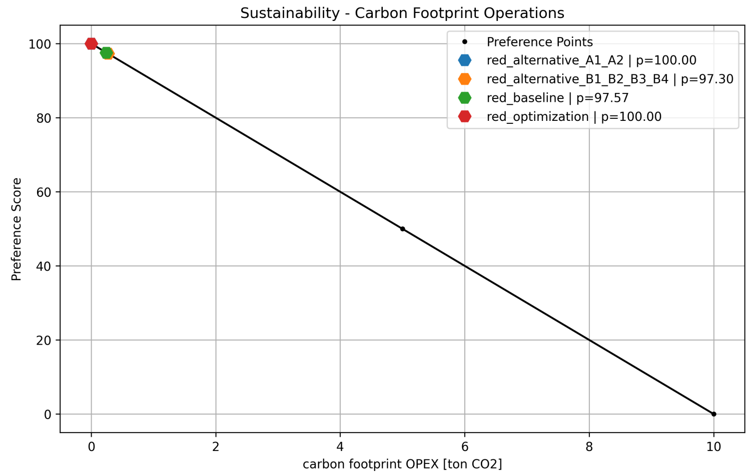

**(a)** Preference Curve CAPEX as sub-objectives from 'Affordability' (design for -ty objective)




**(b)** Preference Curve OPEX as sub-objectives from 'Affordability' (design for -ty objective)

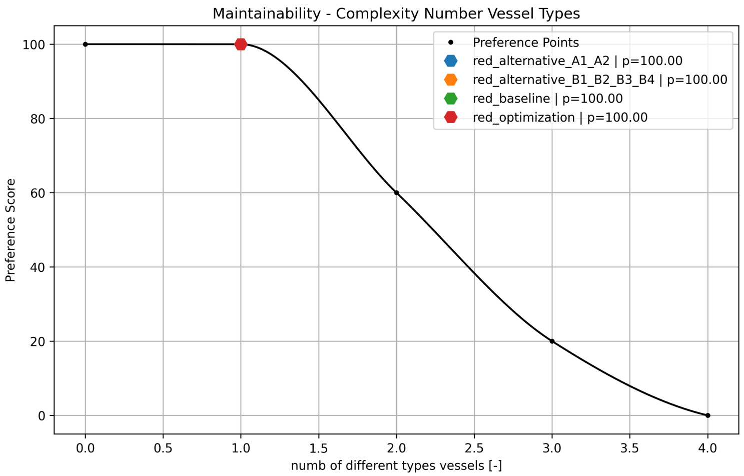



**(c)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)

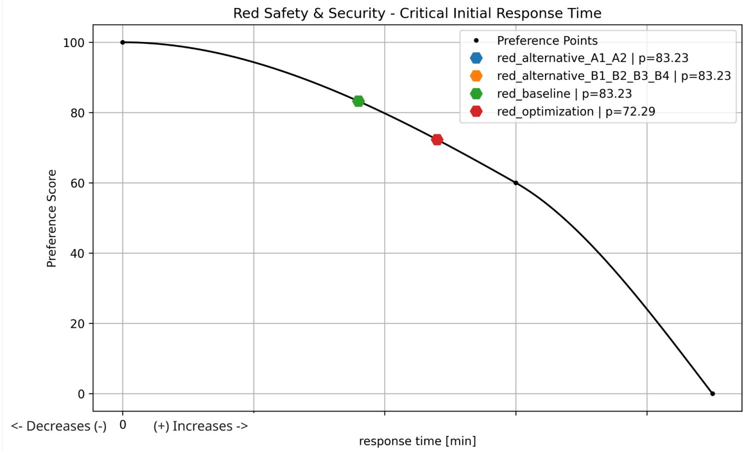



**(d)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)

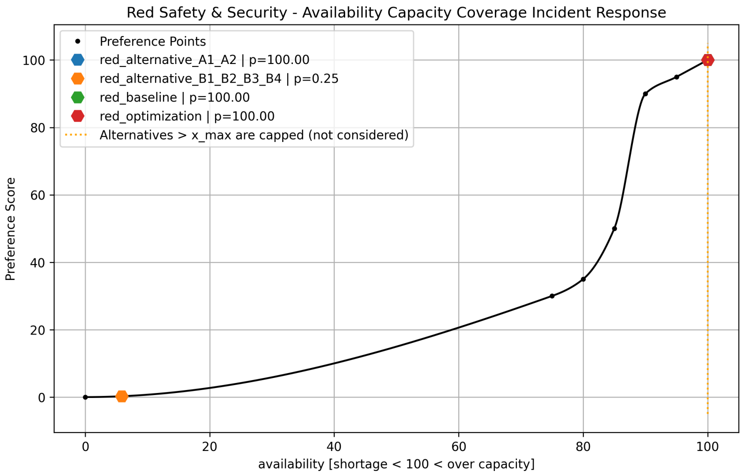
**Figure L.8:** Preference Curves for Affordability and Sustainability. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.



