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Faculty of Technology, Natural Sciences and Maritime Sciences
Department of Science and Industry Systems

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S.W.I.M

Sky Warden Interception Module

A Drone Protection System for Oil Platforms in the North Sea

Kine Mirjana Antilla, Nathanael Nega Getaneh, Simone Hoem Frøyset, Vibecke Wernersen Aass, Thomas Lunde, Jonathan Christoffer Bergius & Daniel Opsahl Tjernet

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Abstract

This report is intended to cover a systems engineering approach for developing a drone protection system tailored to oil and gas platforms in the North Sea. Our proposed solution, the Sky Warden Interception Module (S.W.I.M), aims to safeguard the safety zone of offshore platforms by detecting and identifying drones early, and intercept before any danger is near the platform or the people near it.

Note to the reader:

The report presents our process in a linear sort of fashion, while our actual process has always been iterative. We chose to present it in a linear way to make it easier for the reader, but be aware that many of the decisions made throughout the process have been through multiple iterations of discussion and planning. If you are interested in the whole story, more detailed information or earlier versions of diagrams and techniques can be found in the appendices [A].

Contents

List of Figures

1 Introduction

1.1 Group 1

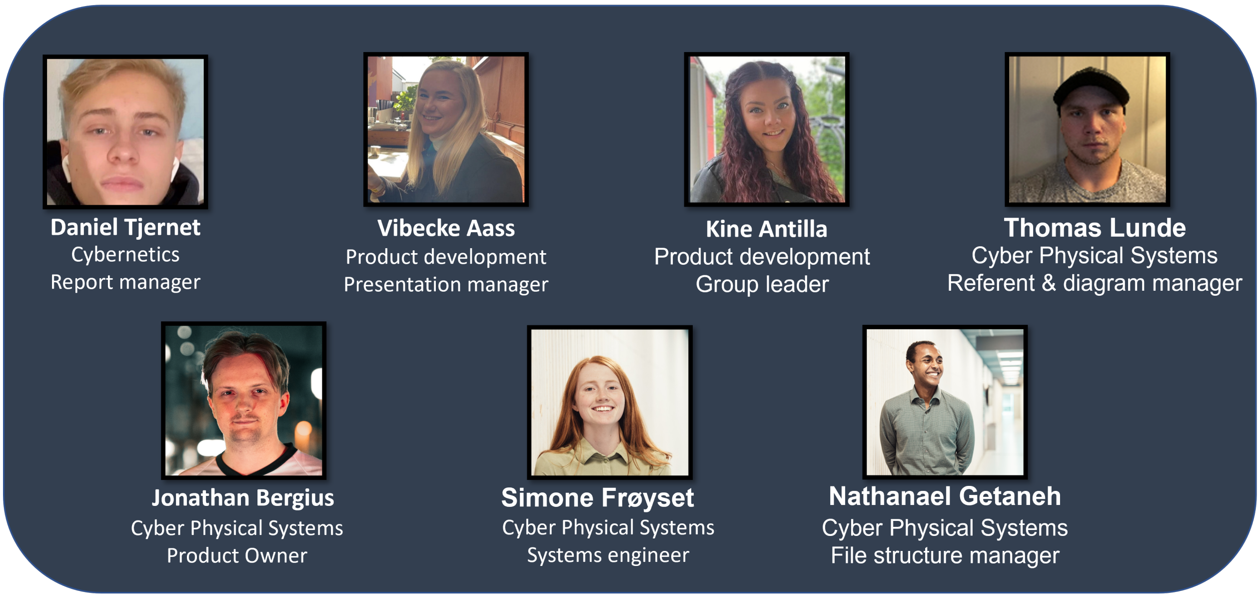


Figure 1: The group

Our team consists of one electrical engineer, two mechanical engineers and four software engineers. We have had a good group dynamic and multiple academic, multidisciplinary group discussions throughout the process. Our differences are one of the key factors that has made our group so strong, as our contrasting experiences have forged different viewpoints and allowed us to see multiple sides of each problem. This has often led us to change up parts of our solution or gained new insight on how to improve it. For more information about the team work and our project strategies, read [Appendix A.1].

1.2 Situation Today

Unmanned Aerial Vehicles (UAVs), also known as drones, have seen a significant rise in usage during the past years. Their applications vary from fields such as surveillance, agriculture, construction and infrastructure. As technology advances, so does the potential for malicious intent. Due to drones' ability to reach previously inaccessible areas undetected, and their increasing speed and carrying capacity, they are being identified as a growing threat to critical infrastructure around the globe. One such critical infrastructure are offshore oil and gas platforms in the North Sea, which are at this moment particularly vulnerable.

1.3 The Case

Our primary focus for this report will be on how to protect the Johan Sverdrup oil and gas field from unmanned aerial vehicles. It is one of Norway's largest fields, and drones have been observed drones in the area, so we consider this particular field as high risk [4]. The four platforms located on the field have a 500 meter safety zone, which we will show the importance of later in the report. To learn more about the case see [Appendix A.2].

Figure 2: Johan Sverdrup.

2 System Context

When designing and developing a solution, it is important to take into consideration the context that the system operates in and what functional inputs the system needs to interact with. This can be anything from people and weather, to rules and regulations, or even time itself. When understanding what environment the system will exist in, one should come closer to developing the "perfect" system for the case.

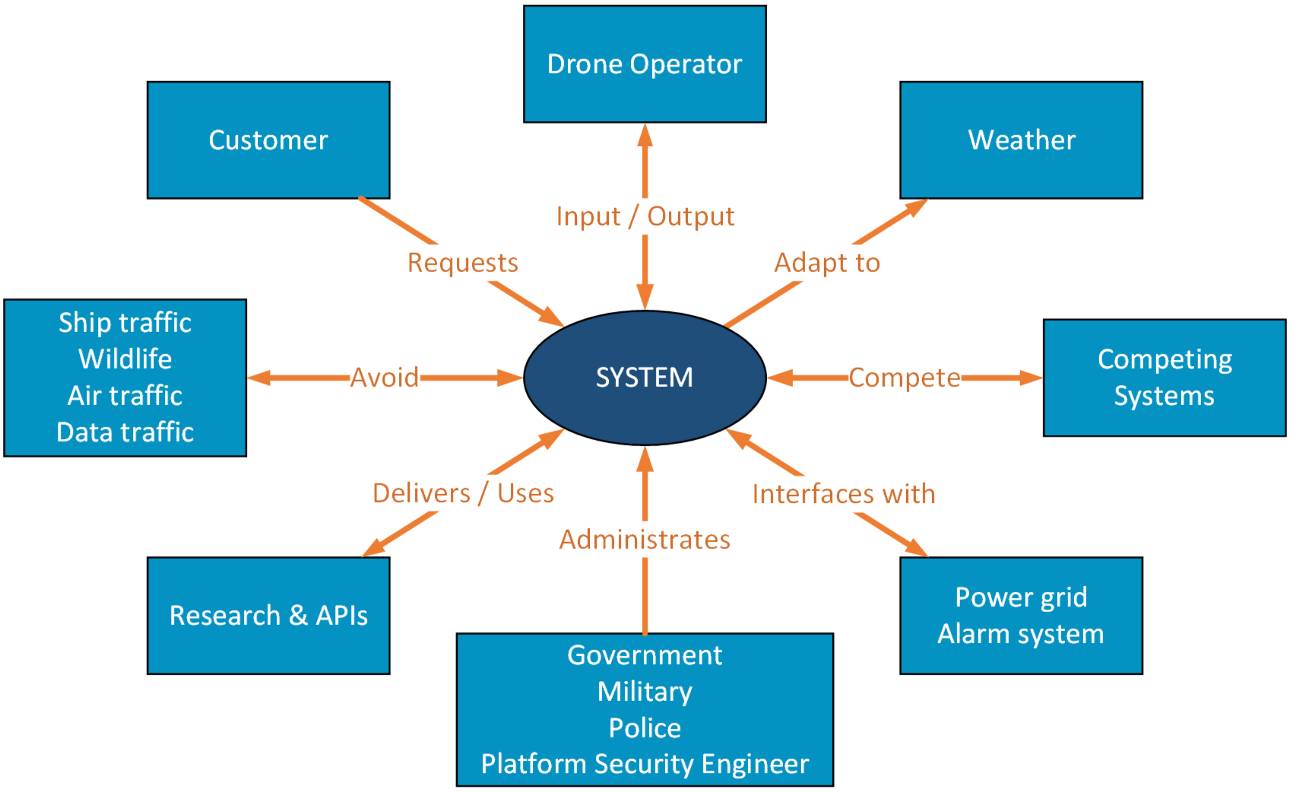


Figure 3: Context diagram.

Our system will live out on the open sea, but also within a strictly regulated industry: It will have to avoid and adjust to many sorts of traffic and wildlife surrounding the platform, it must be configured to fit the platform's power grid, and it could potentially be a central topic within the government and military. All of these factors are important to fully understand the setting in which our system shall be built to fit in.

2.1 Stakeholder Needs

To better grasp who we are designing this product for and who will be involved, we mapped out our primary stakeholders and their needs and concerns as seen in [Fig. 4]. We divided our stakeholders into *customer* stakeholders, *life cycle* stakeholders and *external* actors, to make it easier to distinguish the different sorts of needs and concerns our system would have to abide to.

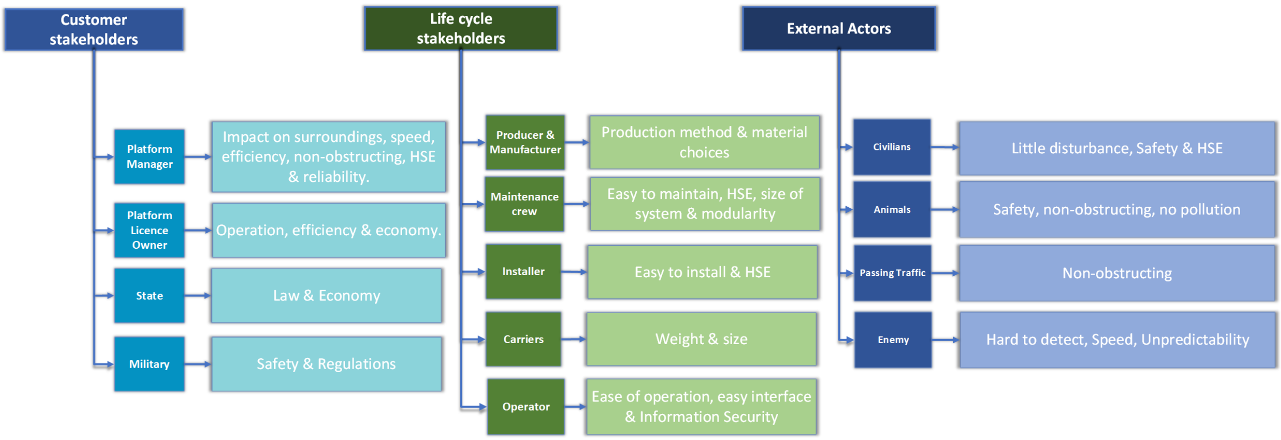


Figure 4: Primary stakeholders and actors.

Customer	Life Cycle	External
Cost efficient system No production disruptions No safety hazards for staff (HSE) Safe for surroundings and structures Seamless integration with the traffic flow Environmentally friendly Laws and regulations	Simple guidelines Easy to handle materials Plug & play HSE	Not to be disturbed Safety No pollution

Table 1: Stakeholder and Actor Needs Summarized.

With the most important concerns mapped out, we got a better understanding of our context, who we needed to please and how to please them. Through this process we learned that ease-of-use was important for all life cycle stakeholders and that our system had to be non-intrusive, not getting in the way of anything happening around the platform. We also understood better what our customer would be willing to pay for our system. You can read more about our stakeholders in detail in [Appendix A.3].

2.2 Legislation and sustainability goals

Referring to [Forskrift om sikkerhetssoner m.v.] § 6; *"Sikkerhetssonene skal være på 500 meter regnet fra innretningens ytterpunkter, med mindre Kongen fastsetter noe annet."* and [Etablering av sikkerhetssoner] § 52; *"Rundt og over innretninger, unntatt undervannsinnretninger, rørledninger og kabler, skal det være sikkerhetssone, med mindre Arbeids- og sosialdepartementet fastsetter annet."*. Taking these laws and regulations into account, we made a system that should cover a safety zone of 500 meters in radius around the platform, both horizontally and vertically above sea level. We also knew that the radius of this particular zone, Johan Sverdrup, was under debate, so we wanted to make sure our system could adapt accordingly to stay relevant for larger radius as well.

During our development process, it was important for us to work towards a better and more sustainable future for all. Therefore, we wanted our system to cover several of UN's sustainability goals, as shown in [Fig. 34] in the appendix. For example, our system will observe and identify unauthorized drones. This way, we will keep peace, justice, and strong institutions, as goal 16 says. For some of the customer stakeholders, a focus on these goals were important too. One of the goals were climate action and being environmentally friendly by, for instance, choosing reusable products, like we can see in goal 13 [Fig. 34 (c)].

2.3 Requirements

By understanding the context our system should be operating in, the rules and legislation it would have to abide to, and the needs mapped out from each stakeholder and external actor, we were able to construct system and stakeholder requirements that would later define our system.

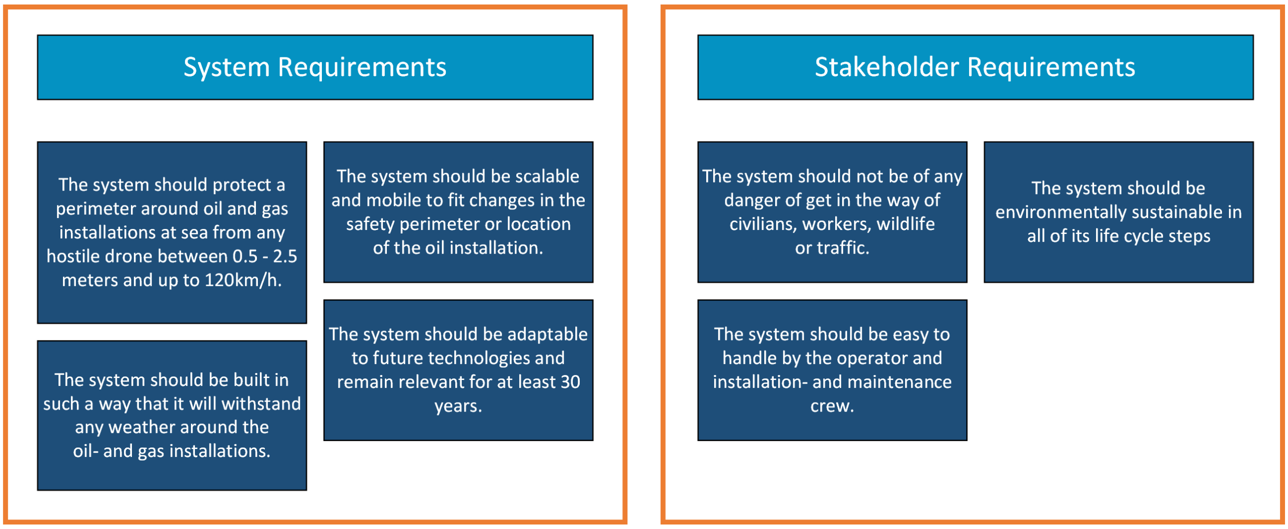


Figure 5: Primary Requirements.

2.4 Key Performance Parameters (KPP)

In [Fig. 32] the requirements were further translated into measurable quantities for the function and design of the system, called key performance parameters (KPP). These were important to establish early on in the process and to verify our concept against throughout the entirety of the development process. This method often made it clear what choices were of benefit for our stakeholders and environment, and what were "wishful thinking".

Each requirement were mapped out to one or multiple key performance parameters using a modified and simplified version of the Key Driver Graph. An example of how we did this process, and an in-depth-version can be found in [Appendix A.4]

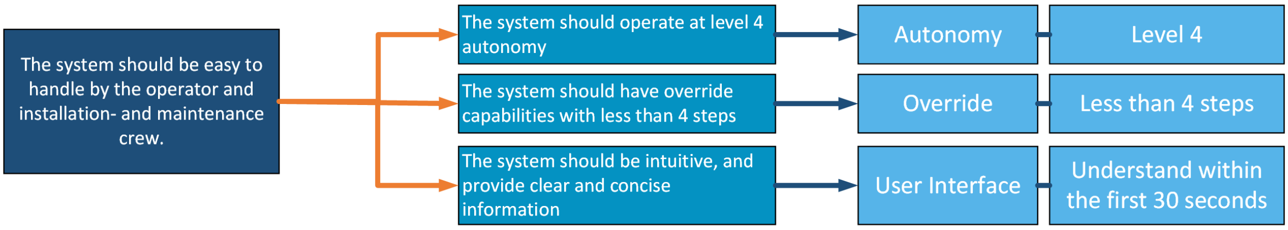


Figure 6: Example of KPP mapping.

2.5 Concept of Operation (CONOPS)

The story found in [Appendix A.5] was one of the techniques used to capture our Concept of Operation. This process helped us understand our worst case scenario, while ideas for possible drone prevention systems developed. The illustration in [Fig. 7] was also a way to map our context and place or system within. This made it easier to express what we wanted our system to achieve, and by visualizing it we made sure that the entire team was on the same page.

Figure 7: CONOPS.

3 System Boundary and Use Cases

After analysing what and who our system would interact with, we began to develop the structure and functions of our system.

3.1 External Interfaces

When viewing our system as a black box (i.e. only including the direct interfaces that will affect the system), we started to develop an idea of what our system would be. With the help of diagrams such as [Fig. 8], we were able to identify some parts of the system. We understood that our system needed an external human interface, some way of overriding the warning subsystem, and power from the oil platform grid. More importantly, our system would need to detect and neutralize its target.

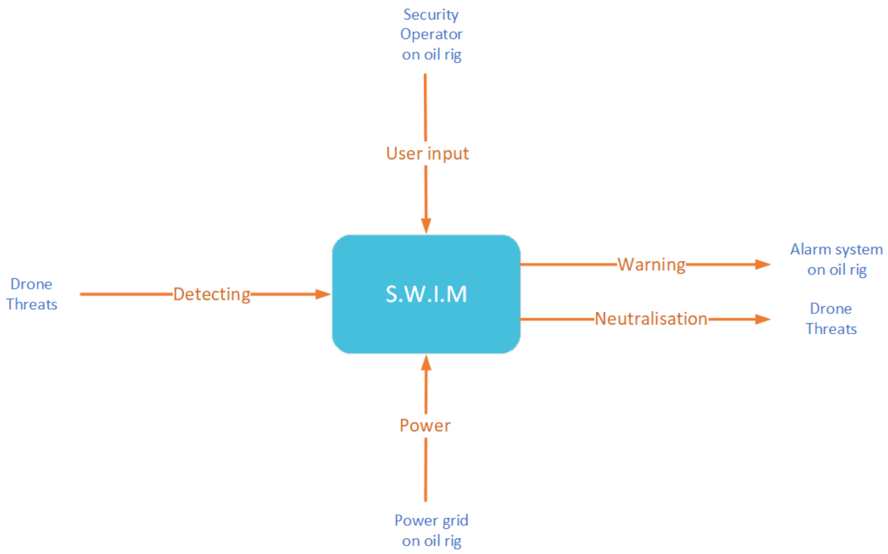


Figure 8: System interfaces.

3.2 Overall system use cases

From the viewpoint of our system-operator and our enemy, we gained an even clearer understanding of how simple our system really had to be. This sort of use case diagram is another way of showing the system as a black box, with only the *actors'* interactions going in and out of the system.

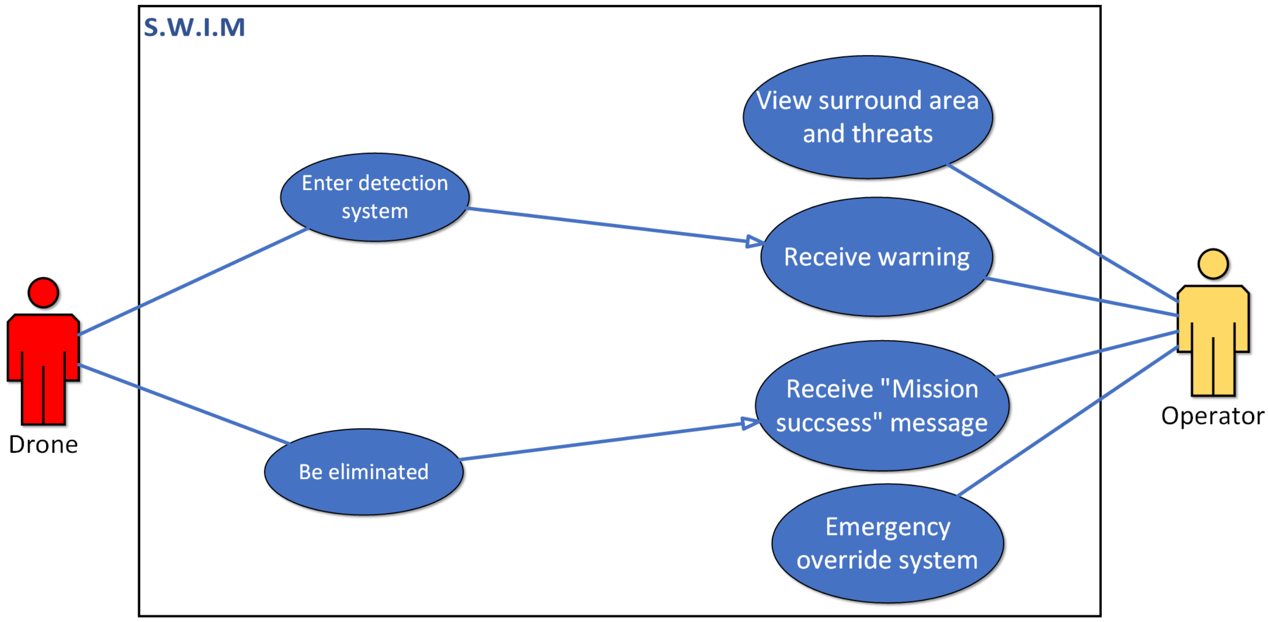


Figure 9: Use case diagram.

3.3 Overall functions of the system

[Fig. 10] is a simplified version of the functional analysis done when developing our system. This diagram summarizes the key central components our system needs to have in order to be an effective drone protecting system. The full version of the diagram can be found in the appendices [Fig. 42].

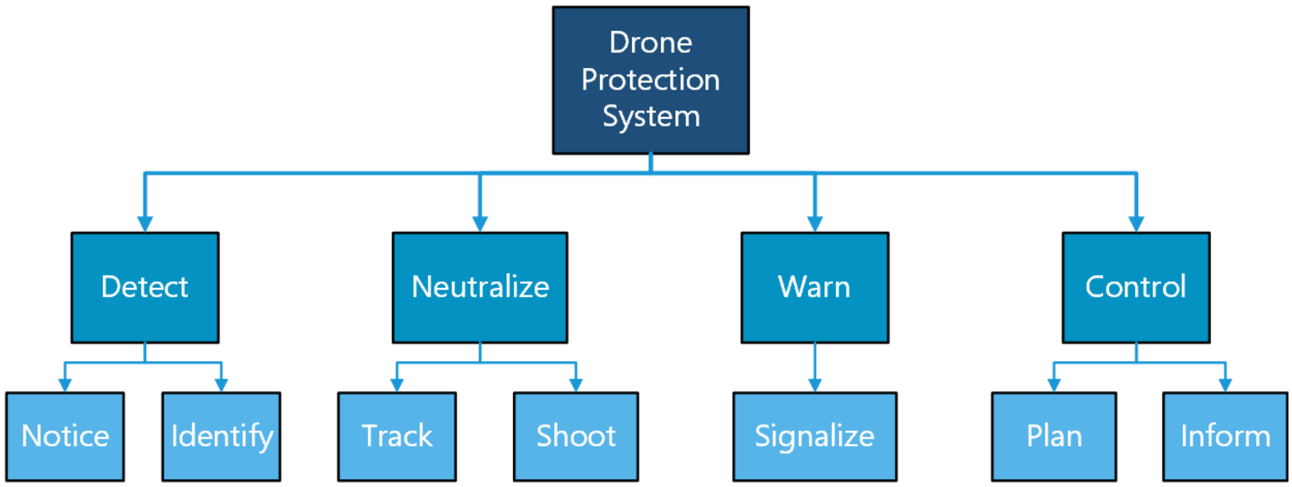


Figure 10: Simple functional analysis.

4 Design Choices

4.1 Placement of the system

Because S.W.I.M has to live in such a challenging environment, the placement of the system is crucial. When we became aware of the overall functions our system would need, we wanted to look at a few alternatives for placement. We compared our alternatives through Pugh Matrix analyses where we looked at some important Key Performance Parameters and how they would fit each proposed solution.

4.1.1 Detection

For the detection of our system we considered having the sensors placed on the platform itself, on buoys in the water around the platform, or on autonomously driven boats [Fig. 11].

Key performance parameters	Bouy sensors	Platform sensors	Autonomous boat	Autonomous boat w/solar panel
Radius (4)	4	2	5	5
Non-obstructing (5)	2	4	4	4
Uptime (5)	4	5	4	5
Cost (2)	3	4	4	4
Energy consumption (3)	4	4	2	4
Maintenance (4)	2	4	4	4
Safety (5)	1	4	4	4
SUM	77	109	110	121

Figure 11: Pugh Matrix for detection placement.

The conclusion after the analysis was that our detection system needed to be placed on autonomously driven boats carefully placed around the platform. This would ensure less potential danger, more coverage, and very little extra maintenance compared to the other alternatives. If we were to put sensors on the rig, the constructs around might obscure the view, and if we put detection out on statically placed buoys our system would need a lot of manual work and not be as scalable as wanted.

One advantage of using autonomous boats is their ability to adjust to their environment and move out of the way to not disturb traffic. By putting solar panels on them we would decrease the risk of draining the power used for equipment, which would increase our uptime kpp. Additionally, by using 100% electrical boats, we imagine that the total energy consumption would be more environmentally friendly which are important for the stakeholders, the sustainability goals, and it is a key performance parameter [Fig. 33].

4.1.2 Neutralization

Another decision we had to make was what type of neutralization weapon we would use and where to place it. Here we looked at different solutions such as lasers, jamming and kamikaze drones. [Fig. 12]

Key Performance Parameter	Laser on platform	Jamming/dome	Directed jamming	Kamikaze drone	Watercannon	Laser on boat
Coverage (4)	3	2	2	4	2	5
Protection (5)	4	4	4	5	3	4
Response time (5)	3	2	2	2	1	4
Accuracy (5)	5	1	4	2	3	5
Non-intrusive (5)	1	1	1	4	5	5
Scaleability (4)	5	3	3	3	1	4
Collateral (5)	1	3	3	1	5	5
Cost (2)	3	3	4	2	5	2
Sum	103	81	98	102	107	155

Figure 12: Pugh Matrix for neutralizing.

Through this analysis we discovered that our best solution was to put lasers out on the autonomous boats, because this solution had the best coverage, response time and a lot less collateral damage than the other option. According to FFI, lasers deliver extreme heat on a small area, close to the speed of light, are extremely precise and have a long range (5-10km), which is exactly what we needed for our system. [3]

After conducting a risk analysis [Fig. 57], a critical edge case was revealed: if the enemy drone is flying right above the platform, falling drone remnants would prove to be a safety hazard for the workers on the rig. Our solution was to implement a "drone-catcher" subsystem that would use a drone with a net to capture the drone instead of shooting it down in this particular scenario. More information about our decision in [Fig. A.11.1]

4.2 Our system gets developed

After analysing our system's position and what type of neutralization weapon we would want to use, our system started to become clear. The S.W.I.M system would consist of multiple boats located around the oil rig, scanning for incoming threats. The lasers should be installed onto the boats, and the drone catcher system would act as backup neutralization system. The usage of boats developed a need for a charging hub, somewhere the boats could recharge without any human interaction necessary.

As mentioned previously, we wanted our system to be fully autonomous to fit the extreme environments of off-shore industries, so the entire system had to be able to connect and communicate wirelessly and without assistance from personnel. This lead to the hub also becoming responsible for all communication going across the boats, along with mapping out the positions of each boat, being like a brain in the whole system. Finally we had to think about warning, and developed a system for monitoring the behaviour of the boats, and that could receive alerts and warnings when necessary.

A reworked version of the CONOPS with our system details implemented [Fig. 13], and a combination of story, CONOPS and animation [Fig 43] helped us with visualize our ideal system.

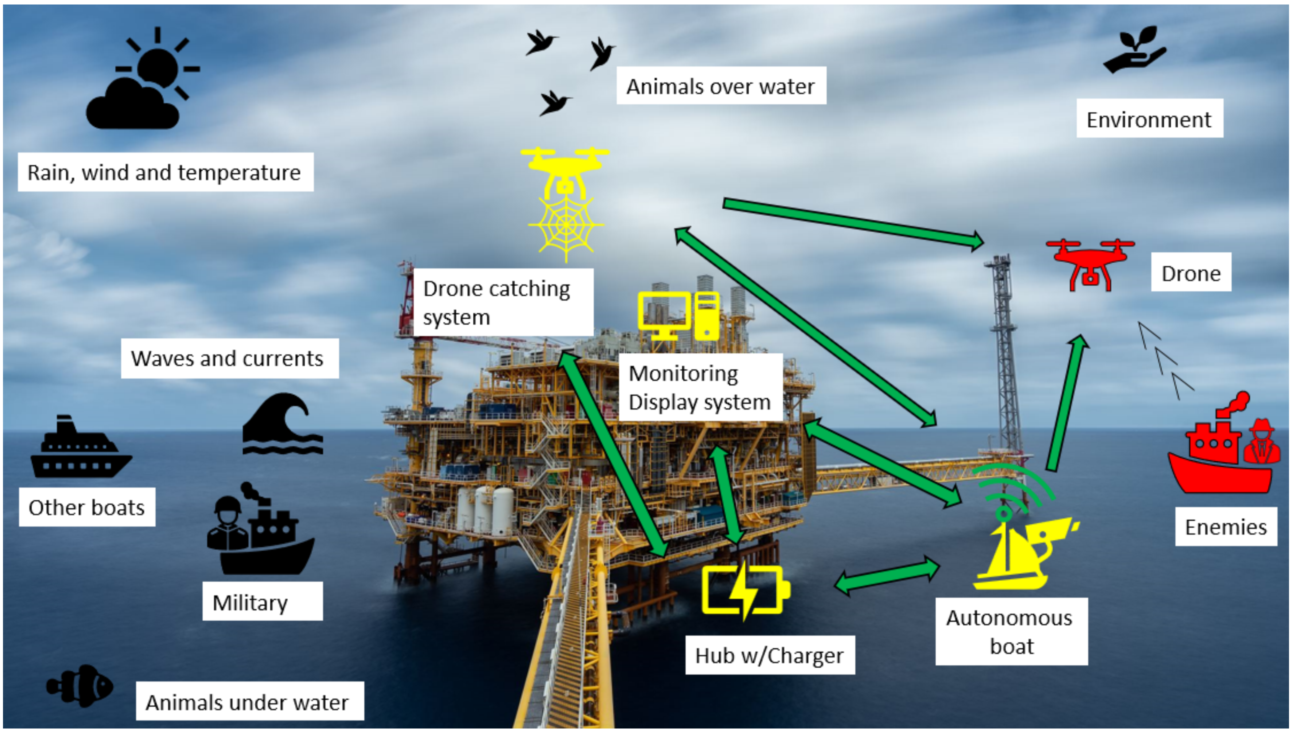


Figure 13: CONOPS Implemented.

[Fig. 14] presents our subsystems as actors in a use case diagram. Through this sort of mapping, we can gain an understanding over what actions/use cases are available within our system. For example, we can clearly see that the boats are tasked with detecting, analysing and eliminating threats. We observe that the hub is both responsible for charging, updating and directing the boats, and that our Monitoring Display System (MDS) is our primary source of communication with the platform through alerts.

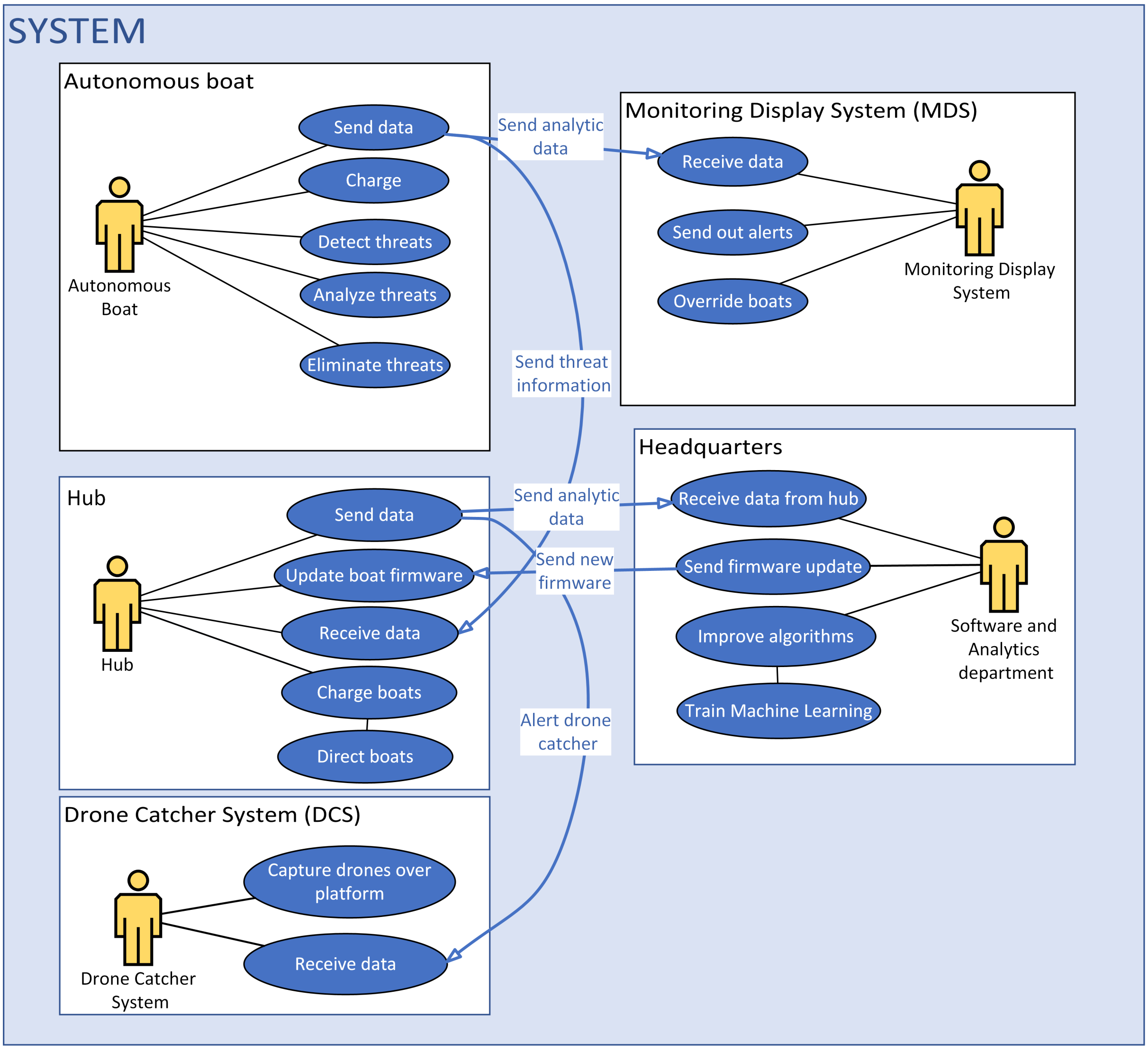


Figure 14: System use case.

More use cases for the system can be found in [Appendix A.6.2]

4.3 Internal Interfaces

After mapping out what subsystems we would want for our system, we developed an internal interface diagram to make sure we had not missed any important communication or connections, while also getting a greater understanding for how our system physically would interact. This diagram along with a description can be seen in [Fig. 40].

5 Operational Scenarios

[Fig. 15] illustrates how the logical flow of the use cases *Detect threats*, *Analyze threats* and *Eliminate threats* [Fig. 14] are acted out. This is one of many diagrams we have used to understand the flow within our system.

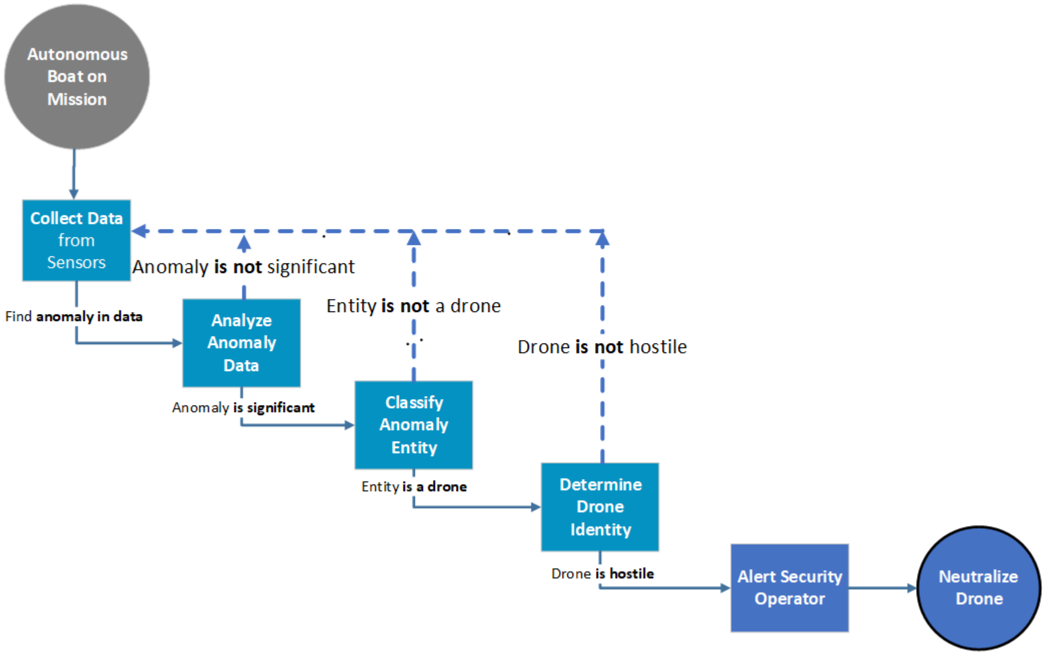


Figure 15: Functional flow diagram for autonomous boats on mission.

Another way of illustrating this flow can be found in [Fig. 16] where the various subsystems of S.W.I.M are represented with the most basic communication going between them.

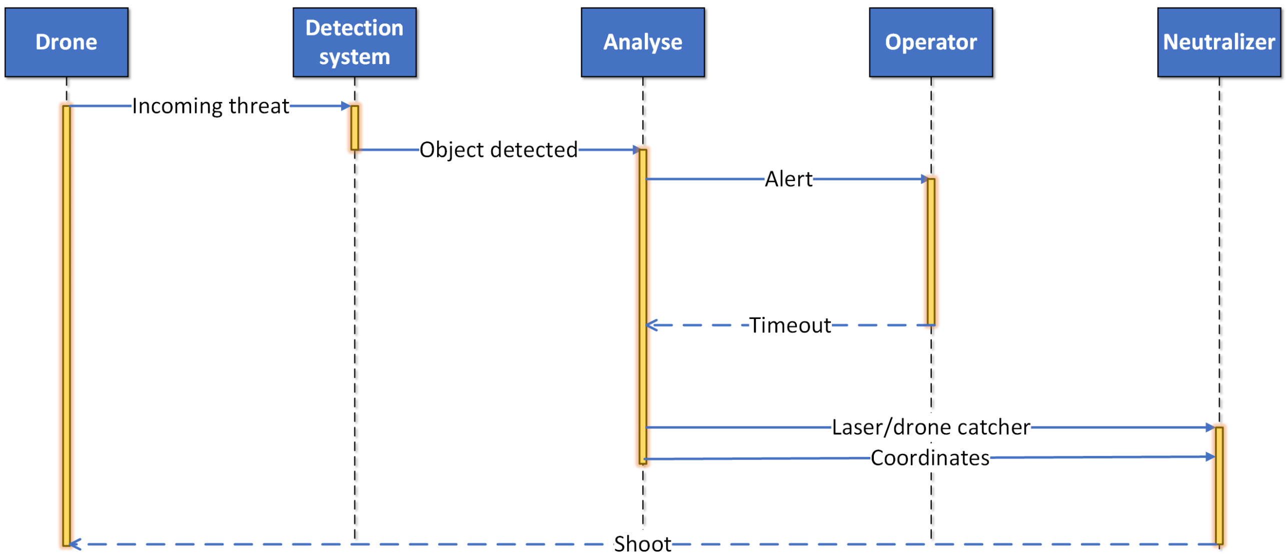


Figure 16: System sequence diagram.

When a drone is detected by the detection system on an autonomous boat, data is sent from the sensors to an analysing algorithm that detects and classifies the object detected. More details about the analysis in [Appendix A.9.2, Fig. 52]. After the analysing segment is done the operator has a small time frame where he can review the data collected and abort the neutralization if necessary. If the operator fails to abort or no input is given, the boat will go ahead and alert the neutralizer located on the boat to neutralize the drone. The neutralizer subsystem will receive real time the coordinates and if the coordinates are close to, or above the oil rig, the drone catcher system [Fig. 17] is alerted and sent out instead of the laser.

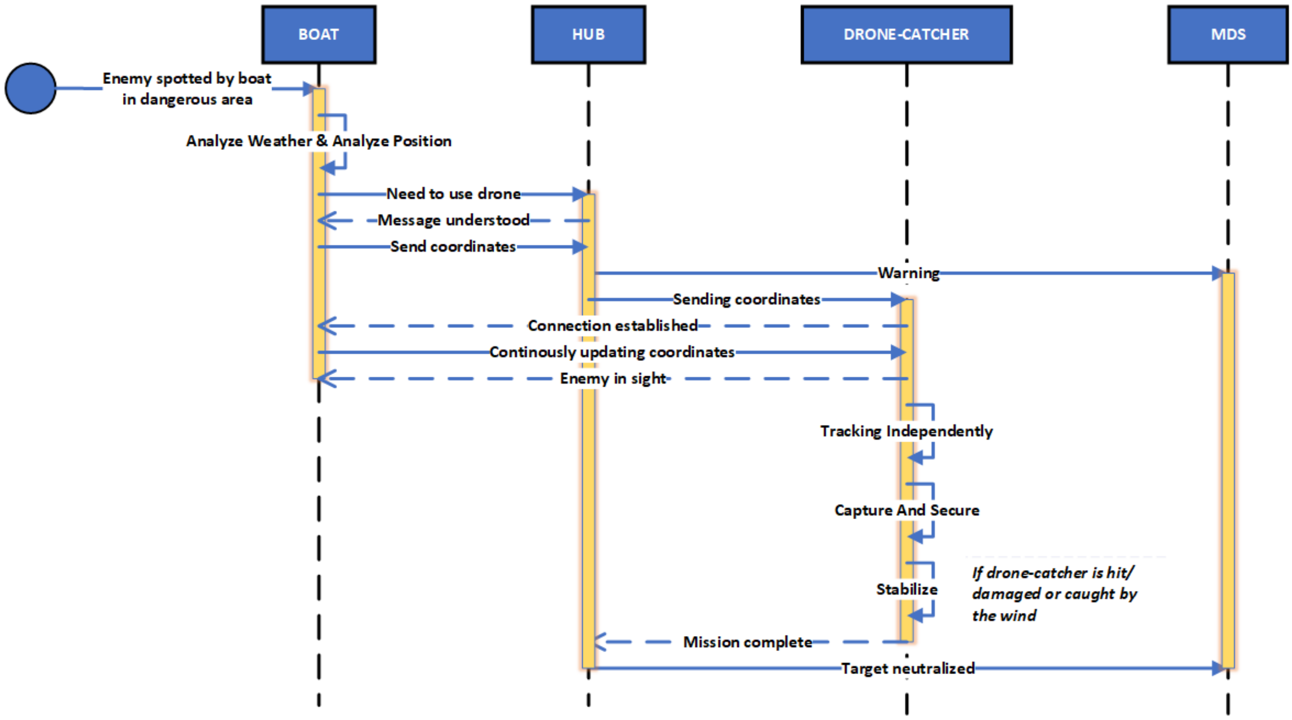


Figure 17: Drone catcher sequence diagram.

The technical level of each diagram depends on how far into the system you delve, and how critical the information is. This sequence diagram [Fig. 17] is a lot more detailed than [Fig. 16] because it was important for our team to understand in what order the sequences were taking with the drone catcher system, while the overall system already were detailed in the other diagrams. More information about the drone catcher sequence diagram in the [Appendix A.11.2].

6 Subsystems

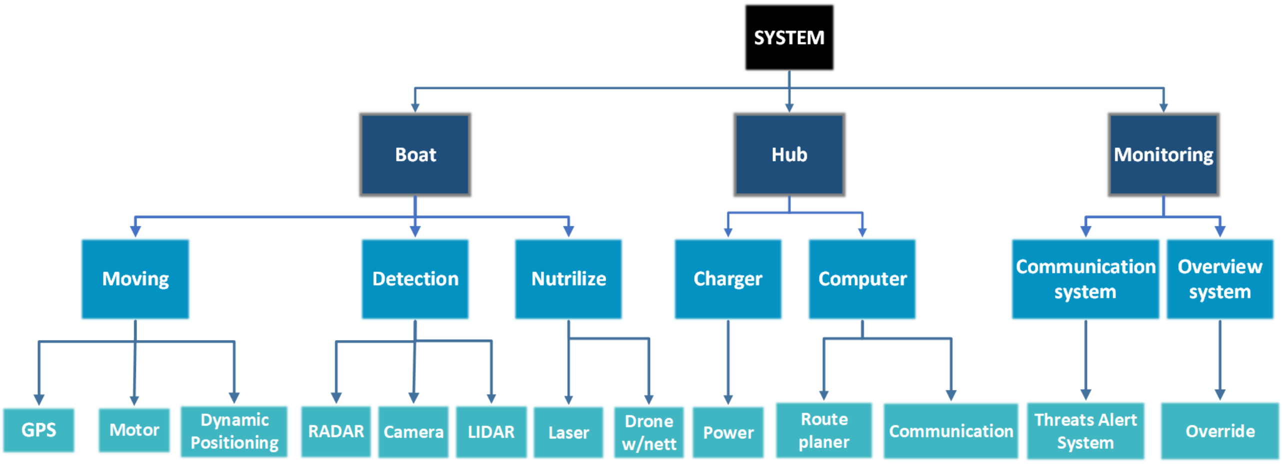


Figure 18: Subsystem diagram.

Our system can be divided into three subsystems, where one is a monitoring display for the security on the platform, and two of them are big, physical systems as illustrated in [Fig. 18], an autonomous boat [Fig. 22], and a hub [Fig. 20]. Each of them consists of several sub- and subsubsystems, and so on. And this is what makes the entirety of the system.

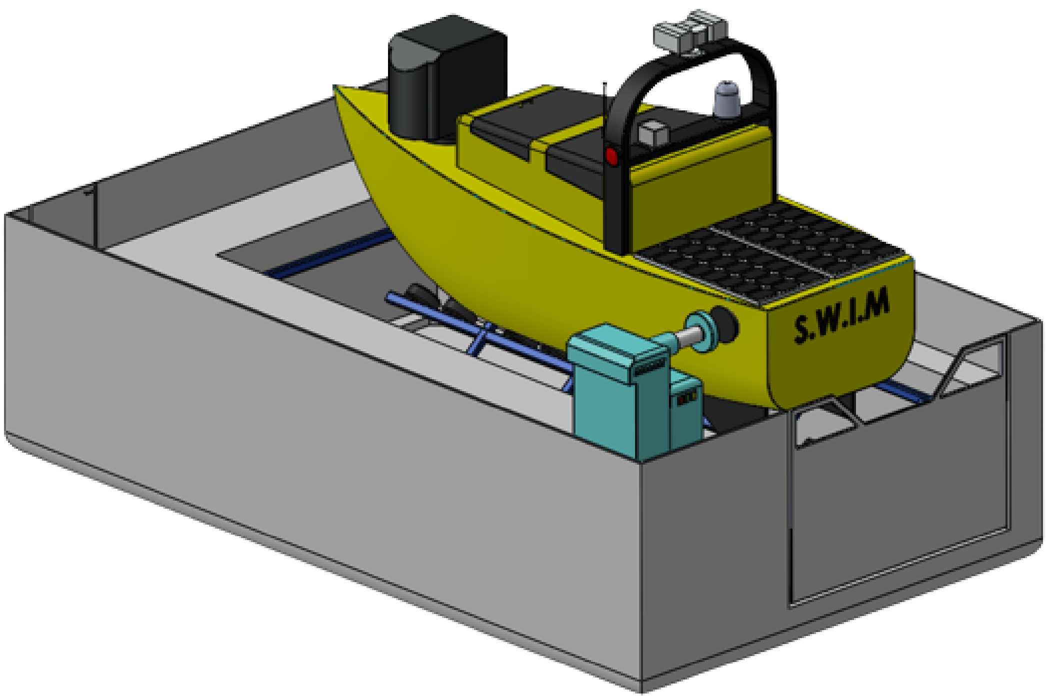


Figure 19: Assembly.

6.1 Hub

The Hub functions as a connection point and charger for all boats operating within S.W.I.M. It consists of several charging docks in a harbor formation and a main computer. The dock has a simplistic design, as illustrated in [Fig. 20], with room for one boat per dock. Several docks can easily be connected together to expand the Hub. It's designed with a slipway for raising and lowering the boat into the water. Illustrated in [Fig. 21] we can see that the boat and the hub communicate through a computer on the Hub, which raises and lowers the slipway autonomously when needed. The computer has control over all the boats, their conditions in form of power and maintenance, in addition to position planning.

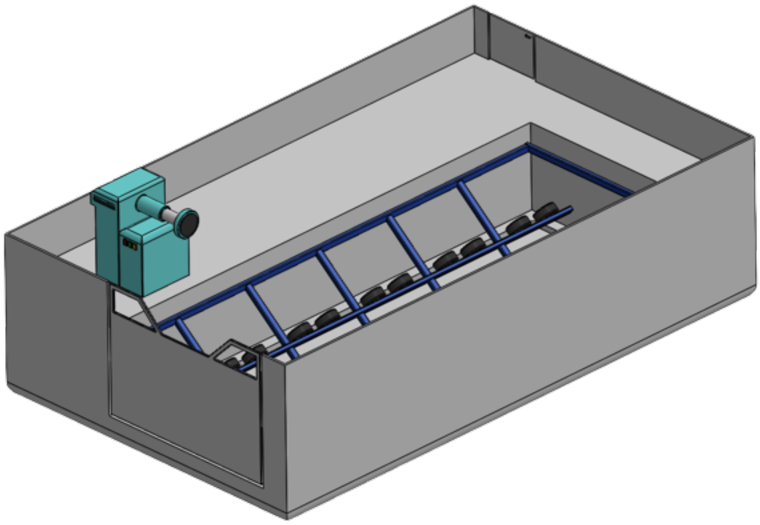


Figure 20: Docking station on Hub.

On the Hub there is a charger [Appendix A.7.3]. When the boat is in the right position, the charger will connect wirelessly to charge the boat. This design is chosen because it provides the most optimal charging regardless of waves and weather, which again eliminates wearing parts. It also contributes to maintaining a system that requires minimal maintenance and human intervention. When the boat is charging, it also transfers all relevant collected data over to the computer on the Hub, which uploads it to the Analysis & Development Department's head quarters, and downloads software updates if available.

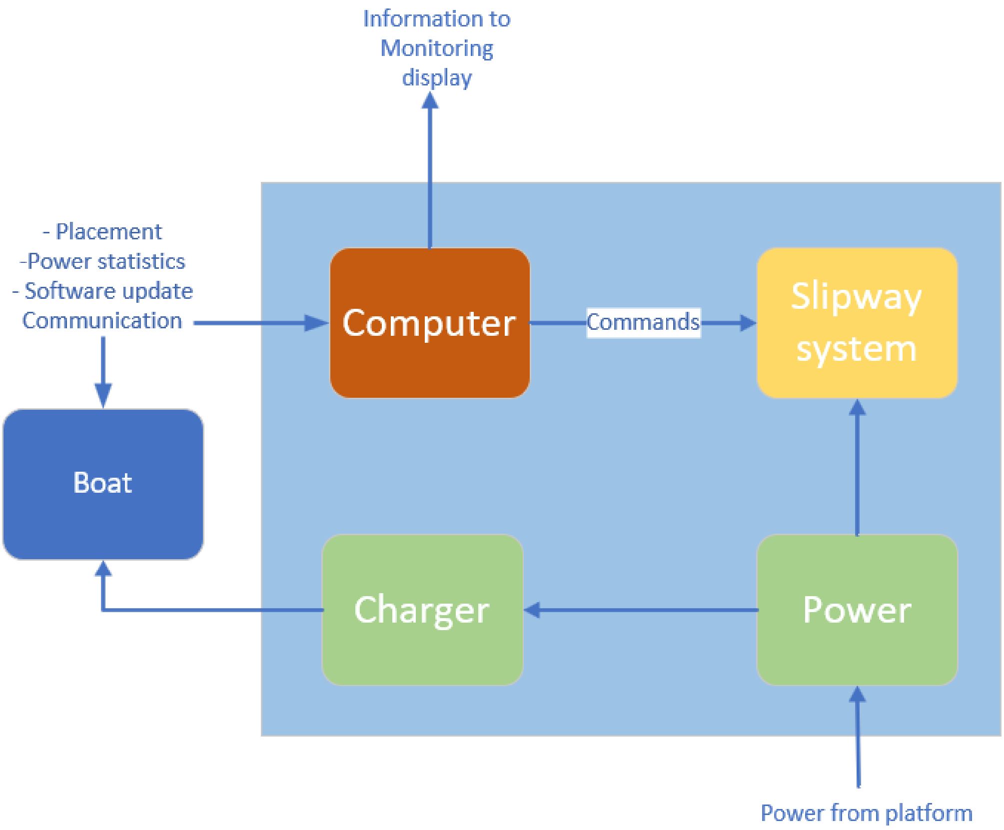
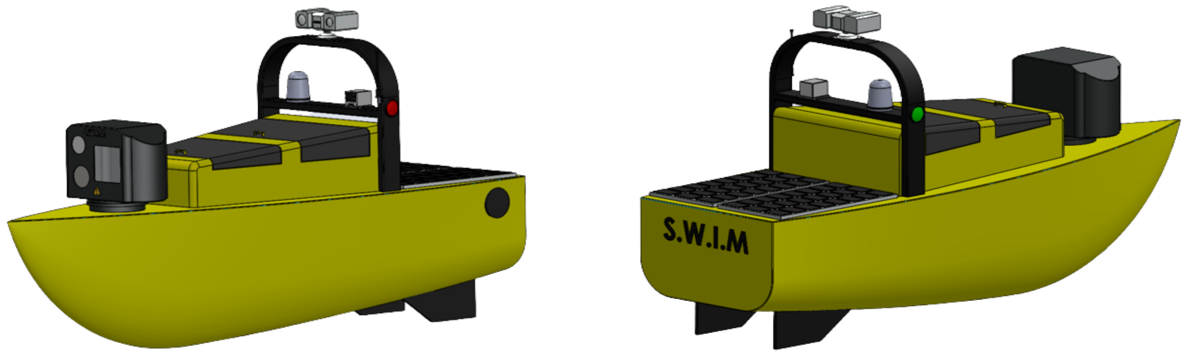


Figure 21: Hub diagram.

6.2 Boat

Looking at the KPPs [Fig. 33], the boat has some requirements that have been a focus during the design process. For example, mobility and portability has been important to us because of easy shipping and installing. We also think it is important to be sustainable as we have discussed in [Section 2.2]. Therefore we wanted to make sure that, amongst other things, the material we use is mainly recyclable.

From these requirements we also made some other decisions regarding the design and production method for the boat; it's designed for an optimal weight relative to both shipping and function on the water. The hull design also makes it easy to transport, but more importantly it glides easily through tough waves, and ensures optimal, stable and smooth operations at sea. All of these requirements and decisions have now left us with a multi functional, autonomous boat for detecting and neutralizing drone threats. (Physical view: [Fig. 22], Component View: [Fig. 23]. To read more upon the various components of the boat, please see [Appendix A.7.1]).



(a) (b)

Figure 22: Boat models: (a) Front of boat. (b) Back of boat.

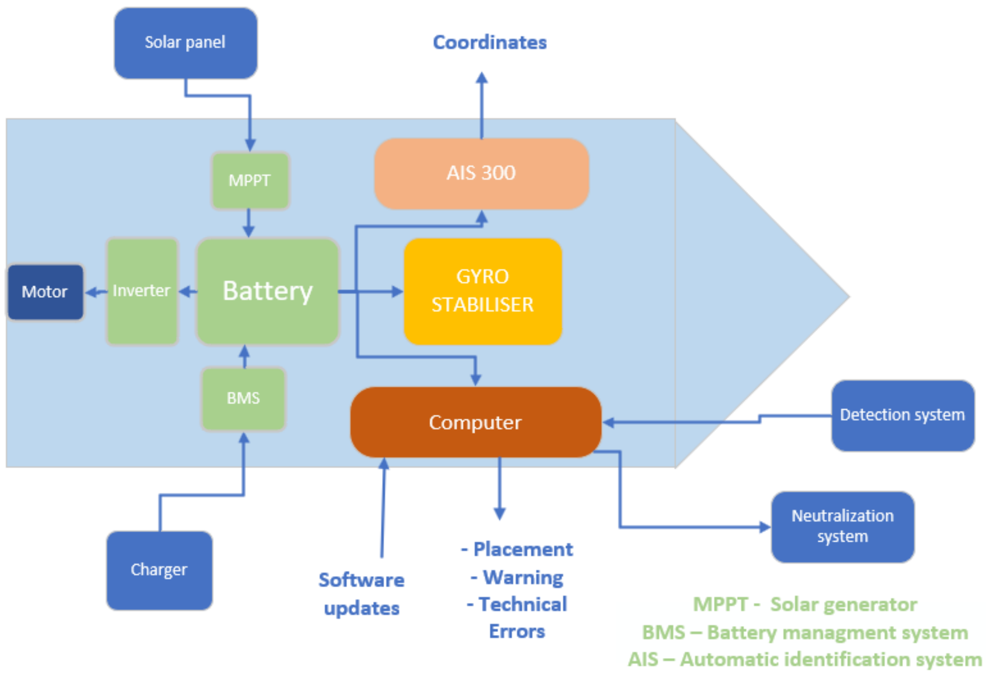


Figure 23: Diagram of the inside components and interfaces.

6.3 Detection

To answer our key performance parameters *Accuracy, Protection & Scalability* illustrated in [Fig. 33], we would need a detection system that is able to adhere to the criteria. After evaluating multiple different sensor types that could be used we landed on camera, Lidar and doppler radar and fusing them together with sensor fusion, this is further elaborated upon in [Appendix A.8.1]. Technical aspects for these sensors can be seen in [Appendix A.7.4, A.7.5, A.7.6]. To be able to distinguish drones from the environment around, an amount of analysis has to be done by the system on the boat before making a decision. Information about this can be found in [Appendix A.9].

6.4 Neutralization

To answer our key performance parameters *Accuracy, Response Time & Protection* given in [Fig. 33] we required a neutralization system capable of adhering to the criteria. After going trough numerous possible neutralization methods we landed on using a laser. Since shooting down drones over the platform with a laser can end up catastrophic, we ended up adding a drone-catcher. This were to combat drones in the specific scenario where a drone enters the safety zone over the platform. Technical aspects for the laser and drone-catcher can be seen in [Appendix A.7.7 & A.10] and [Appendix A.11], respectively.

6.5 Monitoring Display System (MDS)

Our human-machine interface, the Monitoring Display System, is a rather small part of our system, yet a relatively important one. A crucial part of providing security is giving the people you are protecting insight and information. The S.W.I.M Graphical User Interface (GUI) [Fig. 24] does this job efficiently, and will be integrated onto the already existing systems within the security offices, granting the user familiarity and a gentle learning curve. On this screen the user can view real time statistics, a map of the boats' placement and potential dangers, along with warnings and a few actions to perform in case of need.

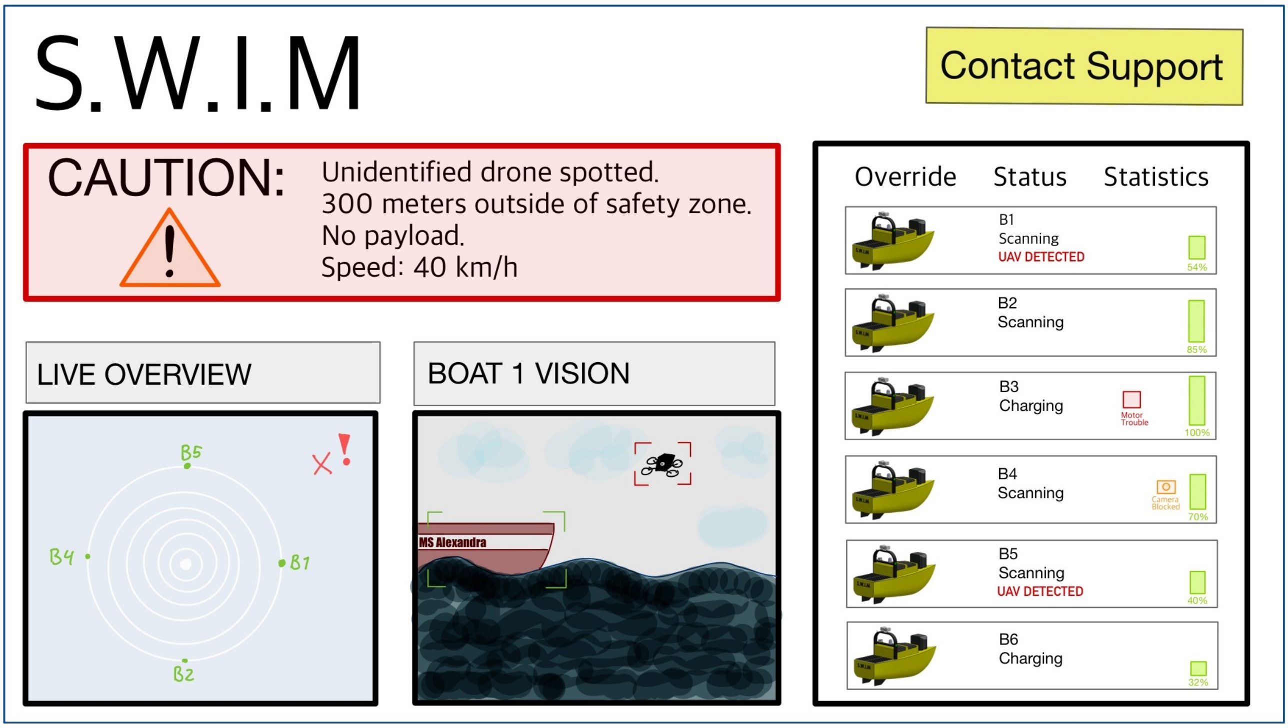


Figure 24: Graphical User Interface.

The system would also be connected seamlessly with the AIS (Automatic Identification System) and alarm system on the oil rig. This will provide our boats with data about accepted ships and traffic, and allows us to alarm the entire platform autonomously if necessary.

6.6 Analysis & Development Department

The Analysis & Development Department (ADD) is a support system of S.W.I.M, and our way of communicating with the system from on-shore. Its main function is to deliver software updates to the system and the boats within it. When the autonomous boats are out analysing, they collect sets of data. Some of this data is then transferred to the Hub when docking and charging.

The Hub forwards the collected data through a secure private network connection to the Analysis & Development Department for further research. At the ADD, our analysis team then uses this data to train the machine learning models that are to be deployed on the boats. The development team ties this together in a new software update for the boats, and also makes sure to update Hub and MDS. When the update is ready with newly trained Machine learning (ML) models for the boats, and have been through consistent testing, the update is deployed back onto the Hub which distributes it out in the system and updates the boats when they are back on charging. More information about the ADD and the ML models in [Appendix A.8.4].

6.7 Communication

All of the above-mentioned subsystems need to communicate efficiently for S.W.I.M to function as optimally as possible. For this communication we have looked at different approaches for sending messages within the system. We chose a star-shape network topology for our boats' communication and a communication service called FileCatalyst for high speed data transmission. Both of these are elaborated upon in [Appendix A.13], with explanations of the decisions we made along the way.

7 Technical

7.1 How we use boat positioning to solve KPPs

The physical position of the boats is an important factor that facilitates for the operation of our other subsystems, like the detection and neutralization systems since these are physically placed and operate on the boats. Thus arose the need for a mathematical model that calculates how many boats are required and what their optimal physical position is to protect a safety zone of varying sizes within our scope. This model will be used to advise our customers on how the operation of the system will look like and give a price point on its purchase. The below texts and figures will discuss what parameters we expect to use, and what results we expect to find given a complete model.

The model must consider a spherical safety zone A_{safe} with radius r_{safe} where we are allowed to neutralize hostile drones and a spherical demilitarized zone (DMZ) $A_{platforms}$ with radius $r_{platforms}$ where the assets to protect are physically located and where we are not allowed to operate. This is visualized in [Fig. 25].

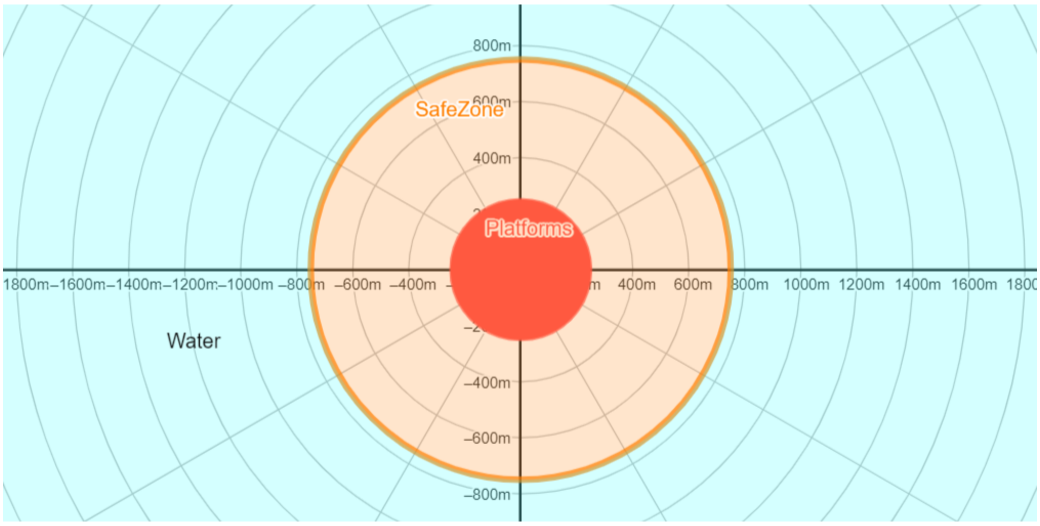


Figure 25: Safety zone A_{safe} and DMZ $A_{platforms}$ visualized.

Furthermore, the model should consider the laser weapon radius r_{laser} that will form spherical zones A_i around each boat. These boats will cumulatively and simultaneously work to satisfy important system requirements and improve key performance parameters like:

1. The system should cover 100% of the spherical safety zone of 500 meters.
2. The system should have a response time from detection to neutralization of less than 7 seconds [Appendix A.14.1].

This is further elaborated upon in [Appendix. A.14.2].

8 Financials

The figure below [Fig. 26] visualizes the estimated costs of production found in their corresponding tables [Fig. 65] and [Fig. 66]. The blue line represents our economic growth under ideal circumstances while the yellow line represents our growth if production was delayed by one year. The price of our system is estimated to approx. 7 million USD (price may vary depending on the size of the platform, desired number of add-ons etc.) The cost of system manufacturing, deployment and more is approx. 3 million USD, giving us a net profit of 4 million USD per unit sold after tax. See our Cost of Ownership Model [Fig. 63] in [Appendix A.16] for more details.

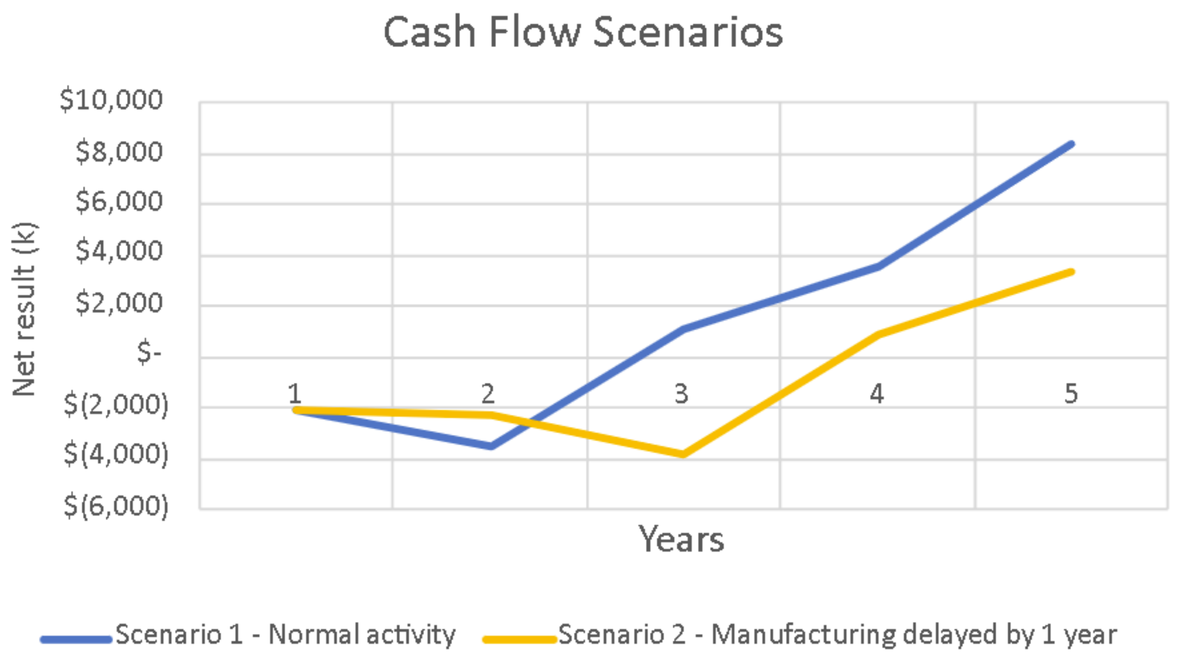


Figure 26: Cash flow scenarios.

For our plans regarding future development of S.W.I.M, please see [Appendix A.15].

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A Appendices

A.1 Appendix 1: Project Plan

Throughout this semester we have been using different development techniques to understand our problem, building a solution and working together as a team. Underneath are some of the tools that helped us throughout the process.

A.1.1 Group Contract

The **group contract** seen in [Fig. 27] was signed at the beginning of the process and helped us to get clear expectations from each other, and it was a motivator through the process for doing our best.

A.1.2 The Vee Model

In our work we took a lot of inspiration from an iterative V-model approach. We worked along the different steps of the V-model [[5], Fig. 28], and iterated. This meant **Analysing - Developing - Verifying - Validating - Repeat**. It frequently happened that we restarted our iteration at various steps, because we understood that we had to go back and make changes. In this way we approximated a sort of Agile V model.

The V model taught us to always look ahead, and consider how we were to verify and validate our system. Whenever we would try to create a requirement for our system, we asked the question "how would we verify this" and "does this truly solve our problem". We learned that it is easy to jump to conclusions regarding fancy and exiting ideas, but it is also important to take a step back and look at what is actually necessary for our problem to be solved.

A.1.3 Task management

A task management tool we used was **time boxing**, which involves working on a specific task or subject within a preset limited time frame. By introducing a deadline stress factor to the group work sessions we were forced to make quicker decisions. This tool proved particularly useful in increasing our productivity in early stages of exploring a subject where we valued creative quantity above quality.

In addition to time boxes, we saw that managing what tasks were to be done, and in what priority, was important. In this case we used a **Kanban board** (A technique within the Agile model) to our advantage [Fig. 29]. This board helped us to get an overview over what were to be done, what had already been done, and who was responsible for a certain task.

Kontrakt Gruppe 1

- Vi jobber mot en A.
- Vi skriver timelister.
- Referat skrives under hvert møte. Vi gjør de oppgavene som står i referatet / Det som har blitt tilegnet.
- Referatskriving følger malen og skrives av Thomas.
- Kine er gruppeleder.
- Møter avholdes 12.30 mandager og torsdager. (Slik at vi rekker lunsj først)
- Vi benytter Teams som faglig plattform, og Messenger som kontaktsted for å for eksempel melde ifra om fravær o.l.
- Møte presist til avtalt tidspunkt.
- Forsinkelser meldes fra på Messenger.
- Sosialt snakk skal foregå utenfor møtetid.
- For å forhindre ukonsentrasjon og sosialt prat i møtetid har vi avtalte pauser.
- Flertallet bestemmer i en potensiell konflikt. Om ikke alle er til stede får siste person svare i ettertid.

Signaturer:

Simone Hoem Frøyset

Jonathan Bergius

Thomas Lunde

Daniel Opsahl Tjemet

Vibecke W. Aass

Kine Mirjana Antilla

Nathanael Nega Getaneh

Figure 27: Group Contract.

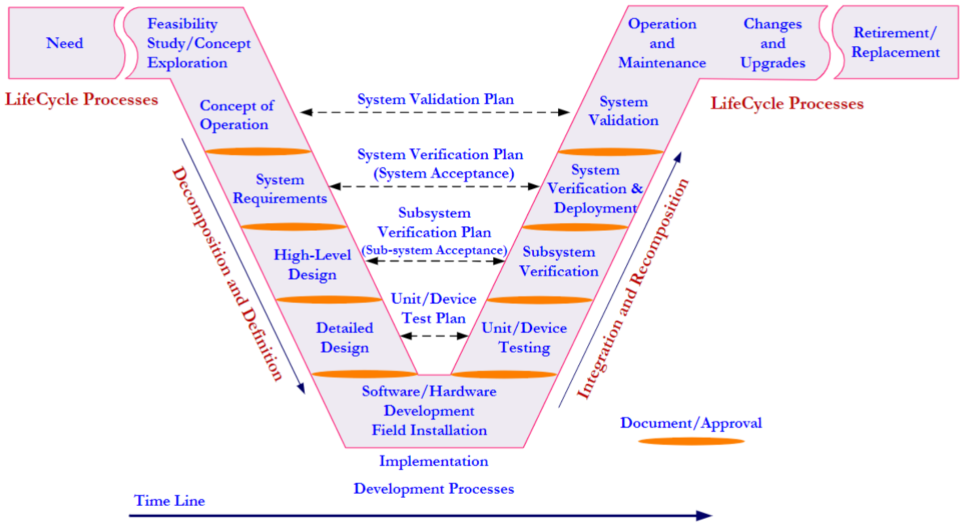


Figure 28: Vee Model.

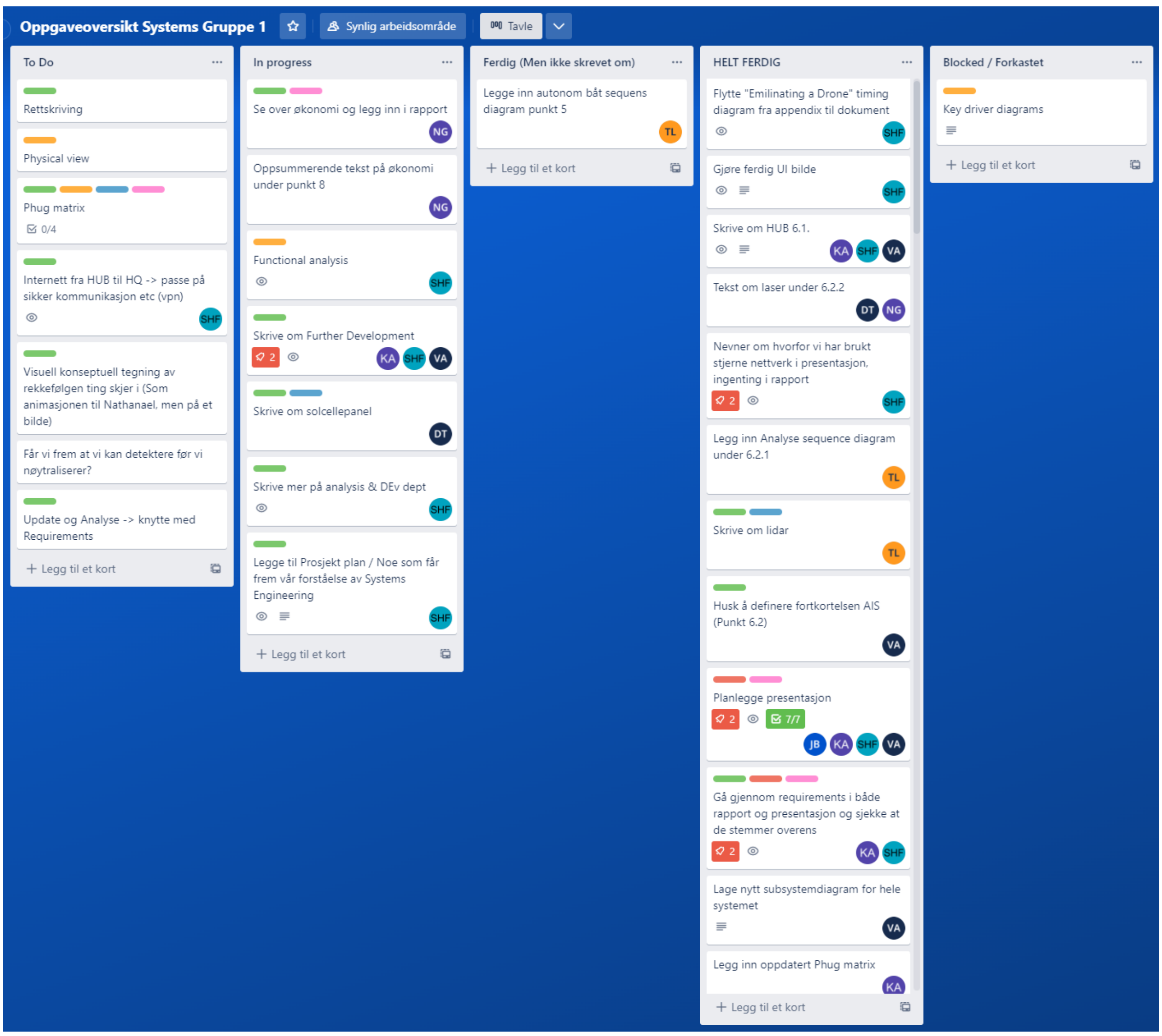


Figure 29: Kanban Board.

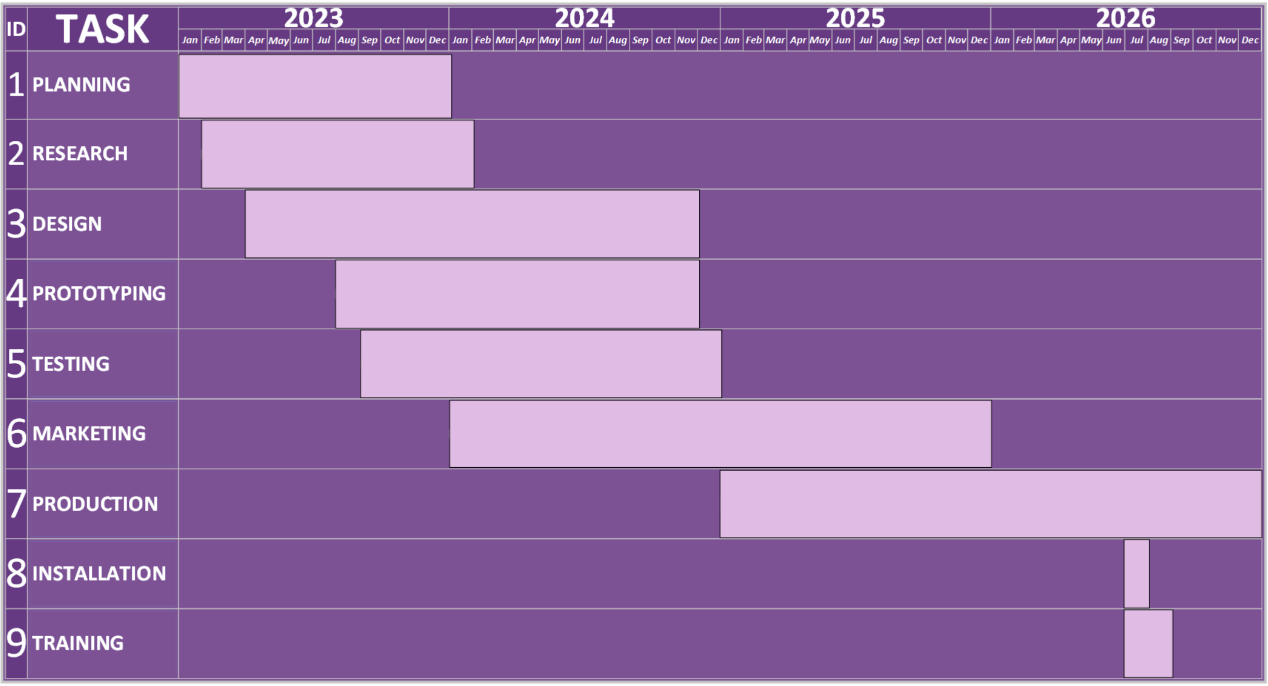


Figure 30: Development Timeline.

A.2 Appendix 2: The Case

The law states that it is forbidden to travel less than 500 meters from the oil installations, without approval from the responsible companies [6]. Yet, more and more platforms are reporting unknown drones hovering within the safety zone. No one knows who are controlling them, or what their motives are.

As Russia perceives that they are at war with NATO, and has made natural gas a weapon in the conflict by stopping Russian export of natural gas to Europe, the situation has never been more critical. The police are getting help from the Armed Forces, the Norwegian military vessels have increased their presence, and the Home Guard are watching the installations on the main land [7].

In this report, our primary focus will be on how to protect the Johan Sverdrup oil and gas field. It is one of Norway’s largest oil and gas fields, located 140 kilometers west of Stavanger on the geographical height formation ”Utsirahøyden” within the North Sea. It is composed of five platforms with specialised purposes, including housing-, processing-, drilling- and a riser platform. [8–10]

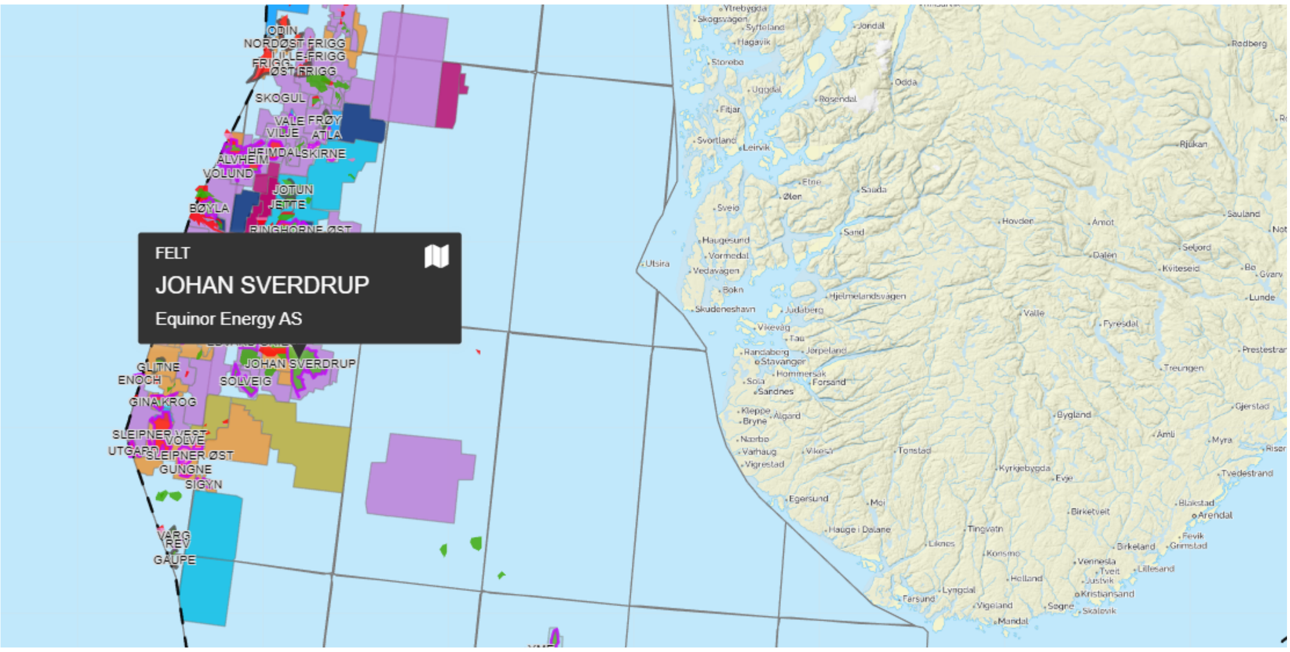


Figure 31: Johan Sverdrup location [1].

A.3 Appendix 3: Stakeholders

A.3.1 Primary Customer Stakeholders

Our primary customer stakeholders include some of the state's most important people and companies. Since our product is protecting one of Norway's most valuable assets, crude oil and natural gas, our customers have high demands, but are also able and willing to spend a good amount of resources for a protective system. Because of this, we gained much freedom and flexibility in what we could and couldn't develop.

Illustrated in [Fig. 4] the *Platform Manager* refers to Equinor Energy AS - the oil producer and operator on the rig, while the *Platform Licence Owner* refers to the five licence owners for the Johan Sverdrup field - Equinor Energy AS, Lundin Norway AS, Petoro AS, Aker BP ASA, and Total E&P Norge AS. [10]

A.3.2 Primary Life cycle Stakeholders

The life cycle stakeholders are the people involved with producing, installing and maintaining the system, along with the people responsible for operating it. These stakeholders have one important need in common: They all want their job to be as easy as possible. To achieve this, we must develop a system that is easy to handle, easy to operate and easy to maintain. This is particularly important since our system is to be installed on an oil rig, where the weather is tough and maintenance already is difficult.

The *operator* in [Fig. 4] refers to the Chief Security Officer responsible for the platform.

A.3.3 Primary External Actors

The external actors are the ones who don’t necessarily interact directly with the system on a daily basis, but can somehow be affected by it. A good example of this is our enemy, illustrated in [Fig. 4]. This is an important actor who gives us a good perspective on what the system should be able to do to function optimally.

A.4 Appendix 4: Requirements

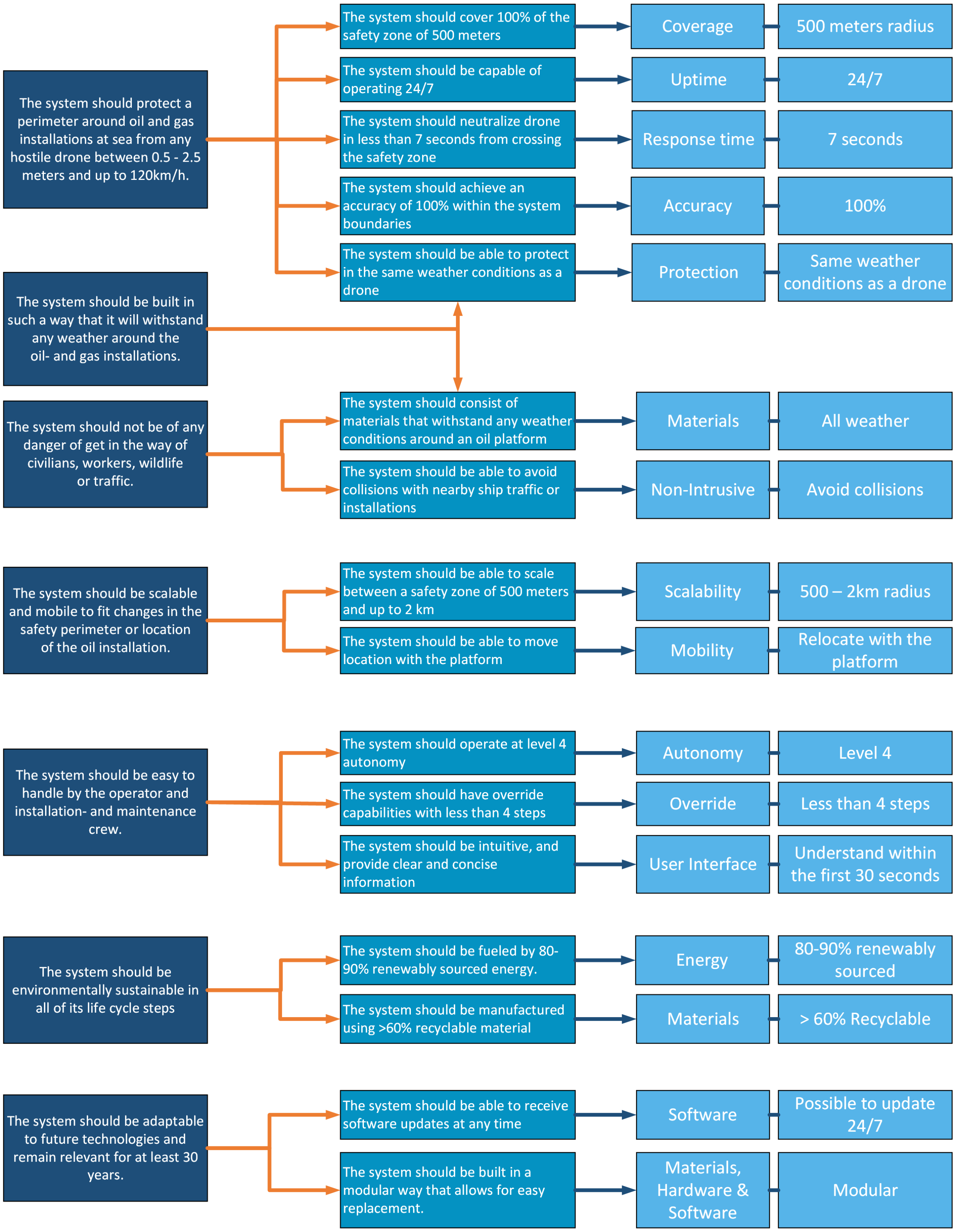


Figure 32: Requirement Mapping.

Figure 33: Key Performance Parameters.

Older versions of the Key Driver Graphs can be found in [Appendix A.17].

A.5 Appendix 5: Story

It is a cold and cloudy Autumn day in 2023 - it's pouring rain. Daniel (26), Thomas (28) and Kine (24) are three undercover agents working for one of Norway's largest competitors within oil and gas. They want to destroy Johan Sverdrup, Norway's largest oil rig located in the North Sea. With the hacking skills of the cyber criminal Thomas, they have gained access to classified inside information about routines and protocols on the platform, which they want to use to their advantage, and with Daniel and Kine's expertise within electrical and mechanical engineering, they design the ultimate autonomous drone that does not emit radio signals, making it harder to detect and track, and cannot be jammed. In addition, the custom design of the drone makes it lightweight and fast.

The distance is too great to fly the drone from the mainland to the oil platform, but unfortunately they know someone who can let them into a passing container ship. When they are close enough to the safety zone of 500 meters, they open their suitcase with the drone inside and calibrate the drone towards the oil rig. The terrorists have hooked up C4 explosives to the drone that will be detonated kamikaze-style.

It is 3 a.m. and visibility outside is poor, making their drone practically invisible to the naked eye. On the oil platform, there is only a sleepy security guard - Frank (54). In addition to their drone being virtually silent, it is almost impossible for Frank to see it. They send the drone towards Johan Sverdrup at 80 km/h. Will the villains succeed?

No! As soon as the drone crosses the safety perimeter, it is detected by the Sky Warden Interception Module (S.W.I.M). A warning signal is sent to the platform and reaches Frank's eyes and ears. Frank has no chance to evaluate the situation in time, so the system does it for him. S.W.I.M evaluates the threat, and eliminates the drone within 7 seconds, 340 meters before it reaches the platform. This means the C4 doesn't explode, rather it sinks with the drone.

Because of this terror attempt, Equinor decides to implement extra security measures: They increase the safety zone from 500 to 1000 meters radius, to adjust to the improving technical capabilities of the drones. Fortunately, they do not need to buy a new protection system, as S.W.I.M will be capable of adjusting to this change.

Johan Sverdrup will soon be emptied of oil and the platform will be moved two kilometers. The system's modular design allows this relocation to take no more than a day.

A.6 Appendix 6: Diagrams

A.6.1 UN Sustainable Development Goals

Figure 34: [2] Relevant UN Sustainable Development Goals: (a) 8. (b) 9. (c) 13. (d) 14. (e) 16. (f) 17.

A.6.2 Use Cases

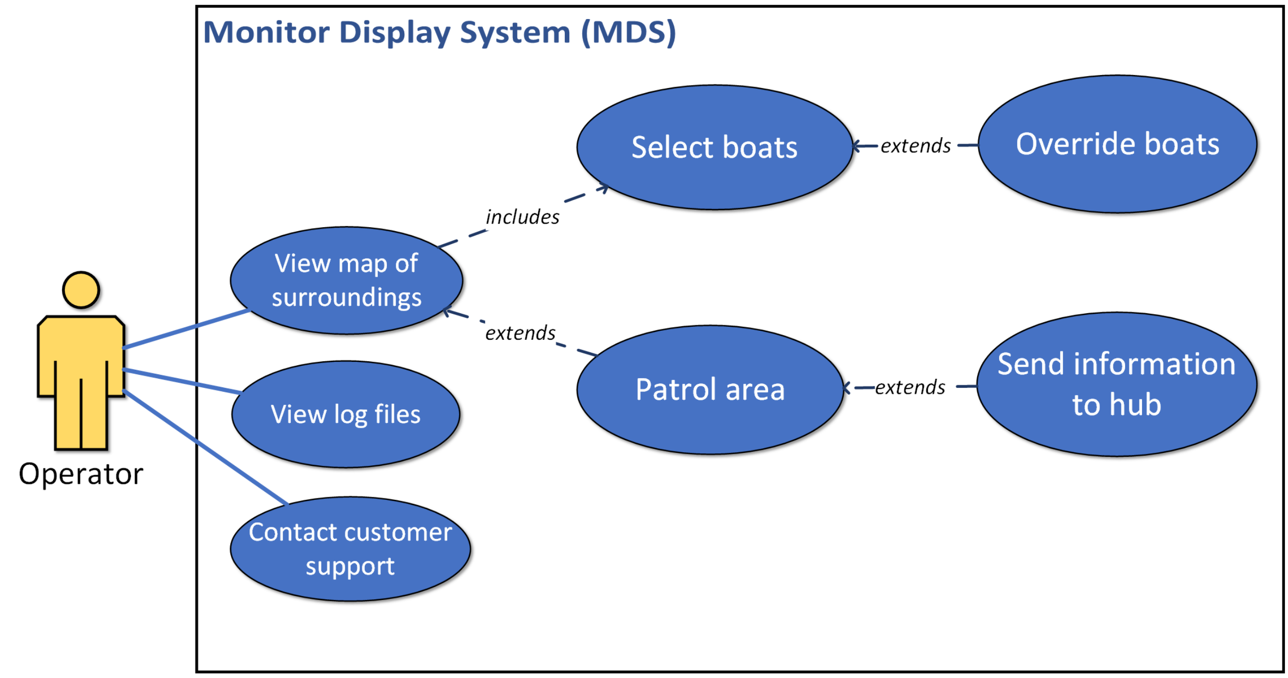


Figure 35: Operator using MDS use case.

[Fig. 35] Represents the actions that the main operator of the system can do. This operator is likely to be the Chief Security Officer or some other security personnel located on the platform.

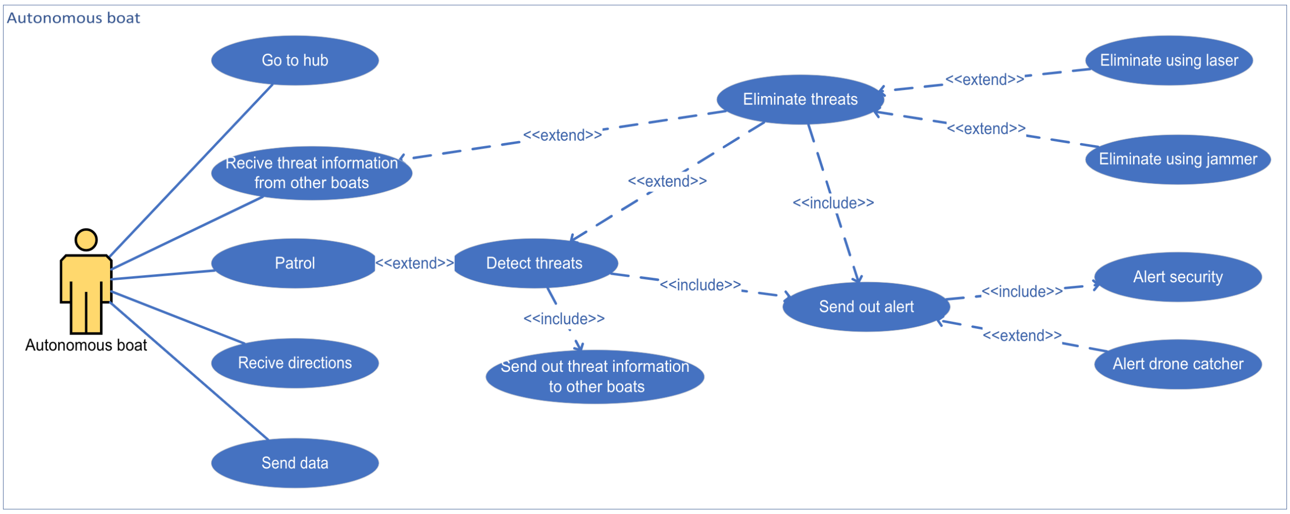


Figure 36: Autonomous Boat use case.

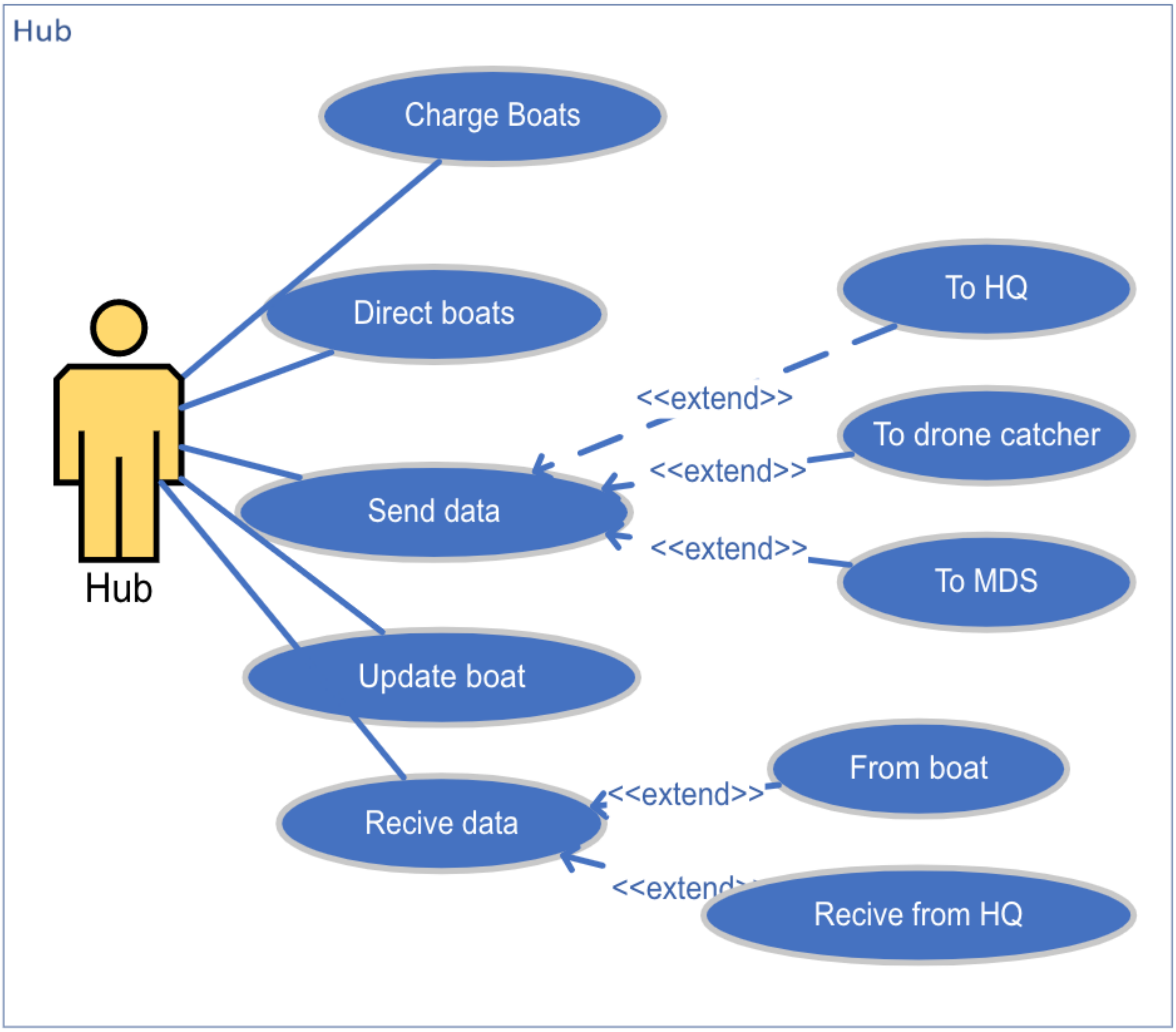


Figure 37: Hub use case.

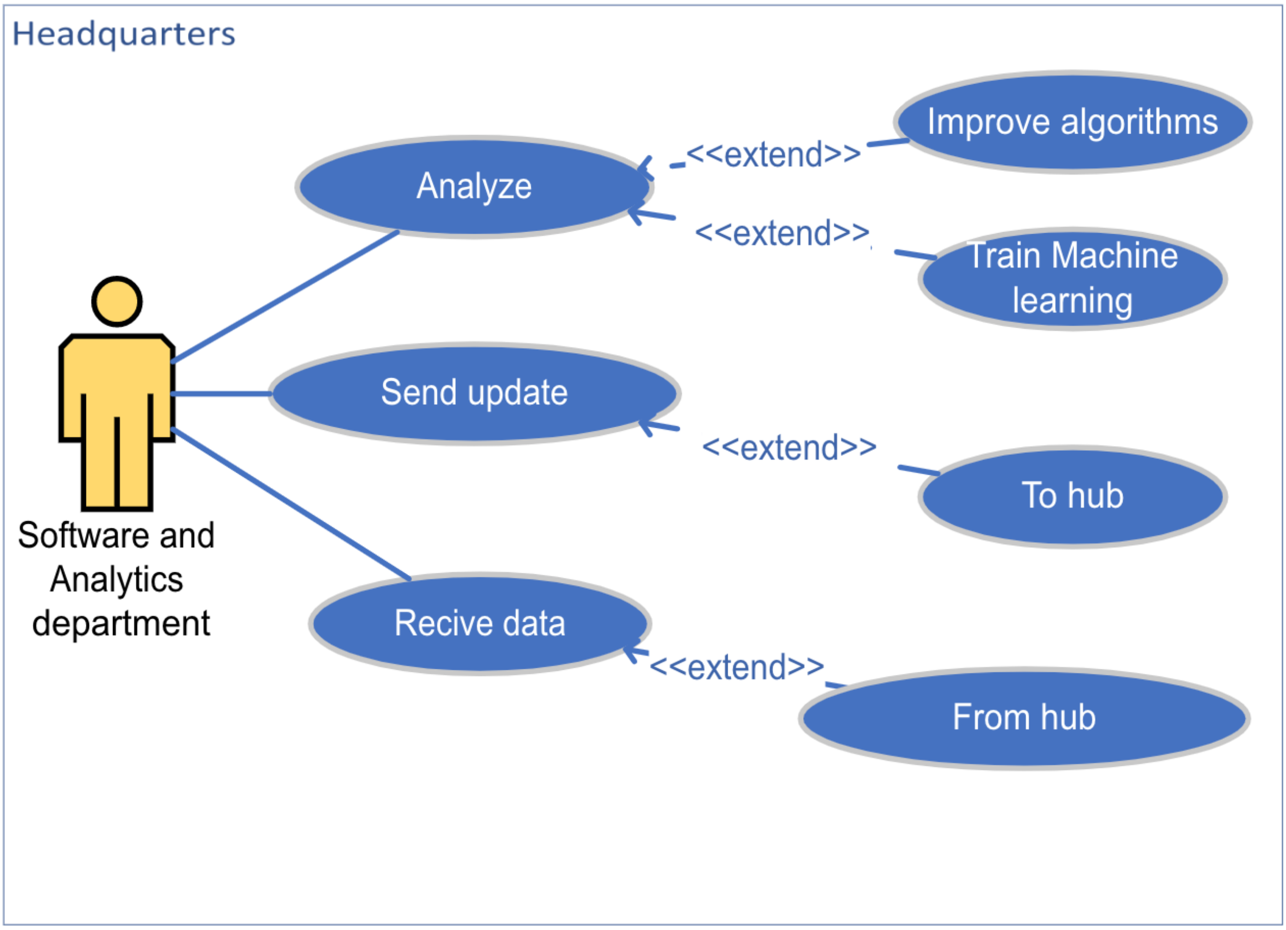


Figure 38: Headquarters use case.

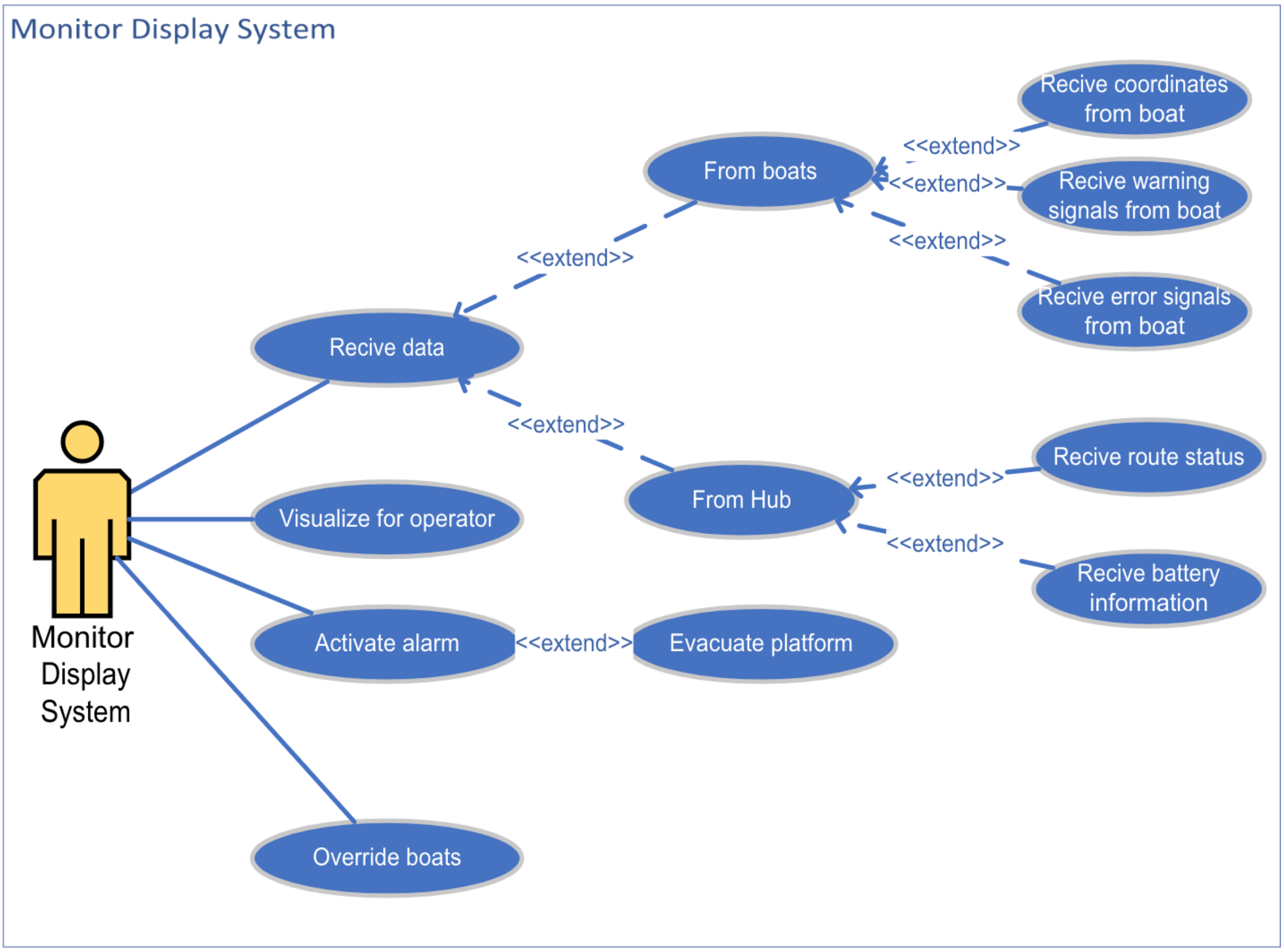


Figure 39: Monitor display system use case.

A.6.3 Interfaces and Functions

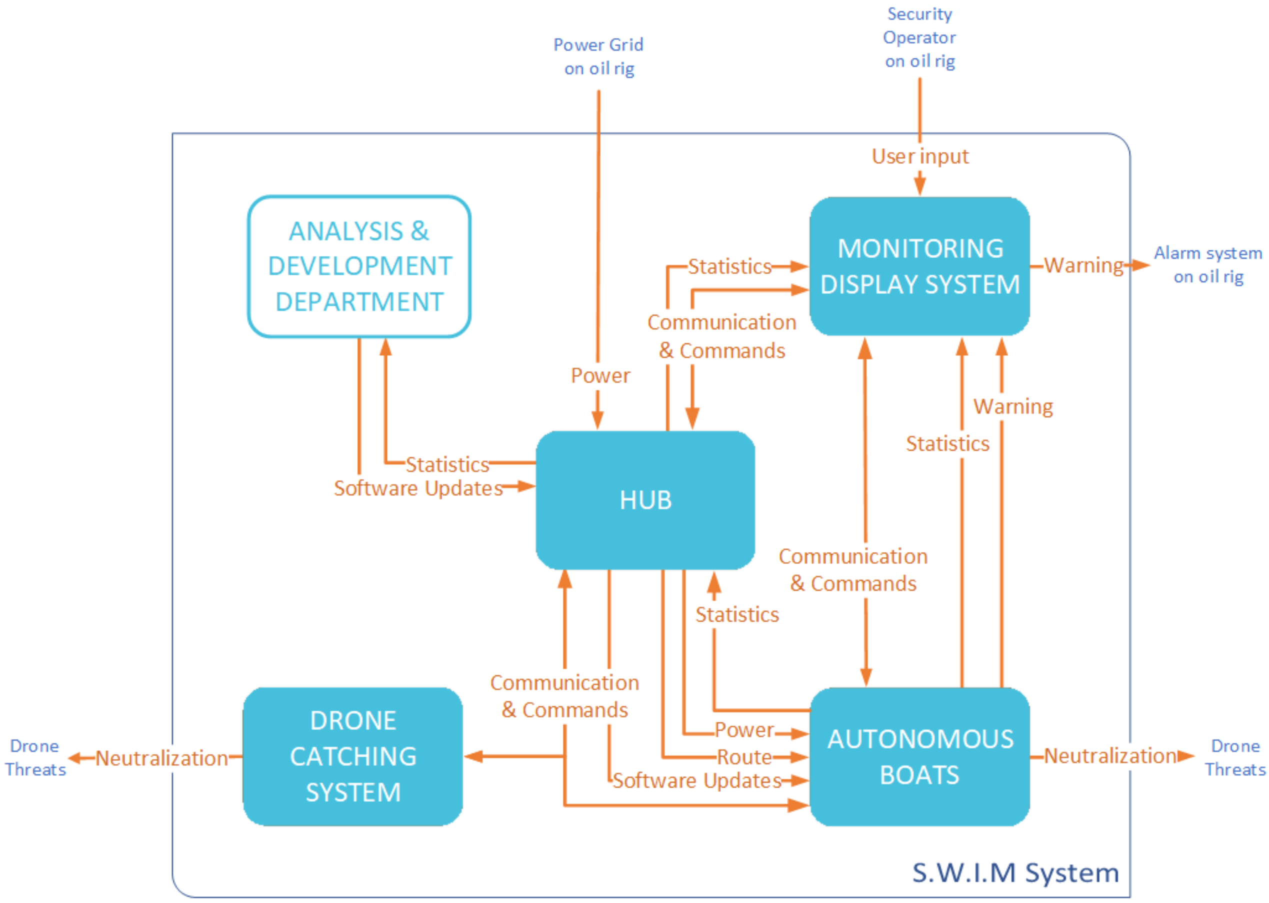


Figure 40: Internal Interfaces Overview.

The internal interface diagram [Fig. 40] maps the various interfaces going between the four main subsystems and the fifth support subsystem within S.W.I.M. From this diagram we can understand exactly how our subsystems are to interact. The first thing we can gather is that everything seems to be connected through the hub. There are still some direct communication lines going between other subsystems, but this is mainly to make up for the damage caused if the hub was to go down at some point due to faults or even hacking. We see a variety of interfaces, both information and energy, that we have to consider when creating the building blocks for our system.

[Fig. 41] illustrates how the different levels of interface diagrams depends on each other, and together make up the entirety of the system hierarchy. It also illustrates how we have had to scope up and down within our system to fully understand it.

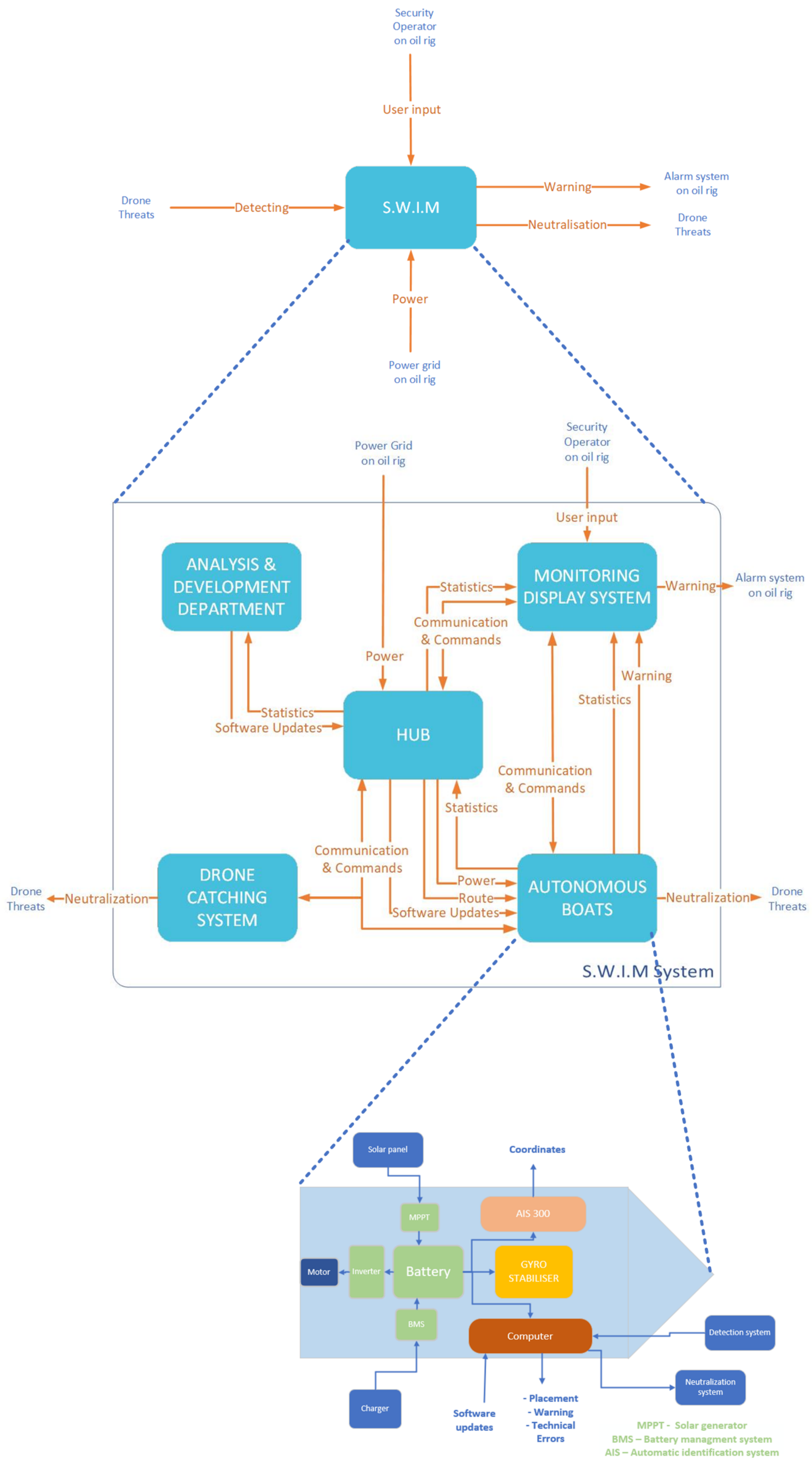


Figure 41: System Hierarchy.

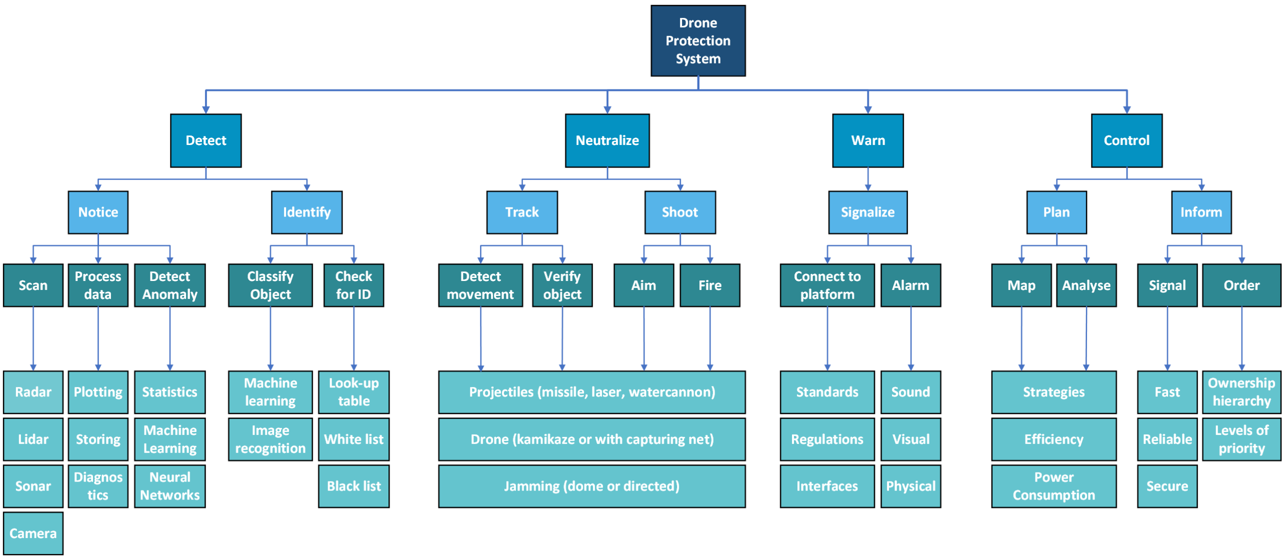


Figure 42: Full Functional Analysis.

The three first levels of the functional analysis diagram in [Fig. 42] shows the entire system as functions, while the last row suggests solutions, methods, and things to take into consideration with the previous function.

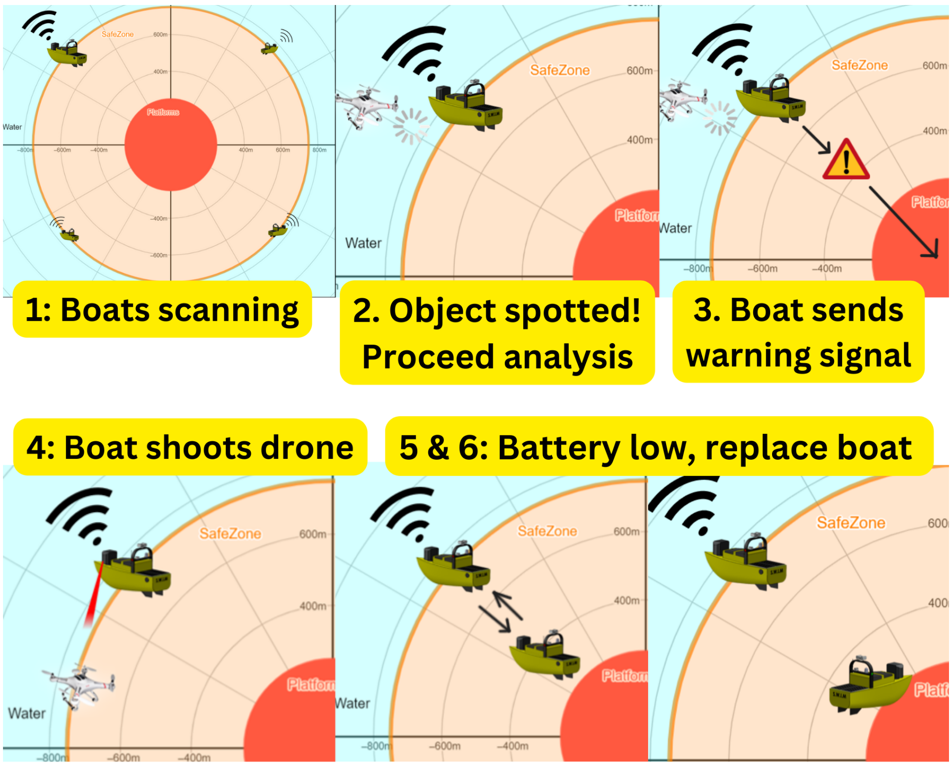


Figure 43: CONOPS Story.

A.7 Appendix 7: Physical Components

A.7.1 The Boat

We have looked at a couple of material choices, but not made any decisions yet. One of them is polyethylene, which is a 100% recyclable material with minimal maintenance requirements. Another is composite and a sandwich-construction. This provides good strength, stiffness, and wear resistance. When it comes to load, this method takes up pressure and tension while giving the construction a solid and strong surface. The core material absorbs all shear forces from load.

The mast on the boat is designed to flip down for transportation so it can easily fit into a container. On top of the mast, there are different types of sensors for detection and navigation. By having them all on the mast, instead of on the hull, we get a better view, and less distractions from the surrounding details on the boat. There is also room for more equipment, in case of upgrade or expansion of the system.

Inside the boat there is a Gyro stabilizer, and outside there is stabilizing fins to dampen the roll and pitch movements. This is to keeps the boat stable and to optimize the surveillance and neutralization by keeping the boat as still as possible. It also contains AIS-300,an automatic identification system which is a 4th generation AIS class A mobile station designed to be fully integrated in a ship's bridge environment. It's a standard system so other boats can keep track of each other while at sea.

The solar panel on the outside is connected to a solar generator MPPT (maximum power point tracking) that maximizes the charge. The solar panel gives power that contributes to navigating the boat. The other power source is a battery management system that gets power from the charger at the hub. The maximum power on a full battery is 200 kW. We can see how it's estimated that the power is spread through the different components with the technical power budget in Fig.44. These are the average values and will change depending on the status of the components. For example, the radar may have a high, peak power, but less average power. All of the components will not be active at the same time either, as the boat is supposed to be stationary when it is out on mission, and the laser is only used once a drone threat is detected.

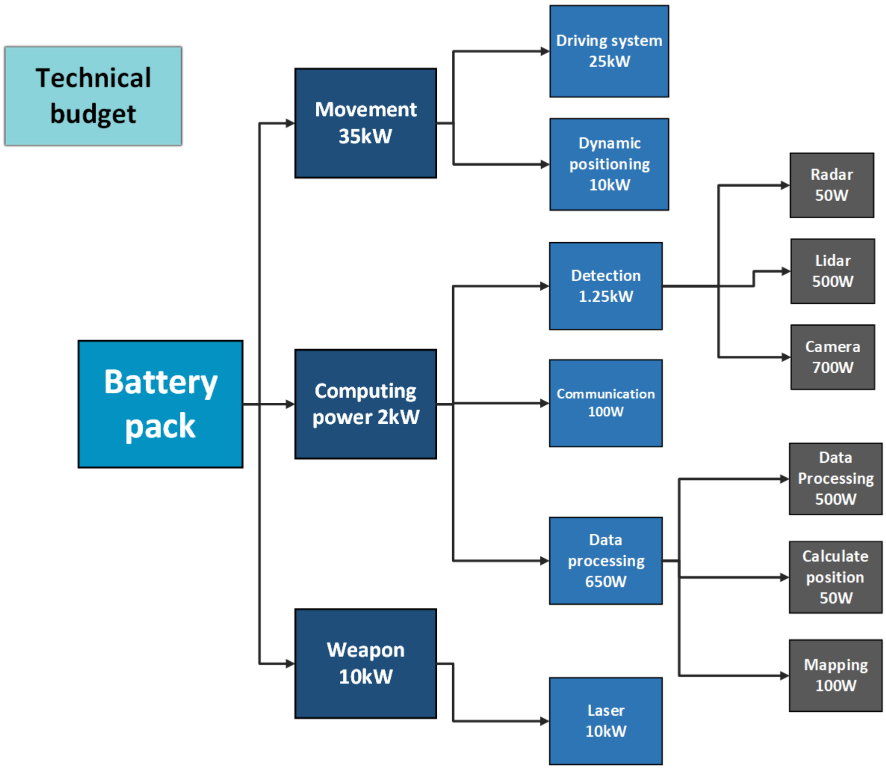


Figure 44: Technical budget for average power.

When the boat's power is down at 40% it will notify the Hub that it's about to need charging. The Hub will start calculating and send out a new, fully charged boat to replace it. Only when the new boat has arrived, is the first boat retracted to the Hub. This way there will be no gaps in the safety zone, and a solid 24/7 surveillance time.

The computer on the boat keeps track of statistics and analysis, and sends it to the hub, which processes it, and sends it to the monitoring display on the platform. This way the security on the platform can overlook the system, and override it if necessary.

A.7.2 Solar cell panel

In order to ensure that our boats can stay out on mission as long as possible, we have placed solar panels on the back of the boat illustrated in [Fig. 45]. The solar cell panel will be able to supply the battery with energy as long as the weather conditions allows it. Therefore, the solar panels are more of an extra power source, and not the main one.

The solar cell panels works by converting sunlight into direct current. The panels are created with a semiconductor material, silicon, which absorbs the energy from the sunlight and releases electrons, which creates the electrical current.

The solar panels are made up of individual solar cells, which are connected together to form a module. Each cell contains a layer of negatively-charged silicon and a layer of positively-charged silicon. When sunlight hits the cell, it knocks electrons from the negatively-charged layer into the positively-charged layer, creating an electric field. This electric field generates a flow of electrons, which is captured and used to charge the battery. To use the electricity generated by the solar panels, an inverter is required to convert the direct current into alternating current, the current is then connected to the battery.

Since our solar panels are placed on a boat, its important to clear away any salt which may end up on the panels. Our solar panels are therefore integrated with an automatic cleaning system.

All in all, the solar panels will not be able to completely power the boat by itself, so it's therefore necessary to have a main power supply in form of a charger.

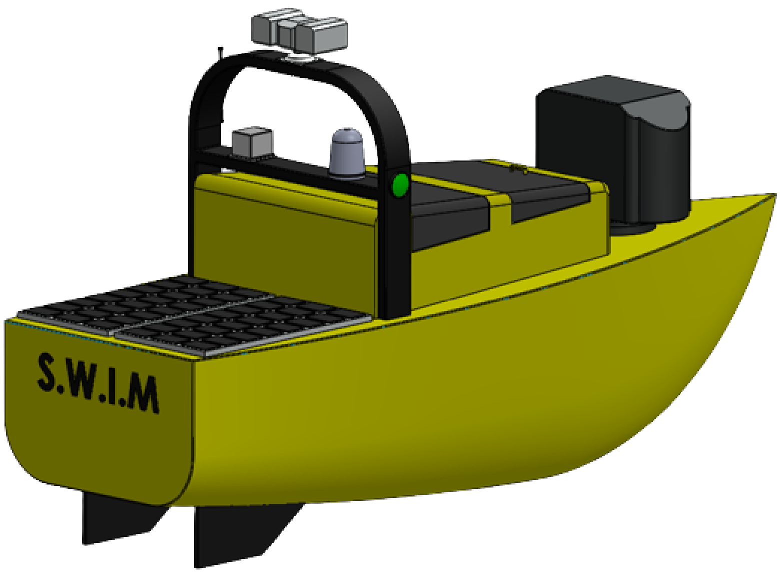


Figure 45: Solar cell panel on the back of our boat.

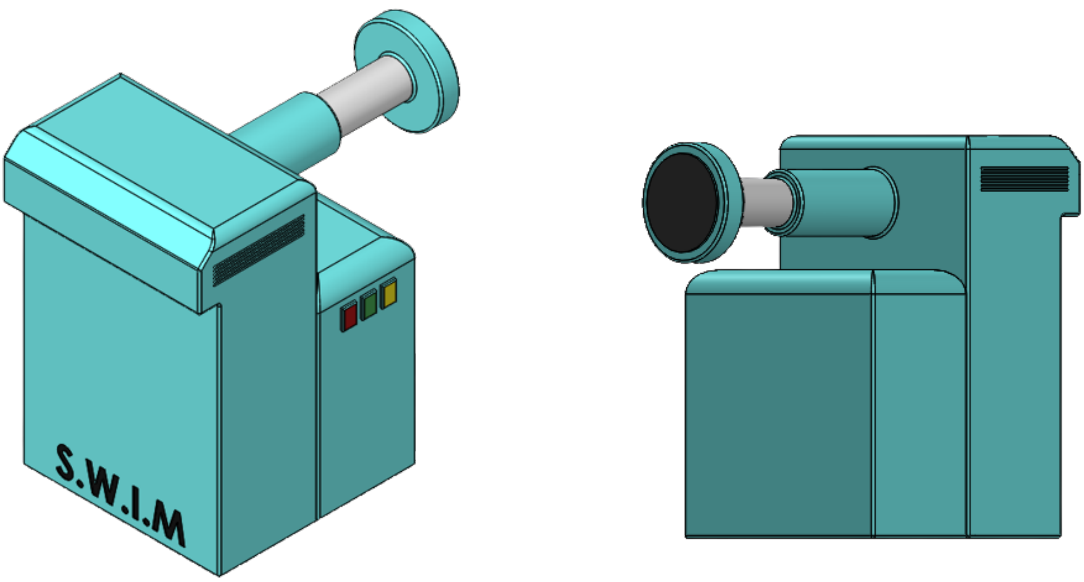
A.7.3 Charger

Our charger uses inductive power transfer technology, making the charger wireless. When the boats enters the docking station, the charger will detect the boat's presence, automatically moor the boat, and start charging it.

The inductive power system works by having a transmitter device connected to a source of power on the docking station, and a receiver device on the boat. These two parts forms the power transfer part of the charger.

In the transmitter device in the charger you have a transmitting coil, connected to an alternating current. By Faraday's Law, an oscillating magnetic field is created when an alternating current passes trough a coil. This oscillating magnetic field then strike the second coil located in the receiver device on the boat. This induces an alternating current in the receiver. Since the battery is charged using direct current, a rectifier is connected in the receiver device [11].

We chose to use the wireless charger with induction technology, since it is important that the system is as autonomous as possible. With the inductive charging, there is no need to constantly plug and unplug the device, meaning less wear and tear, allows for more frequent charging, and minimizes the risk of electrical failures from the wet environment. A proposed model of the charger is illustrated in [Fig. 46].



(a) (b)

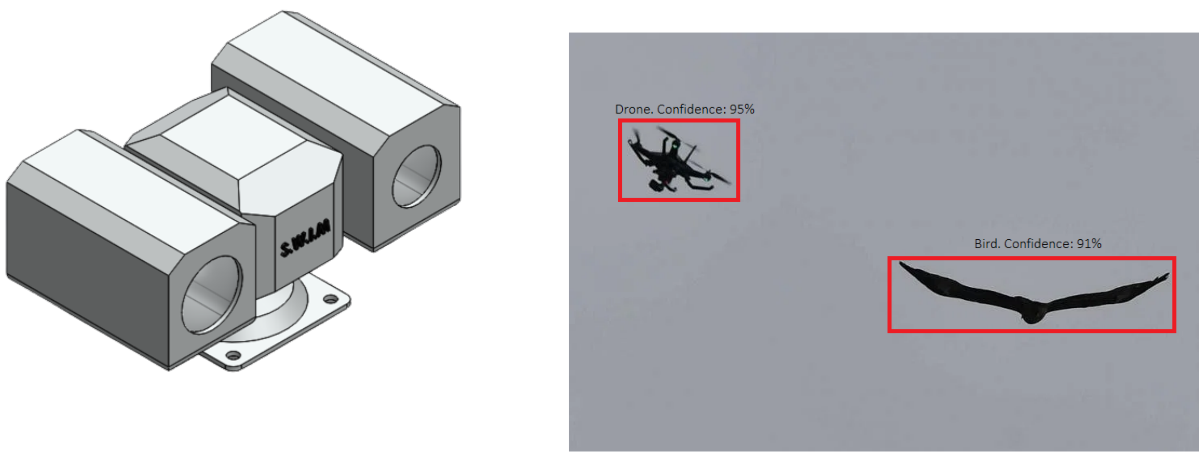
Figure 46: Charger models: (a) Back of charger. (b) Front of charger.

A.7.4 Camera

The camera for the system is one of the key elements for both the detection and tracking of the drone. Our camera is an all-weather, long-range camera using technologies such as long-wavelength, and short-wavelength infrared light, as well as a long-range IR laser for detection during the night. The camera can detect drones up to 2 km, in all directions, as well as lock onto a drone to track and estimate its position. The camera has a high-resolution CMOS sensor for the digital signal processing.

For classifying drones we use a deep learning algorithm. We can therefore classify the anomaly detected with a certain confidence value by using deep learning technology. We can therefore differentiate between drones, birds, and other anomalies inside the camera radius [Fig. 47 (b)]. A proposed model of the camera is illustrated in [Fig. 47 (a)].

Due to the extreme weather conditions which may appear out on the rigs, it's important that the camera is able to both withstand the rough environment, as well as being able to keep the detection rate. One of the weather conditions which may interfere with the detection is heavy fog. To combat this problem, We take use of a defogging algorithm which effectively minimizes the fogs effect on the camera.



(a) (b)

Figure 47: (a) Camera model. (b) Example of detection and classification.

A.7.5 LiDAR

Our lidar sensor is another key component used to measure the distance and position of a potential drone threat. Our lidar sensor is a modified verion of a LSLidar lS30MVA which has a range of 2 km and accuracy of ± 15 cm and °0.01 The lidar works by sending pulses of laser beams, if the laser beams hit an object the laser beam is reflected and the distance is calculated using [eg. 1]. The angles the lidar beam is sent out at is used for calculating the position in an X,Y,Z plane getting an accurate measurement of position.
Using lidar technology alone has some drawbacks. LiDAR will not work well in foggy and rain filled environments, but it has a great range detecting capability so using it. a proposed model of the lidar is illustrated in [Fig. 48]

$$Distance = \frac{Speed\,of\,light \cdot time}{2} \tag{1}$$

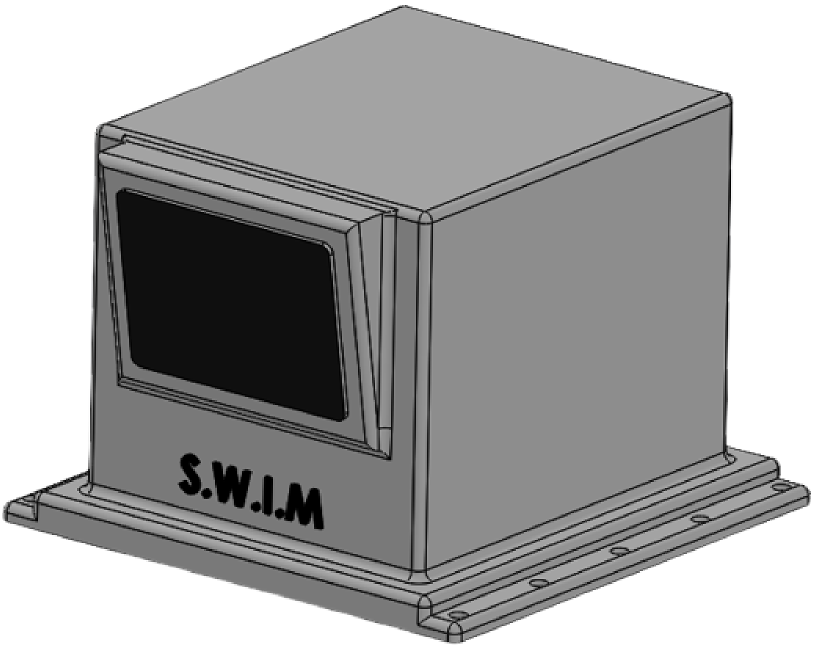


Figure 48: Lidar model.

A.7.6 Radar

The radar used for our system is based on frequency modulated continuous wave technology (FMCW), and uses micro-doppler signatures to differentiate a drone from other anomalies.

A FMCW radar is a radar where a stable frequency continuous wave is transmitted from the radar, and then received from any reflecting objects that the waves hit. Objects are then detected using the doppler effect, causing the received signal to differentiate in frequency from the original transmitted signal. This allows for detection by filtering out the transmitter frequency. By analyzing the received signals we can therefore easily differentiate between drones and other flying anomalies. It's also easy to filter out reflected signals from large stationary objects, as well as clutter returned from the sea and/or weather conditions, making it a perfect choice for use around oil rigs.

The radar has an instrumented range of 5 km, and can detect drones in a dome like area over the boats. The proposed model for the radar is illustrated in [Fig. 49].

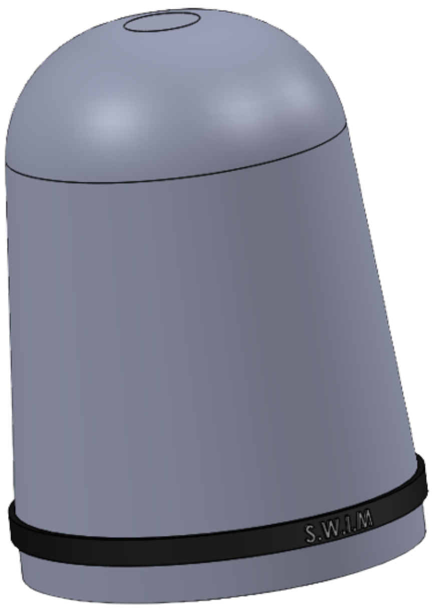


Figure 49: Radar model.

A.7.7 Laser

The laser proposed for our system is an 10 kW laser created for drone elimination purposes. Since the radius of the laser beam increases as the distance increases, its important that the laser beam is focused down to the smallest possible size. This is done by using a beam shaping optic that greatly reduces the beam divergence over longer distances.

Due to the safety zone being 500 meters, we won't face any immediate problems from the beam divergence, but if it should increase at a later time it could potentially become a problem. The laser beam will have its highest damage potential in the middle of the beam, so centering it on the drone is important. Due to our accurate tracking algorithm and camera, we can assure that the laser will be able to lock onto a specific point on a drone long enough for the drone to be destroyed. A proposed model of the laser is illustrated in [Fig. 50].

Figure 50: Laser model.

A.8 Appendix 8: Sensor Fusion

A.8.1 Sensor fusion

Sensor fusion is the process of combining different sensor data to get less uncertainty in the measurements than you would using only one type of sensor. No matter what type of sensor you have their measurements will not be 100% accurate. Using sensor fusion will reduce the noise given by the different sensors, and getting a more accurate result. Another benefit of sensor fusion is that if one sensor measurement differs notably from the other sensors, or that sensor data is lost, that measurement will be ignored and not throw off the combination of measurements from the other sensors. For our case combining the sensor data allows our system to track and classify objects in real time.
We have with our system chosen to use a combination of camera, Lidar and radar technology and combining the result to get an accurate detection for drones, since accuracy is one of the most important factor to our system. Using only one of these sensors is not enough to reliably detect, track and classify drones, so a combination of senors result in the best accuracy for our system. Combining the data will make sure we can fulfill our key performance parameter *accuracy*.

A.8.2 Kalman filter

The Kalman is one of the algorithms often used in sensor fusion. The Kalman filter is a prediction and correction filtering algorithm. Kalman filter takes noisy and inaccurate measurements as an input and output are often more accurate and less noisy estimates and predictions. The kalman filter outputs a combination estimate of the measurements from multiple different sensors. Kalman filter can also output estimates are neither measured nor observed, for example velocity with measured position. For that reason the Kalman filter is used in real time systems that need reliable information [12].
For our system we have created an visual example of how Kalman filter is used in our system to estimate and predict the trajectory of a drone and the combination of Radar and Lidar measurements. This is illustrated in [Fig. 51].

A.8.3 Object recognition

For the classification in our detection system a deep learning algorithm is used. The algorithm is trained on a large data set from the different sensor data. The object recognition algorithm will be able to spot out anomalies in the sensor data. We have in our case decided to use the doppler radar sensor for one part of the classification system. Drones spotted by the doppler radar have their own signatures. These types of signatures is generated by the rotating blades and the body of the drone. The deep learning algorithim can then differentiate between a drone or another object (e.g. bird). Another sensor used for object recognition is the camera. The camera will produce an image that a deep learning algorithm can spot out drone signatures from.

The reason for using a deep learning algorithm is that one of our key performance parameters is accuracy. This means we need great confidence in our classifying. Another benefit for using a deep learning algorithm is that it can be trained from data collected, and it can learn from previous interactions [13]. An example on how the visual image is used in our system is illustrated in [Fig. 51]

We have chosen to not go to much in to detail in what algorithm(s) that will be used for the classification. We are going to use an already existing algorithm or create a new algorithm, but there are currently a few real time object classification algorithms that are used in systems for other purposes (e.g. YOLO, R-CNN, Faster R-CNN).

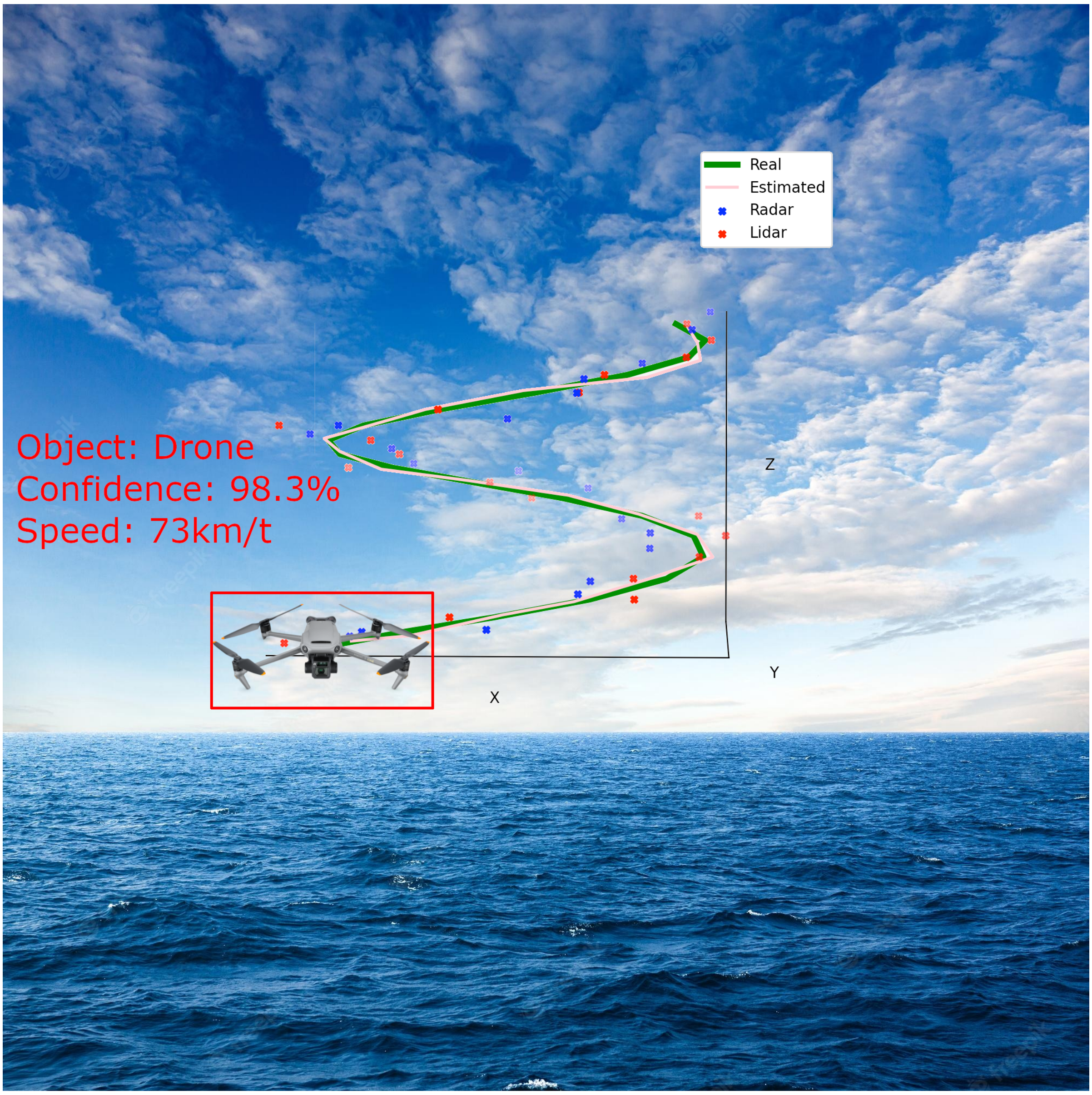


Figure 51: Sensor fusion example.

A.8.4 Training and Developing the Models

To train up the machine learning models, we need lots of data. Our boats can provide this. How can we use our boats to provide data, while they themselves are not at risk of being underdeveloped? Through analysing this problem we have developed a smart solution for gaining and using the appropriate data.

The first iteration would be to train the model on test data such as simulations, and gather data from various weather APIs. The second iteration would be to send the boats on training missions where they can scan their surroundings and where we can send drones onto them to let them get used to the sight of drones. When the training phase is done, the boats shall be trained well enough for a general drone, but the ocean is vast and the weather differs from each day, so we would need even more data.

The autonomous boats collect thousands of sets of data during missions. When they detect a drone they collect data, when they detect a bird they collect data, and so forth. All of the various things happening around the boats are collected through the boats and this data is valuable. Through docking to the hub, the boats gain a private, secure internet connection with the Analysis & Development Department. From here, the boats can upload their data, and know that the department will develop new algorithms and models based on this new data.

A.9 Appendix 9: Analysis

A.9.1 Analyzing anomalies

The timing diagram in [Fig. 52] shows what happens inside the analysis algorithm in [Fig. 56], and how long each step takes (S&C stands for Sensors & Camera).

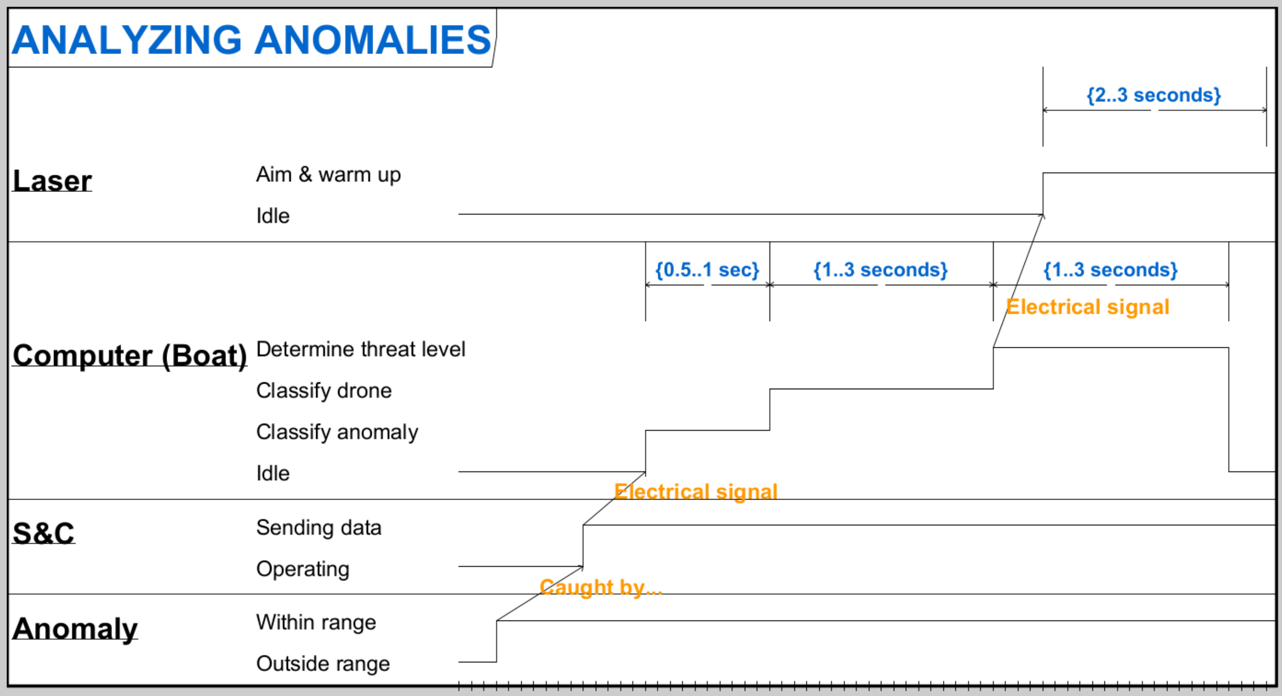


Figure 52: Timing diagram for drone neutralization.

The boat's built-in computer uses a binary (2 possible outcomes) machine learning algorithm to determine if the anomaly is a drone or something else. Because of this simplistic approach, the estimated time for this is relatively short (0.5-1 s). When the anomaly is identified as a drone, it has to be classified as either hostile or friendly. For classifying friendly drones see [Appendix A.12]. If the drone is determined to be hostile, the laser warms up (unless the drone is right above the platform or the visibility is poor. Please see [Appendix A.11] to see how those exceptions are handled). The algorithm then analyzes the threat before deciding if we need two boats for neutralizing. This step also determines what safety precautions the platform crew should follow.

A.9.2 Analyse sequence diagram

This diagram goes a bit more in detail on how the analysing software onboard the autonomous boats is used. The sensor data received from the Radar, Lidar and camera. The serial number checker is further elaborated upon in [Appendix A.12]. Data from the sensors is sent to two algorithms simultaneously. The Kalman filter is responsible for combining data, the classifier classifies the object from a visual image and radar data. The serial number checker returns

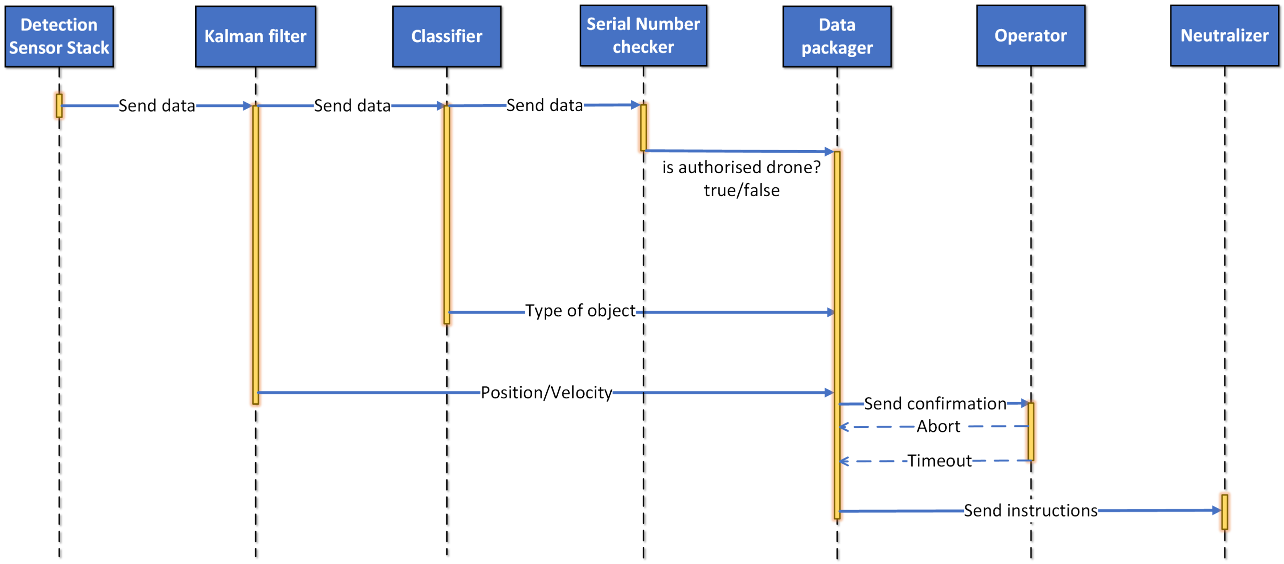


Figure 53: Sequence diagram for analysing threats.

a true/false statement, indicating if the drone is allowed to operate. The data packager combines the data and sends information to the operator located at the Monitor Display system. Information about the algorithms is further discussed in [Appendix A.8].

A.10 Appendix 10: Laser

A.10.1 Drone Swarms and Deciding Laser Effect

Contrary to popular belief, lasers are capable of neutralising multiple threats simultaneously. A concept study conducted by Forsvarets Forksningsinstitutt [3] revealed that one laser can eliminate up to multiple drones, the total amount depending on the laser's reengangement time (i.e. the time it takes to move on from one target to the next).

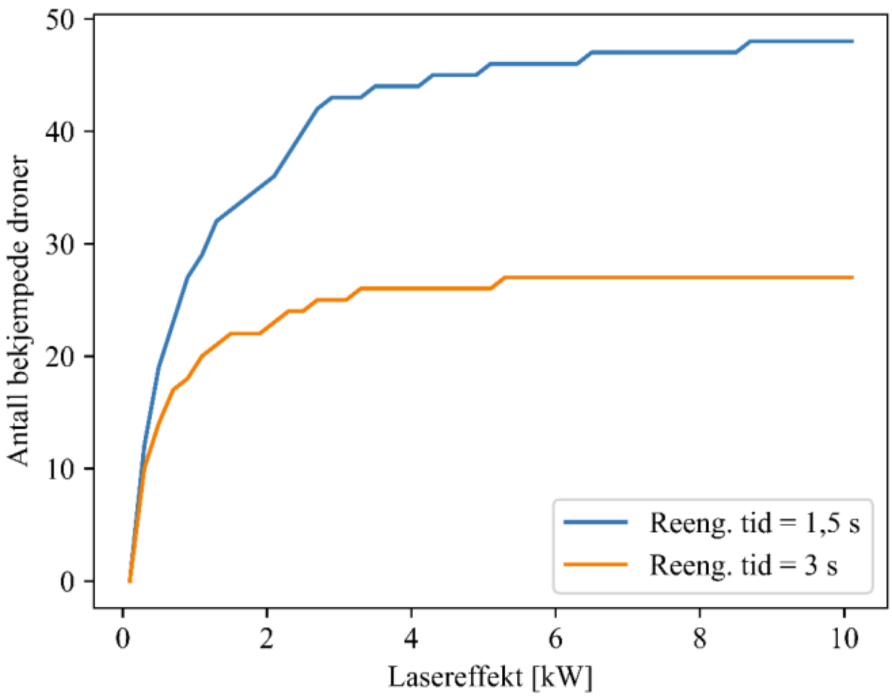


Figure 54: [3] Number of neutralised drones with the laser's reenactment time and effect.

It is important to note that the drones in this study were initially 1km away from the target, not 500 m. We, thus, have deduced that the number of defeated drones is approx. half of that [10-20 drones].

If we analyze [[3], Fig. 54], we observe that we reach diminishing returns at approx 6 kW laser effect, regardless of re-engagement time. Rain and fog will of course reduce our range, but not so much in our case since our lasers will only fire off at objects 500 meters away from it, which is a relatively short distance. From these results, we deduced that S.W.I.M should use 10 kW lasers. The additional wattage provides a slight buffer for the aforementioned impact from bad weather. The one major downside to using lasers is that certain metals have sub 10% absorption rate. Fortunately, though, the rate of absorption for such materials can reach close to 100% as they rise in temperature.

This of course consumes time. To rectify this, S.W.I.M. can use two lasers simultaneously to neutralise, as shown in [Appendix A.10.2].

A.10.2 Two lasers

In most instances, one laser is sufficient for neutralizing. However, in order to always meet our KPP regarding a 7-second neutralization time, we have designed S.W.I.M. with the capability of firing two lasers simultaneously at the same target. This solution is unorthodox, but is a more viable option than one might think at first. For one, a 10 kW laser is not powerful enough to displace the enemy drone from its expected trajectory.
One concern is that combining two beams could result in the wavelengths cancelling each other out due to the principle of superposition. Fortunately, this is not an issue for since the beams will not be directly pointing at each other, the target drone will stand in between them.

Figure 55: Using two lasers to neutralize.

The one true weak point our solution has is if the enemy drone is flying at surface level. In that case, it might not be safe to use two lasers as the beams could end up firing directly at each other, damaging our equipment. However, this is a edge case with a low likelihood of occurring.

A.10.3 Verification of two lasers in seven seconds

For visualizing and verifying how our two lasers can neutralize a drone in less than 7 seconds a timing diagram was used illustrated in [Fig. 56].

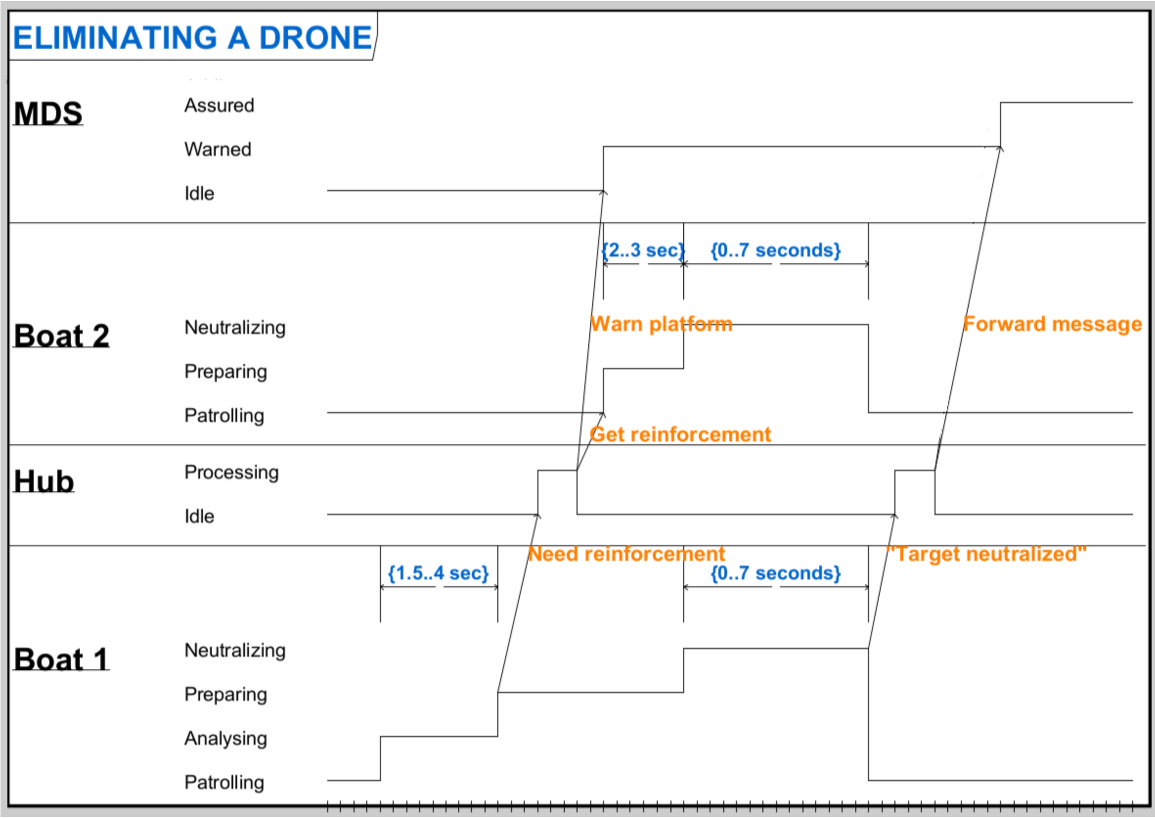


Figure 56: Timing diagram for drone neutralization.

Once an anomaly is spotted (by Boat 1 in [Fig. 56]), the boat analyzes it. This step occurs way before the anomaly has trespassed the 500 m boundary, giving us more time. The boat then sends a signal to the Hub, informing it that there might be a nearby threat. The Hub forwards the warning to our Monitoring Display System (MDS). How this warning signal is handled depends on the threat level of the drone, based on speed, distance from the platform, size and potentially information about the payload.

If the anomaly is identified as a hostile drone, Boat 1 signals the Hub that it needs reinforcements from another boat. The Hub then informs the most suitable boat for the mission, in this case Boat 2. Both boats then take aim and heat up their lasers. Once the enemy trespasses the 500 m security zone, both lasers fire off at it in less than 7 seconds, represented with a duration constraint. One of the boats then informs the Hub (which forwards the message to the MDS) that the target has been neutralized. For future analysis and to strengthen our machine learning algorithm, all the collected sensor data is uploaded to S.W.I.M's Analysis & Development department when the boats dock into the Hub.

A.11 Appendix 11: Drone Catcher

A.11.1 Rapid Risk Analysis

For risk assessments, we have seen from tables for assessment of consequence, probability, risk matrix and risk levels. With help from the various tables, we can assess what may occur and the degree of severity from minor damage to catastrophic. We did a risk analysis for the system where we have considered some scenarios and carried out rapid risk ranking.

ID	Risk	Reason	Preventive measures	Consequence			Probability	Risk		
				People	Environme	Structure		People	Environme	Structure
1	Hostile drone above platform.	The drone can be flown above the safety zone and down on the platform.	Catching hostile drone with net carried by drones from platform. Good protection of the air space, and alarm system. Detection has a	1	1	1	E	H	H	H
2	System failure.	The system fails while observing.	Good backup system. Control guy can override. Spare parts.	3	2	2	C	H	H	H
3	Weather and waves that makes hard conditions for boats.	Weather and waves making surveillance and use of laser challenging.	Several types of sensors connected. