Validating Operational Scenarios Through Simulation

by

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN WRTITING

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Abstract

Due to recent legislative changes and shifts in global markets, the task of ship design has grown considerably more complex. The integration of groundbreaking technologies, such as remotely controlled or autonomous vessels, poses additional challenges during the concept design phase, primarily due to a lack of familiarity and experience with these technologies. Simultaneously, these advancements make designing a vessel that can consistently meet its objectives throughout its entire life cycle increasingly difficult.

In the early stages of the design process, designers often face the challenge of making critical decisions without fully understanding their potential consequences. This situation is compounded by the increasing costs associated with these decisions and their influence on design freedom. Consequently, the conceptual design stages become especially crucial, as making changes later in the shipbuilding process can result in significant cost escalation for the project.
Considering the various factors impacting the ship design process, there arises a necessity for a novel methodology empowering designers to assess the operational capabilities and performance of conceptual designs during the early stages of ship design.

The presented report introduces the project titled 'Validating Operational Scenarios Through Simulation' and presents findings from a literature review on the utilization of simulation in early-stage design processes.
The introduction chapter begins with an initial description of the problem to be addressed, introduces the involved company, and outlines the motivation behind the project. Following the introduction, the results of the literature review are presented. The second section aims to answer the first set of research questions by examining the current implementation of simulation software within design processes and presenting available options for software to be utilized in the project. The process of selecting the software is then outlined, along with the conclusions drawn from the research conducted.
Subsequently, the formulated methodology is described, containing all steps necessary to structure the workflow during evaluation. The following chapter details the anticipated method of introducing the formulated method into existing design processes, including the main method of evaluation through simulation and the method of integration, using a case study example.
Finally, the last chapter concludes the report by providing considerations from the entire process and presenting recommendations for potential improvements of the formulated process.

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Nomenclature

Abbreviations

MBSE	Model-Based System Engineering
PBDM	Point-Based Design Methodology
GUI	Graphical User Interface
SBE	Set-Based Engineering
DBSE	Document-Based system Engineering
CAD	Computer-Aided Design
NATO	The North Atlantic Treaty Organization
USV	Unmanned Surface Vehicles
USDoD (DoD)	United States Department of Defence
M&SCO	Modeling and Simulation Coordination Office
SBD	Simulation Based Design
DT	Digital Twin
CSSM	Centre for the Ship Signature Management
UCL	University collage of London
VR	Virtual Reality
M&S	Modelling and Simulations
HLA	High Level Architecture
MCM	Mine Counter Measures
ABM	Agent-Based Method
ABS	Agent-Based Simulation
ABMS	Agent-Based Model Simulations
OEM	Operational Evaluation Model
CSSS	Cyber Security Simulation Services
AI	Artificial Intelligence
IDE	Integrated Development Environment
AFSIM	Advanced Framework for Simulation, Integration and Modeling
ITAR	International Traffic in Arms Regulations
GCAM	General Campaign Analysis Model
STORM	Synthetic Theater Operations Research Model
JFOrCE	Joint Future Operating Concept Explorer
JWARS	Joint Warfare System
CPE	Command Professional Edition
CMO	Command: Modern Operations
SE	System Engineering
DA	Document Based
NSIN	National Security Innovation Network
DIU	Defence Innovation Unit
AFRL	Air Force Research Laboratory
DIS	Distributed Interactive Simulation
USAFRL	United States Air Force Research Laboratory
USMC	United States Marine Corps
MWCL	Marine Corps War-fighting Laboratory
AMC	Air Mobility Command (US Armed Forces)
DARPA	Defence Advanced Research Projects Agency
OCD	Operational Capabilities Description
OCA	Operational Concept Analysis
AO	Area of Operation
UV	Unmanned Vehicle
ASV	Anti-Submarine Warfare
ACTUV	ASW Continuous Trail Unmanned Vessel
MDUSV	Medium Displacement Unmanned Surface Vehicle
MUSV	Medium Unmanned Surface Vehicle
LUSV	Large Unmanned Surface Vehicle
EMCON	Emission Control
ROE	Rules of Engagement

1. Introduction

1.1. Motivation

Ships are widely recognized as among the largest and most intricate man-made systems, characterized by their complex structures and subject to numerous regulations and requirements. The design process of ships mirrors this complexity, incorporating various considerations and involving expertise from diverse backgrounds.

The concept design stage is widely believed to be one of the most critical phases of the entire design process. At this juncture, the requirements or missions specified by stakeholders are translated into specific capabilities that the vessel must possess [17]. Additionally, close collaboration with all stakeholders is imperative during this stage to ensure that the designed vessel aligns with their needs.
During concept phase, designers often find themselves making decisions that carry significant weight throughout the entire project. These decisions not only commit costs and constrain design freedom on but also have the potential to impact subsequent decisions later in the process [95] [6]. Unfortunately, at the initial stages of the design, the designers do not possess sufficient knowledge about the decisions that they have to make and their potential outcomes [56]. This lack of insight significantly diminishes the project's effectiveness and may necessitate costly adjustments in later stages (see Fig:1.1).

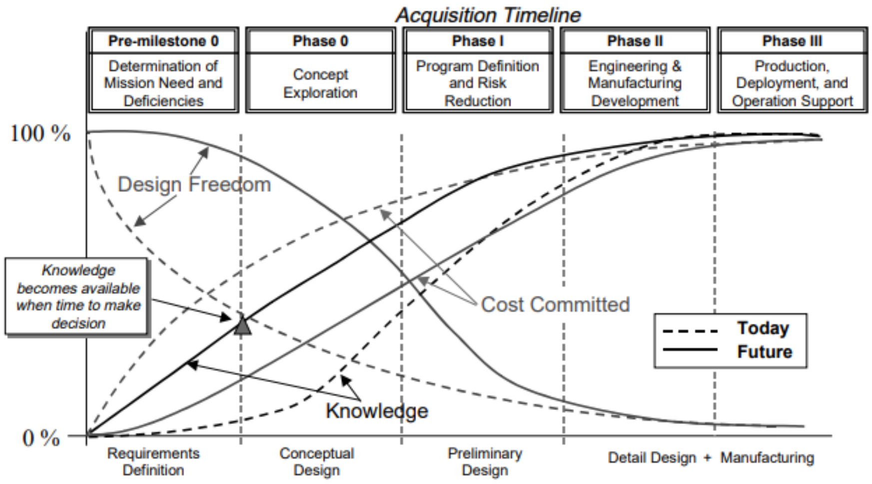


Figure 1.1: The relationship of design freedom, knowledge and cost committed. [56].

As a result, the need for new design methodology has been formulated. Currently, various companies and organizations have acknowledged the potential benefits of the Model-Based System Engineering (MBSE) approach. While this implementation proves advantageous for several purposes, it does not fully solve the presented issue. Especially within the domain of innovative solutions, conventional evaluation methods may fall short in delivering accurate assessments. Often, decisions may be supported by the designer's experience, but this approach has significant limitations. Experience is typically confined to specialized areas and is only accessible to seasoned designers. Furthermore, it is not applicable in the case of innovative design which is a crucial matter for modern companies to adjust to the market and provide long-lasting solutions.
This problem is especially noticeable in contemporary businesses, which must consistently improve their operations to provide the best products for customers and maintain their position in the market. As such, the research gap addressed by the presented project primarily lies within the concept design domain. The objective is to foster a better understanding of potential solutions to support the decision-making process before commitments are made.
The aim of this project is to provide additional means of assessment of the capabilities in conceptual stage of the design by developing a method of implementation of the simulation of military operations with a system model of the operational needs of a future military platform. This development should be able to improve knowledge about the required capabilities of the designed vessel in the initial stage of the design by offering a tool to explore the "performance space" while the full systems composition is still not formulated [27].
Additionally, the outcome from the process would serve as evaluation for the operational needs analysis, which is currently conducted basing on the operational experience of the specialist [26].

1.2. Company Introduction

The project would be done in strict collaboration with one of the biggest naval companies in Netherlands, namely, Damen Naval which is a dedicated naval shipbuilding division of the Damen Shipyards Group. This division holds responsibility for overseeing all naval-oriented projects within the Damen Shipyards group, with its main headquarters situated in Vlissingen, Netherlands, and additional smaller facilities located globally. The main goal of the company is to provide highly specialized naval vessels to clients around the globe. Given that the company has undergone rapid growth and development over the last few years, it consistently explores new approaches and technologies to enhance its capabilities in the design and construction of naval vessels [18]. The company also oversees the organization of training programs for future crews and staff working on their products. Furthermore, there is an increasing interest in investigating and possibly incorporating simulation, virtual reality, and augmented reality technologies into the company's operations. Damen Naval is eager to assess the capabilities of simulation software utilized for evaluating vessel designs to enhance the overall design process.

The model-based system engineering approach was already implemented by the company through the Arcadia methodology, utilizing the Capella software as a tool to articulate system needs and conduct analysis. Furthermore, there is a strong interest in developing new approaches to evaluate results obtained from operational needs analysis. To achieve this objective, the collaboration will focus on exploring and refining a potential methodology for utilizing design method outcomes as input parameters for simulation. Currently, Damen Naval is in the experimental stage with simulation software, assessing its suitability across different scenarios.

1.3. Background

Early in the process of formulation of the main goal of the project it was recognized that there is several different aspects that may be improved due to the introduction of simulation in early stages of the design. These potential challenges affect not only the design team actively involved in the project but also the stakeholders responsible for setting the initial requirements and ultimately shaping the project's capabilities and final outcomes.

1.3.1. Decision Making Process

The evolving legislation and dynamic shifts in the market introduce new challenges when it comes to designing vessels that can effectively fulfill their intended tasks over their entire lifespan.
It is acknowledged that, particularly in the case of complex and large-scale engineering projects, challenges stem from the characteristics of the design process [42]. Designers or design teams must make decisions based on limited knowledge, addressing uncertain matters that are temporal or fragmented in nature [60]. Additionally, the full extent of the influence of certain decisions on other aspects of the design is not yet fully understood in the initial stages of the design process, further intensifying the complexity of decision-making [44].

This challenge is faced by designers due to their lack of necessary knowledge to anticipate and adapt to market and legislative changes, particularly when confronted with budgetary fluctuations. Significant alterations to the design space may be necessary and must be addressed. On the other hand, the complexity of the decision-making process may also be heightened by the expectation that decisions are often required earlier in the design process to reduce overall process time and gain a competitive advantage.
As example of hidden implications of the decisions the measures of effectiveness or measures of performance (or Key Performance Indicators KPI) may be used. These metrics serve as representations of characteristics desired by stakeholders, considering both performance and capability aspects of the designed vessel. Every design decision made during the process can impact the available space in the performance spectrum, potentially limiting the vessel's performance or capability [27], [Fig.1.2].

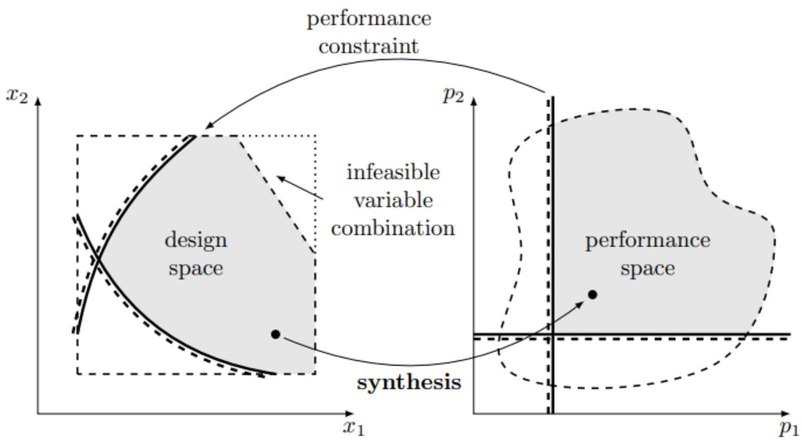


Figure 1.2: "Complex interactions between design and performance space". Diagram visualizing the complex nature of connections between design space and performance space.[27]

The relationships and influences between these measures are often complex and not easily discernible, making the process of achieving the optimal compromise between performance and capability challenging and time-consuming. Many vessel characteristics can influence other capabilities by introducing new systems or altering the volume occupied by existing systems. The success of the design may depend on finding the optimal balance point for these measures, ensuring that the ship is fully capable and highly efficient in performing desired tasks.

Given the multitude of unknowns at these early stages of the process and the relative scarcity of specific knowledge about proposed problem-solving solutions, developing tools that offer support throughout the complete life cycle of a vessel becomes challenging. The traditional shipbuilding approach follows an iterative, multi-disciplinary process that typically involves multiple employees and spans a considerable amount of time. This approach, commonly known as the "Design Spiral," sees designers addressing specific aspects of the design in a sequential and iterative manner. The process begins with the use of low-fidelity tools in the initial iteration due to a lack of certain knowledge, progressing to the utilization of relatively high-fidelity tools for detailed design [85].

This Point-Based Design Methodology (PBDM) is considered to introduce significant challenges to the decision-making processes, particularly in the early stages or initial iterations [95]. Its impact on the project is substantial, given that the majority of committed costs are "locked" during the first stages of the complete development cycle [41], coinciding with the period of highest risk [Fig.1.3].

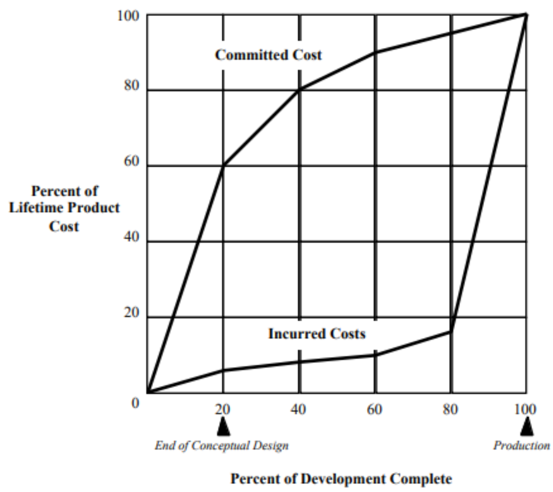


Figure 1.3: "Designing-in cost". Diagram visualizing that the costs are committed to the product's life-cycle early in the process. [6]

1.3.2. Understanding of Requirements and Solutions

Especially in domain of early (preliminary) design, the main characteristic of the process is often described as "ill-defined". This can be attributed to the fact that, while the goal of satisfying customer requirements is well-defined, the requirements provided by stakeholders are often vague, incomplete, or even conflicting. As a result, there is no single "correct" solution to this complex problem [24]; instead, there are many different solutions, some of which may offer additional benefits that are unknown at the early stages of the design process.

This complicated situation may be tackled by several methods; however, researchers have identified that specific design approaches within the domain of system engineering may not always be applicable when dealing with intricate military designs, potentially introducing additional complications.

In particular, the "Requirement Engineering" approach, which yields non-material-specific outputs (solutions) [2], can present challenges. This complication stems from a shift in the primary focus of clients, emphasizing military capabilities over equipment performance [39]. The neglect of material solutions in the design process can render the derived solutions unattainable in subsequent stages [83], consequently resulting in extra expenses and time delays for the entire project. The ability to balance the performance factors of the vessel with its effectiveness in anticipated missions becomes crucial for success of the project.
Certainly, while the requirement engineering method may prove successful in numerous instances [40], it is crucial to recognize that in situations where the primary design challenge is intricate and requirements are not thoroughly comprehended, the implementation of requirement engineering should be avoided.

Moreover, introducing a new methodology for requirements elucidation would reduce the likelihood of potential issues emerging later in the design process. Enhancing the transparency of the overall process requires an improvement in traceability within the process, as outlined in references [76] and [88]. The capacity to trace back decisions, understand their context, and identify the decision-making body would significantly enhance comprehension and facilitate the evaluation of past processes. Due to this recognition, it becomes crucial for the newly formulated methodology not to compromise the transparency of the design process at first stages and potentially lead to its improvement during future development of the method.

1.3.3. Communication with the Stakeholders

Additionally, it was determined that if done correctly, the final outcome of the project may contribute to new methods of enhancing the communication processes with the stakeholders. This would greatly improve the efficiency of the process, as the design team would gain access to tool that would be able to recreate particular missions of the vessel and precisely showcase which capability (provided by certain system) would be vital in order to complete the assigned task.

It is of significant importance to address the challenges associated with the free flow of information between designers and stakeholders. Especially at the beginning of a new project, the relationship between the design team and stakeholders plays a pivotal role in determining the project's success. This is particularly true in the context of complex projects, such as naval vessels, where stakeholders can wield considerable influence over the design process. The decisions made by stakeholders add complexity to the decision-making process, introducing additional requirements and diverse perspectives on various matters.
Furthermore, it becomes crucial to establish clear communication channels among all stakeholders in the project. It ensures that every participant comprehends current considerations and can clearly discern the processes that lead to the outcomes.

Additionally, some stakeholders may not possess engineering knowledge or operational experience needed to understand every aspect of the proposed solution. Therefore, it is essential to implement improvements to ensure that all participants can clearly grasp present matters and remain fully engaged in discussions. This inclusivity is key to ensuring that cooperation among all sides leads to successful development.

1.3.4. Model-Based System Engineering

At present, researchers are actively working to tackle these challenges and develop potential methodologies that would defer the decision-making process until a thorough understanding of all possible outcomes for various solutions is achieved. There is a noticeable shift in focus towards innovative design approaches, such as set-based engineering (SBE) [41] and system engineering (SE). This shift is gaining traction as more companies integrate system engineering into their frameworks. Additionally, contemporary trends emphasizing a reduction in the use of documents in the design process have prompted a move from the Document-based System Engineering (DBSE) approach to the more modern Model-based approach (MBSE).

The model-based approach is not solely centered on the digitization of the process; it also prioritizes enhancing communication channels among various design participants and stakeholders [45]. This approach integrates the consideration of system requirements, design, analysis, and verification and validation activities from the outset of the design process. Moreover, these considerations are intended to persist throughout the entire life cycle of the product, such as a vessel, representing a long-term approach to achieving design objectives. Importantly, this shift is advantageous for several reasons, all without a substantial increase in costs [38].

The model-based system engineering approach is distinguished by heightened traceability within the system, with the option of incorporating 3D Computer-Aided Design (CAD) models for added reference. This approach not only supports a top-to-bottom methodology but also accommodates a bottom-to-top approach, rendering it a versatile method applicable to both present and future applications.

This methodology is deemed particularly valuable when applied to intricate design challenges, such as naval or highly specialized vessels. In the initial stages of the project, it concentrates on the requirements and operational aspects of the system, enhancing overall comprehension. In contrast to the document-based (DB) approach, which decomposes the system into a pre-defined architecture, the model-based approach provides means to evaluate the system as a unified entity during the final stages of the project [25].

MBSE has garnered substantial interest in the maritime sector, with an increasing number of companies and government-level projects, like NAVAIS [15], exploring its implementation and potential enhancements.
On the other hand, the Model-Based Systems Engineering (MBSE) methodology overlooks potential challenges related to the operational evaluation of a proposed solution. This drawback can be especially significant when dealing with innovative designs that have not yet been extensively implemented, as is often the scenario with emerging technologies. To overcome this limitation, the new evaluation method could be integrated into the system. This would enable the evaluation of results from the initial prediction of the vessel's capabilities, providing a means to verify if the initial system created within the MBSE process fully complies with the requirements and would be able to fulfill intended missions.

1.4. Research Gap

As described above, the conceptual phase of design is crucial for success of the complete process. Critical decisions made at this stage not only, impact the overall project cost, but also shape the capabilities and characteristics of the final outcome.

While the MBSE methodology can notably enhance certain aspects of the design process, there are still some aspects that require attention. Namely, this methodology does not provide specific solutions for assessing of the initial design. Currently, addressing this issue relies on the expertise of the designer or the assigned specialist. Consequently, further enhancements are necessary, particularly when dealing with modern and unconventional topics within the naval domain. Hence, it is believed that to enhance the comprehension of requirements, establish future-proof evaluation methods for cutting-edge designs and to support the idea of Requirements Elucidation method [2], there is a need for an additional method or tool.

Thus, the research gap was determined. Presented project would address the lack of knowledge during the conceptual stage of the design by providing greater understanding of the requirements as well as possible solutions for the vessel's capabilities. The main aim is to create the methodology for simulation use in order to explore the performance space for the design. This would also improve the effectiveness of overall design process and reduce the amount of the experience that the designer needs to base on during decision-making process.

Furthermore, it was recognized that the introduction of simulation into the design process may additionally improve the communication channels with stakeholders providing clear understanding of the justification made for certain decisions or propositions. This additional benefit, however, would not be examined during the project due to present limitations.

1.5. Research Questions

In order to streamline the workflow of the project and maintain clear aim for developing the methodology the set of research questions was formulated. The main research question for the thesis is focused on the primary aim of the project, namely:
"How to develop methodology to utilize simulation for assessing the operational capabilities of a designed vessel, thereby offering an additional source of knowledge for designers during the early stages of ship design?".

To answer this question additional sub-questions are required to tackle different aspects of the work that would need to be done. First pair of questions will be addressed through literature research, focusing on understanding the data that forms the basis of the project and clearly identify the research gap. Answers to these questions will shed light on various applicable solutions, enabling the determination of the feasibility of the outcomes for future operations.

1. What is the current application of the simulations within the ship design domain?
2. Which simulation software would be sufficient for conducting vessel capability evaluation and operational needs analysis for presented project?

The second pair of questions centers around aspects that will be tackled in the later stages of the project. Answers to these questions are not readily available in existing literature and will require exploration through hands-on work with the software and collaboration with the company's representatives to optimize the project's outcome.

3. Which precise information should be obtained in order to formulate the complete input for the simulation software?
4. How the presented methodology may be incorporated into present design processes?

For this project, an unmanned surface vehicle (USV) was selected as a case study. The project's objective is to empower designers to assess the operational capabilities of the vessel within the context of real-time operations, even in the absence of detailed knowledge about specific systems or their placement on the vessel. Thus, primary emphasis of this exercise is not on the design intricacies of the unmanned surface vehicle but on identifying aspects that can be evaluated without a precisely specified design.

1.6. Scoping of the Project

The identified research gap could be addressed by integrating simulations of military operations into the early stages of the design process. This approach would enable designers to test a range of potential vessel capabilities within simulations of intended missions. Consequently, designers could better grasp the requirements by analyzing the vessel's intended use and assess initial predictions regarding the vessel's capabilities to determine the optimal relation between performance and effectiveness of the design.

The ultimate goal of the project's final product is to offer a platform for conveying knowledge about the design space while serving as an additional tool for evaluating operational capabilities of the designed vessel. The simulation should be integrated within the conceptual design process and possibly automatized. This would ensure that the designer would not need to possess specific knowledge about the additional methodology and would be able to use it freely for the evaluations.

Moreover, the capability to produce multiple output files from the simulation, coupled with a clear user-friendly graphical interface (GUI), could reduce the complete time of simulation preparation, and provide easily understandable feedback from the evaluation. The capacity to replicate the simulation and identify the elements used to justify particular design decisions would enhance the overall comprehension of those decisions. This feature would be particularly valuable to justify the decisions made by the designer basing on the evaluation outcomes.
Simultaneously, the product should adhere to reputable (NATO) standards for modeling and simulation architecture [65] to ensure acceptance by clients.

1.6.1. Initial Tools

It is essential to establish a method for seamless information exchange between the simulation software and the system model of operational needs. In this instance, it has been decided that the system model will be developed using the Model-Based Systems Engineering (MBSE) methodology, employing Capella MBSE software, which is presently utilized by the Damen Naval company.

The Capella software had its origins as a specialized modeling tool within the Thales Group. Originally named ”Melody Advanced,” it was developed in conjunction with another Thales Group innovation project known as the Arcadia Method [72]. The Arcadia method, created in 2007, is aimed at definition and validation of the architectural design of complex systems. It is heavily based on the model-based system engineering approach and since development was adopted into other companies that deal with complex designs, with primary emphasis on military applications [90].

The adoption of the Arcadia method has proven advantageous for engineering processes, as it encompasses all aspects of the engineering life cycle. It commences with the examination of operational needs and missions and extends to the verification and validation of the design. The Arcadia process takes into account multiple levels of engineering, offering the necessary tools to ascertain the full life cycle of the product. Furthermore, being a model-based system engineering method, Arcadia facilitates enhanced communication among all participants in the design process, including stakeholders.

The results of the design process carried out using Capella software can be translated into official documentation and stored in a database. As additional benefit, Capella software allows for the integration of a Python scripting tool through additional plugin installation. Furthermore, selecting the suitable simulation software is crucial. The chosen software should have the capability to conduct operational simulations involving both individual and multiple assets across various scenarios. Additionally, it should feature a high level of detailed interactions between the environment, the vessel, and other subsystems to ensure the most accurate outcomes from the simulation. The exact simulation software that would be used for the project would be chosen basing on the knowledge obtained through literature research.

1.6.2. Structure of the Report

To achieve the project’s main objective, the first step involves conducting literature research to establish the current state of the art in integrating simulation into ship design processes. This research aims to provide a clear overview of current simulation applications and introduce possible software options that may be utilized in later stages of the project.

Secondly, building upon the outcomes from the literature research and additional project work, the methodology will be described. This description should encompass all necessary details to facilitate understanding and replication of the proposed processes within the context of current design practices.
Lastly, the anticipated method of integrating the described methodology into the existing design process will be outlined. This chapter aims to offer a more technical approach to the proposed process, showcasing the basic mechanics and facilitating the understanding of the main ideas.
This proposed integration method will be supported by a case study example, which will be evaluated following the proposed process. The primary objective of this process is to demonstrate some of the capabilities of the methodology and validate its potential benefits for the overall process.

The case study employed to illustrate the methodology’s outcomes from the project will address the operational needs of the Unmanned Surface Vehicle (USV). Specific requirements will be formulated for this case, serving as the basis for the creation of distinct operational scenarios. Precise performance metrics will be formulated based on the particulars of the case. The objective is to offer a clear understanding of the impact of design decisions, such as the choice of sensor type, on the operational capabilities of the vessel.

2. Literature Research

This chapter aims to address the first set of sub-questions posed at the beginning of the project. It is intended to provide valuable insights into the existing applications of the simulation in the ship design domain. Additionally, it will provide information about potential simulation software available on the market that could be utilized for the project.

The interest in applying simulations to model specific operations has been present for many years, particularly as increased computational capabilities have become widely available. For instance, the United States Department of Defense (DoD) established a dedicated office, namely the Defense Modeling and Simulation Office (DMSO) (currently known as the Modeling and Simulation Coordination Office (M&SCO)), in mid-1991. The primary goal was to conduct research and standardize simulations for specific evaluations [68].

Moreover, simulations have demonstrated success in various aspects of ship design. For example, the application of simulations has enabled researchers to devise and enhance methods for detecting and identifying different vessels, as well as terrain, based on the sound emitted or reflected by them [30]. Presently, simulations have become valuable tools for determining and evaluating specific behaviors within vessel operations, such as noise emissions, structural strength, or propulsion efficiency. However, in certain domains, simulations are not yet widely adopted, and their implementation is still under research. One such area is the early-stage or conceptual design, where the simulation may be used to evaluate early concepts of solutions, providing additional knowledge to the designer on specific outcomes from his decisions.

The presented research will encompass an examination of the current state of simulation utilization in design practices. Additionally, this section will explore methods for evaluating and verifying simulation outcomes and provide insights into the existing norms and regulations governing simulations.

2.1. Applications of Simulation for Ship Design

2.1.1. Simulation for Life-cycle Estimation

The concept of Digital Twin (DT) and the assessment of vessel life-cycle have garnered increasing interest from researchers in recent years [55]. The capacity to anticipate the future utilization and potential challenges of a vessel enables the design team to address potential issues before they impact the vessel's operations. This becomes particularly crucial in the context of the imminent transition to less polluting solutions, ensuring that newly created vessels remain relevant in the near future.

The matter of evaluation of different performance through simulation is being actively researched by different governmental institutions as well as by private companies. One such company is the BAE Systems Group, which is investigating the capabilities of an already created vessel through the use of the Digital Twin concept. This concept revolves around the continuous updates of the digital model to achieve a close representation of the real-time state of the vessel and its properties. Primarily utilized for data collection throughout the full life-cycle of the vessel, this concept offers essential insights into its capabilities and potential future improvements [50].

According to the article from the company official website [5], the data obtained from the real world construction is digitized and reformulated into the digital version of the vessel. Basing on the model obtained from this method, the performance in different conditions may be evaluated. For example, the performance of the propulsion system, maximal range, and maximal speed of the vessel, when additional payload is being transported. Furthermore, this methodology may be used to evaluate the performance of the systems in different (even off-design) conditions, which may help improve the products in later iterations. The additional advantage of that methodology is present in context of contact with different parties from the supply chain.

Thanks to this solution, problems with the subsystems may be detected and addressed independently from the real time operations. Problem does not have to appear during the operation in order to be detected as it can be done by simulation. On the other hand, this approach is only applied for the vessels that were already created. This does not solve initial problems with the design process, rather it focused on maintaining operational capability of the vessel through its life cycle. Furthermore, it remains unclear from the article, how the evaluation is being done. As the design is already known, the high-fidelity tools may be used at any stage of evaluation.

According to the information published in [36] paper, the researchers were investigating the different ways of implementation of the simulations environments for estimation of changes in the ship capabilities during the life-cycle of the vessel. Those studies were carried out in partnership with multiple governmental organizations as well as the Centre for the Ship Signature Management (CSSM).

In that paper, the attempt at estimation of change in ship underwater and above-water signature was made. Those studies were involving multiple different programs such as Sensor Error Notification System (SENS), SigMa Acquisition Sensor Server (SASS) and Signature Control Room Simulator (SCORSim). The simulator included all of the potential environment and ship state influences on the signature of the vessel. It enables to estimate the signature of the ship during different operations as well as in real time.
Moreover, there are various ongoing efforts to establish a valuable simulation method for the life-cycle evaluation of vessels. These evaluations must take into account numerous influences acting on the vessel, anticipate outcomes from its exploitation, and ultimately enhance understanding of different impacts on the ship [29]. While this topic is still under investigation by researchers, it is anticipated that multiple new solutions will likely be discovered in the near future, especially with the increasing interest in new zero-emission solutions.

2.1.2. Simulation Based Design

Simulation-Based Design (SBD) is a relatively ancient methodology that predates the invention of computer systems. It is employed to analyze and comprehend specific phenomena and approximate the outcomes of decisions made. Tools such as military maneuvers or mock-ups are among those used to implement this method [62].

Nevertheless, in recent years, the use of simulation software has become an increasingly intriguing aspect for designers and researchers. Due to recent advancements, simulation-based design has been implemented in various sectors, including automotive, maritime, military, and production. In particular, the primary application of this methodology is to model and analyze supply chains, aiming to enhance planning and proactively prevent critical issues from arising [62].

Although not yet widely adopted, there is a belief that integrating simulations into the design process could enhance efficiency and reduce the overall time required for the entire process. Unlike trial-and-error development, there is a continuous and active verification of each step in the process (see Fig. 2.1). This enhancement enables the quicker identification and resolution of potential issues in contrast to non-simulation approaches, leading to a considerable reduction in process time. Especially with the widespread accessibility of high-computational-power computers, this methodology holds the promise of enhancing the design process across diverse industries.

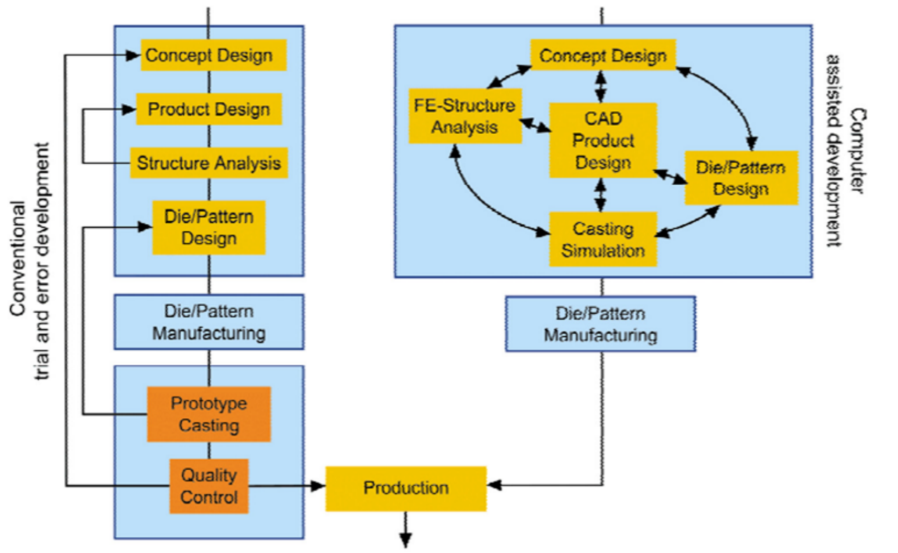


Figure 2.1: Trial-and-error development (left side of the diagram) versus Computer Assisted Development as presented in [33]

Current research efforts are focused on developing a methodology for utilizing Simulation-Based Design (SBD) in ship design practices, particularly in the early design stages. The introduction of an additional simulation-based tool set to explore the decision space before making significant commitments could be a crucial breakthrough in shipbuilding. Studies in this field suggest that a simulation-based design framework can be employed for the preliminary assessment of fleet configuration generation. This involves generating various configurations for a fleet of vessels and evaluating them

based on specific boundaries or requirements [89].
Similar assessments for single vessel configurations can be especially valuable for all maritime applications. The integration of more sophisticated simulations containing precise vessel capabilities would significantly enhance the understanding of the influence of requirements and the design space. This evolution of simulation-based design is achievable today through advanced simulation environments specifically designed to emulate certain missions, such as military operations or search and rescue operations [81].

2.1.3. Software in Initial Phases of Design

Recognizing the significance of initial phases of the design, researchers want to gain a deeper understanding by employing available software tools during this crucial stage. For instance, researchers are exploring the integration of Virtual Reality (VR) into the conceptual ship design processes to enhance understanding of the designed vessel's capabilities and improve the design process [31].

The application of virtual reality proposed in the mentioned publication focuses on the perception of sea states by the designers. The tool developed by the authors is meant to provide additional knowledge about the weather conditions in which the future crew would have to operate on the work deck of the vessel. The designer's ability to anticipate the conditions on the work deck is critical, particularly for ensuring the vessel remains fully operational in significant sea state conditions. This capability is often derived from the designer's personal experience, making it somewhat limited in availability. The development of VR simulation provides a means for a relatively swift evaluation of work conditions in specific parts of the ship, enabling designers to gain additional knowledge that might otherwise be unattainable.

Furthermore, researchers from University College London (UCL) have also experimented with the utilization of a VR tool, as outlined in [11]. This tool was designed to enhance the spatial awareness of designers during the initial stages of working on the general arrangement of a vessel. Through the VR software, designers would virtually navigate the 3D model of the designed space. Moreover, this tool allows designers to measure specific dimensions within the design and offers an enhanced understanding of available space by enabling the placement of human-sized mock-ups in areas under investigation.

This tool serves the dual purpose of offering supplemental knowledge to the designer and facilitating the evaluation of the design to ensure it meets essential requirements. However, as presented in the paper, the tool appears to have limitations in functionality. It's noteworthy that the authors acknowledge these limitations, and improvements are anticipated in the near future. Furthermore, it's acknowledged that by the time general arrangement drawings are being formulated, key decisions have already been made, making it considerably more challenging to address any consequential issues.

The educational realm has also acknowledged the advantages of knowledge derived from simulations. As highlighted in the webinar [8], simulations can enhance the understanding of the dynamics inherent in contemporary naval encounters. Furthermore, it offers valuable insights for aspiring designers by shedding light on the crucial aspects of design that hold significance in specific operational situations. Students can acquire valuable insights into the operations of the vessel they design and understand the consequences of the decisions made during the initial stage. While the presented software is relatively simple and lacks some details essential for comprehensive evaluation, this simplicity is justifiable as it serves as a tool for initial predictions.

The incorporation of such software into educational programs suggests a demand for similar solutions to gather additional information on decision consequences, particularly in the early stages of ship design. The utilization of this software in the UCL course also indicates its potential to offer supplementary feedback and context for the final design decisions.

2.2. Evaluation of the Simulation Models

As the interest in incorporating simulations to facilitate the decision-making process grows, there is a concurrent need for methods to ascertain the validity of a given simulation. The processes of verification and validation of simulation results are integral components of many different approaches, ensuring that the work undertaken to achieve specific results can be deemed trustworthy.

As outlined in the work of Robert G. Sargent [74], four fundamental methods are identified to assess the validity of simulation results. The first the presented method is relatively subjective, relying on the knowledge and expertise of the development team responsible for the evaluation. The assumption is that the team tasked with developing the simulation would also be responsible for verifying its accuracy based on their expertise and understanding. Although prone to potential errors, this approach is frequently utilized in various evaluations, including predictions of operational needs.

The next method is somewhat similar, involving evaluation by a third-party that did not participate in the simulation setup process. This approach, known as ”independent verification and validation” (IV&V), is particularly suitable for large and complex projects that typically involve multiple design teams. However, a potential drawback lies in the extensive knowledge required by the team members responsible for the evaluation. This can pose challenges, especially in cases of heavy workloads, potentially affecting the efficiency of specialists within the company. From this approach, two different methods can be derived [91]. In the first method, the validation team participates in the simulation creation process, providing feedback as necessary. In the second approach, the evaluation team conducts a review of the simulation once it is fully completed. It is noted that, especially for the second method, the evaluation process may be significantly more costly and time-consuming than other methods.

The last method involves using a scoring model based on predefined scores for different aspects of the simulation [32]. However, this method is seldom used in practice [74]. This is because the model may receive a passing score while still having significant defects, the passing scores are usually established in a subjective way, and the score may lead to overconfidence in the model.

Other method of validation of simulation is to conduct model tests for desired simulated operation [61]. This method is able to closely examine and determine the areas of simulation that are correct and those that need to be corrected. It is especially useful to evaluate operations such as underway replenishment. On the other hand, this methodology requires additional costs and time for creation of the experiment, thus this evaluation would be usually done only once to confirm if the software is correct. Furthermore, this method is not able to evaluate simulations used for capability evaluation of the vessel or multiple vessels.

2.3. Present Norms and Regulations

In recent years, there has been a concentrated legislative initiative aimed at maximizing the utilization of Modeling and Simulation (M&S) to its fullest capacity within the North Atlantic Treaty Organization (NATO), with the goal of enhancing operational efficiency and cost-effectiveness [64]. These efforts led to formulation of Modelling and Simulation Strategic & Implementation Plans for the Alliance, which are regarded as M&S implementing document and would set bases for all future development efforts (2010).

With the introduction of High-Level Architecture (HLA) in the evaluation and simulation systems, the STANAG 4603 standardization agreement was issued. This document’s purpose is to provide system-level interoperability between Command and Staff, Tactical and Individual modelling, and simulation systems. All participating nations are required to incorporate specific standards into their processes, as outlined in various norms published on the subject [65].

In accordance with the STANAG agreement, the exact norms to be adhered to during the simulation creation process include:

- IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Framework and Rules [79]
- IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Federate Interface Specification [78]
- IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Object Model Template (OMT) Specification [77]
- IEEE recommended Practice for High Level Architecture (HLA) Federation Development and Execution Process (FEDEP) [48]
- IEEE Recommended Practice for Verification, Validation and Accreditation of a Federation - An Overlay to the High Level Architecture Federation Development and Execution Process [93]

The outlined standards establish guidelines for the simulation's adherence, encompassing aspects such as model construction, behavior, interactions, and specific connections among different simulation elements. Primarily, these norms address the structure of the simulation software and the interactions among its various components. Given the project's nature, it was decided at the beginning, that the methodology presented should align with current norms and regulations, particularly considering the project's intended audience, which is a NATO client.

2.4. Simulation in Military Applications

In recent efforts to maximize the effectiveness of military operations, new strategies and tools have been incorporated into evaluation and validation processes. The development and implementation of modern equipment and systems to support operations would be rendered futile if the strategy is no longer applicable. Additionally, the use of simulations is actively researched by relevant military organizations, with successful implementations in various fields of interest [10].

At this stage of the project, it was necessary to precisely distinguish between two different aims of the simulation software employed for military applications. Firstly, there is the wargaming application, which primarily aims at evaluating operations from a tactical perspective [9]. Such simulations are often deployed to identify the most appropriate tactics and strategies for specific operations (not limited to military applications). This process often requires advanced modeling tools to accurately simulate decision-making processes during simulated conflicts, as well as to simulate human-like reactions (see. 2.4.1).
The second type of simulation, which is particularly important for the project's purposes, involves evaluating equipment performance that is not directly related to employed tactics. This type of evaluation primarily focuses on the capabilities of the assets and their performance under different scenarios. The behavior of the examined asset is predetermined within the input data and standardized to obtain repeatable and comparable outcomes.

Both of these simulation types can be integrated into a single process. For example, initially, wargaming software can be used to establish the most optimal vessel behavior based on the intended use of the vessel. This created tactic would then be incorporated into the evaluation process to ensure that the outcomes from the simulation closely reflect the actual vessel capabilities during intended missions.

The primary objective of the project is to formulate a methodology for integrating the evaluation of vessel capabilities into the early-stage design process. Therefore, the emphasis will be placed on the second type of military simulation presented, which focuses on the evaluation of equipment performance. The potential integration of both types of military simulation will be discussed in the "Additional Considerations" chapter. Another method of categorizing military-originated simulation methods is based on the specific simulation software used to conduct these simulations. The choice of simulation software often depends heavily on the specific aim of the evaluation being conducted.

Certain situations are of particular interest to researchers due to the increased risks posed to both the vessel and the onboard crew. One example of such operations is mine countermeasure (MCM) operations. This is especially crucial considering the advancements in mine functionalities, incorporating counter-countermeasure means such as delayed fuse or the ability to react to specific magnetic signatures [73]. The need for the evaluation of MCM operations is continually researched using various simulation methods, including numerical approaches based on game theory, as well as sophisticated computational tools such as Agent-Based Methods (ABM) and other computer-based simulation software.

Most of currently available military simulation environments were originally designed for operational evaluation purposes. In order to carry out the project, every considered software would need to examine for its design evaluation capabilities. This primary includes the number of detailed descriptions for vessel's subsystems, the interactions between the designed vessel and potential targets or the environment, and the presence of comprehensive damage models. [see section 2.4.3].

2.4.1. Agent-Based Model Simulation

The use of simulation to gain a deeper understanding of military operations and the operational needs of vessels has been extensively researched. In these evaluations, the most popular approach is to employ an Agent-Based Model (ABM) to simulate the behavior of elements within the simulation. The primary element in this methodology is the "Agent", an entity that interacts with the system and other agents. An agent can be described with basic attributes such as (in a naval context) maximal speed or sensor range, as well as in more advanced properties such as memory or the ability to learn from previous actions and their outcomes [49]. The complexity of the simulation depends strongly on the attributes of the agents participating in the evaluation.

Moreover, this method can be employed to assess and potentially enhance maritime research operations [67]. Considering that the origin of Agent-Based Model Simulations (ABMS) was to predict the behavior of units in different societies or market changes [70], this method would be particularly feasible for evaluating the tactics and instructions designed for naval operations, such as those for crew members. This simulation method is further reinforced by an increasing number of companies offering supporting software for military evaluations, as well as governmental projects looking into its further development. Existing solutions for similar military applications are already present on the market, such as the Stage software developed by the private company Presagis Inc [71]. Additionally, this software has been researched by the NATO Modelling & Simulation (M&S) Centre of Excellence (COE). However, these studies were focused on Cyber Security Simulation Services (CSSS) with the implementation of Artificial Intelligence (AI) [63].

According to research on the application of Agent-Based Simulation (ABS) [13], it is possible to use this method in various scenarios, such as evaluating the combat effectiveness of a squad with a decreased number of soldiers or predicting the influence of certain aspects on the operational capabilities of the military. However, Agent-Based models require significant modeling effort to provide the necessary level of detail for vessel capability evaluation. For instance, implementing specific tactics and orders that must be obeyed by the vessel may pose significant challenges within different Agent-Based Model (ABM) environments.

The specific interest in developing a comprehensive methodology to evaluate initial design capabilities with Agent-Based Simulation (ABS) is evident in the [3] paper. The authors of this study are conducting research to create an Operational Evaluation Model (OEM) to assist designers in the decision-making process. In the presented paper, they describe and compare the methodology and results obtained from four different simulation environments that incorporate Agent-Based Models (ABM). The authors concluded that Agent-Based models are a feasible way of creating military simulations.

However, the different interactions between parts of simulations in the case of simulations presented in the paper [3] do not fully represent the real-life situation. The presented simulation lacks in consideration for several critical aspects of naval warfare, such as the probability of detection influenced by weather or sensor status, the extent of damage based on the contact point of the warhead, or the survivability of both types of vessels.

As mentioned earlier, it is possible to incorporate those interactions within the Agent-Based Model (ABM) simulation, but this would necessitate a significant additional effort from the modeler. This factor may introduce additional limitations to the ABM method, making it less feasible compared to other simulation software. Especially, that missing interactions are present in different simulation environments that are available on the market [53]. Therefore, it would be necessary to investigate whether the capability evaluation for naval vessels could be conducted more efficiently in other simulation environments than ABM.

2.4.2. Custom-Made Software

Sometimes, depending on specific capabilities of the ship that should be evaluated, different software may be necessary. This situation is already present in specific design stages in which the team is able to focus on hydrodynamic or strength evaluations using dedicated simulation software.

Less complex simulations may rely on governing equations to describe subsystem behavior and their responses to various inputs. These simulations, which do not necessitate extensive calculation methods or graphical interfaces for user interaction, are often employed to provide initial predictions of capabilities. While their precision may be reduced, they serve as valuable tools for preliminary assessments [1].

At times, the ability to assess maneuverability in real-life operations, such as projectile evasion, can be crucial for decision-making support in the early stages of design. Consequently, some researchers are dedicated to developing specialized software for these specific evaluations. These programs are primarily crafted to meet the needs of specific clients, designed to address specialized problems, even if it means sacrificing other aspects of the evaluation. As demonstrated in the paper titled "Performance analyses of naval ship based on engineering level of simulation at the initial design stage," the software created by the authors is utilized to evaluate the maneuverability and detection capabilities of submarines [23].

The researchers successfully developed a simulation environment based on maneuvering and sonar equations. The simulation incorporates the influence of various types of sonars and different levels of emitted sound based on the orientation of the surface or submerged vessel. Moreover, the software enables the simulation of a submarine's attack on a surface ship, considering the deployment of decoys by the ship. Additionally, the simulation is equipped with a Graphical User Interface (GUI) that can be used to visualize the course of the simulation and provide additional explanations for the obtained outcomes.

On the other hand, the simulation appears to lack details regarding certain behaviors, such as the influence of so-called ”scattering layers” on the detection performance of the submarine [22]. Additionally, the complexity level of both vessel types, particularly regarding survivability or specific subsystems, is simplified to essential components for the simulation, which may make it less adept at accurately portraying alternative missions.

It is acknowledged that the information available to the designer about the solution is severely restricted during the initial design stage. However, the simulation should not be constrained in the level of detail it incorporates. The greater the level of detail present in the simulation, the more robust and comprehensive the response to the user’s inquiries. Particularly in contemporary naval scenarios, numerous seemingly unrelated factors may diminish the overall effectiveness of the entire vessel.

Due to constraints in time and lack of specific knowledge, it has been concluded that, for the purposes of the presented project, an off-the-shelf solution should be selected. This choice aims to significantly minimize potential errors caused by the user and enables a concentrated focus on formulating the methodology, which is the primary objective of the project.

2.4.3. Methodology Requirements

It is recognized that correct simulation software would have significant influence on the success of the project. When chosen correctly, it would allow to focus fully on the formulation of methodology, at the same time providing sufficient level of details in the simulation. It is noteworthy that the majority of advancements in the military simulation field are geared towards operational evaluation. However, given that the primary objective of the project is to assess the initial design, it becomes imperative to identify software that, while primarily designed for different purposes, can effectively meet the project’s specific requirements.

It is essential to determine a simulation that is suitable for evaluating the capabilities of a single unit in a naval environment. Consequently, the selected software for the project should enable the simulation of naval operations for both individual vessels and groups of vessels. Additionally, to ensure precise evaluations, the simulation environment must incorporate significant influences on vessel capabilities and operations.
Furthermore, certain projects may necessitate the modelling of other influences, such as rules of engagement orders, which could be pivotal. Moreover, for a more comprehensive understanding of events occurring during the simulation and to facilitate the communication of results to stakeholders, the software should feature a clear and user-friendly graphical user interface (GUI). Optionally, additional tools for preparing and formulating results would be beneficial.

It would be necessary for the vessel to behave in predefined way according to operational instructions of client, in this case NATO. This behavior should ideally be incorporated at the scenario formulation level within the input phase of the methodology. The utilization of a scripting language within the simulation software is assumed to enhance the overall efficiency of the process.
Moreover, to enhance the automation of the methodology, an external computer script may be employed. This script would particularly contribute to the simulation creation and results formulation, facilitating the extraction and implementation of input or output data.

2.5. Available Software Options

2.5.1. Advanced Framework for Simulation, Integration and Modeling (AFSIM)

The AFSIM simulator was originally created in the C++ environment by Boeing Co. and is currently managed by the United States Air Force Research Laboratory (USAFRL). This software comprises three main components: the framework used as a methodology, the Integrated Development Environment (IDE), and the VESPA visualization tool [14].
The structure of the methodology is divided into several separate parts. The functional architecture of the software supports routines for the top-level control and management of the simulation, including time, events, and database utilization. Furthermore, it supports standard simulation interfaces, such as the Distributed Interactive Simulation (DIS) protocol.
The top-level characteristics and capabilities of the presented framework include all the components needed to model the simulation, namely:

- The simulation objects with their class hierarchy, such as sensors, weapons, communication networks and processors.
- The event classes to control time, the processing elements and the entity data logs.
- Standard math libraries to coordinate systems, random number generators, DIS communication and generalized software routines.
- Terrain representation and the importing standards for importing additional terrain database formats.
- General purpose scripting language for access to framework objects using text input files.

- Communications network modeling.
- Electronic warfare modeling including the deceptive jamming techniques.
- Modeling of information flow between player and system elements to define Network Centric Operation (NCO).
- The ability to run AFSIM application in constructive and virtual models.
- User interface elements for integrated scenario generation and post-processor visualization.

The AFSIM IDE has been integrated to allow the analyst to create or edit input files for the simulation, execute operations, and visualize outcomes along with any possible error reports. This addition enables the analyst to receive immediate feedback from the process. Lastly, AFSIM also incorporates a visual environment called VESPA. This tool was created to support analysis by providing a visual context to the simulation processes. VESPA can display real-time entity interactions and enables the user to gain a better understanding of the situation through the inclusion of Graphical User Influence (GUI).

Due to current constraints in International Traffic in Arms Regulations (ITAR) (2016), AFSIM may only be distributed among the Department of Defense contractors [94]. However, recent efforts have been directed towards modifying the framework to allow broader use and incorporate a component-based architecture within the software. Regrettably, the software was deemed unattainable for the purposes of this research.

2.5.2. General Campaign Analysis Model (GCAM)

The General Campaign Analysis Model was developed by Systems Planning & Analysis, Inc for conducting campaign analysis for the United States Department of Defense. This tool is meant to develop time-step, agent-based models for air and naval units in maritime operational scenarios. GCAM was originally developed using the C++ programming language; however, in the current version (3.3), it utilizes a custom Constructive Object-Oriented Modeling Language (COOML) to script all elements within the simulation. The complete GCAM package consists of three different parts: ObjectManager, a development environment for scripting in COOML; GAME, an environment for running scenarios, providing graphical displays and numerical data; and Case Launcher, for running scenarios multiple times in batch-processing mode. The simulation is formulated based on several different components: maps, units, statistics, conditions and triggers, and phases [12].

The simulation created in GCAM can be used to evaluate the operations for a specific unit, task force, as well as for the evaluation of a whole campaign [20]. While it is possible to create a separate vessel and evaluate its operational needs and capabilities, the simulation software is not specifically designed for that purpose. Additional work would be needed to provide a valid evaluation of the vessel's behavior. All influences from different environmental factors on the weapons to additional details of systems onboard would need to be added to the simulation. Furthermore, the overall GUI, as well as the method of using the software, requires an additional understanding of the processes, which may be unnecessary in the case of most commercially available software.

2.5.3. Synthetic Theater Operations Research Model (STORM)

The STORM software is described as a campaign analysis tool used by the Office of Naval Operations, Assessment Division, and other DOD-related organizations. It is stochastic, theater-level campaign simulation software used for the evaluation of tactics and analysis of campaigns. This highly advanced tool supports a stochastic approach toward military campaign simulations [80]. The simulation is based on assets representing surface vessels, submarines, air, and orbital units that are simulated, along with the world region and weather conditions. The tools offered to the user can be divided into three categories: input, execution, and output. Additionally, the simulations are supported by a graphical user interface (GUI) that visualizes the simulation, and a report tool (operating on HTML or .csv) that can be used as an additional means of context and to further support the results [7].

Furthermore, the potential of the Synthetic Theater Operations Research Model was recognized by multiple organizations as it was implemented for evaluations within many branches of the US armed forces. On the other hand, the successful use of the mentioned software requires a significant amount of invested time and effort to model the simulation. Additionally, the potential use for relatively small-scale operational needs simulation was not yet tested, thus it is assumed that there are some changes that would need to be implemented into the STORM software in order to evaluate the operations of a single vessel.

2.5.4. Joint Future OpeRating Concept Explorer (JFOrCE)

JFOrCE is an agent-based model written in the NetLogo language. It is a closed-loop, stochastic simulation in which the parameters of the model define the physical attributes of the entities, control their behavior, and define the scenario [4]. This simulation method enables analysts to evaluate the behavior of single units as well as complete task forces. Although capable of simulating operations at sea, on land, and in the air, the implemented functionalities within JFOrCE primarily support land operations. Furthermore, it allows for the setup of specific rules of engagement (ROE) that are dependent on different triggers causing specified reactions [35]. All necessary interactions between agents are implemented via sensor platforms, weapons, or information-sharing capabilities (communication channels). Additionally, the assets are described by the number of assets, speed, sensor range, weapon range, and weapon probability-to-kill. New aspirations are also directed toward implementing modern Electronic Warfare (EW), namely jamming the means of communications between agents of a certain side of the conflict.

This simulation environment possesses a high level of detailed interactions between systems and scenario elements and is capable of simulating operations of only singular entities. However, without improved implementation of naval operations, this methodology may prove ineffective in evaluating naval operational capabilities due to the increased amount of additional work that would be needed.

2.5.5. Joint Warfare System (JWARS)

The Joint Warfare System is a campaign-level simulation software for military operations currently under development by the Office of the Secretary of Defense (OSD). It is an event-stepped simulation written using a custom Smalltalk programming language. This software is used to describe the interaction of military forces across the joint spectrum at a high level of resolution at the campaign level. It involves a three-dimensional battle-space, considers the effects of weather and terrain, and includes the representation of key information flow and perception-based command and control affecting the results of the simulation [57]. The complete JWARS design consists of three components: the platform domain (hardware, scenario construction, experimental design, output), the simulation domain (environment, database), and the problem domain (behavior, units). The precise interactions between the components within the JWARS framework are visualized in the figure below (Fig.2.2).

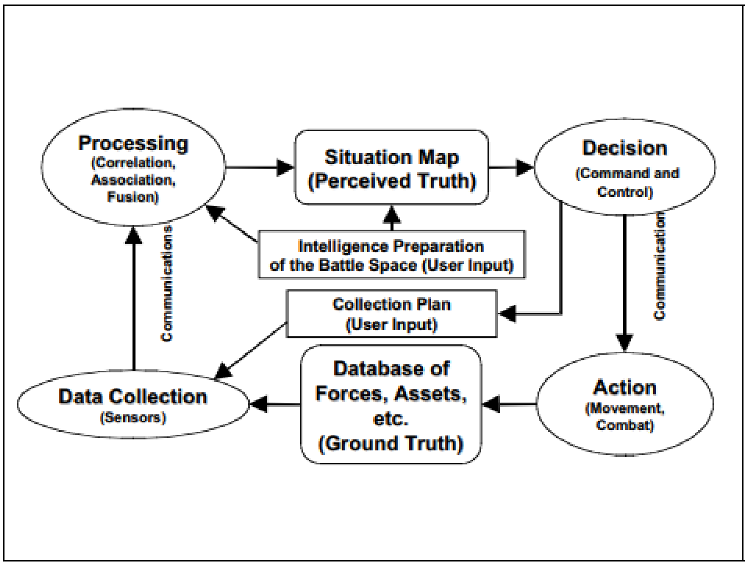


Figure 2.2: Graphic visualizing JWARS Logical Structure [57].

JWARS is a highly advanced simulation environment that already incorporates certain environmental influences crucial for accurate vessel operation evaluation. Although, according to the publications [84] its functionality would be expanded in the future, its current use to examine the operational needs of a single vessel may introduce additional challenges.

2.5.6. Command: Professional Edition

The Command: Professional Edition software is capable of simulating naval and aerial operations at tactical/operational scale offering the flexibility to modify every aspect of the scenario. Simulations can range from basic naval assets, such as patrol vessels to comprehensive aircraft carrier groups with accompanying support vessels. The professional version of this software functions as an evaluation tool within various organizations, including the United Kingdom's Royal Navy, the aerial warfare branch of the Bundeswehr, and several branches of the United States Military [51].

Figure 2.3: Organizations presently employing the Command Professional Edition software [53].

he assets utilized in the simulations have specific characteristics, encompassing main properties like top sailing speed or maximal range, as well as the onboard systems of the vessels, and are defined by data sourced from a relevant database, detailing their specific features and capabilities. This is especially important factor for early-stage design evaluation as the simulation does not require knowledge about the exact positioning of the systems onboard the vessel.

The main difference between professional and commercial (Modern Operations) versions of that software is the ability to change the information gathered in the database. By using professional version, it is possible to change the main properties of the vessel, systems onboard of the vessel or even create new systems with custom properties [Fig2.4].

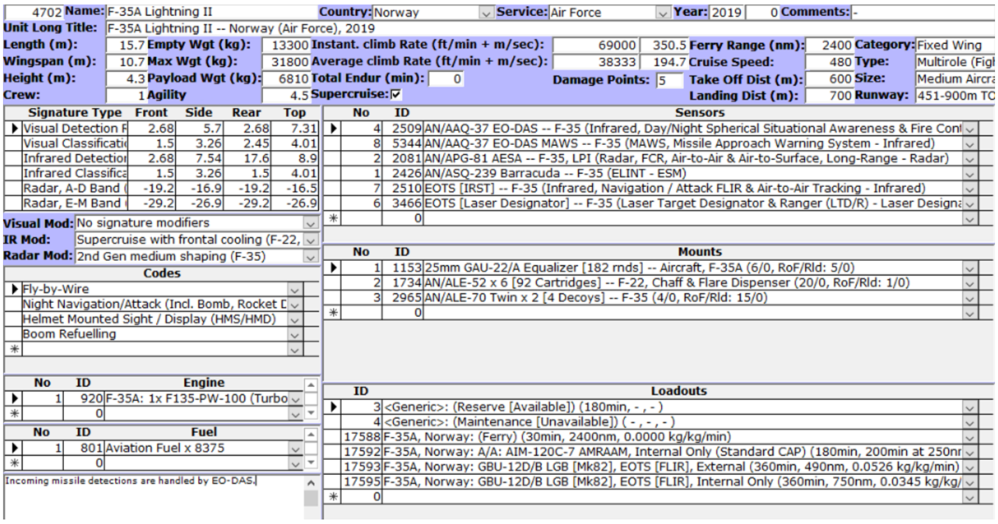


Figure 2.4: Example of data present in database for the simulation that may be changed by the user with professional version of Command software.

The creation of simulation scenarios can be achieved through two distinct methods: one involves utilizing the Lua programming language, while the other leverages the built-in GUI functionalities. This feature within the software offers notable advantages, particularly due to the potential ”cooperation” between Lua and Python scripts.

Additionally, as evidenced by researchers examining the implementation of Command software for simulation and modeling purposes [37], the inclusion of features such as Monte Carlo simulation and the Lua language enables the creation of more intricate and precise simulations.
Although the researchers were conducting simple evaluation basing on predetermined assets already implemented into the software, it was concluded that the tool demonstrates the capability to simulate large-scale operations involving various naval and air platforms. Nevertheless, the authors underscored the significance of validating outcomes through independent evaluations. Furthermore, as accurately highlighted in the conclusions, it would be essential to undertake more extensive testing of the capabilities to thoroughly ascertain its utility.

Furthermore, the Command: Professional Edition software is also considered as valuable mean of simulation for wargaming and educational applications. This potential was recognized among others by the United States Marine Corps (USMC), particularly Marine Corps Warfighting Laboratory (MWCL), in the newest attempts to include the simulations in the organization of war games at tactical level, for exercises practices [82].
Potential benefits were also identified in the field of mission analysis by other military branches such as Air Mobility Command (AMC) [34]. Especially the relatively small amount of time and cost required to research new tactics as well as the visualization aspect for conducted simulations were the aspects that prove advantageous.

In conclusion, the Command: Professional Edition software has already been integrated into several projects within the military and naval industry. Its incorporation of features, such as an external scripting language and support for Monte Carlo analysis, coupled with the capability to simulate operations for a single vessel, is regarded as beneficial for the project.

3. Solution Evaluation

To ensure that the formulated methodology effectively addresses the research problem, a set of requirements would need to be established. These requirements will serve as criteria for what need to be obtained in order for the methodology to be successful.

Based on the acquired knowledge, the conclusion has been drawn that the methodology should be segmented into three distinct phases. The first phase involves formulating and preparing the input data for evaluation, encompassing vessel description, scenario details, and the intended information for simulation assessment. The second phase is centered around creating the simulation based on the input data and conducting the evaluation. This requires establishing a clear data flow into the simulation environment. The final stage focuses on formulating and analyzing the results obtained from the simulation. This step includes the potential formulation of a final analysis and the appropriate export of outcomes into the report document. It is believed that this proposed division would expedite the identification and elimination of potential problems.

Basing on the knowledge obtained through research and considering the general requirements, it has been determined that specific capabilities must be attained, namely:

- Ability to formulate clear description of the vessel with inclusion of systems and subsystems that may be used in the simulation. Furthermore, clear description of the scenario of the vessel implementation and the conditions of evaluation.
- Ability to export the vessel and scenario description into the simulator environment, possibly by reformulating the descriptions and saving them in correct manner.
- Ability to import the input data to the simulator and to formulate the scenario basing on those data. This would need to include establishing all of the simulation properties basing on previously formulated data, such as the vessel representation or the mission that the described vessel should carry out.
- Ability to carry out the evaluation. Simulate the mission and present the outcomes in clear and understandable manner.
- Ability to analyze and export the results from the simulation into report, providing additional context to decision making processes within early-stage design.

Basing on the information acquired through literature research, an evaluation of existing solutions was carried out (see section 2.4.3). Initially, a comparison of various software options was conducted to determine the most suitable one for the researched case. The outcomes of this evaluation are presented in the table below (refer to Tab 3.1).

Software	**Availability**	**Ability to simulates single unit OP.**	**Level of integrated details**	**Overall Applicability**
AFSIM	Commercially Available	No	Low	Require significant modifications (single vessel + details)
GCAM	Restricted Access	No	Low	Not accessible
STORM	Commercially Available	No	Low	Require significant modifications (single vessel + details)
JFOrCE	Commercially Available	Yes	High	At current stage the naval operations are not fully implemented
JWARS	Government Developed	No	High	Require additional work to implement accurate simulations for one unit
Command PE	Commercially Available	Yes	High	Require implementation of specific tactics that the vessel should follow

Table 3.1: Comparison of available software options presented in State of Art (see section 2.5)

Two main issues have been identified with the simulation environments that could be employed. The first pertains to a focus on campaign evaluations, which affects the ability to prepare evaluations for single units. The second issue involves the absence of certain influences on the operational capabilities of the unit. While these issues can be addressed, it would necessitate additional work and potentially significant modifications to the source code. Moreover, simulations of campaigns often require the use of agent-based simulation environments to accurately assess different communication channels and varying states of knowledge among units about the battlefield situation. However, for this project, utilizing these functionalities of agent-based simulations is unnecessary, as they would not be fully used.

Nevertheless, as demonstrated in existing solutions [37], the potential use of the Python scripting language is recognized as beneficial for effectively reformulating and analyzing results from the simulation (output edition). Furthermore, each presented simulation environment incorporates a scripting language to provide input to the simulation or modify specific aspects of it. In the case of Command Professional Edition, the Lua scripting language allows users to configure every aspect of the scenario, such as establishing weather conditions, unit placement, and the region of operations. This additional feature would significantly enhance the variety of operational situations that can be simulated.

On the other hand, according the Matrix Games developer, the Command: Professional Edition software presently conforms to the Distributed Interactive Simulation (DIS) norms [16], which serve as precursors to the current High-Level Architecture (HLA) regulations. Originally designed to meet the requirements of the Defense Advanced Research Project Agency (DARPA), these norms were subsequently incorporated into the NATO standardization agreement STANAG 4482 in 1995 [21]. The Distributed Interactive Simulation is currently defined under set of IEEE standards, including:

- IEEE 1278.1-2012 - Standard for Distributed Interactive Simulation - Application Protocols [58]
- IEEE 1278.2-2015 - Standard for Distributed Interactive Simulation - Communication Services and Profiles [59]
- IEEE 1278.3-2010 - Recommended Practice for Distributed Interactive Simulation - Exercise Management and Feedback [87]
- IEEE 1278.4-2010 - Recommended Practice for Distributed Interactive Simulation - Verification, Validation and Accreditation [92]

In the context of the presented project, the conclusion was made that non-compliance with contemporary norms would not be treated as a significant factor. This is because the primary focus of the project, which revolves around the methodology, remains unaffected by the HLA and DIS standards, which predominantly impact the simulation software rather than its usage. Moreover, given the prior acceptance of DIS norms by NATO officials, it is anticipated that client opposition to this process would be minimal.

In conclusion, it has been determined that the project will be based on Command Professional Edition software. Despite the requirement for some additional work, this software is considered the most suitable option currently available in the market. The additional work will primarily focus on defining the specific tactics that the vessel must obey in the simulated scenario.

Moreover, since the Python script and Command Professional Edition simulator have been successfully interconnected previously, opting for these programs is expected to establish a robust foundation for the methodology. This choice is intended to minimize the potential risk of program compatibility conflicts, enabling a concentrated effort on the substantive aspects of the task. Additionally, as highlighted earlier, the division of the complete methodology into three parts ensures that potential debugging becomes more manageable, consuming less time. This approach allows for focused attention on a specific part without the need to address previous stages simultaneously.
Additionally, the method of evaluation chosen for the project would be based on the connected first and second methodology presented above (see section 2.2). Specifically, the simulation would be evaluated by a team consisting of the entities responsible for providing the input data and specialists unrelated to the simulating process (Independent Verification and Validation, IV&V), who would provide feedback at crucial milestones of the project. This would ensure that the formulated simulation process is correct and would result in valid outcomes for the considered cases. Furthermore, this solution is made possible by the full support of specialists located at Damen Naval Company.

4. Conclusions

Based on the existing solutions found through the literature research, it has been concluded that the evaluation of operational needs through simulation is not adequately addressed. Furthermore, the integration of operational simulation into the early design process is an area that lacks sufficient research. Given the novelty of this subject and its close connection to the industry, it is plausible that researchers are either currently working on it, or the relevant work has been conducted but not yet published, possibly due to commercial considerations within companies.

Basing on what was formed above, the Command Professional Edition software has been selected as the foundation for the formulated methodology. This choice is driven by its suitability for simulating single-unit actions, incorporation of complex environmental influence models, and accessibility for the project (refer to Table 3.1). Additionally, the inclusion of the Lua programming language in this software is deemed advantageous, as it is expected to significantly enhance efficiency, automate processes, and increase the complexity of scenarios.

The integration of the simulation into the design process necessitates the use of two types of ”connections” (Fig:4.1). In the initial step of the process, the description of the vessels systems and capabilities prepared by the designer would be used as the vessel description within the Command software’s database. It’s crucial to organize the data from the initial analysis for future use. This involves formulating a draft file for export to ensure accessibility and usability. Following this, the next step is to create new systems based on the properties outlined in the operational analysis. These systems will then need to be assigned to the test vessel for further evaluation. The second part of the process involves initiating the Command Professional Edition software and implementing the Lua script. This script will utilize the prepared data to operate the simulation effectively.

The Lua script, within the simulation software, will then create the scenario, utilize the database to spawn the test vessel, enforce the correct tactics for the vessel, and collect information regarding the vessel’s performance within the simulation. Finally, the intended output will be saved into a separate text file, serving as a report from the evaluation.

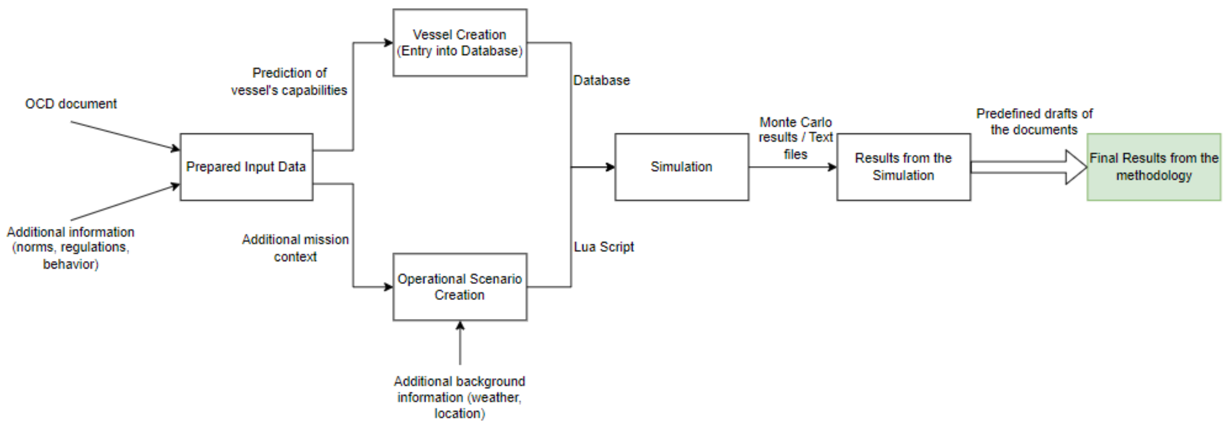


Figure 4.1: Visualization of the intended data flow according to the initial assumptions.

The initial data used within the methodology would be obtained mostly from the analysis of the design requirements for the designed vessel (Case Study). Moreover, the main outcome of this methodology would lead to results from the evaluation, which would be presented in a specially composed document. This document would serve as a means of potential communication with stakeholders and the rest of the design team and is intended to be included in the official documentation.

4.1. Considerations Related to the Simulation

The initial investigation into the selected simulation software revealed predetermined procedures for implementing a vessel into the simulation and various methods for creating the scenario. While a detailed description of the chosen methodology's implementation will be provided in subsequent chapters, this chapter serves to introduce potential methods and outline additional considerations or findings that may prove advantageous in future processes.

4.1.1. Simulation Handling

This subsection aims to highlight that during the project's realization, at least two methods were identified for both vessel and scenario creation processes. It is acknowledged that there may be additional methods yet to be discovered. However, this section will primarily focus on the main methods deemed particularly useful, especially in the context of automating the entire process of conducting evaluations through simulation.

Firstly, the method of vessel creation will be described. As mentioned earlier, there are two methods available, although they are not drastically different from each other in this context. The first method involves creating a database entry within a specially designated database that the software uses as a reference to import the vessel into the simulation. This database is modified separately from the simulation scenario and requires the use of another external tool to create or modify the entry, as well as to save the database in the appropriate format.

The precise information needed for the database to formulate the new vessel would consist of the main entry with the description of the vessel such as its main dimensions, the propulsion used, the entry describing the mounts present on the vessel and the weapon and sensors entries that would determine which systems are present on board of the vessel. Additionally, there are separate entries for communications systems and magazines which describe the type and amount of ammunition available to the crew, as well as available aircraft or watercraft stationed onboard. Furthermore, all systems used onboard of the vessel described through this database have their own separate entries in the file containing their properties such as range, capacity or ability to mount specific subsystems [Fig.4.2].

Moreover, some of the properties of the vessel are being checked within the database in order to ensure that all determined values do not contradict each other [52]. This "self-check" may be presented on the example of the engine and its connection to the Speed and Range fields determined in general vessel properties. This proves additional complication to the process of the vessel creation, at the same time ensuring that sufficient level of realism is present within the simulation. The precise description of different properties of the vessel is placed in Appendix A [See App.A.1].

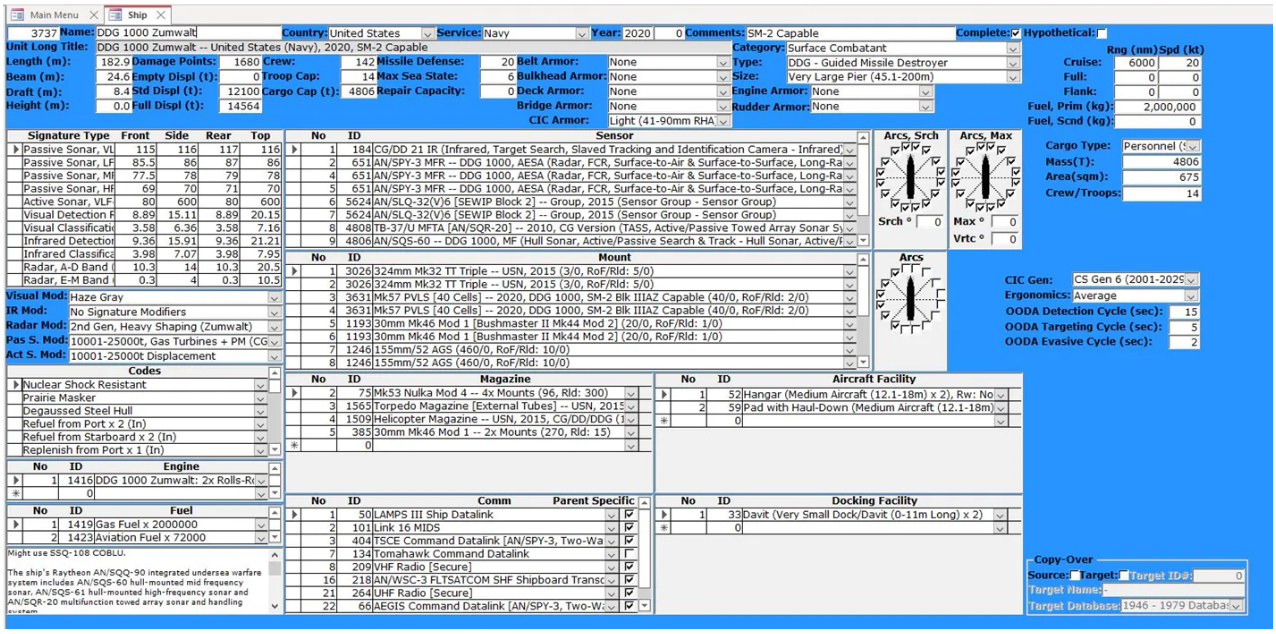


Figure 4.2: Example of the database entry for the 'ship' category from Command: Professional Edition.

The second approach to vessel creation relies on an additional function within the simulation software, which enables the modification of the composition of systems onboard the vessel directly from the simulation's graphical user interface (GUI) or by utilizing the integrated scripting language.

To fully implement this approach, the database entry would only contain general description of the vessels hull and propulsion while the systems composition would be implemented through in-sim modification. This option would enable quick changes for the systems onboard enabling quick evaluations for certain capabilities. On the other hand, it would create additional problems with more complicated evaluations, for example ones that would include changes in main dimensions of the vessel.

To sum up, while the 'database' approach may be especially beneficial in the case of full incorporation of simulation within the design process, it would allow for conducting thorough simulations using the system entries created based on specifications provided by cooperating suppliers. On the other hand, the second approach may also be beneficial at early stages of incorporation, as it would allow for conducting quick, relatively uncomplicated evaluations that may serve as initial tests before proceeding to more comprehensive simulation evaluations.

The scenario creation may be handled by means of the integrated user graphical interface as well as through the integrated scripting language (Lua). The precise determination of the method employed for specific evaluations would be dependent on the level of proficiency of the team conducting the simulation. The GUI approach would require a basic understanding of the processes and provide the same functionality as the employment of Lua scripting language; however, it is anticipated to take significantly more time and does not allow for automation of the overall process.

Regardless of the method that would be employed to create the scenario, it would need to encompass all operational aspects within the simulation. Therefore, the dataset bound to the scenario setup should already comprise information that enables clear identification of the vessel's behavior, mission, tasks, goals, enemies, and boundary conditions.

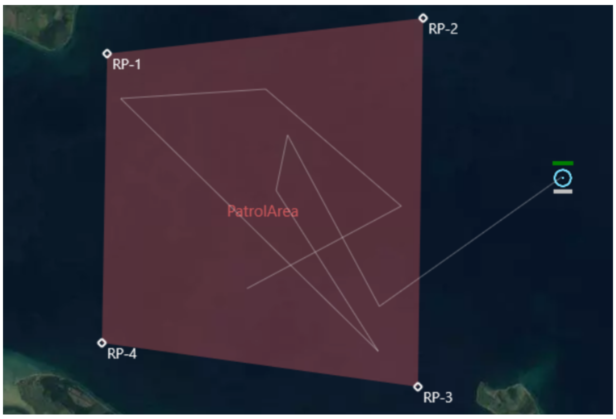
Boundary conditions are believed to be of crucial importance as they would determine the outcomes of certain actions within the simulation or when the evaluation should conclude. Furthermore, boundary conditions can also serve to store additional information for later stages of the process. For example, vessels present within the scenario may be required to report their current position, course, and speed at predetermined intervals.

While the fundamental process of scenario setup may remain unchanged, certain details could vary depending on the complexity and specific type of simulated operation. The final project report will include a detailed description of the simulation's development, particularly in relation to the case study.

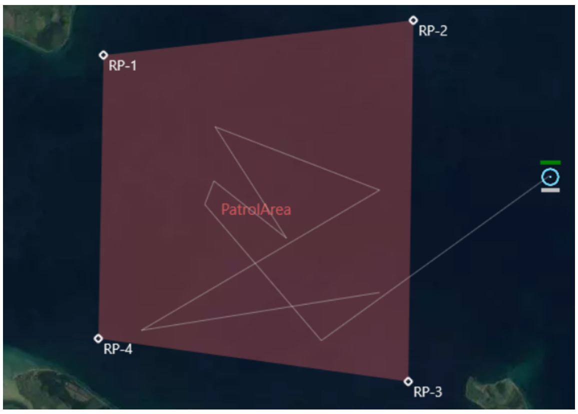
4.1.2. Behaviour of the Vessel

The intention of the project is to focus on the simulation created for a NATO-related client. This assumption implies that the vessel would operate according to certain rules described within NATO standards.

The first test aimed to establish the default behavior of the vessel within the simulation. Initially, it was examined how the vessel behaves during a patrol mission in the simulation when no instructions are provided regarding its course or patrol pattern. To achieve this, a simple simulation was created, with the addition of a 'boundary condition' that would generate position logs for the vessel every five minutes, allowing us to determine the vessel's course pattern. Additionally, the test included several simulations to determine not only if a pattern is implemented in those operations, but also what pattern it is (see Fig. 4.3).



(a) Example simulation, the vessel was tasked with conducting patrol mission in the 'PatrolArea' region.



(b) Example simulation, the task of the vessel or the area of mission were not changed, only the scenario was restarted.

Figure 4.3: Examples of different paths taken by the vessel when conducting the same mission, the route of the vessel was not specified in the simulation

After conducting tests, it was found that the simulator randomly selects the vessel's pattern. Initially, the vessel determines its route to the designated area of operations at a transition speed set to 'cruise' (around 12 knots). Once in the mission area, a new course is randomly selected within the area of operation (AO), and the speed is adjusted to 'creep' (around 5 knots). Depending on the rules of engagement (ROE) and the type of mission, if a target is detected, the vessel may transition to the target location at full speed (specify knots), engage in fire, or choose to ignore the target and resume patrol activities.

Following this discovery, it was decided to attempt implementing predetermined tactics for naval operations. To achieve this, it would be necessary to study appropriate NATO documents to determine how the tested vessel should behave within the simulation. This introduces another required input into the simulation, which would vary for each operation.

4.1.3. Behaviour of the Crew

Within the simulation software, various methods are available to describe the crew's experience and their attitudes toward certain mission aspects. The proficiency of the crew is modeled using five different levels, ranging from completely inexperienced to ”Ace”, with each level representing varying degrees of training and operational experience. This setting not only describes the operational effectiveness of the crew but also influences their ability to detect objects or engage enemy vessels within the simulation. It serves as a means of easily simulating differences in battle experience or training among the participating troops [54].

Furthermore, the Command: Professional Edition software can be utilized to set up the Rules of Engagement (ROE). These settings determine the behavior of assets when they encounter hostile units, as well as the weapons that may be employed in combat. Different settings dictate whether the crew should deviate from their assigned course to engage the enemy, the use of weapons, and their overall approach to combat situations, such as their tolerance for deviations in the calculated contact location over time.
These options may be used to determine the attitude of the crew and their stress levels at the beginning of the scenario or through scripted event within the scenario.

Although the simulation is fairly advanced, currently the option to simulate the different levels of fatigue of the crew depending on the time spend in certain alert conditions is not implemented yet. Furthermore, for state of the knowledge currently, it would be impossible to model accurately the effects of the environment and periods of exposure to the dangerous conditions on the crew. This effort would have to be based on purposely created scheme and would need to be additionally implemented into the simulator by modification to its code. Due to this, the aspects such as the crew fatigue over time will not be examined thought the scenarios constructed with presented methodology.

4.1.4. Implemented Mechanics

It is worth pointing out that the simulation also includes certain mechanics that are implemented to increase the realism levels of the operations but at the same time may introduce additional problems during certain evaluations.

For instance, there's the possibility for vessels to sustain damage or be destroyed during scenarios, mirroring real-time operations. However, while these outcomes are realistic, they may not always be conducive to evaluation needs. For example, in the official mine hunting tutorial, it's noted that MCM vessels are often damaged by underwater explosions during successful operations. Thus, appropriate mechanics have been implemented in the simulation to reflect this possibility. It's conceivable that a vessel engaged in mine sweeping could be sunk by such an explosion.

While the results of these simulations are currently deemed valuable, future decisions may necessitate further investigation into additional inputs. The vessel's database indicates numerous factors influencing damage points. To prevent the unit from being destroyed, an additional artificial system may be required to increase the amount of damage the vessel can sustain without adverse consequences.

5. Case Study: Unmanned Surface Vehicle

The topic of unmanned vehicles (UV) has gained significant attention in recent years, especially from defense and research organizations. With the ongoing automation of vessels, the concept of unmanned surface vehicle represents a natural progression for naval vessels, aiming to diminish the unnecessary risk of injury, death or capture during long missions that would require extensive physical or mental endurance. Unmanned surface vehicles (USVs) are primarily intended for missions categorized as ”three D” missions (dull, dirty, dangerous [47]), such as mine countermeasure operations and anti-submarine warfare [43]. Moreover, it is acknowledged that the reduced need for onboard crew space allows for potentially lower production costs for USVs compared to their manned counterparts [66].
This interest in development of naval unmanned vehicle technology is strongly present within the military structures of different countries. United States Defense Advanced Research Projects Agency (DARPA) started experimenting with this technology during the ASW Continuous Trail Unmanned Vessel (ACTUV) [19]. This project resulted in creation and successful sea trials of Sea Hunter medium displacement unmanned surface vehicle (MDUSV) [Fig:5.1]. Similar interest into capabilities of USV is also visible from People’s Republic of China with their rapid development of domestically produced research unmanned surface vehicle with anti-submarine capabilities.

Figure 5.1: (July 28, 2022) Medium displacement unmanned surface vessel Sea Hunter sails in formation during Rim of the Pacific (RIMPAC) 2022

Figure 5.2: (June 22, 2022) Large displacement unmanned surface vessel USV Nomad prototype transferring the Pacific as part of Rim of the Pacific (RIMPAC) 2022

The ongoing research on the topic of unmanned surface vehicles is also present in European based projects such as USV PREMARE [86] for commercial sector, and EUROGUARD [28] for defense applications. As already described, the case study topic, chosen for this project would be concentrated around operational needs and missions of unmanned surface vehicle. Although, according to the knowledge obtained from literature research, the medium (MUSV or MDUSV) to large displacement USVs (LUSV) [Fig:5.2] are not yet fully implemented into naval operations, this project would assume that MUSV vessel would conduct its assigned operations accordingly to NATO tactics. This would allow to formulate the operational profile of the ship and understand fully the requirements.

These requirements may inherently encompass several operations for the USV, including its transition from the port or fleet to the area of operations (AO), the execution of assigned tasks, and the safe return to the endpoint of the operation. Various parameters such as transit speed, search speed, sensor capabilities, endurance, and range would need to undergo testing within the simulator. It has not yet been determined if the vessel would operate as part of a larger group. Furthermore, the detailed design of the vessel would not be taken into consideration due to the nature of the project.
Additionally, several categories of performance factors may be proposed depending on the mission scenario. The first category pertains to ”measures of effectiveness,” encompassing parameters such as the number of mines detected within a specific time frame, the area covered in a given period, or the ability to remain unnoticed by opposing forces. The second proposed category emphasizes performance-related aspects, particularly fuel consumption, effective range, and time spent in the operational area. These performance factors are intended to serve as a rapid assessment tool and a means of optimizing the design.

6. Methodology

After concluding the literature research, the subsequent phase of the work focused on formulating a clear description of the methodology. To achieve this, each component of the methodology underwent thorough research. This process encompassed determining available data, describing methods to be employed, and considering various factors.
The description presented in the following chapters aims to establish the foundation for the complete methodology. It provides necessary insights into the formulation process, offering an anticipated method of implementation and describing all additional considerations.

This section will focus on formulating the main methodology description for using the simulation software to evaluate vessel capabilities at the conceptual stage of ship design. The process will be divided into three separate parts, as described previously: data gathering and input, simulation setup, and output data export and handling.

The primary approach for evaluation revolves around the premise that the initial dataset will consist of predictions of operations conducted by the responsible entity within the company structure, supplemented by data from the system analysis process to attain a comprehensive understanding of the missions the vessel is expected to fulfill. The simulation is intended to occur at the onset of the design process, serving as a means to enhance comprehension of outcomes from various configurations of the final vessel's capabilities.

As mentioned, the primary objective of the project is to establish a framework for assessing the performance of the design at the conceptual stages. Therefore, the methodology should encompass a broad spectrum of projects rather than focusing on specific cases.

6.1. Input Formulation

To execute the project, the first step involves clearly identifying the data needed for the process. This entails determining which data is necessary to create the simulation and identifying the sources responsible for providing this information. At the outset of the process, the input data is already predetermined by the requirements of the simulation software. However, it can be unified into four separate input datasets, each responsible for different parts of the process.

Firstly, the main input regarding the vessel should be described. This input needs to sufficiently describe the current (predicted) vessel capabilities, including the systems located onboard, fuel storage capacity, main propulsion characteristics, and the basic characteristics of the design. The main characteristics would include information such as general dimensions, crew number, and class of the vessel, while the systems list should precisely determine which systems are allocated and their capabilities or performance in specified conditions.

The second distinguished input dataset consists of the description of the scenario to be used for conducting the evaluation. This input should include all information about the tactical situation within the scenario, its precise location, the objectives of the mission, and all other aspects that describe the current situation within the scenario. This dataset is expected to be the most tedious to create, as the total number of different descriptions would vary depending on the complexity of the conducted simulation.

Next, the need for a third input dataset was recognized. This dataset is intended to govern the behavior of assets within the simulated scenario. The description of precise instructions for the evaluated vessels and the opposing forces would need to be created based on respected military sources, such as NATO handbooks, including orders such as Rules of Engagement or Emissions Control (EMCON). This dataset is anticipated to be created in strict collaboration with stakeholders to ensure that the most realistic tactics are employed.

Finally, the last dataset would need to provide all additional information used during the process. The information within this dataset and its specific structure would remain relatively vague, as its composition would depend on several factors such as the desired outcomes (measures) from the simulation, the capabilities to be examined, and additional variables introduced into the simulation. This dataset should be carefully examined, as some simulation software may require the determination of the desired output composition at the beginning of the process. The required information would then be provided within this dataset.

During the research stage of the project, certain actors within the company responsible for providing information for the datasets were identified. The main entity responsible for the initial dataset for the vessel is anticipated to be the design team, as it would be responsible for formulating the systems prediction and all vessel-related decisions. The "scenario" dataset would need to be created in cooperation with the Operational Analysts, who would be responsible for creating the Operational Capability Description (OCD), which would be the main source of information for the scenario and system prediction. Finally, the additional input dataset, including the behavior of the vessel, is expected to be created in collaboration with the Naval Operations Expert, who would provide valuable insights into naval operations and typical operations from the commander's point of view.

It is believed that the entire process would greatly benefit if the appropriate information for datasets were collected through predefined document drafts. These drafts would help limit the required knowledge level from specific participants to create the simulation. Additionally, the documents would enhance traceability within the entire evaluation process as they could be included in the documentation.

During the work on the project, potential document sources were also identified for the initial datasets. However, this information will be presented in the next chapter, " Method of Implementation," (see Chapter 7) as it is unknown if similar processes or documents would be present in other instances.

6.2. Implementation of Input Data

The process of implementing the data established in the previous subchapter into the simulation software requires the establishment of a special "connection." The data needs to be translated into a format that can be used within the software to create a defined scenario, allocate the described vessel with its properties and characteristics, and implement the intended behavior of the assets within the simulation.

The mentioned "connection" can be realized through two different approaches. These approaches can be divided based on the level of proficiency required to implement them into the existing design process, or the functionality of the software used to implement them. Following this method of division, the first approach would involve the introduction of an additional team member who would be responsible for inputting the presented datasets into the simulation software and creating the scenario. This process would primarily be conducted through the built-in Graphical User Interface, allowing for the manual input of predetermined data.

The second approach assumes that the process of exporting the input data into the simulation software would be entirely realized by a specially created function. This function would be responsible for correctly utilizing input datasets and simultaneously creating the scenario. The precise method or software used may vary depending on the chosen simulation software. However, from the examined options presented in the previous chapters (see section 2.5), the simulation software may include an integrated scripting language that could be used for similar purposes.

As mentioned earlier, it may be assumed that the presented approaches would depend on the level of proficiency or the level of incorporation of the evaluation through simulation within the present design process. It is recognized that the process of creating an automated function that would implement the datasets would require additional financing and time. Thus, it may be assumed that for initial tests, the first evaluations would be done using the first approach, employing a "simulation specialist" to conduct the evaluation using the chosen simulation software.

6.3. The Simulation Setup

The second step of the methodology focuses on creating and conducting the simulation. Once the input datasets are formulated and exported into the simulation software, the simulation needs to integrate all created elements into the main scenario.

The final product of this process, the scenario consolidating all predefined elements, would be directly used for evaluation. This scenario must be saved and submitted for separate evaluation. Initially, this step would be conducted by the members of the design team who were responsible for formulating the input data at the beginning of the process. This ensures that the created scenario fully represents all necessary factors to evaluate the vessel's capabilities. Furthermore, if necessary, an in-depth examination of the scenario should be conducted by an entity (simulation specialist) not involved in creating the simulation to ensure that the scenario was created correctly and would provide the desired outcomes (see section 2.2).

The end result of the second step of the presented methodology would be achieved when the previously prepared and evaluated scenario is used to assess the desired capabilities of the designed vessel. The specific method of final evaluation may differ in detail; however, the main principles should remain unchanged. The evaluation should be conducted through multiple iterations of the simulation, with each scenario starting anew and the results of one iteration not influencing the others. This ensures that each run is independent and provides valuable outcomes that can be used to draw conclusions.

6.4. Export of the Results

The concluding step of the methodology focuses on gathering, presenting, and evaluating the data obtained from the simulation. The entire process of data collection must span all steps of the methodology. Firstly, the specific data to be collected needs to be determined and implemented through appropriate datasets. Subsequently, an action must be implemented within the simulation software to save all relevant data from the simulation into the desired file format.

This saved data may include all parameters processed by the software, such as vessel position logs, vessel status, or reports of actions. The precise composition of this saved information may depend on the case being investigated. For example, it could include detection cycles for sensor prediction or data related to fuel consumption, speed, and vessel position during the examination of the propulsion system. Moreover, some simulation software can provide output files that recreate the conducted scenarios and their outcomes in 3D environments, effectively creating visualizations for simulated processes.

At the end of the process, the results would need to be exported from the simulation software into files containing the saved information and then integrated into a predefined draft. This draft would serve as the official result of the complete evaluation process. It is believed that incorporating the final draft with the results into the design process documentation would greatly improve traceability and provide justification for decisions made.
The process of extracting the data obtained from the evaluation could also be conducted as described for the initial data export into the simulation software. This is anticipated to be done by a ”simulation engineer” initially, while the complete method is still being researched and, with time, it may evolve into a fully automated process, using additional or integrated scripting languages.

The described process is expected to ensure that the designer gains a comprehensive understanding of the data obtained from the evaluation. This process would enable the design team to explore the design spaces and identify potential results for design problems without having to make concrete decisions that would have implications at further stages of the project. Additionally, the utilization of simulation would provide an opportunity to evaluate the same design in different operational scenarios that the design vessel would need to fulfill. This is especially beneficial, as often, the ability to predict the effectiveness of the design in off-design conditions would ensure that the vessel can fulfill its tasks throughout its full lifetime. Furthermore, through integration into the appropriate documentation, the obtained results can be efficiently published for stakeholders, providing additional context and explanations for the decisions made.

7. Method of Implementation

The presented section aims to describe the potential method of implementing the previously outlined methodology into the design process. This intended implementation serves as an example for the methodology described in the previous chapter, ensuring that it is well-understood and possible to recreate in other instances. This prediction is based on the processes observed within Damen Naval company, which support the presented thesis.

The described method encompasses all technical details of the implementation, including assumptions made for the project up to this point. These assumptions include the use of Command Professional Edition software to conduct the simulation and the potential integration of the methodology with the system engineering process, which serves as the main source of input data. Furthermore, the description includes anticipated methods of translating the input data into the format required for the simulation, with the inclusion of software-specific solutions.

Finally, this section establishes the basis for the next chapter, which presents the process carried out to evaluate the initial system's prediction for the case study example (see chapter 8). The presented implementation will be followed and fully utilized during the mentioned process.

7.1. First Part: Input Data

As described previously, the initial data would be used to describe the vessel's capabilities (prediction of onboard systems) and the scenario used within the simulation to evaluate these capabilities. Additionally, potential additional sources for the required data were recognized. In the following subsections, the precise composition of information and the sources expected to provide them will be described.

It is assumed that at the beginning of the design process, stakeholders would provide a set of requirements and additional descriptions of the operational scenarios in which the designed vessel would operate. This information would be examined and expanded upon by the Operations Analyst responsible for formulating the Operational Concept Description (OCD) document. The OCD would then be provided to the designer, who would create the prediction of the vessel's systems or capabilities. Furthermore, the OCD document would serve as a description for the operations, operational conditions, and measures of effectiveness required within the simulation.

In summary, the input data would be obtained from the work of the Operations Analyst and Naval Operations Expert, through the OCD as well as knowledge about the operational behavior of vessels, and from the designer through the prediction of systems onboard the vessel.

7.1.1. Description of Information from OCD

The level of detail present in the OCD is relatively low, as this document is used at the complete beginning of the process to describe some basic capabilities for the vessel. Usually, the description of precise systems with their catalogue numbers is not included unless the stakeholder demands specific systems in the requirements. Due to this, the systems are usually described as simplistically as possible, only indicating their specific purpose, for example, "sonar" rather than "MG-25 Yakhta". On the other hand, the OCD needs to clearly identify the missions and capabilities of the vessel, including environmental states as well as other states in which the capabilities must be preserved. The capabilities can already point out which specific operations would be evaluated using the simulation.

Furthermore, there are already descriptions of other properties of designed vessel, such as signature, if relevant from stakeholders' perspective, or the presence of docking facilities with their sizing.
It may be concluded that most of the important properties are already described within the OCD, and so when the data from it would be completed with the designer's prediction for specific systems, then the entry to the database of the software should be complete.

Additionally, it is worth pointing out that the "measures of effectiveness" would already be present in the OCD document. These measures serve to quantify the capabilities of the vessel and may be used while determining the output data that would be saved or the boundary conditions for the simulation to end. Ultimately, the goal of the simulation would be to provide value for those measures of effectiveness, thus answering the question "how good is the proposed design at fulfilling its tasks?".

For the project's purposes, it was crucial to precisely identify the specific information available in the operational concept description. This process involved identifying the necessary information and its sources. Consultation with a Damen employee responsible for OCD formulation was necessary to ensure accurate descriptions. The results of this research are presented in Table 7.1. Some of the data obtained from the OCD refer to the entry into the vessel creation database (see Figure 4.2), as the vessel draft served as the main basis for describing the requirements during meetings with the operations analyst.

Name	**Description**	**Relevancy**
General Description	Name/Country/Service/Year/Category	Vessel Creation
Main Dimensions	Length/Beam/Draft/Height	Vessel Creation
Displacement	Empty/Standard/Full	Vessel Creation
Cargo Capacity	Troop/Cargo Capacity	Vessel Creation
Additional Description	Ship Type/Size of dock/Max sea state	Vessel Creation
Docking Facilities	Aircraft / Docking Facility description	Vessel Creation
Signature Description	Visual/IR/Radar/Passive/Active Mods	Vessel Creation
Codes (add. prop.)	Hull Material/Multi-hull/Degaussing/Refueling cap.	Vessel Creation
Weather conditions	Atmospheric conditions during evaluation	Scenario Creation
Participating sides	List of Units/Facilities/Proficiency/Attitude	Scenario Creation
Starting State	Starting States/Locations/Conditions for each side	Scenario Creation
Mission Specific	Mission Goals/Targets/Actions	Scenario Creation
Measures of Effectiveness	Description of wanted capabilities with additional context	Scenario Creation

Table 7.1: The prediction for data that would be obtained from the Operational Capabilities Description document, with the description for which process would it be used.

As mentioned earlier, measures of effectiveness should be identified by the specialist and described within the OCD. However, it's essential to note that any additional parameters requiring examination through the simulation should also be identified and described beforehand. This addition would enable the designer to pinpoint the most viable areas of the design and ensure that the simulation data provides a comprehensive answer to the research question.

7.1.2. Prediction Formulated by the Designer

Previously discussed, the Operational Concept Description document would serve as the designer's foundation for estimating the onboard systems of the vessel. The primary objective is to anticipate which systems would be capable of providing the desired capabilities to the designed vessel.

The designer's prediction would need to include a list of systems to be included onboard the designed vessel. These systems can be described in two ways: by specifying individual systems—for example, by naming a specific sensor and detailing its capabilities—or by providing comprehensive technical information about each system's performance, such as detection arc, maximum range, or operational modes. The first approach enables the selection of specific systems from the software's database to create the vessel and evaluate its performance, while the second method requires the creation of a separate database entry for newly added systems.

The designer's prediction should include a comprehensive list of systems intended to be installed on the vessel, along with their respective capabilities, such as detection arcs or specific technical data. A key advantage of this methodology is that the designer is not required to specify the placement of the systems or their serviceability. When utilizing existing database entries for systems, only minimal information needs to be provided to "add" a system, typically limited to its name or ID and the detection arcs for systems equipped with integrated sensors (in some cases, mounts or weapons may also have dedicated sensors).
The specific details of the required information and their utilization are outlined in the table below (see Table 7.2). This table pertains to the method in which the designer utilizes systems already present within the database.

Name	Description	Relevancy
Engine	Selection of the engine for the vessel	Vessel Creation
Fuel types	Selection of the fuel types and amount of it on the vessel	Vessel Creation
Sensors	Selection of sensors from present database entries (No./ID/Name)	Vessel Creation
Mounts/Weapons	Selection of mounts and weapons from present database entries (No./ID/Name)	Vessel Creation
Magazines	Selection of magazines from present database entries (No./ID/Name)	Vessel Creation
Comms	Selection of comms from present database entries (No./ID/Name)	Vessel Creation
Arcs	Determination of search and maximal arcs of detection for each sensor and mount	Vessel Creation

Table 7.2: The prediction for data that would be obtained from the designer, with the description for which process would it be used.

It is anticipated that for quick estimations the first method of choosing already existing system would be sufficient as it would positively influence overall time of simulation setup. However, it necessitates the designer to possess a certain level of experience to comprehend the advantages and disadvantages of each system choice. Conversely, the second method is anticipated to reduce the required experience level, allowing the designer to create specific systems at the initial stages of evaluation. Once deemed adequate, specific existing sensors can be chosen based on the predicted capabilities. Although potentially advantageous, this method would require more time to set up the simulation due to the creation of additional database entries and inputting additional information.

It is believed that the method for formulating the designer's input may vary depending on the intentions and level of knowledge of the designer. In cases where the design parameters are well understood, the designer may opt to utilize specific systems already present within the software's database. Additionally, this may include systems introduced by the company to the database through potential collaboration with certain subcontractors.

The second approach of introducing "fake" systems into the database may be employed when the level of knowledge about the potential operational capabilities of the vessel is limited. By manipulating specific properties of these "fake" systems, it becomes possible to gather precise information regarding the impact of different capabilities, such as maximum range, on the overall operational performance of the vessel. Detailed instructions on what information is required to create a new entry in the sensor database can be found in the database manual provided by the Matrix Pro Sims Company [52].

7.1.3. Descriptions of the Vessel's Behavior

The input data should also specify the desired behavior of the vessel within the simulation. This entails various aspects of simulated operations, ranging from predetermined Rules of Engagement (ROE) and EMCON settings to the specific courses taken by the vessel during its tasks, such as search patterns. As previously mentioned, adherence to NATO standards is crucial, and therefore, available NATO publications will serve as the primary reference for describing all additional input. Optionally, this information may be supplemented with input from the Naval Operations Specialist, who can provide expertise and formulate additional documentation entries if deemed necessary.

Furthermore, this supplementary input may encompass additional details specifically related to the simulation setup. This could involve descriptions of events to be incorporated into the simulation, as well as the timing and scheduling of operations, along with any other pertinent details necessary for simulation creation. While the exact source of this data is yet to be determined, it is expected that the simulation specialist will play a crucial role in this process. This involvement is essential to ensure that designers do not need to become proficient in the intricacies of simulation software to utilize this methodology effectively.

The data outlined in the table below (see tab.:7.3) is primarily intended for the technical aspects of simulation setup. Therefore, it was decided that these inputs should be delineated from other inputs, as there may be multiple sources for them and they typically do not directly impact decision-making processes. Furthermore, it was acknowledged that further investigation is warranted to ensure that it will be feasible to compare and accurately replicate the simulation results and vessel behavior.

Name	Description	Relevancy
Time	Time of start / duration of the scenario	Scenario Creation
Date	Date at which scenario is taking place (influencing day/night cycle)	Scenario Creation
Location	Location of the area of operations	Scenario Creation
Starting locations of each unit	Positions at which the units would be placed at the beginning of the scenario	Scenario Creation
Bases	Facilities to which specific unit would be assigned	Scenario Creation
Areas of Operations	The specific locations in which the vessels would conduct its assigned operations	Scenario Creation
Events	Additional actions that should be triggered by certain outcomes in simulation	Scenario Creation
Behavior of the Units	Predetermined behavior of the units (actions/courses/speeds/maneuvers)	Scenario Creation

Table 7.3: The prediction for the additional data that would be obtained from the Operational Analyst and Simulation Engineer, with the description for which process would it be used.

The intentional overlap between some of the data and the information provided by the OCD is designed to address scenarios where certain details relevant to the simulation may not be explicitly covered in the OCD. In such cases, the operational analyst or simulation engineer would need to formulate assumptions to fill these gaps. These assumptions would then be included in the additional data section to highlight their supplementary nature and indicate that they are subject to change as more information becomes available.

7.1.4. The Output Data Determination

Output data may also be divided into two separate types. One of them would be the default output that may be saved using appropriate settings of the simulation software. As a result, determining the description of specific data types and instructions on how to automatically save them is relatively straightforward.

Output Data		
CSV	Comma-separated values	
XML	Extensible Markup Language	It defines and store data in a shareable manner. Supports information exchange between computer systems such as websites, databases, and third-party applications.
Tacview 1x / 2x	Different formats for Tacview software	This allows to save and recreate simulation in 3D software.
MC Access	Microsoft Access	Database management system (extensive GUI)
SQR Server	"Designed to generate reports from database management"	SQR is a specialized programming language for accessing, manipulating, and reporting enterprise data.
SQLite	Database engine	It is a Library embedded within certain applications.
SIMDIS	Software developed by Naval Research Laboratory to show the results from simulations	Software provides 2D and 3D interactive graphical and video displays of live and postprocessed simulation, test, and operational data

Table 7.4: Different formats of output data that may be saved using predefined saving method within the simulation software. May be also defined during setup of Monte-Carlo simulation.

The method of automatically determining which data should be saved is based on the input exporting method, namely, the designer or other member from the design team would need to fill separate drafts in Excel or a text file that would then be translated and implemented into the correct place in the simulation. A sample of such a draft may be created based on the setup file (EventExport.ini) that is used to determine which data is being saved from Monte Carlo simulation.

The input information would be saved, and the appropriate file in the software would be automatically replaced by a Python script. Additionally, there is an option to adjust some presets manually within the Monte Carlo analysis setup panel. These settings will be left unattended for now since, apart from the function of saving the message log output, they do not introduce any additional functionality.

Second method is basing on mentioned option for saving the text messages output. It is possible to set up manually (through Lua script or GUI) and, using additional events, custom messages containing the desired information would be printed into the message log during the simulation and then saved through a CSV file. This method may be used to include information that is not directly available in the table above, such as the 'time to enter the OA' message for designated units.

Those additional outputs would need to be identified at the beginning of the setup process and then included in "Additional Input" files. This would enable including everything in one Lua script that would be implemented at once, instead of a couple of separate files being implemented at different stages of the simulation setup.

7.2. Datasets and Exports

The collected data would need to be divided into specific datasets depending on the use case or source and then imported into the simulation software to be used in the relevant processes. At this point in the project, four different datasets were identified.

The specific composition of the information presented in the first set should not be changed between different evaluations. Therefore, it was possible to directly create a template for the design team, ensuring that the members would not need to possess any specific knowledge about the simulation process in order to provide data in the correct format. An example of the entry table in the vessel creation dataset template is provided below (see tab.7.5).

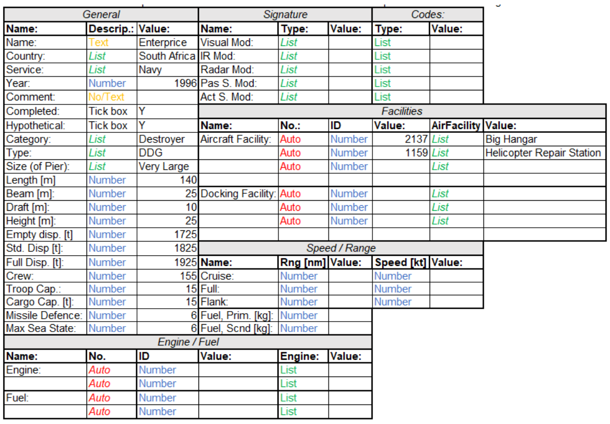
Name of the field in the database:	Description:	Type:	Values:
General Properties			
ID	Autogenerated (Do not edit)	Number	**Auto**
Name	Name; appears in long title and in-sim	Text	
Country	Operator Country	Chosen from the list	
Complete / Hypothetical	Is the vessel completed or is it purely hypothetical	Tick Box	

Table 7.5: Example of the input table present within the vessel creation dataset template. Complete template would be presented upon request.

The most crucial information regarding the correct format of the data and a brief description of the method of integration would also be present within the template. This ensures that the entire team is able to evaluate the input and make adjustments if necessary. Complete template would be presented upon request.

The implementation of the first dataset is anticipated to be fully realized by the database approach described earlier. Namely, this approach would take full advantage of the database present within the simulation process. To achieve this, the data gathered in the template would be extracted using an external script (Python Language Script) and implemented appropriately into the new database entry to create the vessel.

In case of the "research" stages of the complete integration of the methodology into the design process, a less advanced approach may be chosen. The vessel entry for the evaluated design may be created manually by using the database modification tool provided by the developers of simulation software (fully manual), or through a more automated process of manually implementing the vessel data into the correct format, which would then be easier to export into the database using an external script. For the second approach, several programs were identified such as Microsoft Excel or Access that would allow saving the wanted input for the vessel into the correct format file that may be then easily extracted (see Fig. 7.1).



General			Signature			Codes:	
Name:	**Descrip.:**	**Value:**	**Name:**	**Type:**	**Value:**	**Type:**	**Value:**
Name:	Text	Enterprice	Visual Mod:	List		List	
Country:	List	South Africa	IR Mod:	List		List	
Service:	List	Navy	Radar Mod:	List		List	
Year:	Number	1996	Pas S. Mod:	List		List	
Comment:	No/Text		Act S. Mod:	List		List	

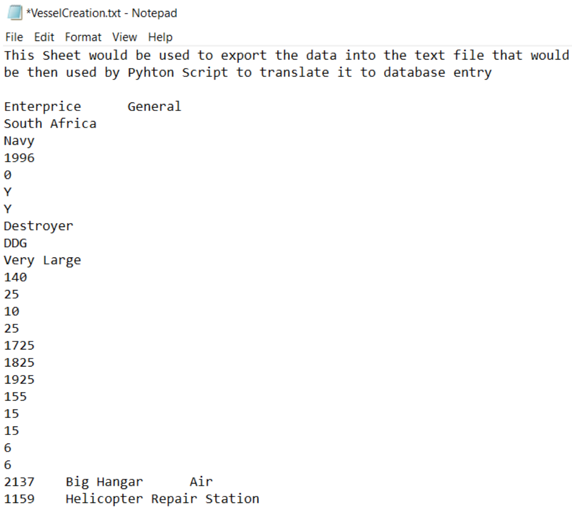
Name:	Descrip.:	Value:
Completed:	Tick box	Y
Hypothetical:	Tick box	Y
Category:	List	Destroyer
Type:	List	DDG
Size (of Pier):	List	Very Large
Length [m]	Number	140
Beam [m]:	Number	25
Draft [m]:	Number	10
Height [m]:	Number	25
Empty disp. [t]	Number	1725
Std. Disp [t]:	Number	1825
Full Disp. [t]:	Number	1925
Crew:	Number	155
Troop Cap.:	Number	15
Cargo Cap. [t]:	Number	15
Missile Defence:	Number	6
Max Sea State:	Number	6

Facilities					
Name:	**No.:**	**ID**	**Value:**	**AirFacility**	**Value:**
Aircraft Facility:	Auto	Number	2137	List	Big Hangar
	Auto	Number	1159	List	Helicopter Repair Station
	Auto	Number		List	
Docking Facility:	Auto	Number		List	
	Auto	Number		List	
	Auto	Number		List	

Speed / Range				
Name:	**Rng [nm]**	**Value:**	**Speed [kt]**	**Value:**
Cruise:	Number		Number	
Full:	Number		Number	
Flank:	Number		Number	
Fuel, Prim. [kg]:	Number			
Fuel, Scnd [kg]:	Number			

Engine / Fuel					
Name:	**No.**	**ID**	**Value:**	**Engine:**	**Value:**
Engine:	Auto	Number		List	
	Auto	Number		List	
Fuel:	Auto	Number		List	
	Auto	Number		List	

(a) Example of MS Excel file that may be used to input the data for the vessel creation.



*VesselCreation.txt - Notepad

File Edit Format View Help

```
This Sheet would be used to export the data into the text file that would
be then used by Pyhton Script to translate it to database entry

Enterprice      General
South Africa
Navy
1996
0
Y
Y
Destroyer
DDG
Very Large
140
25
10
25
1725
1825
1925
155
15
15
6
6
2137    Big Hangar      Air
1159    Helicopter Repair Station
```

(b) Example of text file that was obtained from Excel input and translated into .txt format.

Figure 7.1: Example of the entry template that would be used to translate the data into more manageable file format using Microsoft Excel.

Second and third datasets would primarily address the scenario creation process and would consist of data describing the specific scenario as well as additional input such as the vessel behavior and strategy (orders) used by the respective sides of the simulated conflict. The distinction between the mentioned datasets was introduced to clarify that the second set is created based on the information gained through OCD, while the third dataset would primarily contain all the additional data obtained through naval specialist experience and other sources. On the other hand, their anticipated implementation process would be the same as they both would be eventually realized by Lua scripting language code that would be implemented within the simulation software.
In order to achieve that, firstly the appropriate dataset would need to be composed. However, in the present case, the precise composition of these datasets would depend solely on the specific scenario being evaluated, as some scenarios require more data to be properly scripted (such as the introduction of enemy units). Furthermore, the primarily descriptive nature of the input data would eventually need to be translated into a number of commands that would then be used to set up the scenario. Although, according to gathered information, it would be possible to achieve this by the means of external tools, the main intention at the current stage of the project is to put emphasis on the collaboration with the 'Simulation specialist'.

Some of the commands are essential for every scenario setup process and are predetermined from the beginning. For those commands, the additional description provided within the scenario input dataset template should be sufficient to enable the members of the design team to provide the correct format for input information (see Fig. 7.6). On the other hand, some of the operations, such as the event handling and creation within the simulation scenario, would require more experience with the integrated scripting language in order to be conducted correctly.

Command Text	Description:
ScenEdit_SetTime({Date="02.11.2023",Time="08.43.00"})	Setting up current time that is present within the scenario
ScenEdit_SetStartTime({Date="2.12.2023", Time="08.46.23", Duration="00:24:00"})	Setting up the start time of the scenario with its duration
ScenEdit_SetWeather(10, 5, 0.3, 2)	Baseline temperature in C Rainfall (0 - 50) Amount of sky covered by clouds (0.0 - 1.0) Sea State (9 - 0)

Table 7.6: Example of the input data description from the scenario dataset entry template. Complete template would be presented upon request.

At this stage of the process, the simulation specialist would be tasked with checking the validity of the input data provided by the design team, as well as collaborating with all the involved entities to ensure that all the commands within the created Lua script are correct and will result in a valid evaluation scenario. The inclusion of this additional member of the team would ensure that the complete process was done correctly, while at the same time keeping the members of the design team free of specialized knowledge on the simulation tool. This approach would allow minimizing the influence of incorporating the evaluation through the simulation process on the time of the entire design process.

The fourth dataset would be aimed at describing all the desired output data that would be implemented into the simulation. Especially, this dataset is aimed at setting up the main data that would be saved from the Monte-Carlo evaluation and may be chosen through a separate configuration file that is present within the simulation software folders. This option offers the option to save several different types of data from the evaluation. An example breakdown of which formats may be saved and a short description of available formats are presented in the table below (see tab. 7.7).

CSV Settings		
UseZeroHour =	True / False	Refers timesteps to the time from the scenario
SplitFilesBySide =	True / False	Creates separate entries for every side
ExportSensorDetectionSuccess =	True / False	Export about successful sensor detection
ExportSensorDetectionFailure =	True / False	Export about failed sensor detection (what was not detected)
ExportWeaponFired =	True / False	Information about fired weapons and their target
ExportWeaponEndgame =	True / False	State of the weapons at the end of the scenario
ExportUnitPositions =	True / False	Export unit location every selected period of time
ExportEngagementCycle =	True / False	
ExportUnitDestroyed =	True / False	Save information about the destroyed units
ExportFuelConsumed =	True / False	Save information about the fuel consumption during the scenario
ExportFuelTransfer =	True / False	Save information when the vessel is refiled
ExportAirOps =	True / False	Export information about the aircraft docking /landing operations
ExportDockingOps =	True / False	Export information about the watercraft docking operations
ConsolidateCSV =	True / False	This option lets to create separate CSV file for every evaluated scenario specifically

Table 7.7: Example of the input data description from the scenario dataset entry template. Complete template would be presented upon request.

The precise composition of the data that may be saved from the evaluation is presented through the part of the setup file located in the appendix A.2 . This complete breakdown includes every possible format of data that may be saved, with some formats offering the same output while others offer different functionalities. Due to this fact, sometimes it may be viable to choose several options in order to capture every value that would be viable for the evaluation.
When exporting the gathered data from the last dataset, it would be placed into the appropriate .ini file using an external script (Python language), and then this file would replace the default file within the software folder. The same process may be conducted relatively easily by manual input in the initial stages of the methodology implementation.

7.3. Second Part: The Evaluation

As described previously, the process of importing the initial data into the simulation software is intended to be done automatically by a specially created external program (Python-based script) or manually by the prescribed simulation specialist. The implemented data would directly establish a scenario that needs to be saved before the simulation can be launched. This saved file would then be used as the base for the evaluation process.

Following the initial stage of work within the simulation software, the saved file would need to be evaluated to ensure that the base scenario correctly represents all the desired input and to check for any potential bugs that may occur due to the automatization of the process. As identified through the literature research (see chapter 3), the evaluation of the simulation scenario should be done as described in the first and second methods presented in the work of Robert G. Sargent [74]. This evaluation of the scenario is anticipated to be initially conducted by the members of the design team that were responsible for providing the initial data. This inclusion would ensure that the simulation matches the used input data and may be used to evaluate the described case. Additionally, a third-party member with simulation software (CPE) experience should also be involved in the evaluation as it would ensure that all processes within the scenario are correctly modeled, and the complete process of creation was done according to accepted standards.

Finally, the Monte Carlo analysis should be created using the predetermined settings for the desired results that were included at the beginning of the process. The setup file would be properly implemented within the files containing the simulation software either by a specially scripted external program (Python Script) or manually. Afterward, the simulation may be launched.

At this stage of the process, another input value is needed to determine the number of iterations within the Monte Carlo analysis tool. At this stage of the project, it is believed that this input should be provided manually as it would provide additional opportunity for quick determination if the input data regarding wanted outcomes was implemented correctly. Alternatively, it would be possible to automate this input by means of an additional external script that would input the desired data and start the evaluation.
Once the evaluation is started, the predetermined output files, divided with respect to the number of iteration they belong to, would be saved in a designated folder.

7.4. Third Part: Outcomes

The last step within the process would be concentrated around the methods of analyzing and importing results into the documentation. The output data obtained from the evaluation are saved in a specially designated folder in formats that were prescribed at the beginning of the process. Due to the different nature of the files obtained from the evaluation, some may be directly imported into the documentation while others would need to be previously analyzed.

Based on conducted research, it becomes clear that the most essential information for quick estimation of the events that occurred within the scenario is located within the message logs file. This file contains prints of all the messages that would, by default, describe the detected vessels, the actions taken toward those vessels, and outcomes of conducted actions or indicate if predetermined events occurred. These data do not describe in-depth every aspect of the simulation; however, they may be used to quickly gain information regarding the potential outcome of the simulation.

Secondly, there are the data that may be used for in-depth analysis of the evaluation. These may contain all sorts of information in accordance with the setup file presented above. It is anticipated that the potential analysis process does not require any additional specialized software, as these data are compatible with programs included in Microsoft Office or available through Google services. Lastly, it is possible to obtain files that may be used to recreate the full scenario with respect to iteration through specially designated external software. Although, at this moment, the list of available formats only includes two potential tools to recreate the evaluation, it allows for the full recreation of events based on 3D models of the assets used within the scenario. Namely, the software tools that may be deployed for those operations are SIMDIS (developed by Code 5770 in collaboration with NRL) and Tacview (developed by Raia Software Inc.).

As a final part of the complete methodology, the results from the evaluation, along with the description of the input and the scenario, should be exported into a predefined draft for documentation purposes. This draft document would then serve as the official report from the evaluation, providing necessary justification for future design decisions taken by the design team, as well as establishing a clear description of the conducted process that would be used to enhance communication between the design team and involved stakeholders.

The draft for the final documentation from the process has been created. Together with the input drafts for the desired results, scenario creation, and vessel creation, these drafts may be obtained by contacting the author of the presented project.

8. Use Example: Case Study

The primary objective of the presented evaluation is to demonstrate that the described methodology can enhance the design team's understanding of the design space by evaluating operational capabilities during the conceptual stages of the process. This evaluation was conducted based on the implementation method outlined in the previous chapter.

To illustrate the methodology's applicability, an example focusing on evaluating the initial vessel's system composition across different scenarios was created. Specifically, a case study involving an unmanned surface vehicle tasked with two distinct operations was chosen. These operations were developed using two different processes outlined in the previous chapter: Lua coding and manual configuration through the graphical user interface (GUI). This approach enables to identify the potential strengths and weaknesses of each method and highlight the characteristics of both approaches.

Furthermore, at the conclusion of this chapter, the obtained results will be presented, offering initial insights into the information gleaned from the evaluation process and how this data can be utilized. This discussion will also address potential challenges encountered during the evaluation and propose solutions to mitigate them.

8.1. Case Study Description

8.1.1. Description of the Missions

The evaluation was conducted based on input from both the design team and naval analysts. The compositions of the unmanned surface vehicles (USVs) to be evaluated were determined according to the tasks these vessels would need to fulfill.

The primary task identified by stakeholders involves the patrol and inspection of critical underwater infrastructure within a specific area of the Dutch Economic Zone. Protecting such infrastructure has become increasingly vital in modern naval operations, particularly due to disruptive activities by certain eastern countries. In recent years, parts of European countries have experienced sabotage acts, highlighting the need for enhanced security measures. Current developments in naval doctrine indicate that the newly researched USV fleet would be entrusted with patrolling, investigating, and preventing similar acts. As such, the evaluation aims to assess the effectiveness of these USVs in fulfilling these critical tasks.

The transfer underwater cables located at the bottom of the English Channel are considered particularly vulnerable due to the shallow depth in the area and the high volume of civilian vessel traffic passing through. These conditions create a prime opportunity for potential sabotage attempts, as the cables are relatively easy to access, and the busy maritime traffic can conceal the presence of a sabotaging vessel.

The scenario begins with an intelligence report indicating a suspicious OPFOR (Opposing Force) vessel in close proximity to vital underwater infrastructure within the Dutch Economic Zone. To prevent potential sabotage on crucial infrastructure between Dutch and United Kingdom territories, USVs are dispatched from a nearby naval base to investigate the activities of the suspected enemy vessel and conduct routine inspections of the underwater structures to detect any explosive materials.

The precise location of the OPFOR ship is known from the outset, and the USVs set sail from Den Helder naval base to patrol the area near the suspected contact. Unbeknownst to the USVs, the OPFOR ship has already managed to place at least one explosive device on the underwater structure's surface. While the surface vessel does not exhibit any hostile behavior toward the USVs in the area, its objective is to evade potential pursuit and head north into the North Sea.
The designed USV must be capable of navigating to the designated area of operations identified by the location of the OPFOR vessel. Once there, it must conduct thorough research to detect any potential dangers and report its findings back to base.

As previously described, the area designated for operations is situated at the northern entrance of the English Channel 8.1a. The respective underwater cables extend from 99 nautical miles (Zeus Cable) to 66 nautical miles (Farland North Cable) from the Den Helder naval base.

(a) The identified area of operations for first scenario that would be used for evaluation. Screenshot from Command Professional Edition software.

(b) The identified area of operations for second scenario that would be used for evaluation. Screenshot from Command Professional Edition software.

The second task scenario involves an aircraft with sensitive equipment or data onboard crashing within the Dutch Economic Zone in the North Sea. Given the nature of the equipment within the wreckage and the potential interest of various parties in retrieving it for their specific purposes, a rapid response, and the ability to locate and identify the potential threat are essential. In this scenario, the USV would need to swiftly travel to the area of interest, locate the wreckage on the seabed, and deploy an Unmanned Underwater Vehicle (UUV) to retrieve or neutralize the contents of the wreckage.

The anticipated area of operation is depicted in the figure above (see 8.1b). The expected location of the crash site is approximately 70 nautical miles from the Den Helder naval base; however, the search area must account for potential movements caused by currents present in the area. The precise description of anticipated tasks created basing on the input from the stakeholders would be presented within the appendix A.3.

Both tasks necessitate the USV's ability to conduct underwater search, recovery, or neutralization operations. While these capabilities are initially structured for naval applications, the solutions identified could have broader applications in civilian markets. The ongoing need for maintenance or location of underwater structures within the industry underscores this potential. It's important to emphasize that the methodology presented here can be freely applied within both civil and naval realms of ship design. This underscores the adaptability and relevance of the methodology for a wide range of applications.

8.1.2. Examined Designs

For the purpose of evaluation, several configurations for the systems onboard the USV were developed. The primary differences among these configurations pertain to the number of Unmanned Underwater Vehicles (UUVs) carried onboard and the performance characteristics of the USV platform, such as speed and fuel consumption.

To establish the foundation for the USV, the widely produced Damen 5009 Patrol vessel was selected. The primary design assumption is that this vessel would serve as the basis for the USV, equipped with systems enabling autonomous operations. Operational systems would be strategically placed onboard the vessel in a modular fashion, utilizing purpose-designed storage units. To create the vessel within the database entry, missing data were extrapolated based on similar-sized USV vessels, primarily the USV Nomad vessel.
Initially, it was assumed that the Kongsberg HUGIN would serve as the unmanned underwater vehicle for the design. This would provide the foundational capabilities for the UUV utilized in the presented design.

The first design assumes that the USV would be equipped with systems to deploy one underwater unmanned vehicle from the deck. The main USV itself would not possess any systems for conducting underwater searches independently; instead, its primary task would be to transit to the area of interest and deploy the UUV. Similarly, the second design would also be outfitted with systems to deploy one unmanned underwater vehicle from the deck. Additionally, it is anticipated to be equipped with hull-mounted sonar equipment (TSM 2022 Mk3). This configuration is intended for similar operations, with the USV capable of conducting the search without relying solely on the UUV. The third configuration assumes that the USV would be capable of deploying two unmanned underwater vehicles for conducting the search. However, due to the added weight of the equipment, it would not be equipped with onboard sonar.

The initial designs were based on the assumption that the entire operation would be carried out by a single vessel, without the possibility of replenishing fuel at sea. However, the design team recognized that, given the time pressure imposed by the operational situation, deploying two USVs simultaneously could be advantageous. One USV would be tasked with patrolling a distant area from the starting position, while the second would patrol two closely located areas.

Therefore, the fourth identified case involves two USVs, both capable of deploying one unmanned underwater vehicle. The surface vessels would not be equipped with sensor equipment for conducting underwater search operations. The fifth case is based on the second configuration of the systems, where the USV is capable of deploying one UUV and is equipped with the hull-mounted sonar TSM 2022 Mk3, enabling the surface vessel to actively participate in search operations. Previous designs assumed the use of the Hugin AUV for search operations due to its superior capabilities. However, the high cost of the Hugin significantly impacts the overall project expenses. Therefore, for the sixth scenario, the evaluated vessel would still deploy only one UUV, but the choice of UUV would be changed to the Mk 18 Mod 2 Kingfish. This alternative is being considered to potentially reduce the overall costs of the product.

The specific performance indicators and capabilities for each design are summarized in the table below (see 8.1). It is evident that the values for fuel consumption and speed vary depending on the configuration of onboard systems. This variation is primarily influenced by changes in the overall weight of the vessel due to the additional weight of the systems.

Number of Configuration:	Speed:	Range:	Capabilities:
1	18 knots	273 nm	1 UUV (HUGIN), No Sonar
2	15 knots	236 nm	1 UUV (HUGIN), TSM 2022 Mk3
3	10 knots	163 nm	2 UUVs (HUGIN), No Sonar
4	18 knots	273 nm	1 UUV (HUGIN), No Sonar
5	15 knots	236 nm	1 UUV (HUGIN), TSM 2022 Mk3
6	18 knots	273 nm	1 UUV (Kingfish), No Sonar

Table 8.1: The performance data and capabilities description for all design predictions that would be evaluated using formulated methodology.

Based on the established capabilities and performance characteristics of the evaluated configurations, three different basic vessels were created within the database used by the simulation software. These entries into the database would be utilized to implement the vessel into the simulation scenario. As described previously, it would have been possible to achieve similar results by modifying an already existing vessel within the database. However, it was determined that the presented solution would offer a more accurate representation of real evaluation application.

Vessel one was created for the evaluation of designs with the ability to deploy one unmanned underwater vehicle, and it does not possess any mounted sensors that would allow it to conduct underwater searches (see Fig.8.2). This particular vessel has a transit speed of 18 knots and a maximal range of 273 nautical miles. These parameters were chosen based on the fact that it is the lightest configuration examined during the presented evaluation, and the drivetrain of the vessel chosen as the example is optimized for a speed of 18 knots. Therefore, it was anticipated that, for other speeds, it was assumed that the overall fuel economy would decrease.

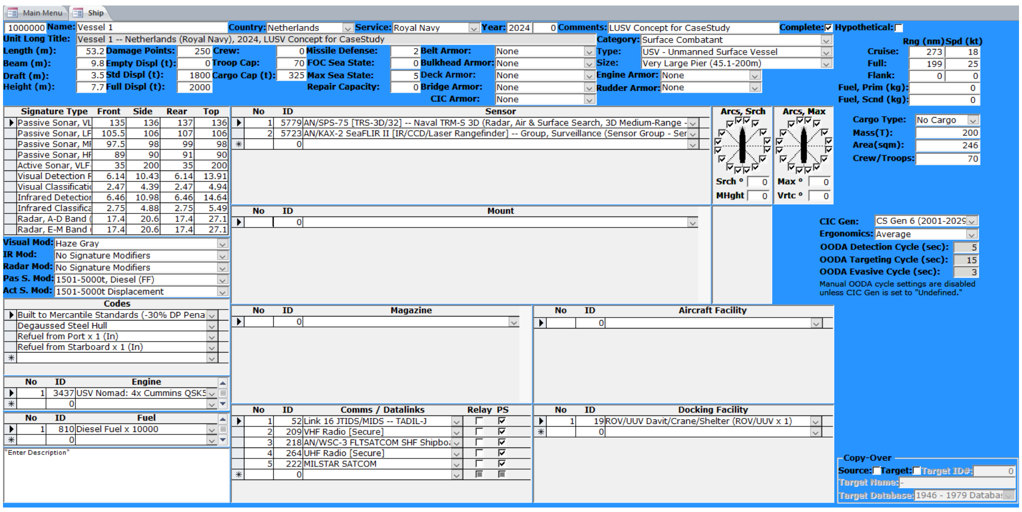


Figure 8.2: Database entry for the first vessel configuration used for the evaluation. It has one docking facility for UUV operations. Some of the details were obtained basing on similar vessel already existing in the database (USV Nomad).

The second vessel created in the database represents the design configuration that is able to conduct underwater operations through its docking facility, allowing it to deploy one UUV (see Fig. 8.3). Additionally, it features an onboard sensor, namely a hull-mounted sonar. As previously explained, the performance parameters were established based on the assumption that this system composition would introduce additional weight to the vessel, increasing the resistance of the hull and thus lowering the transit speed of the USV. Additionally, due to the characteristics of the drivetrain used onboard, the shift from the optimal speed would result in a slight increase in fuel consumption.

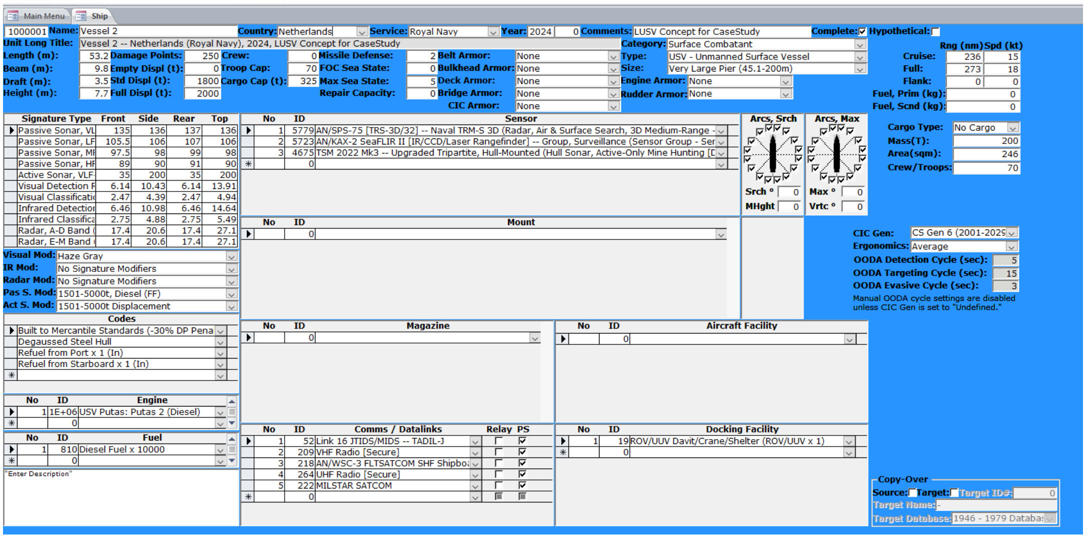


Figure 8.3: Database entry for the first vessel configuration used for the evaluation has been created. It features one docking facility for UUV operations as well as a sonar that may be used to conduct underwater search operations. Some of the details were obtained based on a similar vessel already existing in the database (USV Nomad).

The last vessel introduced into the database was created to accommodate the third system composition, namely two docking facilities for unmanned underwater vehicles (see Fig. 8.4). The vessel would not be capable of conducting underwater searches on its own. Furthermore, this configuration is expected to introduce the greatest additional weight to the vessel. As explained before, it is anticipated to be the slowest version of the examined vessel. This may become crucial for the performance of the USV in the scenario, as it would significantly influence the ability to stay for the predetermined period of time in the furthest patrol areas.

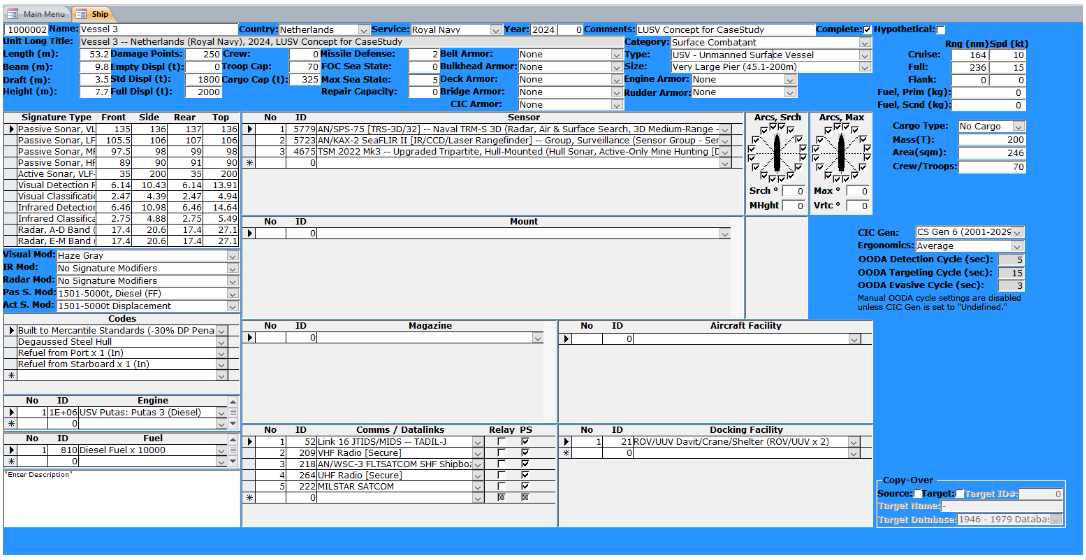


Figure 8.4: Database entry for the first vessel configuration used for the evaluation has been created. It features two docking facilities for UUV operations. Some of the details were obtained based on a similar vessel already existing in the database (USV Nomad).

8.2. Description of Used Scenarios

As described above, two different scenarios were formulated for the presented configurations of the designed vessel. To create each scenario as described in the appropriate chapter, input datasets were generated based on knowledge obtained from involved parties within the company, aiming to simulate predicted real-life applications of the described methodology.

The approach used to create each specific scenario differed. The first scenario, which models the operation of localizing and neutralizing a potential explosive device placed in close vicinity to critical water infrastructure, was created entirely using integrated Lua scripting language. In contrast, the second scenario, revolving around the search operation of a wreck with sensitive equipment onboard, was created using the Graphical User Interface (GUI) already integrated within the software.

Both approaches were discussed in the previous chapter while describing the process of scenario creation. The intention behind using both methods within the case study evaluation is to outline their respective advantages and disadvantages, as well as to demonstrate that the final results obtained through both methods are suitable for evaluation purposes.

8.2.1. The Critical Underwater Infrastructure Scenario

Once all necessary information was gathered, examined, and compiled into the input drafts described in chapter 6, the process of creating the scenario commenced. For the first scenario, it was decided to utilize Lua scripting. The main body of scripting was done manually, as the current level of implementation of the complete method is still at relatively early stages. Developing a separate script would have significantly extended the overall project timeline.

The first step involved formulating the basis of the scenario using the submitted forms. This included establishing parameters such as the current time of the scenario, the start time of the scenario, the prevailing weather conditions during the evaluation, and the duration of the evaluation.

```
ScenEdit_SetTime(Date=”2.12.2023”, Time=”08.46.23”)
ScenEdit_SetStartTime(Date=”2.12.2023”, Time=”08.46.23”, Duration=”01:06:00”)
ScenEdit_SetWeather(10, 5, 0.3, 2)
```

Secondly, the participating sides in the scenario were introduced, and their postures towards each other were set as predicted in the input forms. The scenario involves four different sides: ’Civil,’ representing commercial traffic within the English Channel; ’Blue,’ representing the side operating the USVs (Dutch Navy); ’Red,’ tasked with conducting the sabotage mission on highlighted underwater infrastructure; and ’Natural,’ introduced to simulate potential natural contacts that may be detected during underwater search operations.

```
ScenEdit_AddSide(Name=’Blue’)
ScenEdit_AddSide(Name=’Red’)
ScenEdit_AddSide(Name=’Civil’)

ScenEdit_SetSidePosture(‘Blue’, ‘Red’, ‘H’)
ScenEdit_SetSidePosture(‘Red’, ‘Civil’, ‘N’)
ScenEdit_SetSidePosture(‘Civil’, ‘Blue’, ‘F’)
```

At this stage, the simulation engineer responsible for creating the simulation preferred to set up reference points to mark actions and vital locations for each participating side. These reference points are used to establish spawn points for units within the scenario and trigger missions and events later in the process.
While setting up reference points is not always necessary except for specific mission end triggers, including them at this relatively early stage of coding allows for the evaluation of anticipated locations. It’s important to note that reference points belong to the predetermined side, so if any of them are the same for both sides, they need to be set up twice.

```
ScenEdit_AddReferencePoints(side=’Civil’, name=’T11’, lat=’N52.40.39’, lon=’E03.22.09’, highlated=true)
ScenEdit_AddReferencePoints(side=’Civil’, name=’T12’, lat=’N52.39.07’, lon=’E03.22.16’, highlated=true)
ScenEdit_AddReferencePoints(side=’Civil’, name=’T13’, lat=’N52.39.07’, lon=’E03.19.40’, highlated=true)
ScenEdit_AddReferencePoints(side=’Civil’, name=’T14’, lat=’E52.40.36’, lon=’E03.19.42’, highlated=true)
```

The next step in the process is to introduce the vessels into the scenario. These vessels must be assigned to specific sides of the conflict, and if applicable, their course and base should be added at this point in the script. While it's not necessary to assign a global value for every unit, doing so may prove useful for later operations if the vessel is used within events or specific missions.

```
C_4=ScenEdit_AddUnit(type='Ship', unitname='Nippon Princess', dbid=144, side ='Civil',
lat='N51.50.38', lon='E03.29.21')
C_5=ScenEdit_AddUnit(type='Ship', unitname='Dorysia', dbid=1055, side='Civil',
lat='N51.42.21', lon='E03.23.55')
C_6=ScenEdit_AddUnit(type='Ship', unitname='Esvagt Capella', dbid=3279, side ='Civil',
lat='N52.08.50', lon='E02.04.56')
C_7=ScenEdit_AddUnit(type='Ship', unitname='AlicanteKnutsen', dbid=222, side ='Civil',
lat='N52.04.48', lon='E02.02.17')
```

After reaching this point, all necessary components of the scenario should be present within the simulation. However, the main part of the process is still pending—the introduction of missions and events. These elements serve as the primary determinants of the actions of the evaluated vessel and may yield additional potential information at the end of the scenario. The process begins with the introduction of missions, which directly dictate the actions of the vessels as they conduct their assigned tasks. In this case, the task is the underwater search for explosive devices. Therefore, the type of mission was set to 'Mineclearing,' and the specific area of the mission, marked with reference points, would be located around the intersection of the known route of the hostile vessel and the cable on the seabed.

```
ScenEdit_AddMission('Blue', 'Patrol_1V', 'Mineclearing', Zone='PT11', 'PT12', 'PT13', 'PT14')
ScenEdit_AssignUnitToMission('USV_1', 'Patrol_1V')
```

The action type predominantly used throughout the scenario setup process is the 'LuaScript' option. This allows for the inclusion of another part of Lua code in the action, resulting in the execution of that script. In the presented case, this option was utilized to facilitate the switching between operation areas (missions) for the evaluated vessel, as well as to trigger the deployment of the UUV once the USV arrives at the designated patrol area.

```
ScenEdit_SetAction({mode='add', type='LuaScript', name='Rearmed', ScriptText="
USV_1.course={{lat='N52.57.26',lon='E04.42.02'}, {lat='N52.54.58', lon='E04.39.23'}}
USV_1 = ScenEdit_GetUnit({name='USV_1'})
ScenEdit_AssignUnitToMission('USV_1', 'Patrol_3V')"})

ScenEdit_SetAction({mode='add', type='LuaScript', name='Switch 2', ScriptText="
ScenEdit_DeleteUnit({side='Blue', unitname='Echo_2'})
ScenEdit_AssignUnitToMission('USV_1', 'Patrol_1V')"})
```

Furthermore, the 'LuaScript' function was utilized to generate additional feedback messages that would be incorporated into the results output. These messages serve to denote outcomes from specific actions within the scenario and report the precise times at which the vessel arrived at certain areas of interest. As of the current state of knowledge on the simulation software, these functionalities are not available within the predetermined output options and thus need to be artificially implemented. The process of determining which data should be obtained and how they should be obtained would require collaboration between the simulation engineer and the design team. Both entities would need to actively participate to establish which values are desired and what is feasible to obtain from the software perspective.

```
ScenEdit_SetAction({mode='add', type='LuaScript', name='1th area of sabbotage', ScriptText="
local d = ScenEdit_AddMinefield({side='Red', dbid=3401, number=math.random(0,1),
delay=87200, area={'T11', 'T12', 'T13', 'T14'}})
print('Number laid ' ..d)
ScenEdit_SpecialMessage('Blue', '1Laid' ..d)"})
```

Additionally, while actions and triggers do not require the specification of the side of the conflict to be created, the 'specialmessage' function does. This means that messages appearing in the message log due to certain events being triggered will only appear for the prescribed side. However, it should be noted that when saving the message log output in the Monte Carlo evaluation menu, logs for all factions are saved in one file, with a small indication of which specific side the message belongs to.

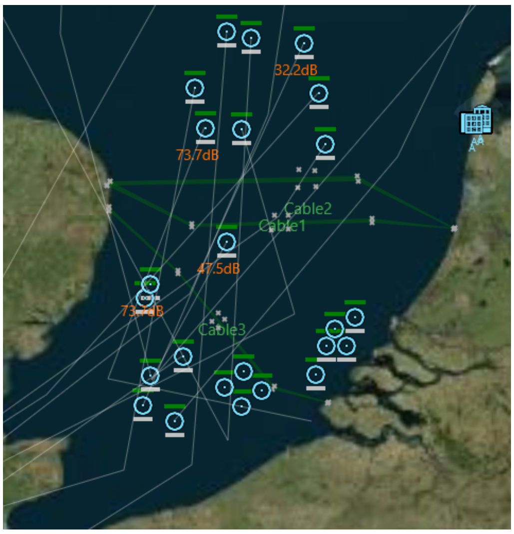
Finally, events may be created using correct triggers and actions that are already present in the simulation software. This highlights the importance of the correct order of presented commands, as failure to describe the trigger before assigning it to the event could result in errors.

```
ScenEdit_SetEvent('1th Area Attempt',{mode='add', isActive=true})
ScenEdit_SetEventTrigger('1th Area Attempt', {mode='add', name='1th Attempt'})
ScenEdit_SetEventAction('1th Area Attempt', {mode='add', name='1th area of sabotage'})
```

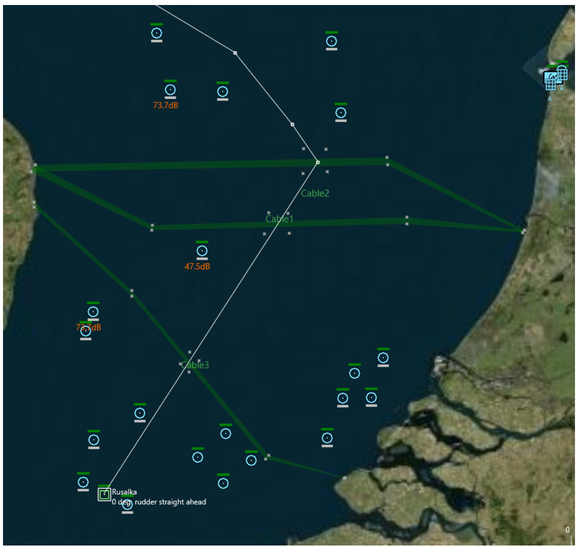
The structure of the Lua Script was designed with specific vessels used to populate the scenario and simulate normal marine traffic in the English Channel (see Fig 8.5a), based on data obtained from the MarineTraffic website [46]. The red vessel was tasked with laying 0 to 1 charge every time it passes over known underwater infrastructure locations (see Fig 8.5b). Meanwhile, the USV would launch approximately two hours after the red vessel begins its operation, mimicking real-time behavior and reaction time, including reports obtained from civilian vessels regarding suspicious behavior of the red vessel. The USV would initially be sent to the first known intersection of the red vessel's route and the cable, initiating underwater search operations by deploying the UUV upon arrival (see Fig 8.6a).

The unit would spend a predetermined amount of time in each patrol zone to simulate the process of scanning, detecting, and neutralizing the explosive device before moving to another area of interest. This specified amount of time would vary between different versions of the scenario, influenced by the capabilities of the specific vessels being evaluated. This variation was implemented to replicate differences in the ability to scan certain areas of the seabed among different configurations of USVs.

The primary objective of this scenario is to determine which design can fulfill the mission in the shortest amount of time. However, due to the distances the vessel needs to sail between areas, fuel replenishment may be necessary. For this reason, the overall duration of the scenario was set to 1 day 6 hours, covering the entire operation. The specific times of arrivals at specific sections and detections of potential contacts would be obtained from messages appearing in the message logs and created through appropriate events (see Fig 8.6b).



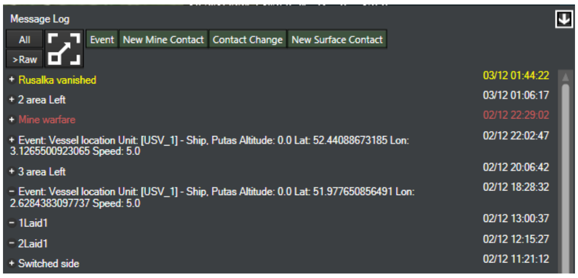
(a) Screenshot from the Command Professional Edition software that shows the civilian vessels that were introduced to the scenario in order to imitate the real-life traffic in the English Channel (basing on data obtained from marinetraffic.com)



(b) Screenshot from the Command Professional Edition software showing the red force vessel ("Rusalka") and its course, which crosses all three underwater cables at different locations. Its task is to lay a maximum of one explosive device on the cable whenever it sails over it.

Figure 8.5: Screenshots from the simulation software showing the separate steps described earlier through a Lua script. (First Scenario Type)

(a) Screenshot from the Command Professional Edition software showing the transit route of the USV vessel to the first area of operation, located at the first intersection of the Red ship's course and the first underwater cable.



(b) Screenshot of the message log window within the simulation software displaying various additional messages introduced through special events.

Figure 8.6: Screenshots from the simulation software used to show the specific parts of the scenario creation process. (First Scenario Type)

8.2.2. Sensitive Equipment Recovery Scenario

As mentioned previously, this scenario was entirely created using the built-in graphical interface present within the simulation software. While conducting this process, it was noted that this approach is relatively easy to understand and replicate. However, it falls short in comparison with the Lua approach when working on complex scenarios or modifying existing ones. At this stage of the project, it is believed that the Lua approach should be adopted immediately after gaining a basic level of experience with the software. This would allow for quick modifications of created scenarios and more advanced implementations for additional feedback messages within the scenario.
It is worth noting that a method for implementing additional messages without using any Lua code has not yet been found.

For this evaluation scenario, the USV vessel would be tasked with locating the wreckage containing highly valuable equipment onboard. The start location of the USV would be nearby the Den Helder naval base, and the vessel would need to transit approximately 70 nautical miles to reach the suspected crash site. Afterwards, depending on its systems configuration, the vessel would conduct an underwater search either through deployable UUV or using its onboard sensors. Upon positive detection of the wreck, the UUV would be deployed to retrieve or destroy the valuable equipment, while the main vessel would provide security for the operation in the northern area of the crash site. The primary objective is to establish the time of detection of the wreck by specific vessel configurations, as the equipment needs to be retrieved as quickly as possible to prevent it from being stolen by opposing forces.
The presented task is intended to be fully carried out by one USV vessel. Therefore, in this case, there would be only three main configurations of the vessel that would be evaluated.

The order of actions during the creation of this scenario closely followed the process previously employed using the Lua scripting method. Firstly, basic information was introduced to the simulation software, describing the sides present within the simulation, as well as the start times, duration, and present weather conditions.

Similarly, the second step focused on identifying the precise locations of specific areas, such as vessel or land infrastructure placements, or targets and mission areas. This step resulted in the introduction of reference points into the scenario (see Fig. 8.7a), which served to measure distances between different stages of the task and facilitate future creation processes during the scenario creation stage.

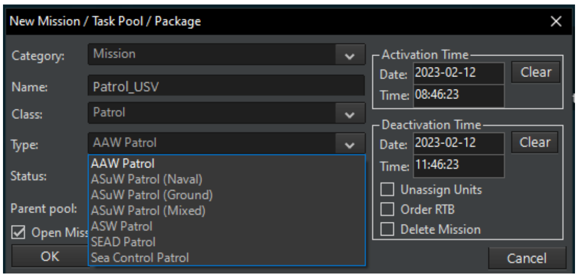
Once the identified areas of interest and potential vessel locations have been checked, the next step would mainly focus on introducing the units into the scenario (see Fig 8.7b). During this process, the courses for certain vessels would already be determined. This step often does not require any specific actions, as these vessels are mostly not crucial for evaluation purposes; rather, they are used as background for simulated actions.

(a) Screenshot from the simulation software used to showcase the introduction of the reference points into the scenario that is being created.

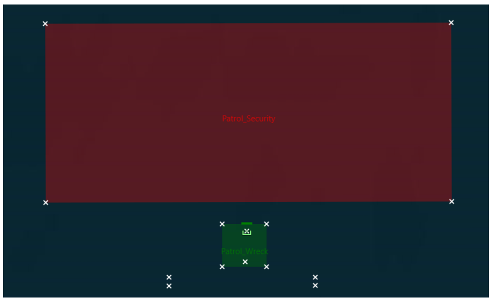
(b) Screenshot from the simulation software presenting the introduction of civilian vessels into the scenario being created. The course of each vessel must be manually introduced through the course/throttle tool.

Figure 8.7: Screenshots from the simulation software used to show the specific parts of the scenario creation process. (Second Scenario Type)

After introducing the vessels into the scenario, the missions would need to be introduced. This step may be perceived as relatively easier when employing the GUI method, as it does not require knowledge of specific commands and their correct syntax. Most of the options for the missions can be described through the drop-down lists present within the mission setup menu (see Fig 8.8a). Additionally, once the mission was introduced, the "Mission Editor" window would open, highlighting the prescribed area of the created mission (see Fig 8.8b).



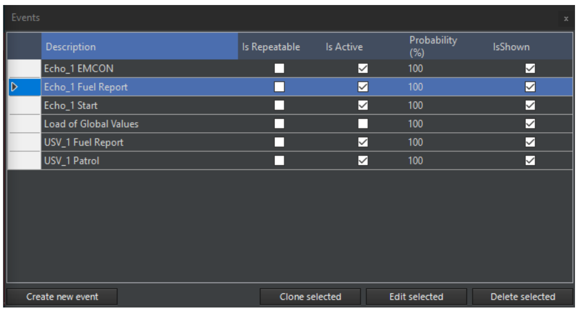
(a) The screenshot from the simulation software presenting the menu used to introduce the specific mission into the scenario using the GUI approach.



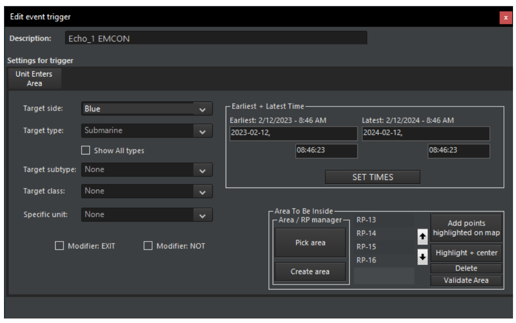
(b) The screenshot representing the mission area marked through the mission introduction within the Command Professional Edition.

Figure 8.8: Screenshots from the simulation software used to show the mission introduction menu and the mission area representation in the scenario creation process. (Second Scenario Type)

Finally, the events would need to be introduced. Similar to editing missions, this action would be carried out through the appropriate menu for triggers, actions, and events present within the scenario editor. Likewise, these menus are considerably more user-friendly for newcomers as they allow for the proper utilization of functionalities within the simulation software without the additional knowledge required for Lua scripting. However, as mentioned earlier, the actions used in most events would need to be implemented through Lua script, which would necessitate some level of scripting capabilities.



(a) The image depicts the main event menu within the simulation software. Through this menu, users can create, modify, or delete existing events in a scenario. Additionally, settings on the right side of the window allow users to specify additional conditions under which the event will occur.



(b) The screenshot shows the menu for setting up the UnitEnterArea trigger. It's important to note that this menu may vary depending on the specific type of trigger chosen.

Figure 8.9: screenshots depict various menus related to events used in the scenario creation process (Second Scenario Type).

After completing all the preceding steps, the scenario was established. In total, six events were created to structure the overall behavior of the vessel and to output results from the evaluations. The output data-related events are responsible for providing information regarding the time of the USV's arrival into the area of operations and the time of arrival for the UUV into the last known position of the aircraft (if applicable).
Following the establishment of both scenarios, separate versions were created introducing variables into the system compositions of the vessels that would be evaluated. As these changes mostly involved alterations in the database ID for the USV vessel, this process will not be specifically described.

At the end of this stage, the evaluation process should take place according to the described process in the methodology implementation chapter. For the presented scenarios, due to limitations at the time of the process, an external member familiar with the simulation software could not be involved in the evaluation process. Thus, the evaluation of prepared scenarios was carried out by the person responsible for setting up those scenarios.

8.3. Description of the Process

After completing the vessel entry into the database as well as finalizing the scenario creation process, the main focus was shifted to the evaluation. In order to do so, the input draft describing the settings of the integrated evaluation program was implemented. This step resulted in obtaining several different outcomes, namely the fuel consumption logs per side, the sensor detection attempts for each side, the endstate summary, and finally, the message logs were also saved in order to utilize the additional output established through the events and Lua script (EventExport.ini file contains presented below).

```
ActiveExporter = CSV
; Changed 5/02/24 J.O.
CSV Settings
UseZeroHour = True
SplitFilesBySide = True
ExportSensorDetectionSuccess = True
ExportSensorDetectionFailure = True
ExportWeaponFired = False
ExportWeaponEndgame = True
ExportUnitPositions = False
ExportEngagementCycle = False
ExportUnitDestroyed = False
ExportFuelConsumed = True
ExportFuelTransfer = False
ExportAirOps = False
ExportDockingOps = False
ConsolidateCSV = True
ExportCargoTransfer = False
UseCustomUnitExportFrequency = False
```

Following, each evaluation was set to repeat for 30 iterations, and the software was set to save data every 5 seconds of in-sim time. As may be spotted earlier, the critical infrastructure patrol scenario is significantly more complicated than the second used evaluation scenario, thus the respectable time of evaluation was also reflecting that. The overall time for conducting the evaluations of the critical infrastructure patrol scenarios took around 23 minutes, while the evaluations based on the second scenario took around 6 minutes to conclude.

Complete output data from the process are scattered throughout 402 different .CVS, .xml, and .txt files for the first type of evaluations, and in total 195 different files for the second type evaluations. The complete dataset obtained from the process exceeds 9 Gigabytes of data.

8.4. Presentation of the Outcomes

At the outset of the data examination process, Microsoft Excel was selected as the tool for analyzing the gathered data. However, it was soon discovered that the Sensor Detection Attempts file did not include data on the detection of all subjects within the scenario. This resulted in a lack of information regarding the location of explosive devices detected by the USVs or UUVs during the evaluation.

Fortunately, the files saved in separate folders, organized per iteration, contained valuable information extracted from the message logs. These files proved to be instrumental in providing necessary data about the detection of explosive devices. Specifically, the message logs contained details such as the precise time of detection, the unit responsible for detecting the contact, and the identification of the specific sensor used for detection.

```
12/2/2023 7:25:52 PM - Blue / New mine contact! Detected by Echo_3 at 162deg - 0.2NM
```

In addition to detecting explosive devices, the message logs contained further valuable information. Specifically, they recorded the time at which each vessel entered and exited areas of interest, providing a comprehensive timeline of vessel movements throughout the scenario. Additionally, the logs detailed the number of targets left in each area of patrol by the Red force unit, offering important context for evaluating the effectiveness of the USVs and UUVs in detecting and neutralizing threats.

```
12/2/2023 10:26:07 AM - Blue / 3Laid1
12/2/2023 6:28:32 PM - Blue / Event: Vessel location Unit: [USV_1] - Ship, ”Vessel_1”, Altitude: 0.0,
Lat: 51.977650856491 Lon: 2.6284383097737 Speed: 5.0
12/2/2023 9:25:27 PM - Blue / 3 area Left
```

Furthermore, the examination of the fuel consumption files revealed that data on fuel consumption were recorded every 5 seconds of in-simulation time, as per the settings used in the evaluation menu. This approach resulted in some of the output .csv files containing over 595,000 entries documenting fuel consumption for each unit belonging to the blue side. Each entry not only includes the amount of fuel consumed by a specific unit but also specifies the type of fuel consumed and provides a unique code corresponding to the in-simulation time, facilitating precise analysis and correlation with other events.

All gathered data throughout the process were utilized to determine the most appropriate configuration of systems on-board the chosen vessel for the two simulated scenarios. It was established that for both scenarios, the primary objectives are to efficiently transit to the area of interest and promptly locate the desired target. In the critical underwater infrastructure scenario, the critical factor is to identify the configuration that can detect all targets most effectively within the shortest time possible. However, the overall operation time (search in all three areas) is considered more crucial than the time taken to detect the explosive device in one area.
Similarly, for the second scenario, the key parameters under assessment include the time taken to complete the entire mission, including the time to detect the target, and the vessel's ability to remain at the area of interest or be redirected for other tasks based on the remaining fuel reserves.

It's important to note that the third configuration created initially was unable to fulfill the mission requirements in the first scenario, as the first area of operation exceeded the vessel's range limit. Subsequently, the decision was made to reassess the estimation of the added weight resulting from the inclusion of the second system to deploy UUV onboard the USV. As a result, the configuration with two UUVs onboard utilized the second vessel from the database. However, this was primarily conducted to assess the impact of two UUVs on search effectiveness, and this configuration was ultimately excluded from the final evaluation. Additionally, this configuration was not examined for the second part of the first scenario or for the second scenario.

Finally, the evaluation of gathered data was conducted for the systems configurations that were formulated. The overall results obtained from the evaluation would be presented below.

At first, the initial three configurations were tested in the simulation, with only one USV participating in the operation. Upon examination of the outcomes, it was discovered that all types of vessels used needed to return to the assigned base for refueling during the scenario. This refueling event mainly occurred during the transition between the second and third areas, or shortly after entering the third area of interest.

First Configuration: Vessel 1 / Hugin UUV		
	From Scenario Start	**From Previous Area**
Average time of arrival to Area 1:	05:42:32	05:42:32
Average time of arrival to Area 2:	09:46:30	01:56:20
Average time of arrival to Area 3:	14:25:14	00:53:00
	Time:	**Rate of Success:**
Average time to detect the target in Area 1:	00:13:00	96.7 %
Average time to detect the target in Area 2:	00:53:37	90 %
Average time to detect the target in Area 3:	00:32:53	50 %
	Fuel Amount [kg]	**Additional Info:**
Total Fuel Consumed by USV:	14383.8	Refuel Necessary
Total Fuel Consumed by UUV:	4532.7	1/2 of full tank

Table 8.2: Results obtained from evaluation of first vessel configuration obtained during first scenario with only one USV.

The first set of results obtained for the vessel outfitted with systems allowing the deployment of one UUV reveals that the transit time to the first area of operation is the longest, as predicted (see Tab.8.2). Additionally, it's evident that the vessel's success rate decreases during transitions between certain areas. This decrease could be attributed to the vessel needing to return to the base for refueling, which is particularly noticeable in the last area, where it may exceed the time constraint for completing the operation. Overall, this led to an estimated total action completion time of over 24 hours and 58 minutes. Although the overall average time was deemed unsafe for this particular operation, during the simulation, the vessel was able to conduct the complete operation without refueling, which led to a minimal time of 16 hours and 30 minutes. The maximum time recorded during that process was around 32 hours. With a calculated standard deviation of 4 hours and 6 minutes, the overall performance of the vessel would still be deemed unsuitable for this operation.

Second Configuration: Vessel 2 (sonar) / Hugin UUV		
	From Scenario Start	**From Previous Area**
Average time of arrival to Area 1:	06:51:37	06:51:37
Average time of arrival to Area 2:	10:38:37	02:18:20
Average time of arrival to Area 3:	22:27:15	10:04:53
	Time:	**Rate of Success:**
Average time to detect the target in Area 1:	00:07:17	100 %
Average time to detect the target in Area 2:	00:19:35	100 %
Average time to detect the target in Area 3:	00:30:13	96,7 %
	Fuel Amount [kg]	**Additional Info:**
Total Fuel Consumed by USV:	13848.17	Refuel Necessary
Total Fuel Consumed by UUV:	9724.14	97% of fuel used

Table 8.3: Results obtained from evaluation of second vessel configuration obtained during first scenario with only one USV.

In the second dataset (see Tab.8.3), which presents results for the vessel capable of deploying one UUV and participating in underwater search operations due to the hull-mounted sonar onboard, it is observed that the vessel's slightly reduced transit speed results in higher fuel consumption and necessitates a refueling operation before reaching the last area of operation. This is particularly evident during the transit between the second and third areas, causing the time of completion of operation to exceed 24 hours and 27 minutes. The overall difference between the minimal and maximal times of operations recorded during this simulation was 17 minutes. With a standard deviation of 4 minutes, the results are determined to be fairly constant and repeatable. However, this does not change the fact that the overall average operation time exceeds the safe margin for similar operations.
The difference between the first configuration may be explained due to the different locations from which the vessel initiates the return operation. In the first case, the vessel was already within the last area of operation, which is the closest one to the home base. In contrast, in the second case, the vessel needs to transit from the second area of operation. This distinction in starting points can significantly affect the time required for the vessel to return for refueling and resume operations. However, this vessel demonstrates a significantly quicker ability to detect the target once it arrives in the zone, maintaining an almost constant success rate.

The third set of presented results displays the values obtained for a specific vessel configuration utilizing two docking facilities for UUV operations (see Tab.8.4). As previously mentioned, this configuration is being examined solely to determine whether the capability to carry two UUVs would significantly impact overall performance in detection and success rates.

Due to the substantial increase in covered area achieved by deploying two Hugin UUVs, the vessel can more quickly cover the entire area and transition to another, allowing quicker completion of patrols in certain mission areas. This caused the vessel to need refueling once it was already in the last area of interest, necessitating a return to base before the entire area was checked. The overall time for the complete operation was estimated to be around 29 hours. Moreover, with the difference between the lowest and highest operation times being 10 hours and a standard deviation comparable to the first scenario, equal to 3 hours and 22 minutes, this solution also proved inconsistent and unable to fulfill the task within the desired time schedule. It can also be observed from the provided results that the success rate significantly decreased. It was acknowledged that this decrease may have been influenced by specific scenario setup decisions. Therefore, a more detailed description of the predicted events influencing outcomes from this particular evaluation will be provided in the discussion chapter.

Third Configuration: Vessel 2 / Hugin UUV x2		
	From Scenario Start	**From Previous Area**
Average time of arrival to Area 1:	06:49:12	06:49:12
Average time of arrival to Area 2:	10:52:43	02:17:39
Average time of arrival to Area 3:	15:33:27	01:45:22
	Time:	**Rate of Success:**
Average time to detect the target in Area 1:	00:09:51	100 %
Average time to detect the target in Area 2:	00:27:28	93,3 %
Average time to detect the target in Area 3:	00:20:42	33,3 %
	Fuel Amount [kg]	**Additional Info:**
Total Fuel Consumed by USV:	13821.59	Refuel Necessary
Total Fuel Consumed by UUV:	10341.88	1/2 of full tank in both vessels

Table 8.4: Results obtained from evaluation of third vessel configuration obtained during first scenario with only one USV.

In conclusion, the second configuration appeared to offer the best performance in the described scenario, although all configurations failed to fulfill the task within a certain safe time period. The advantage of the second configuration may be attributed to the use of the sonar equipment installed onboard, as according to the obtained results, hull-mounted sonar was responsible for over 70% of all target detections (see Tab.:8.5).

	Number of targets detected by USV	**Number of targets detected by UUV**
First Area:	2	28
Second Area:	13	17
Third Area:	9	21
Overall Percentage:	26.67 %	73.3%

Table 8.5: Output data received from the evaluation process regarding the particular vessel that detected the target during the second evaluation.

The main factor negatively affecting the overall operation time for all configurations was identified as fuel efficiency. In particular, in the case of the first and third configurations, the vessels were often unable to detect all explosive devices before needing to refuel. Due to the distance between the operation area and the base, this process significantly prolonged the overall time.
The results for the time to conduct the complete operation per iteration for every composition are presented within the appendix A.4.

To explore potential alternatives, a second type of operation was studied: how the results would change if two USV vessels participated in the same operation. The tested configurations for this scenario were the same as the first and second variants used for the initial version of the scenario. However, the third configuration was replaced by a vessel capable of conducting operations using a single underwater vehicle docking facility with a Kingfish-type vehicle. This variant was introduced to assess the influence of a different UUV platform, which could offer a significant reduction in the overall costs of the final product. Results from conducted evaluations are presented in the tables below.
Immediately, it was noted that all three configurations did not require refueling during the scenario, which was the main issue prolonging the overall operation time during the first version of the scenario with only one USV. Due to this reason, in the presented tables, the fuel consumption was deemed unnecessary, as all results clearly showed that the vessels are able to conduct the full mission on one fuel tank.

Fourth Configuration: Vessel 1 x2 / Hugin UUV		
	From Scenario Start	**From Previous Area**
Average time of arrival to Area 1:	05:52:49	05:52:49
Average time of arrival to Area 2:	04:01:10	04:01:10
Average time of arrival to Area 3:	08:46:49	00:49:21
	Time:	**Rate of Success:**
Average time to detect the target in Area 1:	00:13:51	100 %
Average time to detect the target in Area 2:	00:54:52	100 %
Average time to detect the target in Area 3:	01:28:55	93.3 %
Operation Completion Time:	11:46:49	

Table 8.6: Results obtained from evaluation of fourth vessel configuration obtained during first scenario with two USVs participating in the operation.

As predicted, the overall performance of the fourth configuration improved drastically, as only one vessel was tasked with transiting between areas of operation (see Tab.8.6). This led to a significant improvement in the overall time of the complete operation and a notable increase in the success rate of that particular configuration. While this improvement may be attributed to the vessel's ability to stay longer in the areas of operation before shifting, it may also be influenced by certain simulation issues that will be discussed in detail in the discussion chapter. The overall results changed drastically, with the average operation time significantly shortened to 11 hours and 46 minutes, and a standard deviation of only 30 minutes.

Fifth Configuration: Vessel 2 (sonar) x2 / Hugin UUV		
	From Scenario Start	**From Previous Area**
Average time of arrival to Area 1:	06:51:27	06:51:27
Average time of arrival to Area 2:	04:44:07	04:44:07
Average time of arrival to Area 3:	08:18:32	00:55:33
	Time:	**Rate of Success:**
Average time to detect the target in Area 1:	00:02:56	100 %
Average time to detect the target in Area 2:	00:04:22	100 %
Average time to detect the target in Area 3:	00:24:10	96.67 %
Operation Completion Time:	11:18:33	

Table 8.7: Results obtained from evaluation of fifth vessel configuration obtained during first scenario with two USVs participating in the operation.

In the case of the fifth configuration, although the overall time to conduct the operation decreased significantly, the success rate of the process remained at a similar level (see Tab.8.7). The average operation time was 11 hours and 18 minutes, which is almost half an hour faster than the fourth configuration. Additionally, the standard deviation for the recorded results was only 4 seconds, which guarantees the consistency of this configuration. This decrease in the total operation time may be attributed to the ability to conduct the operation without refueling, which eliminated the additional time spent transiting back to the base and then returning to the designated area of interest.

Sixth Configuration: Vessel 1 x2 / Kingfish UUV		
	From Scenario Start	**From Previous Area**
Average time of arrival to Area 1:	05:42:30	05:42:30
Average time of arrival to Area 2:	04:01:27	04:01:27
Average time of arrival to Area 3:	09:23:15	00:29:08
	Time:	**Rate of Success:**
Average time to detect the target in Area 1:	00:08:09	100 %
Average time to detect the target in Area 2:	00:17:46	96.67 %
Average time to detect the target in Area 3:	00:46:36	96.67 %
Operation Completion Time:	12:53:15	

Table 8.8: Results obtained from evaluation of sixth vessel configuration obtained during first scenario with two USVs participating in the operation.

Finally, the sixth configuration, used to examine the influence of deploying a different UUV vessel, proved to offer a slightly lower success rate of detection with a shorter time to detect the target compared to the configuration based around the Hugin UUV (see Tab.8.8). However, due to the smaller range of the sensors onboard the Kingfish UUV, it required more time to fully examine the area of interest before deeming it safe. This directly influenced the overall operation time, which was around an hour longer than the overall time for the first configuration, equaling 12 hours and 53 minutes.

Additionally, the standard deviation for this particular evaluation was 1 hour and 42 minutes, which may be considered as not consistent enough for similar operations.

In summary, it was distinguished that the proposition to conduct the operation with two USV platforms at once would be greatly beneficial for overall performance and the total time for completing the operation. If this solution is not applicable or would not be accepted by the stakeholders, inclusion of an additional fuel tank with a minimal volume of around 5000 kg of fuel would also lead to improvements in the performance of the examined design. Additionally, from the presented designs, the second composition of USV outfitted with hull-mounted sonar and one UUV was determined to be the most successful, with over 70% of target localized using the hull-mounted sonar (see Tab.:8.9).

	Number of targets detected by USV	**Number of targets detected by UUV**
First Area:	4	26
Second Area:	8	22
Third Area:	14	16
Overall Percentage:	28.89%	71.11%

Table 8.9: Output data received from the evaluation process regarding the particular vessel that detected the target during the fifth evaluation.

On the other hand, if stakeholder demands allow for a slightly longer operation time with simultaneous cost reduction, potential changes such as including a different type of UUV or utilizing the first configuration may be proposed. The first design was able to offer a slightly longer average operation time (around 30 minutes, which is equal to the standard deviation for the first scenario), while still providing a considerable detection success rate, with only one fewer target detected than the most successful counterpart.
The results for the time to conduct the complete operation per iteration for every composition are presented within the appendix A.4.

Following previous results from the evaluations it was determined that for second scenario the compositions of vessels that would be suspected to test would not change. This time the simulated operation already assumes that only one vessel should be able to carry out complete operation and fulfill the main objective using deployable unmanned underwater vehicle. Finally, the data obtained from last evaluation were examined and received outcomes are presented in the tables below.

It was discovered that once again, the lack of precise requirements for the specific range of the vessel may introduce additional problems to overcome during the design process. The tested vessels, although able to fulfill the predetermined mission in this scenario, require around 70% of the total fuel capacity in order to do so. The initial utilization scenario submitted by the stakeholder states that the USV would need to be redirected from a different mission; however, it does not specify the precise start state of the USV with its fuel level. Provided results include predictions for the specific amount of fuel that would need to be located onboard in order to conduct the mission and return to the end location (assigned base). This inclusion is expected to help establish the exact range for the vessel in later consultations with all participants involved in the project.

Second Scenario: Vessel 1 / Hugin UUV	
Time to enter the area of operation:	04:14:55
Time to locate the wreck:	04:15:21
Rate of success of the detection:	100 %
Amount of fuel consumed by the USV:	4259.21 kg
Amount of fuel needed for the transit:	2901 kg

Table 8.10: Results obtained from evaluation of fourth vessel configuration obtained during second scenario with one USV participating in the operation.

For the first tested configuration in the second scenario, the average time from the deployment of the UUV within the search area to the first contact with the target was only 26 seconds (see Tab.:8.10). This result may be attributed to the composition of the UUV system itself. The main sensor used to locate the wreckage was determined to be the generic echo sounder used by the Hugin. Furthermore, the estimated time to achieve the operation's goal was around 5 hours and 20 minutes, with the standard deviation equal to only 21 seconds. This indicates the extraordinary ability to repeatedly conduct the operation within the same time frame.

Second Scenario: Vessel 2 (sonar) / Hugin UUV	
Time to enter the area of operation:	05:01:00
Time to locate the wreck:	05:06:15
Rate of success of the detection:	100 %
Amount of fuel consumed by the USV:	4283.39 kg
Amount of fuel needed for the transit:	3016.6 kg

Table 8.11: Results obtained from evaluation of fifth vessel configuration obtained during second scenario with one USV participating in the operation.

In the second tested configuration, the USV vessel equipped with sonar located the target only 5 minutes after entering the area of operation. However, due to its slower transit speed, the overall operation time increased compared to the first test results, with an average value of 6 hours and 16 minutes (see Tab.:8.11). Furthermore, it's worth noting that, although not significantly impacting the time, the USV would still need to deploy the unmanned underwater vehicle to closely inspect the target and fulfill the mission. The standard deviation for this scenario was also considerably low, at only 6 minutes and 52 seconds.

Second Scenario: Vessel 1 / Kingfish UUV	
Time to enter the area of operation:	04:03:55
Time to locate the wreck:	04:13:17
Rate of success of the detection:	73.3 %
Amount of fuel consumed by the USV:	4259.21 kg
Amount of fuel needed for the transit:	2901 kg

Table 8.12: Results obtained from evaluation of sixth vessel configuration obtained during second scenario with one USV participating in the operation.

Lastly, the configuration utilizing a smaller and cheaper UUV was tested. Although the results directly show that this configuration is able to conclude the mission in a similar overall average time to its direct counterpart (1 minute faster than the first configuration with the Hugin UUV), the success rate for this specific design is significantly lower than in previous cases, at only 73% (see Tab.:8.12). The standard deviation measured in this evaluation was 5 minutes and 54 seconds, with the minimal time to conduct the operation equal to 5 hours and 17 minutes and the longest time of operation equal to 5 hours and 46 minutes. Although not measured in the simulation, this difference in effectiveness of detection may lead to an increase in the mission duration as it would need to spend more time directly scanning the whole area of operation.
Additionally, it may be considered to refit the underwater vessel with a different sensor device that would increase the effectiveness of search; currently, the vessel was using the SSAM sonar. The results for the time to conduct the complete operation per iteration for every composition are presented within the appendix A.4.

The overall performance differences in the second scenario were less visible than in the first one, mainly due to the relatively low level of complexity and short period of simulated time. From the obtained results, it can be concluded that the first configuration tested, namely the USV vessel that fully relies on the Hugin UUV to conduct the underwater search, was the most capable and offered the best results. However, it's worth pointing out that the second configuration, composed of the USV outfitted with sonar equipment and the Hugin UUV, would be able to provide the same or lower time-to-detection value if the UUV participated in the search for the wreckage. The main difference between these two configurations would be related to the transfer time, which is considerably longer in the second case.

Overall, it can be observed that the second vessel, with the ability to participate in underwater search, emerged as the most successful composition in the majority of the evaluated simulations. The results consistently demonstrate its ability to achieve the highest success rate across all evaluations, highlighting its versatility and effectiveness for underwater detection tasks. However, it's important to acknowledge that this design may be perceived as one of the costliest solutions and requires additional efforts to optimize the propulsion system for the increased weight of the USV.
To enhance the received results further, it is suggested to explore different variations of the second proposed design. This could involve the addition of a more cost friendly UUV to reduce overall vessel costs or introducing changes to the main sonar system installed in the USV vessel to optimize its properties for maximizing operational effectiveness while minimizing overall costs.

In conclusion, while simulation-based evaluations have provided valuable feedback on the performance of each design across multiple missions, precise outcomes are not easily determined. The process of determining the correct solution for the design problem cannot be entirely accomplished without the inclusion of feedback from all involved parties. However, the presented method of evaluation is believed to enhance the understanding of potential areas for improvement in the design. It would be possible to identify potential pros and cons of each design in various conditions or operations relatively quickly, providing means for the designer to gain a deeper understanding of the solutions and efficiently present them to stakeholders.

In comparison to currently employed methods within the design processes, the proposed evaluation through simulation would introduce relatively quick evaluations that would not be fully dependent on the operational experience possessed by Naval Operations Experts. Especially in advanced stages of implementation, it is believed that the method would offer a designer-friendly solution to evaluate the operational capabilities or performance of the vessel without the need to incorporate other company departments into the process. Overall, the method should be included in the present iterative process as a valuable tool for evaluating the design performance under various conditions.

Additionally, the presented process relates the information introduced in previous chapters to the actual functionalities of the chosen software and provides an example of the evaluation conducted for the case study. It also offers insights into the potential information that may be obtained from the evaluation. Throughout the presented work, various aspects of the simulation preparation process were explained, and several methods for scenario creation were introduced. This description serves as an overall guide to the process that should be followed in order to create and conduct evaluations using specific simulation software.

9. Conclusions

The main aim of the presented project was to formulate a methodology for using simulation software for evaluation purposes during the conceptual stages of design. Throughout its realization, the viability of this methodology was described, aiming to empower engineers to gain a deeper understanding of the design space and the influence of different compositions of capabilities on the performance of the designed vessel for conducting intended missions. Additionally, research was conducted to explore similar ideas already studied by other researchers, as well as current developments in this specific area.

Subsequently, the universal methodology was formulated and presented with the intention of being as versatile as possible. The description deliberately avoids specific details related to any particular simulation software used in the process. Therefore, potential implementation of the mentioned methodology was introduced, providing an example of a process that may be employed within the design process. This methodology was formulated based on information obtained during work at Damen Naval company and centered around the utilization of Command Professional Edition software. Furthermore, a complete example of evaluation was provided, showcasing several different system configurations and two simulation scenarios. This addition aims to offer specific insights into what may be expected from similar evaluations.

Based on the knowledge gained during the project's realization stages, the author was able to formulate several main points of interest that may prove viable in future work on incorporating the methodology into different processes. These additional considerations are presented in the subsequent subchapters.

9.1. Discussion

The presented discussion section aims to provide an overview of the recognized advantages and potential shortcomings of the presented methodology and the overall utilization of simulation. Given that the inclusion of simulation of operational capabilities in the design stages is fairly unheard of, significant focus will be placed on introducing the knowledge required to correctly set up and conduct the evaluation.

9.1.1. Recognized Advantages of the Methodology

As presented during the project, the proposed solution of introducing evaluation through simulation into design practices is not yet widely adopted in the shipbuilding industry. However, it was recognized that the obtained results can provide a greater understanding of the potential operational capability of a design, which may prove especially useful when dealing with novel and complex design tasks, where experience with assessing operational capabilities is strongly limited.

Of particular emphasis is the method's ability, thanks to the nature of simulation software meant for operational capability evaluation, to not require detailed design information in order to create and conduct the evaluation. This property is especially important as it allows for simulation at the first, conceptual stages of the design. It provides information on whether the initial concept would be a valuable solution to pursue and allows for the pinpointing of potential downsides of specific design configurations.

Through multiple possibilities for the composition of the results, it becomes possible to obtain precise information describing all desired properties of each design, thereby clearly determining potential areas of improvement and strengths of each configuration. Most researched simulation software offers potential means for additional modifications and expansion through integrated scripting languages. As proven during the presented evaluation, the possibility to utilize additional scripts created through such scripting languages can greatly improve the overall flexibility of the simulation. This property should be examined in future work on the matter, as it is believed that through the expansion of different scripting methods and languages, the overall possibilities of evaluation may be greatly expanded.

It was also recognized that it would be possible to connect the proposed evaluation method with appropriate solutions that generate the concept design. This would allow for the near-complete automation of the design space exploration process, thus offering significant improvements to the concept design stage. Additionally, this potential connection of two methods would enable a change in the method of exploring the design space. Specifically, it would be possible to evaluate many different system configurations during the same process, rather than conducting evaluations for a fairly limited number of manually created configurations. This would be realized by establishing a unified simulation scenario and then implementing specific input vessels into the evaluation. Finally, although the time required to conclude this process would be heavily related to the number of designs or details within the scenario, it can be concluded based on obtained knowledge that even longer evaluations would take a reasonable amount of time.

Furthermore, it was recognized during the project that the methodology could also be employed as a means to enhance communication channels with stakeholders. This insight was based on feedback gathered among different team members and employees of the Damen Naval company. Specifically, it offers several different methods of displaying the outcomes of the evaluation, allowing for various stages of consultation. As highlighted, this allows for the adjustment of the presentation method to communicate with different involved parties, such as navy representatives (through an operational view from the GUI) or non-military stakeholders (through the inclusion of Tacview addon, showcasing the scenario in a 3D environment).

In summary, the outcomes of the project are believed to provide valuable initial insights into the potential of the methodology. Additionally, they offer a framework for potential integration of the described method into design processes, allowing for testing and expansion of the presented ideas.

9.1.2. Potential Problems with Simulation Scenario Creation

As mentioned earlier, some of the results published above, especially those related to the third vessel composition within the first scenario, namely the vessel that was able to deploy two UUVs, were recognized as influenced by potential simulation problems. Their inclusion in the final report was motivated by the ability to present those suspected problems and discuss potential methods to mitigate those errors in future work.

The main issue that was discovered lay in the scenario setup during this particular evaluation. Specifically, once the unmanned surface vehicle left a certain area of operation, an additional mechanic was introduced to despawn the UUVs operating within that area. This function was used because once the main vessel redirected to the base for refueling or was reassigned to a different mission, the UUVs launched from that vessel were not retrieved before transit. Thus, without this implementation, the search would continue without USV presence in the vicinity of the predetermined area, inevitably leading to an influence on the results.

However, as it occurred during the study of the results, often the vessel was forced to return to the base for refueling, causing the UUVs to despawn. But once the refueling vessel returned to the area of operation, it was not able to deploy the underwater vehicles. This directly influenced the results of the evaluation for this particular configuration, and as a result, it was not further researched. Additionally, at the initial stages, this configuration was changed from its original state due to problems with range and fuel consumption.

In addition, as identified across all scenarios, the main USV vessel seemed to lack communication with UUVs. This realization is mainly motivated by the fact that, at some instances, after detection of an explosive device in the area, the USV continued its operation as usual, resulting in an explosion (modeled as bottom sea mines). While this did not significantly influence the overall results of the evaluation, as it mainly occurred in the last area of operation, it raises concerns about communication effectiveness.

```
12/3/2023 10:55:22 AM - Blue Event: Vessel location Unit: USV_1 - Ship, Vessel 2 Altitude: 0.0
Lat: 52.654981737512 Lon: 3.3707269196947 Speed: 5.0
12/3/2023 11:24:42 AM - Blue New mine contact! Detected by Echo_12 at 224deg - 0.2NM
12/3/2023 1:59:32 PM - Blue Underwater detonation! Bearing 172 - Range 211m from USV_1
12/3/2023 1:59:32 PM - Blue USV_1 is being hit by an underwater explosion at 701 ft!
```

It is crucial to highlight that although these problems occurred during the iterative process of Monte Carlo analysis, they were not present during the initial examination of the scenario. This may be explained by the fact that the initial examination was done using the GUI system within the simulation software, rather than by running a number of test iterations. Therefore, it was recognized that, firstly, the entity responsible for creating the simulation scenario would need to foresee potential problems regarding used mechanics, thus already possessing some level of experience in conducting simulations. Furthermore, it would be especially important to thoroughly examine the scenario both using the built-in GUI and the Monte Carlo evaluation, as only the full combination of these methods would provide enough data to determine if the prepared scenario is appropriate for analysis.

Although similar problems were expected to appear during the process, their nature strongly limits the potential automation of the scenario creation process. This process requires an extensive level of understanding of simulation operations and different influences on the actions occurring within the scenarios. While it would be possible to introduce some level of automation into scenario creation, at the current stages of research, it is impossible to clearly determine the extent to which this may be implemented.

9.1.3. Connection with Capella MBSE Software

The initial intentions for the method formulated by the company's representative revolved around connecting the Model-Based System Engineering (MBSE) process with the evaluation through simulation method to establish a clear connection between these two processes. It was anticipated that the research would lead to outcomes that would enable the full integration of these two processes, through a physical link between the Capella MBSE software and the Command Professional Edition.

This task was approached from a theoretical standpoint to determine if this connection would be possible to create and what it would require. Subsequently, the decision was made to first focus on understanding the workings of the simulation and establishing a clear framework for formulating evaluations, determining the data needed for scenario creation, as well as for vessel introduction. Following this, the methods for creating the simulation were researched and described.

During the presented work, it was discovered that although the connection between these two methods may be possible, it would require significantly more research and scripting knowledge to determine how it may be achieved. The simulation software demands a significant amount of experience to efficiently use all of its tools and to understand and mitigate all the problems that may occur. As presented in the previous subchapter, the scenario creation process requires some level of evaluation to determine if all the actions within the scenario would result in the desired or acceptable outcomes. Potential automation of the process would need to take into consideration some level of human interaction to evaluate and modify the outcomes, if necessary, thus still requiring at least one member of the design team to possess a relatively high level of knowledge regarding the scenario creation process.
For these reasons, it was determined that due to current limitations in experience with both processes as well as coding-specific knowledge, it would be impossible to formulate a clear method for directly linking the functionality of the simulation presented in the methodology with the Capella MBSE software.

Despite the current limitations, based on conducted research into the matter, it may be concluded that this connection would be possible to obtain through a staged process involving the slow incorporation of simulation into the design processes and the development of necessary in-house specific knowledge that would allow the desired goal to be achieved in the future. Some of the limitations identified during the project may be specific only to the predominantly used simulation software. Thus, during further developments, more capable solutions may be identified. Moreover, the same anticipated development may also be applied to the software responsible for input created based on the model-based system engineering process.

9.1.4. Accuracy of the Simulation

There are many different influences on the overall accuracy of the created simulation, especially when dealing with simulations of operations rather than simulations designed to estimate specific values or outcomes from certain load cases. This is primarily due to the fact that the specific kind of operation used for the project is not focused on specific values of results. Instead, these results are used to identify potential differences in effectiveness during specific operations rather than obtaining precise values. Thus, it is almost impossible to obtain two identical outcomes due to the nature of the simulation. For these reason, the main focus for estimating the accuracy of the simulation used in the proposed project should be on exploring the model's behavior rather than the specific data obtained from the simulation.

Additionally, it was identified that, in some instances, historical data can be used to determine the general accuracy that the simulation software is able to provide. Specifically, highly documented historical engagements can be recreated within the simulation software, and the historical results can then be compared to the results obtained from the simulation. This approach, however, is fairly limited as it only identifies the possible level of accuracy achieved by the simulation. Moreover, the possible level of precision in recalling the historical details should also be considered.

As outlined by researchers [75], the precise determination of the accuracy of operational simulations is strongly related to the validity of the input data used for the simulation. Furthermore, this initial accuracy also impacts the evaluation process, as it may be based on predictions intended for the evaluation.

There are several methods to evaluate simulation outcomes, often directly related to comparing the received outcomes with educated predictions for the mission proceedings or available data. Additionally, the accuracy evaluation process is reinforced by exploring specific mechanics present within the simulation model. However, given the significant influence of input data quality on the overall quality of the simulation, it can be determined that the implemented interactions have a limited impact on the overall accuracy once a certain acceptable level is achieved.

The specific research aimed at determining the level of accuracy that can be obtained from the chosen simulation should be carried out before the software is used for future projects. This would ensure that the validity of the results is accepted by the company and clearly outlined to the client before the process is carried out.

9.1.5. Use of External Software

During the work on the presented project, it was determined at several instances that some of the problems or limitations related to the simulation software were caused by errors within the software itself. These problems often relate to certain mechanics malfunctions or methods introduced by the developers that limit certain aspects of the evaluations.

As an example, it may be mentioned that although the Hugin UUV is outfitted with the CCTV underwater camera, at the time of the evaluation, it was not able to determine the precise class of the contact, even though, based on obtained data, it was at the same location and depth as the underwater contact. This was a result of underwater detection malfunction that unfortunately occurred after the latest update to the simulation software. After reporting, it was addressed by the development team at Matrix Pro Sims company.

Although the team responsible for the development of the simulation software is actively introducing new improvements and solutions to discovered problems and offering quick feedback on any reported issue through multiple accessible channels, it would need to be taken into consideration during the evaluation that some of the mechanics may influence the outcomes. As of now, every detected problem with the software was possible to overcome with other implementations; however, this is highly dependent on the issue itself and the abilities of the entity responsible for the simulation operations. It would be important to take this factor into consideration as a longer period of time may be required for some of the evaluations in order for the appropriate fix to be implemented.

On the other hand, the company responsible for the software is actively working on improving the product and provides support for identified problems. Damen Naval company has access to a direct license manager that is able to quickly answer customer-specific questions and provide support for the processes. Furthermore, due to the presence of the simpler version of Command Professional Edition on the commercial market (Command: Modern Operations), the community gathered on the respective forums is also actively checking for potential errors and providing help in case of some operations. It may be regarded as an advantage over some of the more restricted software as due to the number of users gathered in the community, the company receives almost instant feedback on the software developments and improvements.
All in all, it is believed that presented issues are not related to the chosen simulation software; rather, they are present in all software options obtained from external companies. Thus, the use of Command Professional Edition software, especially at early stages of the incorporation of the methodology, may prove especially beneficial. It would allow gathering necessary experience with simulation in relatively user-friendly conditions with an engaged community able to provide help if necessary.

9.2. Answers for the Research Questions

As described in the introduction chapter, several research questions were established at the beginning of the project to guide the development of the described methodology. This subsection aims to provide clear answers to those questions based on the work conducted and documented throughout the report.

What is the current application of the simulations within the ship design domain?

Simulations in the ship design domain are predominantly utilized during the latter stages of the design process. Through literature research, it was identified that simulations serve several key purposes.

Firstly, simulations, particularly in conjunction with digital twin models of existing vessels, have gained significant traction. This approach enables predictions of vessel capabilities, deterioration over time, behavior in off-design conditions, and potential system malfunctions.
The second area of simulation utilization is widespread across design processes and encompasses evaluations such as ship resistance, stability, and structural strength. While these simulations are often precise, they typically rely on detailed data accessible only at later design stages.
The third identified use case involves earlier design stages, albeit requiring at least an initial 3D model of the vessel. Researchers are exploring the potential of implementing Virtual Reality tools to aid designers in gaining spatial awareness within ship interiors. Additionally, some are experimenting with basic simulations to provide feedback on design capabilities, although this use case has yet to be implemented in real ship design scenarios.

In the cases presented, simulation is predominantly utilized at later stages of the design process. Most of the described simulation applications require an already created 3D model of the vessel with an initial part of the general arrangement. Since the main objective of the project is to provide evaluation means through simulation of operational capabilities at conceptual stages of design, the identified current areas of simulation utilization may not be directly applicable. Detailed descriptions of each identified area of simulation implementation are provided in Chapter 2.1 of the report.

Which simulation software would be sufficient for conducting vessel capability evaluation and operational needs analysis for presented project?

Throughout the project, several simulation software options were identified and studied to determine the most suitable choice for the project's requirements. The selection process involved researching various aspects, including user-friendly graphical interfaces, integrated scripting languages, and the capability to conduct iterative evaluations for single naval assets.
In total, several simulation software options were identified and examined for their applicability to the project. These software options included:

- Advanced Framework for Simulation, Integration and Modeling (AFSIM)
- General Campaign Analysis Model (GCAM)
- Synthetic Theater Operations Research Model (STORM)
- Joint Future OpeRating Concept Explorer (JFOrCE)
- Joint Warfare System (JWARS)
- Command: Modern Operations (CPE)

After conducting evaluations of the available options, the Command: Professional Edition was selected. It met all formulated conditions and offered additional benefits, including compatibility with external add-ons such as Tacview, which would enhance the understanding of simulation outcomes and facilitate comprehensive examination of evaluation aspects. Moreover, its accessibility for new and inexperienced users was recognized as particularly advantageous for the early stages of simulation use within design systems. A detailed description of the software evaluation process is provided in Chapter 3 of the report.

Which precise information should be obtained in order to formulate the complete input for the simulation software?

The composition of input data for the simulation software must encompass all necessary information required by the software. The specific information allocated to each dataset would depend on the company's structure and the simulation software used. In the case presented, four datasets were described.
The first dataset should contain information about the vessel and the predicted systems located onboard, enabling the vessel to exhibit appropriate operational capabilities. This dataset would primarily be supplied by the design team and is essential for accurately recreating the vessel within the simulation software.

The second and third datasets were developed to outline the simulation scenario used for evaluation. The second dataset, primarily sourced from the Operational Capabilities Description document, forms the basis for scenario description. It includes details such as weather conditions, primary tasks of the vessel, and initial unit states. The third dataset supplements the scenario by providing additional information, such as specific vessel behavior within the simulation, and directives like EMCON (Emission Control) and ROE (Rules of Engagement) orders that units must adhere to. The last input dataset identified during the project consists of desired result types and formats for the evaluation. These data instruct the simulation software to generate specific result sets for examining vessel capabilities and performance. These results are integral to the overall process.

Detailed descriptions of the identified data and datasets for general methodology purposes are provided in Chapter 6. Additionally, specific descriptions of data sourced from identified sources and the anticipated method of implementation are presented in Chapter 7.

How the presented methodology may be incorporated into present design processes?

The presented methodology requires the establishment of specific processes to integrate it into existing design processes, enabling direct use for evaluating vessel capabilities. The details of this incorporation would depend on the company's specific processes, structures, and the selected simulation software. However, certain foundational steps would remain unchanged and serve as the basis for the process.

Firstly, the input formulation phase would be necessary to determine the required input information at various simulation points and the anticipated method of exporting this data. Secondly, specific data would be allocated to predetermined datasets, classifying input information based on its provider and the method of importing it into the simulation software. The next step would involve using documentation drafts to create documentation entries, enhancing traceability within the design process and standardizing input. This would enable all participants to contribute without requiring simulation-specific knowledge.

Subsequently, the input data should be implemented into the simulation software, and the complete simulation scenario should be evaluated using the methods outlined in the appropriate subchapter of the report. It would also be necessary to establish a preferred evaluation method (e.g., Monte Carlo Simulation) and initiate the process.
Following this, results would be obtained, and analysis conducted using available external software to manage and work on the data obtained. The official outcome should then be documented within the process documentation entry, providing justification for design decisions, and serving as an additional means of communication with stakeholders.

A detailed description of the anticipated integration method of the presented methodology into Damen Naval company's existing design processes is provided in Chapter 7. This description furnishes all necessary information to fully integrate the methodology, both during the research stages of simulation and for advanced evaluation stages that incorporate a relatively high level of automation in the evaluation process.

10. Recommendations

10.1. Customized Database

During the work on the project, it was determined that the possibility to create new entries into the database of the simulation software, including different subcategories of systems, may be used to implement not only the vessel but also the systems that would be supplied by the contractors.

This inclusion of all the used systems into the database would allow for more accurate results of the evaluation and to mitigate potential false specifications of systems present within the database. The current entries within the database are created based on commonly obtainable knowledge about naval sensors and weapons, so it may be assumed that some of the details may be incorrect.

However, in case of full integration of available resources into the database, the potential for quicker and more accurate evaluations should be increased as the additional modeling work would be decreased per single evaluation. Additionally, the ability to quickly compare different designs would possibly also benefit the complete process as it would allow to determine the best compromise of capabilities and performance with regard to the used operational scenario.

The proposed database creation does not refer to the early stages of integrating the simulation into the present design process, as it may require additional time and effort to create all the appropriate database entries. However, if the benefits of conducting the evaluation through simulation were recognized, the proposed update of the systems would overall reduce the effort and improve the accuracy of the results.

10.2. Data Processing Improvement

As recognized and highlighted at the end of the presented evaluation, potential problems with data processing were discovered. The obtained dataset consisted of 9 gigabytes of mostly text files, and their processing was handled through Microsoft Excel software.

During the data analysis process, certain software and hardware-related issues were encountered, leading to an overall processing time of over 11 hours. In comparison, the entire process of creating and conducting the evaluation is estimated to take around 40 hours, indicating that data processing consumes about a quarter of the overall evaluation time. Furthermore, the complete evaluation process is primarily aimed at examining the operational capability of the design at the early stages of the design process, within a relatively short amount of time. Given this intention, it is highly recommended to conduct research on potential improvements in the data processing area.

Potential developments in data processing may be the easiest way to decrease the overall evaluation time and reduce errors caused by software or human mistakes during analysis. This improvement could be achieved by introducing an additional script created in Python or by implementing MATLAB software. These tools would allow for the deployment of specific programs to conduct the data filtration process and to create initial plots based on the evaluation results.

10.3. Back-of-the-envelope calculation

In order to implement the evaluation through simulation at the considered early stages of the design process, the input information needs to be relatively basic. Although this is the main benefit of the identified method, in some regards, other methods may be incorporated into the process to improve the complete evaluation. For example, it was determined that although the newly created database entry is subjected to an initial check if the presented values are "physically possible," it enforces some assumptions that may be hard to estimate without proper experience. This mainly refers to the propulsion and power plant entries for the vessel, as the designer needs to know the estimated speeds and fuel consumption while creating the input data.

In order to improve the potential future processes, it would be recommended to include an additional script within the process that would conduct a relatively simple calculations that would be used to estimate certain values within the database, basing on the input data created by the designers. Those calculations may be used to estimate the resistance of the hull of the vessel, necessary propulsion power at specific speeds or help to estimate the fuel consumption.

Additionally, if this inclusion would be connected with revisited database used for the simulation it would allow to make initial predictions of the precise systems that would provide wanted capabilities during the operations, thus reducing the complete effort during the design process.

On the other hand, the implementation of such a script should be further researched to precisely determine the specific aim of additional calculations and identify the specific methods that may be implemented to achieve the predetermined goals. During this development, it would be crucial to identify potential methods that would not require new extensive datasets, as the main aim of the process is to provide a means of evaluation at conceptual stages of the design when the level of knowledge is still relatively low.

10.4. Wargame Incorporation

Implementation of appropriate vessel behavior is one of the crucial elements of the simulation scenario as it directly may influence the results from the evaluation. The suggested solution for determining the correct tactics that should be implemented is based on the expertise of a naval operation specialist who would be a member of the team tasked with the project.
However, it was recognized that the process of obtaining the expertise from a person who may have a sufficient level of expertise in naval operations and tactics may be challenging. A prime example of this limitation would be a small company that does not possess such an expert in-house. Furthermore, as explained in the introduction chapter, when dealing with novel technologies such as USV, the operational experience may not be there yet.

These considerations may be solved by incorporating another type of simulation at the beginning of the process to determine the correct tactics for anticipated evaluation through war-game simulations. These simulations are relatively similar to the presented simulation software; however, the main difference is that they mostly concentrate on the tactical aspects of engagements, focusing on modeling the unit's behavior, capabilities, and different aspects of the campaign. In the case of such simulations, it may be pointed out that previously described agent-based simulations would be especially useful to help determine the correct tactics for the initial design evaluation.
The complete process may be presented by modification of Peter Perla's Cycle [69] as presented below (see Fig.10.1).

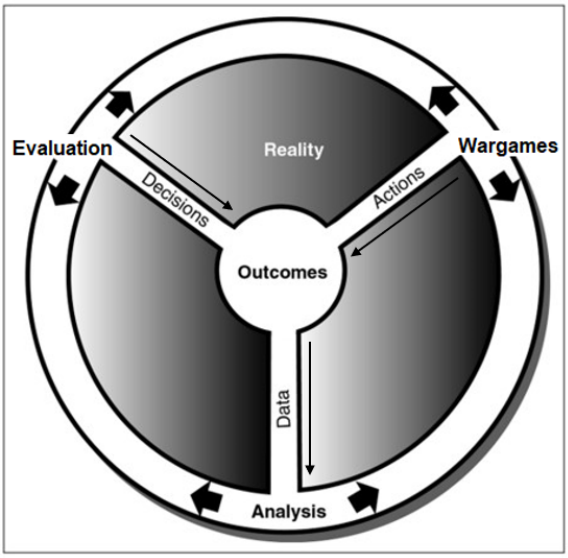


Figure 10.1: Modified Peter Perla's Cycle meant to showcase the relation between the Wargame, Simulation and the Designer's Prediction during the recommended process.

The incorporation of wargaming does not fully eliminate the need for specialist expertise on the matter; however, it may reduce the time and workload required by the specialist. Furthermore, this process would also require the involvement of naval analysts and design team members to initially evaluate the results, as well as stakeholder involvement to ensure that the tactics used reflect real-time missions or their predictions.

The proposed addition to the main process may improve the level of evaluation of the design and provide significantly more accurate outcomes, as the behavior of the vessel may critically influence the evaluation's outcome. Therefore, ensuring that it not only matches present client norms but also represents real engagements is crucial for the success of the method in more in-depth simulations.

11. End Considerations

Societal-Ethical Impact

At the end of the presented project, it would be crucial to determine its potential societal or ethical impact. While the main aim of the work was the development and introduction of a new method into the design process, it may be challenging to directly assess the overall ethical aspect of the outcome. However, considering the context of the development within the naval spectrum of design practices and the predominant use of simulation software for naval operations, the method may also be applicable to the civilian market, providing similar advantages in the overall context of the conceptual design process.

On a micro scale, the potential integration of this method may reduce the level of uncertainty within the early stages of the design, thereby improving the designers' knowledge about potential solutions for the problem at hand. This improvement could enhance the overall experience of the design team, making their work slightly easier than before. Although the method presented within this paper may require certain improvements to directly and consistently affect the designers' work, it holds the potential to improve the overall experience.

Additionally, it is important to highlight that although Damen Naval company predominantly deals with military contracts, its internal policy allows it to provide services only to states determined by specific international organizations, with adherence to the laws regulating weapon production and export. This factor limits the possibility for potential products to be used in direct harm's way and may be considered as a warranty that the potential outcomes from the design processes, which include the presented methodology, would be used to increase the security of the citizens of said country.

Current Developments

Currently the Damen Naval Company is at the early stages of the incorporation of the simulation within the processes. A number of research is being currently done in order to establish the potential implementation of presented technology as well as to prove the advantages of implementing the simulation in different areas of design processes.
The intentions are for the simulations to provide the mean of evaluation at conceptual stage of the design as described within the project. However, as work progressed, additional benefits were recognized. Specifically, the simulation software's potential for visualizing anticipated missions could serve as an additional means of communication with stakeholders involved in the project.

The anticipated improvements could be implemented at various stages throughout the design process. As outlined in the report, they can efficiently facilitate communication and justification of decisions made during this process. Furthermore, recognized areas for improvement include the early stages of OCD creation, where simulations may aid in specifying the vessel's intended use and enhance communication between the team and stakeholders.
During a workshop hosted by the company for a project conducted in collaboration with several European companies, simulations were utilized to identify specific issues for future discussion and to elucidate proposed solutions. As an outcome, this approach gained significant interest from representatives of other companies that are also primarily dealing with naval design.

This reaction suggests that the issues presented in the project report are significant for advancing methodologies that aid design teams during the early stages of design. This statement finds support in presented literature research, which reveals limited public data on simulation integration. However, it has come to light that certain companies are currently experimenting with incorporating simulation evaluations to enhance operational capabilities during the design process. Regrettably, much of the information regarding current industry implementations is not publicly available. Furthermore, public sources lack clarity regarding the specific operations or simulation software utilized in the presented processes.

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A. Appendix A

A.1. The Database Structure

The table presented below (see Table: A.1) was created based on the information presented in the database manual provided by the software developers. This information should provide a clear overview of the desired values in the database entry.

Field Name	Description
ID	Autogenerated (Do not edit)
Name	Name; appears in long title and in-sim
Country	Operator Country
Service	Operator service / branch
Year (in service / out of service)	First field is for year of service; second is for year decommissioned. Set to 0 if unknown
Comments	Additional comments. Leaver a dash if none
Complete	Clerical tool to track WIP entries; no effect in-sim
Hypothetical	Indicates a hypothetical entry. Those entries can be hidden when using in-sim DB viewer
Unit long title	Do not edit Autogenerated
Length	LOA
Beam	BOA
Draft	Draft (draught)
Height	Mast Height. Used for height of radars. Can be 0 then sim assumes value based on size
Damage points	Do not edit
Empty Displ (t)	Displacement w/o fuel, ammo, etc (can be 0)
Std Displ (t)	Normal displacement, used to generate DP
Full Displ (t)	Loaded displacement, can be 0
Crew	The number of base/essential crew.
Troop Cap	The number of extra personnel that the unit is able to carry
Cargo Cap (t)	Weight of cargo that can be carried
Missile Defense	How many missiles should be fired at the vessel. Determines salvo size during the automatic fire.
Max sea state	Highest sea state in which the vessel can operate
Repair Capacity	Not used in-sim
Armor Fields	Not used in-sim
Category	General ship category. Determines unit icon
Type	Specific ship classification. Determines Abilities
Size	The pier size required to hold the vessel
Range / Speed Fields	”Range at speed” values. Cruise speed is required. Speed must match values from engine data.
Fuel Prim (kg)	How much fuel is carried for the primary engines. Used when not all stored fuel is used for consumption. Can be 0, used only if exact numbers are known.
Fuel, Scnd (kg)	How much fuel is carried for secondary engines.
Cargo Type	The type of cargo this unit can carry inside the hull.
Mass (t)	The cargo weight, in tons, the unit can carry. Should match Cargo Cap. Field.

Field Name	**Description**
Area (sqm)	The unit's cargo space, in square meters.
Crew/Troop	The number of extra personnel the unit can carry. Should match Troop Cap. Field.
Nuclear Shock Resistant	Not used in-sim
Prairie Masker	For ships with PM, Agouti, etc. Systems. The "+PM" sonar modifiers are deprecated. Use this code instead!
Advanced Quieting	For ships with quieted machinery spaces, etc. The "+AQ" sonar modifiers are deprecated. Use this code instead!
Helo In-Flight Refuel Capable (HIFR)	Not used in-sim
Can Deploy Amphibious Vehicles from Cargo	Ship can deploy amphibious vehicles into the sea via a Ro/Ro ramp. (without having a well dock)
Passive or single Stabilizers	Not used in-sim
Dual or Triple Stabilizers	Not used in-sim
Low Construction Standards	Reduced DP by 40% Make sure to refresh DP!
All aluminium Construction	Reduced DP by 30% Make sure to refresh DP!
Aluminium Superstructure only	Reduced DP by 20% Make sure to refresh DP!
Wooden Hull Construction	Reduced DP by 30% Make sure to refresh DP!
Glass Reinforced Polyester (GRP) Construction	Reduced DP by 20% Make sure to refresh DP!
Hovercradt/SAS	Reduced DP by 40% Make sure to refresh DP!
Catamaran/Trimaran Multihull	Reduced DP by 30% Make sure to refresh DP!
Laid down before 1930	Reduced DP by 20% Make sure to refresh DP!
Built to Mercantile Standards	Reduced DP by 30% Make sure to refresh DP!
Degaussed Steel Hull	Reduces chance of triggering magnetic mines.
Onboard Degaussing Gear	Reduces chance of triggering magnetic mines.
Wooden Hull	Reduces chance of triggering magnetic mines. Must also add "Wooden hull construction" flag.
Glass Reinforced Polyester (GRP) hull [minesweeper]	Reduces chance of triggering magnetic mines. Must also add "GRP Construction" flag.
Refuel to and Refuel from	Can pass to / receive fuel from another vessel(s), provided said vessel has the corresponding flag
Replenish to and Replenish from	Can pass to / receive stores (ammunition) from another vessel(s), provided said vessel has the corresponding flags.

Table A.1: "Field Guide" for ship entry description provided in the Command: Professional Edition Database Manual [52]

A.2. Possible composition of output data

The part of the file presented below is used as the setup instruction for the simulation software. Through the modification of that file, the user is able to decide which specific values should be saved from the complete process. The complete "EventExport" file is present within the simulation software, and may be obtained from the author of the report if necessary.

```
[General] ; Valid choices: CSV , XML , MSAccess , Tacview1x , Tacview2x,
TacviewRT, SQLServer, SQLite, SIMDIS
ActiveExporter = CSV
; Changed 5/02/24 J.O.
[CSV Settings]
UseZeroHour = True
SplitFilesBySide = True
ExportSensorDetectionSuccess = True
ExportSensorDetectionFailure = True
ExportWeaponFired = False
ExportWeaponEndgame = True
ExportUnitPositions = False
ExportEngagementCycle = False
ExportUnitDestroyed = False
ExportFuelConsumed = True
ExportFuelTransfer = False
ExportAirOps = False
ExportDockingOps = False
ConsolidateCSV = True
ExportCargoTransfer = False
UseCustomUnitExportFrequency = False
SpeedBandFrequency0To20 = 0
SpeedBandFrequency20To40 = 0
SpeedBandFrequency40To80 = 0
SpeedBandFrequency80To160 = 0
SpeedBandFrequency160To320 = 0
SpeedBandFrequency320To640 = 0
SpeedBandFrequency640To1280 = 0
SpeedBandFrequency1280To2560 = 0
SpeedBandFrequencyOver2560 = 0
SpeedBandFrequencyDynamic = 0
```

A.3. The Scenario Description

The tables presented below were created based on drafts of similar documents used for describing the use case scenario (see Tab A.1 and Tab A.2) . They should contain all the necessary information required to recreate the desired conditions within the simulation scenario. The data within these tables should primarily be provided through cooperation with the stakeholders or based on their input into the project.

<table>
<tr><th colspan="5">Case Study #1: Critical Underwater Infrastructure</th></tr>
<tr><td colspan="2">Scenario</td><td colspan="2">Situation</td><td>Own Task</td></tr>
<tr><td colspan="2">CUI Defence</td><td colspan="2">- Underwater Explosive Device is likely present in close vicinity to CUI</td><td>- Survey the area.
- Detect, classify, identify the explosive device.</td></tr>
<tr><td colspan="2">Magnitude of effort required</td><td colspan="2">Threat</td><td>Technique</td></tr>
<tr><td>Area to cover:</td><td>0.5x1.0 nm
1.5x1.0 nm
1.5x1.5 nm</td><td>Present Threat:</td><td>From 1 to 3 bottom explosive devices that are not yet armed</td><td rowspan="2">- Sonar scans of the sea bottom from the USV.

- Deployment of the UUV to closely scan the contacts.</td></tr>
<tr><td>Potential contacts per area:</td><td>0-1 IED per area</td><td>Type:</td><td>Underwater Explosive Device</td></tr>
<tr><td colspan="5">Operational Conditions</td></tr>
<tr><td>Effectiveness</td><td>Coverage rate</td><td>Risk Reduction for Personnel</td><td>Platform Independence</td><td>Visibility of Ops</td></tr>
<tr><td>High</td><td>Low</td><td>N/A</td><td>Shore based modular USV</td><td>Overt</td></tr>
<tr><td colspan="5">Deployability and Logistics</td></tr>
<tr><td colspan="2">Mobility</td><td>MTF Integration</td><td>Self-Sustainability</td><td>External Logistic Support</td></tr>
<tr><td colspan="2">Tactical</td><td>N/A</td><td>N/A</td><td>Rely on ashore facilities</td></tr>
<tr><td colspan="2">Operational Environment</td><td colspan="2">Environmental Conditions</td><td>Essential Capability Requirements</td></tr>
<tr><td>Surface Threat</td><td>No</td><td>Water Depth (m)</td><td>41 – 50 m</td><td rowspan="5">- Ability to localize the target
- Ability to examine and identify the target</td></tr>
<tr><td>Air Threat</td><td>No</td><td>Bottom conditions</td><td></td></tr>
<tr><td>CBRN Threat</td><td>No</td><td>Sonar conditions</td><td>Layers, Reverberation</td></tr>
<tr><td>MCCM</td><td>No</td><td>MS conditions</td><td>N/A</td></tr>
<tr><td>24H – 7D</td><td>Yes</td><td>WX conditions</td><td>Sea State 2,
Temperature +10,
No rain,
Slight cloud coverage / Visibility +15km</td></tr>
</table>

Figure A.1: Table containing the input information regarding the environmental and operational conditions present in the first scenario, namely, the Critical Underwater Infrastructure.

<table>
<tr><th colspan="5">Case Study #2: Equipment Retrieval</th></tr>
<tr><td colspan="2">Scenario</td><td colspan="2">Situation</td><td>Own Task</td></tr>
<tr><td colspan="2">Search and Retrieval</td><td colspan="2">- Helicopter with valuable equipment was downed in the northern part of the Dutch Economical Zone</td><td>- Survey the area.
- Detect, classify, identify the wreck.</td></tr>
<tr><td colspan="2">Magnitude of effort required</td><td colspan="2">Threat</td><td>Technique</td></tr>
<tr><td>Area to cover:</td><td>1.0x1.0 nm</td><td>Present Threat:</td><td>N/A</td><td rowspan="2">- Sonar scans of the sea bottom from the USV.
- Deployment of the UUV to closely scan the contacts.</td></tr>
<tr><td>Potential contacts per area:</td><td>Wreckage of the helicopter</td><td>Type:</td><td>N/A</td></tr>
<tr><td colspan="5">Operational Conditions</td></tr>
<tr><td>Effectiveness</td><td>Coverage rate</td><td>Risk Reduction for Personnel</td><td>Platform Independence</td><td>Visibility of Ops</td></tr>
<tr><td>High</td><td>Low</td><td>N/A</td><td>Shore based modular USV</td><td>Overt</td></tr>
<tr><td colspan="5">Deployability and Logistics</td></tr>
<tr><td colspan="2">Mobility</td><td>MTF Integration</td><td>Self-Sustainability</td><td>External Logistic Support</td></tr>
<tr><td colspan="2">Tactical</td><td>N/A</td><td>N/A</td><td>Rely on ashore facilities</td></tr>
<tr><td colspan="2">Operational Environment</td><td colspan="2">Environmental Conditions</td><td>Essential Capability Requirements</td></tr>
<tr><td>Surface Threat</td><td>No</td><td>Water Depth (m)</td><td>41 – 50 m</td><td rowspan="5">- Ability to localize the target
- Ability to conduct underwater operation of equipment retrieval</td></tr>
<tr><td>Air Threat</td><td>No</td><td>Bottom conditions</td><td></td></tr>
<tr><td>CBRN Threat</td><td>No</td><td>Sonar conditions</td><td>Layers, Reverberation</td></tr>
<tr><td>MCCM</td><td>No</td><td>MS conditions</td><td>N/A</td></tr>
<tr><td>24H – 7D</td><td>Yes</td><td>WX conditions</td><td>Sea State 4,
Temperature +5,
Slight rain,
Slight cloud coverage / Visibility +15km</td></tr>
</table>

Figure A.2: Table containing the input information regarding the environmental and operational conditions present in the second scenario, namely, the Underwater Equipment Retrieval.

A.4. Additional Results from the Evaluation

The results of specific results for specific times of operations were presented in form of the graphs below. Those graphs show the specific time of the mission during each iteration, with respect to certain configuration of the systems onboard. All presented data were obtained as a result from the operational evaluation conducted as presented in eight chapter, using the Command Professional Edition software.

As can be seen in the first graph (see. Fig.:A.3), the second configuration consistently conducts the assigned operation within a certain time. This is further supported by the value of the standard deviation, which is equal to 3 minutes. This may be explained by the fact that the vessel consistently redirected for refueling at a certain point in the route, namely between the second and third areas of operation. Other tested configurations were sometimes able to complete the entire operation without refueling (although this was relatively rare), or the vessels had already entered the third area of operation before refueling. This inconsistency caused the results to be much more varied than those for the second configuration.

In the second presented graph (see. Fig.:A.4), created based on results obtained from the second version of the critical infrastructure scenario, there are two sudden spikes in the values recorded for the sixth evaluated vessel configuration. These anomalies in the obtained data may be explained by the occurrence of unexpected events within the simulation. After conducting research on the topic, it became clear that the main problem occurred during the transition between the second and third areas of operation and may be attributed to one of the identified problems explained in the conclusions chapter.

Finally, the last graph presents the results for the time recorded from the start of the mission until the target was detected (see Fig.: A.5). Based on this figure, it can be seen that the configuration outfitted with the Hugin UUV offers the most consistent detection time. Furthermore, as indicated by the average detection time, the configuration using sonar for the search operation is characterized by the longest time until the target was detected. It is also worth pointing out that the last set of points, recorded for the configuration deploying the Kingfish UUV, includes fewer than thirty points. This may be explained by the fact that in certain iterations, this configuration was not able to detect the target at all, thus the respective points were not included on the presented graph.

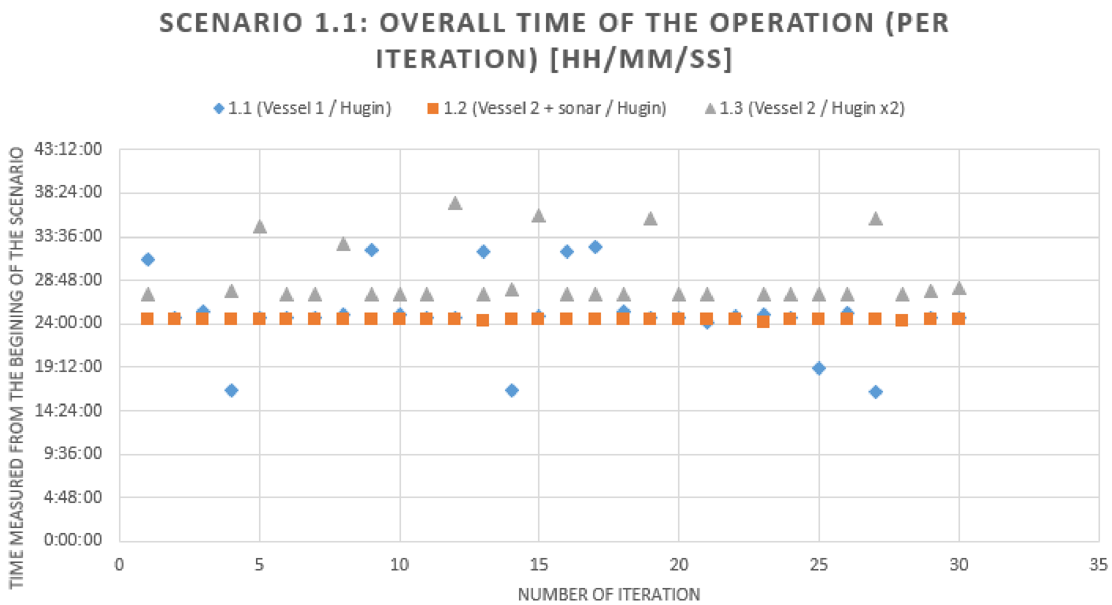

Figure A.3: The graph showing the time to complete the assigned operation in each iteration for each of the configurations. Based on the data gathered for the first version of the critical infrastructure scenario.

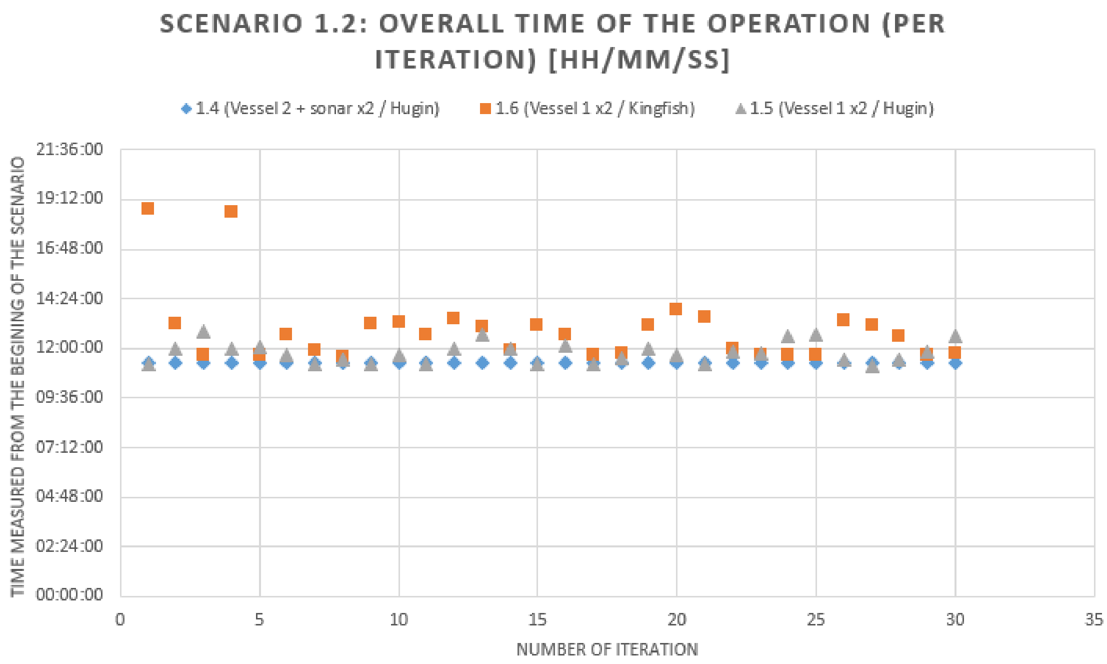

Figure A.4: The graph showing the time to complete the assigned operation in each iteration for each of the configurations. Based on the data gathered for the second version of the critical infrastructure scenario.

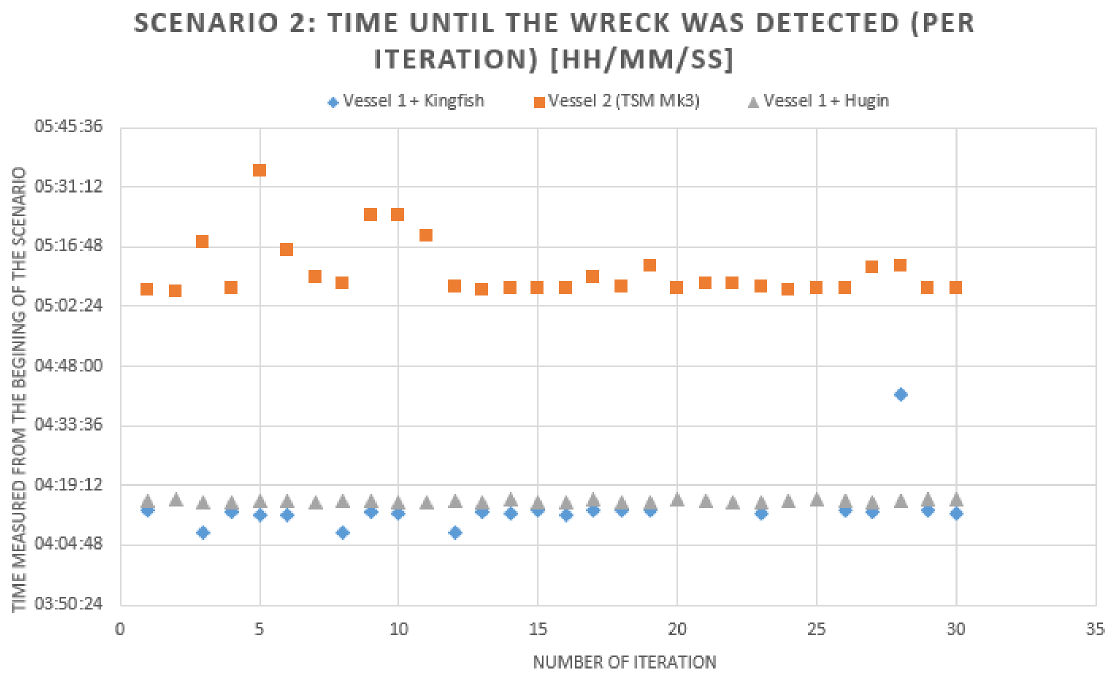

Figure A.5: The graph showing the time to detect the target in each iteration for each of the configurations. Based on the data gathered for the vulnerable equipment retrieval scenario.

B. Appendix B: Research Paper

Attached below is the concept research paper created based on the project described within the main report.

Validating Operational Scenarios Through Simulation

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Abstract

Due to recent legislative changes and shifts in global markets, the task of ship design has grown considerably more complex. The integration of groundbreaking technologies, such as remotely controlled or autonomous vessels, poses additional challenges during the concept design phase, primarily due to a lack of familiarity and experience with these technologies. Simultaneously, these advancements make it increasingly difficult to design a vessel that can consistently meet its objectives throughout its entire life cycle.
In the early stages of the design process, designers often face the challenge of making critical decisions without fully understanding their potential consequences. This situation is compounded by the increasing costs associated with these decisions and their influence on design freedom. Consequently, the conceptual design stages become especially crucial, as making changes later in the shipbuilding process can result in significant cost escalation for the project.
Considering the various factors impacting the ship design process, there arises a necessity for a novel methodology that empowers designers to assess the operational capabilities and performance of conceptual designs during the early stages of ship design. This paper presents the outcomes of a research project on the potential incorporation of simulation software into design practices, along with the framework that originated during the project.

1 Introduction

Ships are widely recognized as among the largest and most intricate man-made systems, characterized by their complex structures and subject to numerous regulations and requirements. The ship design process mirrors this complexity, incorporating various considerations and involving expertise from diverse backgrounds.

The concept design stage is widely believed to be one of the most critical phases of the entire design process. At this juncture, the requirements or missions specified by stakeholders are translated into specific capabilities that the vessel must possess [4]. Additionally, close collaboration with all stakeholders is imperative during this stage to ensure that the designed vessel aligns with their needs.

During the concept phase, designers often find themselves making decisions that carry significant weight throughout the entire project. These decisions not only commit costs and constrain design freedom but also have the potential to impact subsequent decisions later in the process [29] [1]. Unfortunately, at the initial stages of the design, designers do not possess sufficient knowledge about the decisions they have to make and their potential outcomes [13]. This lack of insight significantly diminishes the project's effectiveness and may necessitate costly adjustments in later stages (see Fig:1).

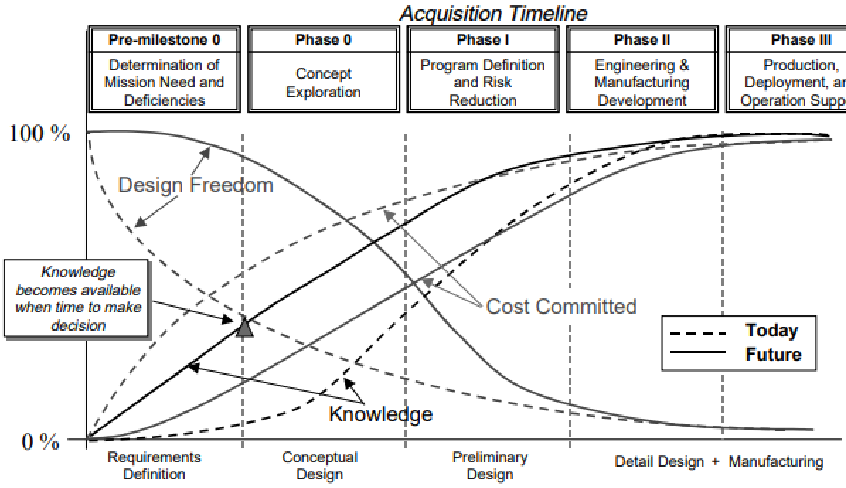

Figure 1: The relationship of design freedom, knowledge and cost committed. [13].

As a result, the need for new design methodology has been formulated. Currently, various companies and organizations have acknowledged the potential benefits of the Model-Based System Engineering (MBSE) approach. While this implementation proves advantageous for several purposes, it does not fully solve the presented issue. Especially within the domain of innovative solutions, conventional evaluation methods may fall short in delivering accurate assessments. Often, decisions may be supported by the designer's experience, but this approach has significant limitations. Experience is typically confined to specialized areas and is only accessible to seasoned designers. Furthermore, it is not applicable in the case of innovative design which is a crucial matter for modern companies to adjust to the market and provide long-lasting solutions.

This problem is especially noticeable in contemporary businesses, which must consistently improve their operations to provide the best products for customers and maintain their position in the market. As such, the research gap addressed by the presented project primarily lies within the concept design domain. The objective is to foster a better understanding of potential solutions to support the decision-making process before commitments are made.

The aim of this project is to provide additional means of assessment of the capabilities in conceptual stage of the design by developing a method of implementation of the simulation of military operations with a system model of the operational needs of a future military platform. This development should be able to improve knowledge about the required capabilities of the designed vessel in the initial stage of the design by offering a tool to explore the "performance space" while the full systems composition is still not formulated [7].
Additionally, the outcome from the process would serve as evaluation for the operational needs analysis, which is currently conducted basing on the operational experience of the specialist [6].

Thus, the research gap was determined. Presented project would address the lack of knowledge during the conceptual stage of the design by providing greater understanding of the requirements as well as possible solutions for the vessel's capabilities. The main aim is to create the methodology for simulation use in order to explore the design as well as performance spaced for the design. This would also improve the effectiveness of overall design process and reduce the amount of the experience that the designer needs to base on during decision-making process.

2 Initial Research

Through the conducted literature research, it was recognized that the proposed incorporation of simulation software in the concept stage of the design process has not yet been sufficiently studied, or the description of such development is not present within publicly available sources. For this reason, it was determined that a comprehensive overview of current norms and potential influences on the process, based on the literature, should be provided to ensure that the baseline for the method is clearly understandable and allows for future use in commercial applications.

2.1 Norms and Regulations

It was recognized that the overall topic of simulation has been acknowledged by the legislative bodies within the naval industry. Due to the primary focus on providing a methodology for real-time applications, it was determined that a closer look into current legislative rules should be taken to ensure that the proposed solutions align with presently recognized recommendations and restrictions.

In recent years, there has been a concentrated legislative initiative aimed at maximizing the utilization of Modeling and Simulation (M&S) to its fullest capacity within the North Atlantic Treaty Organization (NATO), with the goal of enhancing operational efficiency and cost-effectiveness [18]. These efforts led to the formulation of the Modelling and Simulation Strategic & Implementation Plans for the Alliance, which are regarded as M&S implementing documents and set the foundation for all future development efforts (2010).

With the introduction of High-Level Architecture (HLA) in evaluation and simulation systems, the STANAG 4603 standardization agreement was issued. This document's purpose is to provide system-level interoperability between Command and Staff, Tactical, and Individual modeling and simulation systems. All participating nations are required to incorporate specific standards into their processes, as outlined in various norms published on the subject [19].
In accordance with the STANAG agreement, the exact norms to be adhered to during the simulation creation process include:

- IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Framework and Rules [24]
- IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Federate Interface Specification [23]
- IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Object Model Template (OMT) Specification [22]
- IEEE recommended Practice for High Level Architecture (HLA) Federation Development and Execution Process (FEDEP) [11]
- IEEE Recommended Practice for Verification, Validation and Accreditation of a Federation - An Overlay to the High-Level Architecture Federation Development and Execution Process

The outlined standards establish guidelines for the simulation's adherence, encompassing aspects such as model construction, behavior, interactions, and specific connections among different simulation elements. Primarily, these norms address the structure of the simulation software and the interactions among its various components.

On the other hand, some of considered options for the simulation software may presently conforms to the Distributed Interactive Simulation (DIS) norms, which serve as precursors to the current High-Level Architecture (HLA) regulations. Originally designed to meet the requirements of the Defense Advanced Research Project Agency (DARPA), these norms were subsequently incorporated into the NATO standardization agreement STANAG 4482 in 1995 [5]. The Distributed Interactive Simulation is currently defined under set of IEEE standards, including:

- IEEE 1278.1-2012 - Standard for Distributed Interactive Simulation - Application Protocols [15]
- IEEE 1278.2-2015 - Standard for Distributed Interactive Simulation - Communication Services and Profiles [16]
- IEEE 1278.3-2010 - Recommended Practice for Distributed Interactive Simulation - Exercise Management and Feedback [26]
- IEEE 1278.4-2010 - Recommended Practice for Distributed Interactive Simulation - Verification, Validation and Accreditation [28]

In the context of the presented project, it was concluded that non-compliance with contemporary norms would not be treated as a significant factor. This is because the primary focus of the project, which revolves around the methodology, remains unaffected by the HLA and DIS standards, which predominantly impact the simulation software rather than its usage. Moreover, given the prior acceptance of DIS norms by NATO officials, it is anticipated that client opposition to this process would be minimal. However, it should be highlighted that compliance may be crucial when incorporating the created methodology into existing design practices within the company.

2.2 Methodology Requirements

It is recognized that correct simulation software would have significant influence on the success of the project. When chosen correctly, it would allow to focus fully on the formulation of methodology, at the same time providing sufficient level of details in the simulation. It is noteworthy that the majority of advancements in the military simulation field are geared towards operational evaluation. However, given that the primary objective of the project is to assess the initial design, it becomes imperative to identify software that, while primarily designed for different purposes, can effectively meet the project's specific requirements.
The following research and descriptions were created basing on knowledge obtained primarily from studying various simulation software solutions currently present on the market [3], [2], [25], [9], [14], [12].

It is essential to determine a simulation that is suitable for evaluating the capabilities of a single unit in a naval environment. Consequently, the selected software for the project should enable the simulation of naval operations for both individual vessels and groups of vessels. Additionally, to ensure precise evaluations, the simulation environment must incorporate significant influences on vessel capabilities and operations.

Furthermore, certain projects may necessitate the modelling of other influences, such as rules of engagement orders, which could be pivotal. Moreover, for a more comprehensive understanding of events occurring during the simulation and to facilitate the communication of results to stakeholders, the software should feature a clear and user-friendly graphical user interface (GUI). Optionally, additional tools for preparing and formulating results would be beneficial.

It would be necessary for the vessel to behave in predefined way according to operational instructions of client, in this case NATO. This behavior should ideally be incorporated at the scenario formulation level within the input phase of the methodology. The utilization of a scripting language within the simulation software is assumed to enhance the overall efficiency of the process.

Moreover, to enhance the automation of the methodology, an external computer script may be employed. This script would particularly contribute to the simulation creation and results formulation, facilitating the extraction and implementation of input or output data.
Basing on the knowledge obtained through research and considering the general requirements, it has been determined that specific capabilities must be attained, namely:

- Ability to formulate clear description of the vessel with inclusion of systems and subsystems that may be used in the simulation. Furthermore, clear description of the scenario of the vessel implementation and the conditions of evaluation.
- Ability to export the vessel and scenario description into the simulator environment, possibly by reformulating the descriptions and saving them in correct manner.
- Ability to import the input data to the simulator and to formulate the scenario basing on those data. This would need to include establishing all of the simulation properties basing on previously formulated data, such as the vessel representation or the mission that the described vessel should carry out.
- Ability to carry out the evaluation. Simulate the mission and present the outcomes in clear and understandable manner.
- Ability to analyze and export the results from the simulation into report, providing additional context to decision making processes within early-stage design.

Additionally, it should be highlighted that while determining the applicable simulation software for the desired evaluation, potential compatibility with external coding scripts should be considered. For example, as demonstrated in existing solutions [10], the use of the Python scripting language is recognized as beneficial for effectively reformulating and analyzing results from the simulation (output edition). This additional feature would significantly enhance the variety of operational situations that can be simulated.

Two main issues have been identified with the simulation environments currently available on the market for similar applications. The first issue pertains to a focus on campaign evaluations, which affects the ability to prepare evaluations for single units. The second issue involves the absence of certain influences on the operational capabilities of the unit. While these issues can be addressed, it would necessitate additional work and potentially significant modifications to the source code.

Moreover, simulations of campaigns often require the use of agent-based simulation environments to accurately assess different communication channels and varying states of knowledge among units about the battlefield situation. However, for this project, utilizing these functionalities of agent-based simulations is unnecessary, as they would not be fully used.

2.3 Evaluation of the Simulation Models

As the interest in incorporating simulations to facilitate the decision-making process grows, there is a concurrent need for methods to ascertain the validity of a given simulation. The processes of verification and validation of simulation results are integral components of many different approaches, ensuring that the work undertaken to achieve specific results can be deemed trustworthy.

As outlined in the work of Robert G. Sargent [21], four fundamental methods are identified to assess the validity of simulation results. The first the presented method is relatively subjective, relying on the knowledge and expertise of the development team responsible for the evaluation. The assumption is that the team tasked with developing the simulation would also be responsible for verifying its accuracy based on their expertise and understanding. Although prone to potential errors, this approach is frequently utilized in various evaluations, including predictions of operational needs.

The next method is somewhat similar, involving evaluation by a third-party that did not participate in the simulation setup process. This approach, known as "independent verification and validation" (IV&V), is particularly suitable for large and complex projects that typically involve multiple design teams. However, a potential drawback lies in the extensive knowledge required by the team members responsible for the evaluation. This can pose challenges, especially in cases of heavy workloads, potentially affecting the efficiency of specialists within the company.

From this approach, two different methods can be derived [27]. In the first method, the validation team participates in the simulation creation process, providing feedback as necessary. In the second approach, the evaluation team conducts a review of the simulation once it is fully completed. It is noted that, especially for the second method, the evaluation process may be significantly more costly and time-consuming than other methods.
The last method involves using a scoring model based on predefined scores for different aspects of the simulation [8]. However, this method is seldom used in practice [21]. This is because the model may receive a passing score while still having significant defects, the passing scores are usually established in a subjective way, and the score may lead to overconfidence in the model.

Other method of validation of simulation is to conduct model tests for desired simulated operation [17]. This method is able to closely examine and determine the areas of simulation that are correct and those that need to be corrected. It is especially useful to evaluate operations such as underway replenishment. On the other hand, this methodology requires additional costs and time for creation of the experiment, thus this evaluation would be usually done only once to confirm if the software is correct. Furthermore, this method is not able to evaluate simulations used for capability evaluation of the vessel or multiple vessels.

To ensure that the complete evaluation process is conducted correctly and that the outcomes are recognized by every client, it is essential to comply with the presented processes. For the purposes of the proposed process, it is recommended that evaluations should be conducted at predetermined milestones of the project by experts who were not involved in the previous steps. This approach ensures that the overall process is carried out correctly. However, this process may be adjusted according to the described methods to ensure better feasibility for specific applications within different design processes.

3 Methodology

As previously highlighted, the incorporation of simulation software into the concept design phases for evaluating operational capabilities lacks sufficient exploration in publicly available sources. Therefore, there is a clear need to establish a methodology for this purpose. This section will specifically outline the main methodology for using simulation software to evaluate vessel capabilities during the conceptual stage of ship design. The process is structured into three primary parts, as detailed earlier: data gathering and input, simulation setup, and output data export and handling. This comprehensive approach involved assessing available data, defining methods to be employed, and considering various influencing factors.

The core of the evaluation process revolves around utilizing an initial dataset comprising predictions of operations conducted by the responsible entity within the company structure. This dataset is supplemented by data derived from system analysis processes, aimed at achieving a thorough understanding of the missions the vessel is expected to fulfill. The simulation is intended to commence at the outset of the design process, serving as a tool to enhance understanding of the outcomes from various configurations of the final vessel's capabilities.

As previously stated, the primary objective of this project is to establish a robust framework for assessing design performance during the conceptual stages. Consequently, the methodology is designed to be applicable across a wide spectrum of projects rather than being tailored to specific cases.
Drawing from accumulated knowledge and insights, it has been determined that the methodology should be structured into three distinct phases. The first phase involves formulating and compiling input data for evaluation, encompassing vessel descriptions, scenario details, and other pertinent information necessary for simulation assessment. The second phase focuses on creating the simulation environment based on the input data and subsequently conducting the evaluation. This phase necessitates establishing a clear data flow into the simulation environment to ensure accuracy and reliability. Finally, the third phase centers on formulating and analyzing the results obtained from the simulation. This includes potentially crafting a final analysis and appropriately exporting outcomes into the project's report document. This structured division is expected to facilitate the timely identification and resolution of potential issues throughout the evaluation process.

3.1 Input Formulation

To execute the project, the first step involves clearly identifying the data needed for the process. This entails determining which data is necessary to create the simulation and identifying the sources responsible for providing this information.

At the outset of the process, the input data is already predetermined by the requirements of the simulation software. However, it can be unified into four separate input datasets, each responsible for different parts of the process.
Firstly, the main input regarding the vessel should be described. This input needs to sufficiently describe the current (predicted) vessel capabilities, including the systems located onboard, fuel storage capacity, main propulsion characteristics, and the basic characteristics of the design. The main characteristics would include information such as general dimensions, crew number, and class of the vessel, while the systems list should precisely determine which systems are allocated and their capabilities or performance in specified conditions.

The second distinguished input dataset consists of the description of the scenario to be used for conducting the evaluation. This input should include all information about the tactical situation within the scenario, its precise location, the objectives of the mission, and all other aspects that describe the current situation within the scenario. This dataset is expected to be the most tedious to create, as the total number of different descriptions would vary depending on the complexity of the conducted simulation.

Next, the need for a third input dataset was recognized. This dataset is intended to govern the behavior of assets within the simulated scenario. The description of precise instructions for the evaluated vessels and the opposing forces would need to be created based on respected military sources, such as NATO handbooks, including orders such as Rules of Engagement or Emissions Control (EMCON). This dataset is anticipated to be created in strict collaboration with stakeholders to ensure that the most realistic tactics are employed.

Finally, the last dataset would need to provide all additional information used during the process. The information within this dataset and its specific structure would remain relatively vague, as its composition would depend on several factors such as the desired outcomes (measures) from the simulation, the capabilities to be examined, and additional variables introduced into the simulation. This dataset should be carefully examined, as some simulation software may require the determination of the desired output composition at the beginning of the process. The required information would then be provided within this dataset.

During the research phase of the project, several key actors responsible for providing information for the datasets were identified within the company. The primary responsibility for providing the initial dataset for vessel capabilities lies with the design team. This team is tasked with formulating system predictions and making decisions related to the vessel's design. The "scenario" dataset, which outlines operational scenarios and system predictions, will be collaboratively created with Operational Analysts. These analysts are responsible for developing the Operational Capability Description (OCD), which serves as the main source of information for the scenarios used in the simulation.
Additionally, the input dataset concerning vessel behavior will be developed in cooperation with Naval Operations Experts. These experts provide critical insights into naval operations and perspectives from commanders, enriching the behavioral aspects of the vessel within the simulation.

To streamline and enhance the entire process, it is proposed to use predefined document drafts to gather the necessary information for these datasets. These drafts will standardize the information required and reduce the specific knowledge level needed from each participant involved in the simulation process. While specific processes may vary between companies, the fundamental concept remains consistent: employing clearly defined input dataset drafts to minimize the required level of simulation-related knowledge from participants engaged in the evaluation process. This approach aims to improve traceability and efficiency throughout the evaluation process.

3.2 Implementation of Input Data

The process of implementing the data established in the previous subchapter into the simulation software requires the establishment of a special "connection." The data needs to be translated into a format that can be used within the software to create a defined scenario, allocate the described vessel with its properties and characteristics, and implement the intended behavior of the assets within the simulation.

The mentioned "connection" can be realized through two different approaches. These approaches can be divided based on the level of proficiency required to implement them into the existing design process, or the functionality of the software used to implement them. Following this method of division, the first approach would involve the introduction of an additional team member who would be responsible for inputting the presented datasets into the simulation software and creating the scenario. This process would primarily be conducted through the built-in Graphical User Interface, allowing for the manual input of predetermined data.

The second approach assumes that the process of exporting the input data into the simulation software would be entirely realized by a specially created function. This function would be responsible for correctly utilizing input datasets and simultaneously creating the scenario. The precise method or software used may vary depending on the chosen simulation software. However, from the examined options presented in the previous chapters, the simulation software may include an integrated scripting language that could be used for similar purposes.

Additionally, it may be assumed that the presented approaches would depend on the level of proficiency or the level of incorporation of the evaluation through simulation within the present design process. It is recognized that the process of creating an automated function that would implement the datasets would require additional financing and time. Thus, it may be assumed that for initial tests, the first evaluations would be done using the first approach, employing a "simulation specialist" to conduct the evaluation using the chosen simulation software.

3.3 Simulation Setup

The second step of the methodology focuses on creating and conducting the simulation. Once the input datasets are formulated and exported into the simulation software, the simulation needs to integrate all created elements into the main scenario.

The final output of this process, the scenario that consolidates all predefined elements, will be directly used for evaluation. This scenario must be saved and submitted for separate evaluation. Initially, members of the design team, who were responsible for formulating the input data at the beginning of the process, will conduct this step. This ensures that the created scenario fully represents all necessary factors to evaluate the vessel's capabilities. Furthermore, if needed, an independent examination of the scenario should be conducted by a simulation specialist not involved in its creation to ensure its accuracy and reliability.

The culmination of the second step of the methodology is reached when the previously prepared and evaluated scenario is used to assess the desired capabilities of the designed vessel. The specific method of final evaluation may vary in detail, but the core principles should remain unchanged. The evaluation should be carried out through multiple iterations of the simulation, with each scenario starting anew and the results of one iteration not influencing the others. This approach guarantees that each simulation run is independent and yields valuable outcomes that can inform decision-making processes.

3.4 Export of the Results

The concluding step of the methodology focuses on gathering, presenting, and evaluating the data obtained from the simulation. The entire process of data collection must span all steps of the methodology. Firstly, the specific data to be collected needs to be determined and implemented through appropriate datasets. Subsequently, an action must be implemented within the simulation software to save all relevant data from the simulation into the desired file format.

This saved data may include all parameters processed by the software, such as vessel position logs, vessel status, or reports of actions. The precise composition of this saved information may depend on the case being investigated. For example, it could include detection cycles for sensor prediction or data related to fuel consumption, speed, and vessel position during the examination of the propulsion system. Moreover, some simulation software can provide output files that recreate the conducted scenarios and their outcomes in 3D environments, effectively creating visualizations for simulated processes.

At the end of the process, the results would need to be exported from the simulation software into files containing the saved information and then integrated into a predefined draft. This draft would serve as the official result of the complete evaluation process. It is believed that incorporating the final draft with the results into the design process documentation would greatly improve traceability and provide justification for decisions made.

The process of extracting the data obtained from the evaluation could also be conducted as described for the initial data export into the simulation software. This is anticipated to be done by a "simulation engineer" initially, while the complete method is still being researched and, with time, it may evolve into a fully automated process, using additional or integrated scripting languages.

The described process is expected to ensure that the designer gains a comprehensive understanding of the data obtained from the evaluation. This process would enable the design team to explore the design spaces and identify potential results for design problems without having to make concrete decisions that would have implications at further stages of the project. Additionally, the utilization of simulation would provide an opportunity to evaluate the same design in different operational scenarios that the design vessel would need to fulfill. This is especially beneficial, as often, the ability to predict the effectiveness of the design in off-design conditions would ensure that the vessel can fulfill its tasks throughout its full lifetime. Furthermore, through integration into the appropriate documentation, the obtained results can be efficiently published for stakeholders, providing additional context and explanations for the decisions made.

4 Example Evaluation

The primary objective of the presented evaluation is to demonstrate that the described methodology can enhance the design team's understanding of the design space by evaluating operational capabilities during the conceptual stages of the process. This evaluation was conducted based on the implementation method outlined in the previous chapter.
To illustrate the methodology's applicability, an example focusing on evaluating the initial vessel's system composition across different scenarios was created. Specifically, a case study involving an unmanned surface vehicle (USV) tasked with two distinct operations was chosen. This approach enables the identification of potential strengths and weaknesses of the proposed method and clearly pinpoints the benefits of its deployment.

4.1 The Intended Operations

The primary task involves patrolling and inspecting critical underwater infrastructure within a specific area of the Dutch Economic Zone. Protecting such infrastructure has become increasingly vital in modern naval operations, particularly due to disruptive activities by certain eastern countries. In recent years, parts of European countries have experienced sabotage acts, highlighting the need for enhanced security measures. Current developments in naval doctrine indicate that the newly researched USV fleet will be entrusted with patrolling, investigating, and preventing similar acts. Thus, the evaluation aims to assess the effectiveness of these USVs in fulfilling these critical tasks.

The scenario begins with an intelligence report indicating a suspicious OPFOR (Opposing Force) vessel in close proximity to vital underwater infrastructure within the Dutch Economic Zone. To prevent potential sabotage of crucial infrastructure between Dutch and United Kingdom territories, USVs are dispatched from a nearby naval base to investigate the activities of the suspected enemy vessel and conduct routine inspections of the underwater structures to detect any explosive materials.

The precise location of the OPFOR ship is known from the outset, and the USVs set sail from the Den Helder naval base to patrol the area near the suspected contact. Unbeknownst to the USVs, the OPFOR ship has already managed to place at least one explosive device on the underwater structure's surface. The designed USV must be capable of navigating to the designated area of operations identified by the location of the OPFOR

vessel. Once there, it must conduct thorough research to detect any potential dangers and report its findings back to base.
As previously described, the area designated for operations is situated at the northern entrance of the English Channel. The respective underwater cables extend from 99 nautical miles (Zeus Cable) to 66 nautical miles (Farland North Cable) from the Den Helder naval base.

The second task scenario involves a friendly helicopter with sensitive equipment or data onboard crashing within the Dutch Economic Zone in the North Sea. Given the nature of the equipment within the wreckage and the potential interest of various parties in retrieving it for their specific purposes, a rapid response and the ability to locate and identify the potential threat are essential. In this scenario, the USV would need to swiftly travel to the area of interest, locate the wreckage on the seabed, and deploy an Unmanned Underwater Vehicle (UUV) to retrieve or neutralize the contents of the wreckage.
The expected location of the crash site is approximately 70 nautical miles from the Den Helder naval base; however, the search area must account for potential movements caused by currents present in the area.

Both tasks necessitate the USV's ability to conduct underwater search, recovery, or neutralization operations. While these capabilities are initially structured for naval applications, the solutions identified could have broader applications in civilian markets. The ongoing need for maintenance or location of underwater structures within the industry underscores this potential. It's important to emphasize that the methodology presented here can be freely applied within both civil and naval realms of ship design. This underscores the adaptability and relevance of the methodology for a wide range of applications.

4.2 Examined Vessel Designs

For the purpose of evaluation, several configurations for the systems onboard the USV were developed. The primary differences among these configurations pertain to the number of Unmanned Underwater Vehicles (UUVs) carried onboard and the performance characteristics of the USV platform, such as speed and fuel consumption.

To establish the foundation for the USV, the widely produced Damen 5009 Patrol vessel was selected. The primary design assumption is that this vessel would serve as the basis for the USV, equipped with systems enabling autonomous operations. Operational systems would be strategically placed onboard the vessel in a modular fashion, utilizing purpose-designed storage units. Missing data were extrapolated based on similar-sized USV vessels, primarily the USV Nomad vessel. Initially, it was assumed that the Kongsberg HUGIN would serve as the unmanned underwater vehicle for the design, providing the foundational capabilities for the UUV utilized in the presented design.

The first design assumes that the USV would be equipped with systems to deploy one underwater unmanned vehicle from the deck. The main USV itself would not possess any systems for conducting underwater searches independently; instead, its primary task would be to transit to the area of interest and deploy the UUV. Similarly, the second design would also be outfitted with systems to deploy one unmanned underwater vehicle from the deck. Additionally, it is anticipated to be equipped with hull-mounted sonar equipment (TSM 2022 Mk3). This configuration is intended for similar operations, with the USV capable of conducting the search without relying solely on the UUV.
However, the high cost of the HUGIN significantly impacts the overall project expenses. Therefore, for the sixth scenario, the evaluated vessel would still deploy only one UUV, but the choice of UUV would be changed to the Mk 18 Mod 2 Kingfish. This alternative is being considered to potentially reduce the overall costs of the product.

The specific performance indicators and capabilities for each design are summarized in the table below (see 1). It is evident that the values for fuel consumption and speed vary depending on the configuration of onboard systems. This variation is primarily influenced by changes in the overall weight of the vessel due to the additional weight of the systems.

Number of Configuration:	Speed:	Range:	Capabilities:
1	18 knots	273 nm	1 UUV (HUGIN), No Sonar
2	15 knots	236 nm	1 UUV (HUGIN), TSM 2022 Mk3
3	18 knots	273 nm	1 UUV (Kingfish), No Sonar

Table 1: The performance data and capabilities description for all design predictions that would be evaluated using formulated methodology.

4.3 Results From the Evaluation

The following evaluation was carried out using Command: Professional Edition simulation software, which was the primary software used for the presented case. Each operation was repeated for 30 iterations for each vessel system configuration. For the first operation, the average time of evaluation was equal to 23 minutes, while for the second operation, each evaluation concluded in around 6 minutes. The obtained results for each configuration are presented below. The collected results include information regarding the time of arrival at the designated area of operation, the time taken to locate the target after arriving in the AO, the success rate in target identification, and the overall time to conclude the operation.

The first configuration of the USV vessels exhibited an average operation time of 11 hours and 46 minutes, with a remarkably low standard deviation of only 30 minutes (see Tab.2). However, there were two instances where the vessel failed to detect the target in the final area of search during different iterations. This result gives indication as to what may be expected from this composition and may be used as benchmark for other configurations.

First Operation / First Configuration: Vessel 1 x2 / Hugin UUV		
	From Scenario Start	**From Previous Area**
Average time of arrival to Area 1:	05:52:49	05:52:49
Average time of arrival to Area 2:	04:01:10	04:01:10
Average time of arrival to Area 3:	08:46:49	00:49:21
	Time:	**Rate of Success:**
Average time to detect the target in Area 1:	00:13:51	100 %
Average time to detect the target in Area 2:	00:54:52	100 %
Average time to detect the target in Area 3:	01:28:55	93.3 %
Operation Completion Time:	11:46:49	

Table 2: Results obtained from evaluation of first vessel configuration obtained during first scenario with two USVs participating in the operation.

In the case of the second configuration (see Tab.3), the average operation time was 11 hours and 18 minutes, showing an improvement of almost half an hour compared to the first configuration. Moreover, the standard deviation for the recorded results was only 4 seconds, indicating high consistency in this configuration's performance. The reduction in total operation time can be attributed to the capability to conduct operations with hull-mounted sonar, which contributed to 74% of the total detections during the evaluation.

First Operation / Second Configuration: Vessel 2 (sonar) x2 / Hugin UUV		
	From Scenario Start	**From Previous Area**
Average time of arrival to Area 1:	06:51:27	06:51:27
Average time of arrival to Area 2:	04:44:07	04:44:07
Average time of arrival to Area 3:	08:18:32	00:55:33
	Time:	**Rate of Success:**
Average time to detect the target in Area 1:	00:02:56	100 %
Average time to detect the target in Area 2:	00:04:22	100 %
Average time to detect the target in Area 3:	00:24:10	96.67 %
Operation Completion Time:	11:18:33	

Table 3: Results obtained from evaluation of second vessel configuration obtained during first scenario with two USVs participating in the operation.

Finally, the third configuration, used to examine the influence of deploying a different UUV vessel, proved to offer a slightly lower success rate of detection with a shorter time to detect the target compared to the configuration based around the Hugin UUV (see Tab.4). However, due to the smaller range of the sensors onboard the Kingfish UUV, it required more time to fully examine the area of interest before deeming it safe. This directly influenced the overall operation time, which was around an hour longer than the overall time for the first configuration, equaling 12 hours and 53 minutes. Additionally, the standard deviation for this particular evaluation was 1 hour and 42 minutes, which may be considered as not consistent enough for similar operations.

First Operation / Third Configuration: Vessel 1 x2 / Kingfish UUV		
	From Scenario Start	**From Previous Area**
Average time of arrival to Area 1:	05:42:30	05:42:30
Average time of arrival to Area 2:	04:01:27	04:01:27
Average time of arrival to Area 3:	09:23:15	00:29:08
	Time:	**Rate of Success:**
Average time to detect the target in Area 1:	00:08:09	100 %
Average time to detect the target in Area 2:	00:17:46	96.67 %
Average time to detect the target in Area 3:	00:46:36	96.67 %
Operation Completion Time:	12:53:15	

Table 4: Results obtained from evaluation of third vessel configuration obtained during first scenario with two USVs participating in the operation.

In summary, among the presented designs, the second composition of the USV outfitted with hull-mounted sonar and one UUV was determined to be the most successful, with over 70% of targets localized using the hull-mounted sonar.
On the other hand, if stakeholder demands allow for a slightly longer operation time with simultaneous cost reduction, potential changes such as including a different type of UUV or utilizing the first configuration may be proposed. The first design offered a slightly longer average operation time (around 30 minutes, which is equal to the standard deviation for the first scenario), while still achieving a considerable detection success rate, with only one fewer target detected compared to the most successful counterpart.

Based on the previous results from the evaluations, it was determined that for the second scenario, the compositions of vessels to be tested would not change. This time, the simulated operation already assumes that only one vessel should be able to carry out the complete operation and fulfill the main objective using a deployable unmanned underwater vehicle. There was additional consideration for fuel efficiency during this operation to establish whether it would be possible to redirect the vessel from another operation. Finally, the data obtained from the last evaluation were examined, and the received outcomes are presented in the tables below.

Second Operation / First Configuration: Vessel 1 / Hugin UUV	
Time to enter the area of operation:	04:14:55
Time to locate the wreck:	04:15:21
Rate of success of the detection:	100 %
Amount of fuel consumed by the USV:	4259.21 kg
Amount of fuel needed for the transit:	2901 kg

Table 5: Results obtained from evaluation of first vessel configuration obtained during second scenario with one USV participating in the operation.

For the first tested configuration in the second scenario, the average time from the deployment of the UUV within the search area to the first contact with the target was only 26 seconds (see Tab.:5). This result may be attributed to the composition of the UUV system itself. The main sensor used to locate the wreckage was determined to be the generic echo sounder used by the Hugin. Furthermore, the estimated time to achieve the operation's goal was around 5 hours and 20 minutes, with the standard deviation equal to only 21 seconds. This indicates the extraordinary ability to repeatedly conduct the operation within the same time frame.

Second Operation / Second Configuration: Vessel 2 (sonar) / Hugin UUV	
Time to enter the area of operation:	05:01:00
Time to locate the wreck:	05:06:15
Rate of success of the detection:	100 %
Amount of fuel consumed by the USV:	4283.39 kg
Amount of fuel needed for the transit:	3016.6 kg

Table 6: Results obtained from evaluation of second vessel configuration obtained during second scenario with one USV participating in the operation.

In the second tested configuration, the USV vessel equipped with sonar located the target only 5 minutes after entering the area of operation. However, due to its slower transit speed, the overall operation time increased compared to the first test results, with an average value of 6 hours and 16 minutes (see Tab.:6). Furthermore, it's worth noting that, although not significantly impacting the time, the USV would still need to deploy the unmanned underwater vehicle to closely inspect the target and fulfill the mission. The standard deviation for this scenario was also considerably low, at only 6 minutes and 52 seconds.

Second Operation / Third Configuration Vessel 1 / Kingfish UUV	
Time to enter the area of operation:	04:03:55
Time to locate the wreck:	04:13:17
Rate of success of the detection:	73.3 %
Amount of fuel consumed by the USV:	4259.21 kg
Amount of fuel needed for the transit:	2901 kg

Table 7: Results obtained from evaluation of third vessel configuration obtained during second scenario with one USV participating in the operation.

Lastly, the configuration utilizing a smaller and cheaper UUV was tested. Although the results directly show that this configuration is able to conclude the mission in a similar overall average time to its direct counterpart (1 minute faster than the first configuration with the Hugin UUV), the success rate for this specific design is significantly lower than in previous cases, at only 73% (see Tab.:7). The standard deviation measured in this evaluation was 5 minutes and 54 seconds, with the minimal time to conduct the operation equal to 5 hours and 17 minutes and the longest time of operation equal to 5 hours and 46 minutes. Although not measured in the simulation, this difference in effectiveness of detection may lead to an increase in the mission duration as it would need to spend more time directly scanning the whole area of operation.

The overall performance differences in the second scenario were less pronounced compared to the first, largely due to its lower complexity and shorter simulated time period. From the obtained results, it can be concluded that the first tested configuration, which relied solely on the Hugin UUV for underwater search operations, demonstrated the highest capability and achieved the best results. However, it's important to note that the second configuration, featuring the USV equipped with sonar and the Hugin UUV, could achieve similar or slightly lower time-to-detection values if the UUV were actively involved in searching for the wreckage. The primary distinction between these two configurations lies in the transfer time, which is notably longer in the second case.

5 Discussion

Throughout the project, it became evident that introducing simulation-based evaluation into shipbuilding practices remains relatively uncommon. However, the results obtained demonstrate its potential to enhance understanding of operational capabilities, particularly beneficial for tackling novel and complex design challenges where experience in assessing capabilities is limited.

A significant advantage of simulation software for operational capability evaluation is its ability to initiate evaluations at the conceptual design stages without needing detailed design information. This capability provides early insights into whether initial concepts are viable and identifies potential drawbacks of specific design configurations.

The versatility of simulation software allows for precise analysis of desired properties across various design possibilities, clearly pinpointing strengths, and areas for improvement in each configuration. Many simulation tools also support additional customization and expansion through integrated scripting languages. As demonstrated in our evaluation, leveraging such scripting languages can significantly enhance simulation flexibility. Future research should explore further scripting methods and languages to expand evaluation capabilities.

Additionally, it should be highlighted that due to the flexibility to proposed method, its connection with other proposed solutions that would allow to automatically generate different system compositions onboard (or list the capabilities) is possible. This connection would allow to automatically generate and evaluate the potential designs, thus explore the design space more efficiently with severely wider scope of potential solutions.

Finally, it is important to acknowledge that the overall accuracy of the evaluation heavily relies on the quality of the input data provided for the assessment. Therefore, using detailed and realistic input data is crucial for ensuring the reliability and validity of the results.

6 Conclusions

In conclusion, the methodology described during presented project offers promising functionality to examine the operational capability of the initial design without the need to provide any specific data that would be obtained at later stages of the project. Furthermore, it was established that inclusion of this development into the design process may improve several different aspects of the work on the project, such as the understanding of the design matters, ability to recognize certain trade-offs or enhancing the communication channels with other participants of the process.

Although the presented methodology would be believed to solve the research gap identified at the beginning of the project, it is still at relatively early stages of the development cycle. This development should be further perceived by introduction of different improvements such as the investigation for the most efficient simulation software that should be used for said applications or to research potential inclusion of Machine Learning (ML) algorithm within proposed processes.

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