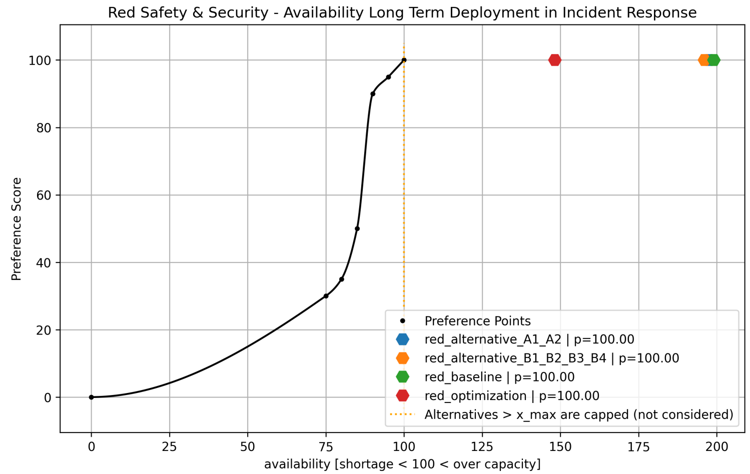

**(a)** Preference Curve Complexity Number of Vessel Types as objective from 'Maintainability' (design for -ty objective)




**(b)** Preference Curve Critical Initial Response Time as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)




**(c)** Preference Curve Availability Capacity Coverage Incident Response as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)




**(d)** Preference Curve Availability Long Term Deployment in Incident Response as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)

**Figure L.9:** Preference Curves for Maintainability and Red Tasks Safety & Security. Preference Curves for Affordability and Sustainability. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.

**Table L.7:** An overview table of the preference scores of the different fleet compositions when only red tasks are considered. Note that only with PFM-aggregation are the scores rescaled to the range [0, 100].

| Design For -Ty | Objective Class | A1 & A2 | B1 & B2 & B3 & B4 | Baseline | Optimisation |
|---|---|---|---|---|---|
| Affordability | OPEX | 82.5 | 82.0 | 85.0 | 86.875 |
| Affordability | CAPEX | 43.26 | 41.94 | 50.14 | 55.61 |
| Sustainability | Carbon Footprint Investment | 71.86 | 74.68 | 70.0 | 78.90 |
| Sustainability | Carbon Footprint Operations | 100.0 | 97.30 | 97.57 | 100.0 |
| Maintainability | Complexity Number Vessel Types | 100.0 | 100.0 | 100.0 | 100.0 |
| Red Safety & Security | Availability Long Term Deployment in Incident Response | 100.0 | 100.0 | 100.0 | 100.0 |
| Red Safety & Security | Availability Capacity Coverage Incident Response | 100.0 | 0.25 | 100.0 | 100.0 |
| Red Safety & Security | Critical Initial Response Time | 83.23 | 83.23 | 83.23 | 72.29 |
| PFM SCORE | | 79.26 | 0.0 | 80.17 | 100.0 |

## L.5. Results red- and blue-tasks combined for verification tool by comparison of alternatives

**Table L.8:** Weight Distribution Optimization Combined Tasks

| Objective | Weight | Sub-Objective | Sub-Weight | Optimization-Weight |
|---|---|---|---|---|
| Affordability | 18.421 | OPEX | 50.00 | 0.092 |
| | | CAPEX | 50.00 | 0.092 |
| Sustainability | 18.421 | Carbon Footprint Investment (construction) | 50.00 | 0.092 |
| | | Carbon Footprint Operations | 50.00 | 0.092 |
| Maintainability | 5.263 | Minimize Complexity Number Vessel Types | 100.00 | 0.053 |
| Red Tasks Safety & Security | 28.947 | Maximizing Availability Capacity Coverage Incident Response | 33.33 | 0.097 |
| | | Maximizing Availability Long Term Deployment in Incident Response | 33.33 | 0.097 |
| | | Minimizing Critical Initial Response Time | 33.33 | 0.097 |
| Blue Tasks Safety & Security | 28.947 | Maximizing Number of Barge Inspections | 33.33 | 0.097 |
| | | Maximizing Number of Inspections Seafarers | 33.33 | 0.097 |
| | | Maximizing Patrol Distance | 33.33 | 0.097 |

**Table L.9:** An overview table of the **aggregated** performance of the different fleet compositions when both blue and red tasks are considered. Keep in mind that PFM scores are compared to other scores. If X scores close to Y, it is because Z scores very differently. For more information about Preference-Functional-Modelling see Barzilai (2022)

| Alternative | A1 | A2 | B1 | B2 | B3 | B4 | Baseline | Optimization |
|---|---|---|---|---|---|---|---|---|
| **PFM score** | 29.34 | 46.19 | 14.83 | 15.18 | 30.03 | 0.0 | 28.60 | 100.0 |

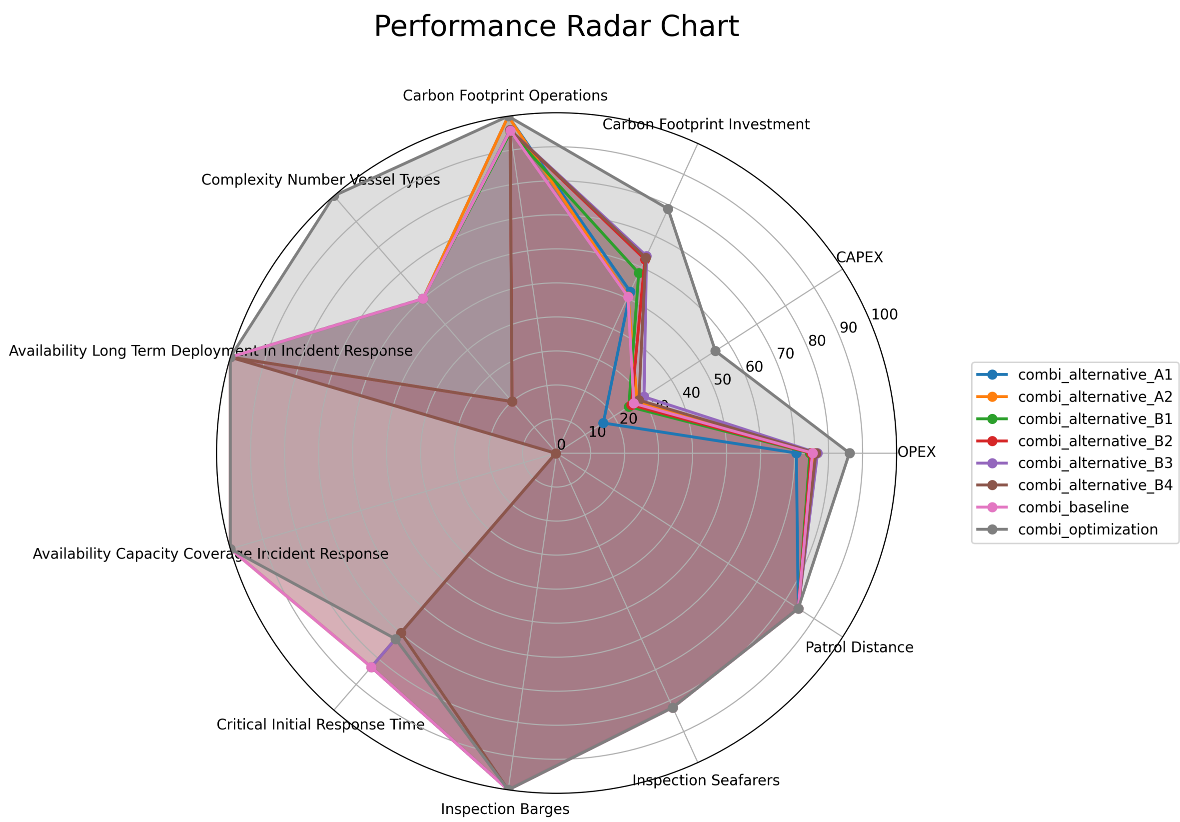
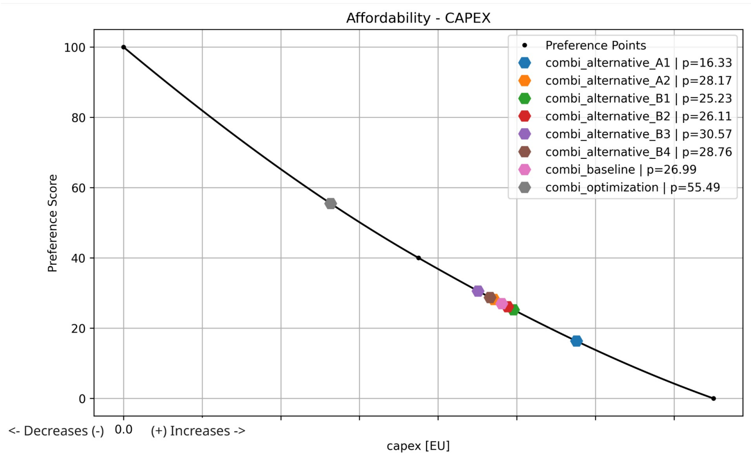
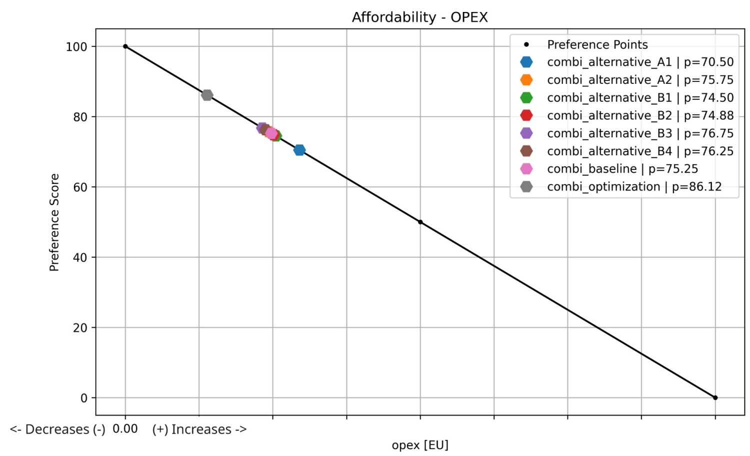


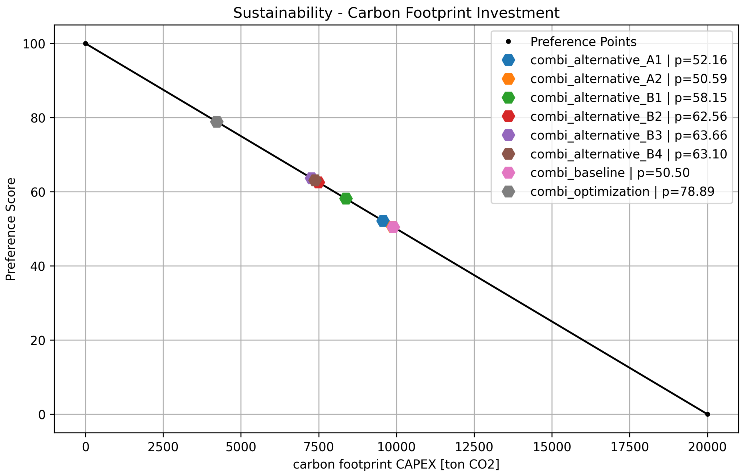

**Figure L.10:** An overview of the performance of the different fleet compositions when only the red tasks are considered.



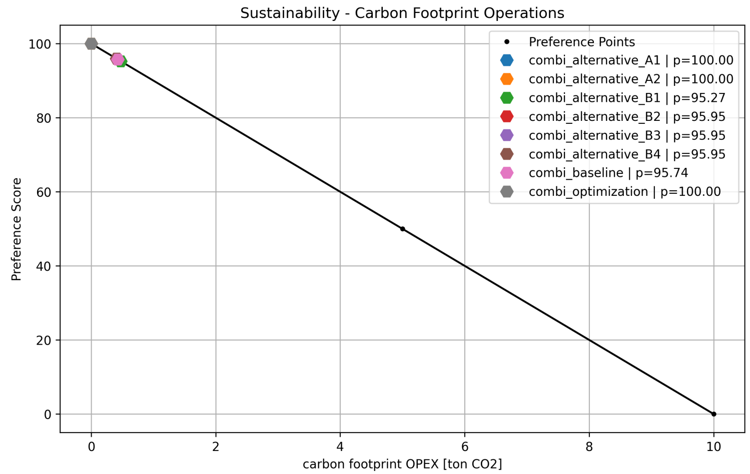

**(a)** Preference Curve CAPEX as sub-objectives from 'Affordability' (design for -ty objective)




**(b)** Preference Curve OPEX as sub-objectives from 'Affordability' (design for -ty objective)

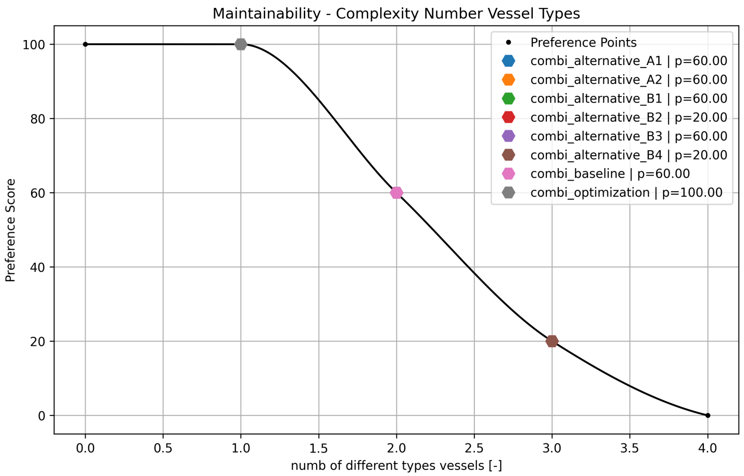



**(c)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)

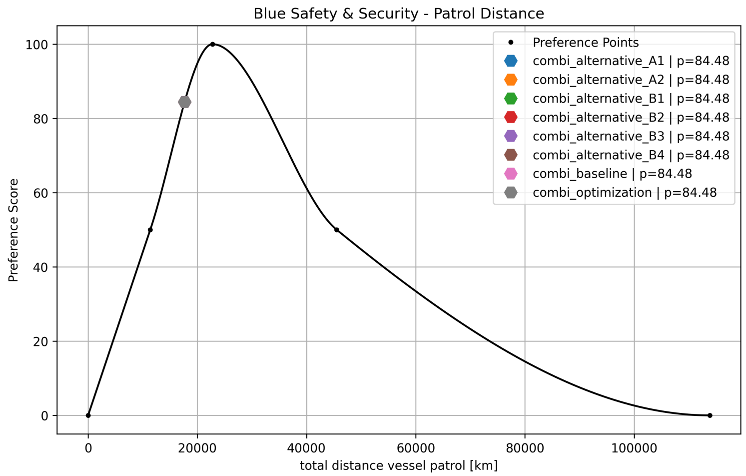



**(d)** Preference Curve Carbon Footprint Investment as sub-objectives from 'Sustainability' (design for -ty objective)

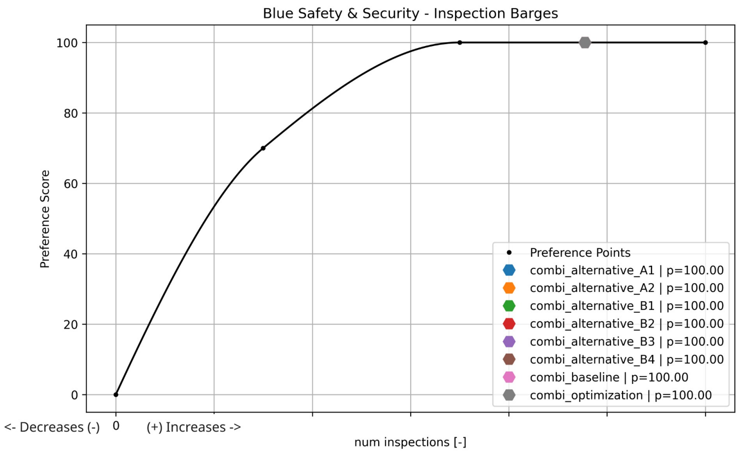
**Figure L.11:** Preference Curves for Affordability and Sustainability. Preference Curves for Affordability and Sustainability. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.



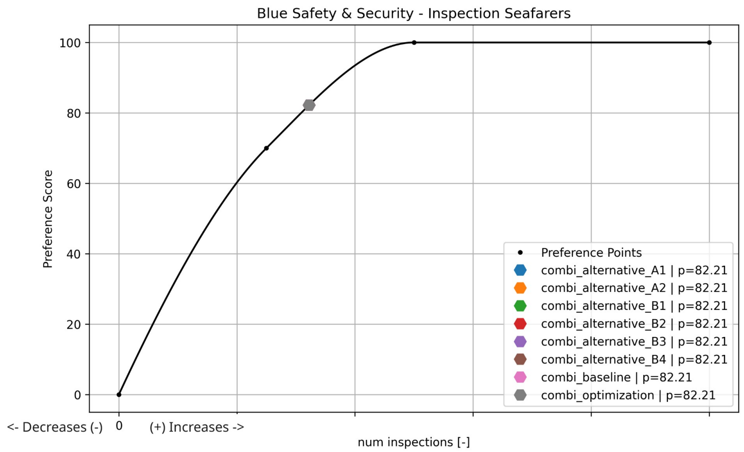

**(a)** Preference Curve Complexity Number of Vessel Types as objective from 'Maintainability' (design for -ty objective)




**(b)** Preference Curve Patrol Distance as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)

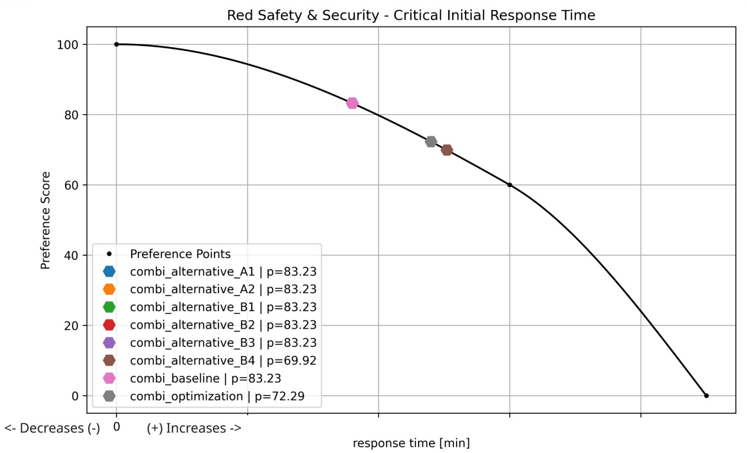



**(c)** Preference Curve Inspection Barges as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)

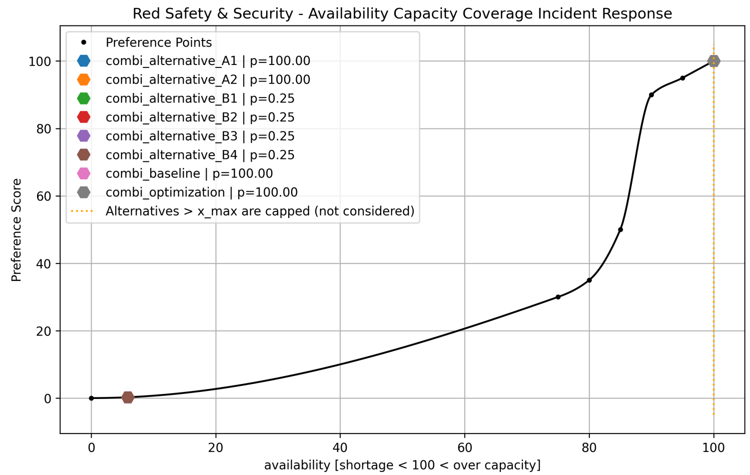



**(d)** Preference Curve Inspection Barges as sub-objective from 'Blue Tasks Safety & Security' (design for -ty objective)

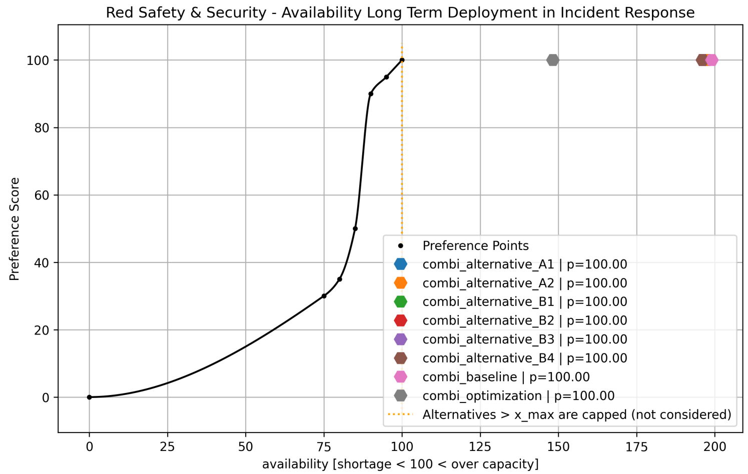
**Figure L.12:** Preference Curves for Maintainability and Blue Tasks Safety & Security. Preference Curves for Affordability and Sustainability. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.




**(a)** Preference Curve Critical Initial Response Time as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)




**(b)** Preference Curve Availability Capacity Coverage Incident Response as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)




**(c)** Preference Curve Availability Long Term Deployment in Incident Response as sub-objective from 'Red Tasks Safety & Security' (design for -ty objective)

**Figure L.13:** Preference Curves for Red Tasks Safety & Security. The Port of Rotterdam has not yet initiated the tender process, therefore some figures have no values on the x-axes.

**Table L.10:** An overview table of the preference scores of the different fleet compositions when both blue- red tasks are considered. Note that only with PFM-aggregation are the scores rescaled to the range [0, 100].

| **Design For -Ty** | **Objective Class** | **A1** | **A2** | **B1** | **B2** | **B3** | **B4** | **Baseline** | **Optimisation** |
|---|---|---|---|---|---|---|---|---|---|
| Affordability | OPEX | 70.5 | 75.75 | 74.5 | 74.875 | 76.75 | 76.25 | 75.25 | 86.125 |
| Affordability | CAPEX | 16.33 | 28.17 | 25.23 | 26.11 | 30.57 | 28.76 | 26.99 | 55.49 |
| Sustainability | Carbon Footprint Investment | 52.17 | 50.59 | 58.15 | 62.57 | 63.66 | 63.1 | 50.5 | 78.90 |
| Sustainability | Carbon Footprint Operations | 100.0 | 100.0 | 95.27 | 95.95 | 95.95 | 95.95 | 95.74 | 100.0 |
| Maintainability | Complexity Number Vessel Types | 60.0 | 60.0 | 60.0 | 20.0 | 60.0 | 20.0 | 60.0 | 100.0 |
| Red Safety & Security | AV. Long Term Deployment I.R. | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Red Safety & Security | Availability Capacity Coverage I.R. | 100.0 | 100.0 | 0.25 | 0.25 | 0.25 | 0.25 | 100.0 | 100.0 |
| Red Safety & Security | Critical Initial Response Time | 83.23 | 83.23 | 83.23 | 83.23 | 83.23 | 69.92 | 83.23 | 72.29 |
| Blue Safety & Security | Inspection Barges | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Blue Safety & Security | Inspection Seafarers | 82.21 | 82.21 | 82.21 | 82.21 | 82.21 | 82.21 | 82.21 | 82.21 |
| Blue Safety & Security | Patrol Distance | 84.48 | 84.48 | 84.48 | 84.48 | 84.48 | 84.48 | 84.48 | 84.48 |
| PFM SCORE | | 29.34 | 46.19 | 14.83 | 15.18 | 30.03 | 0.0 | 28.60 | 100.0 |

## L.6. Results red- and blue-tasks combined with Realization (Net Congestion) for verification tool by comparison of alternatives

Based on the analysis of 'formulating the mess' and specially the 'obstruction' the 'means planning' is conducted. The risks and obstructions are formulated as key-issue objectives and modelled. See the mathematical formulation chapter 3.3. For demonstration purposes, only the key-issue of Net Congestion is used.

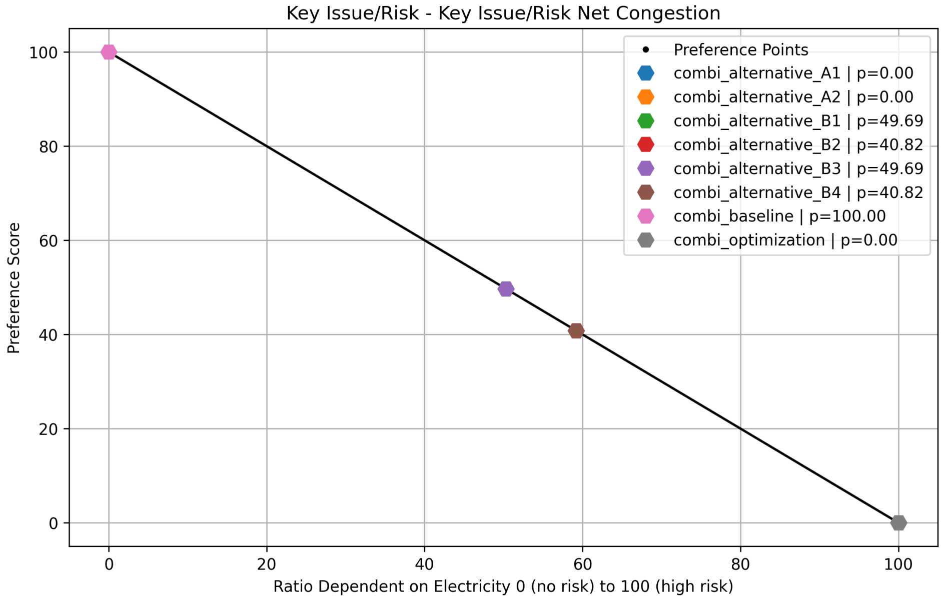



**Figure L.14:** Preference curve societal key-issue net-congestion

**Table L.11:** Weight Distribution Realization Optimization Combined Tasks

| Objective | Sub-Objective | Optimization-Weight |
|---|---|---|
| Affordability | OPEX | 0.0875 |
| | CAPEX | 0.0875 |
| Sustainability | Carbon Footprint Investment (construction) | 0.0875 |
| | Carbon Footprint Operations | 0.0875 |
| Maintainability | Minimize Complexity Number Vessel Types | 0.05 |
| Red Tasks Safety & Security | Maximizing Availability Capacity Coverage Incident Response | 0.0917 |
| | Maximizing Availability Long Term Deployment in Incident Response | 0.0917 |
| | Minimizing Critical Initial Response Time | 0.0917 |
| Blue Tasks Safety & Security | Maximizing Number of Barge Inspections | 0.0917 |
| | Maximizing Number of Inspections Seafarers | 0.0917 |
| | Maximizing Patrol Distance | 0.0917 |
| Societal Key Issues | Net Congestion | 0.05 |

**Table L.12:** An overview table of the **aggregated** performance of the different fleet compositions when both blue and red tasks are considered in the Realization (including Net Congestion). Keep in mind that PFM scores are compared to other scores. If X scores close to Y, it is because Z scores very differently. For more information about Preference-Functional-Modelling see Barzilai (2022)

| Alternative | A1 | A2 | B1 | B2 | B3 | B4 | Baseline | Optimization Idealization | Optimization Realization |
|---|---|---|---|---|---|---|---|---|---|
| **PFM score** | 31.47 | 45.04 | 16.99 | 16.36 | 30.80 | 0.0 | 38.47 | 89.89 | 100.00 |

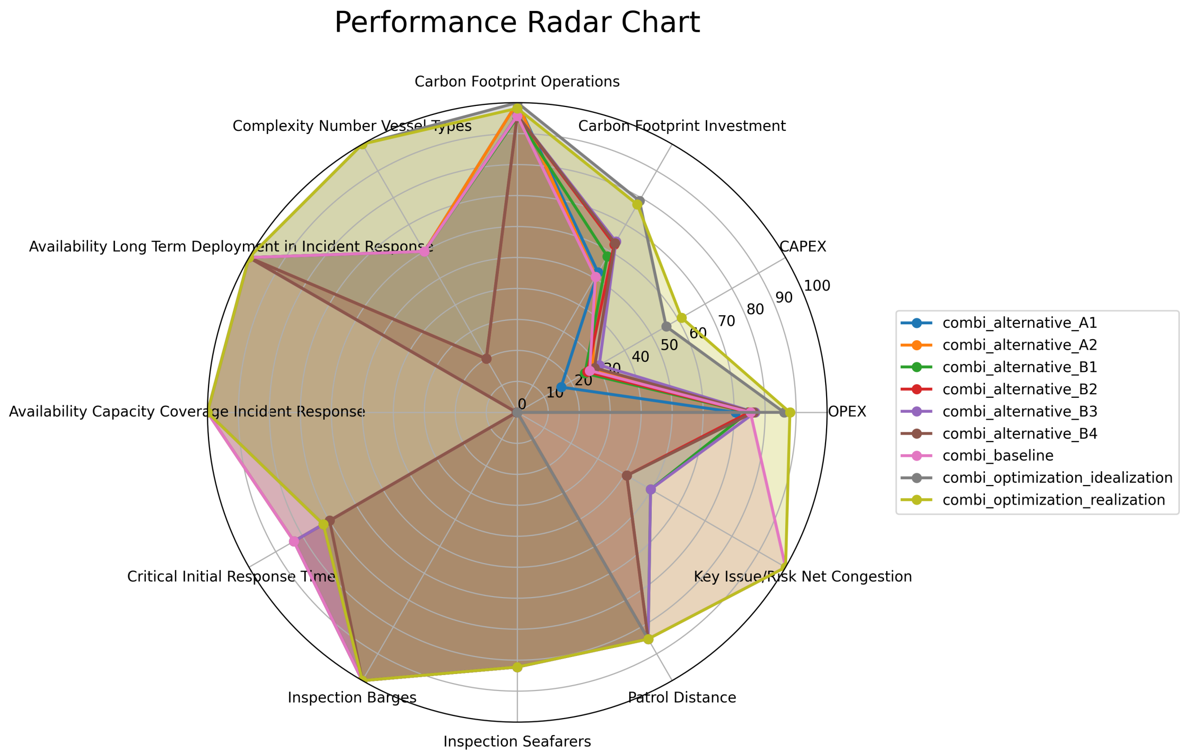



**Figure L.15:** An overview of the performance of the different fleet compositions when only the red tasks are considered for the realiztion (with net congestion).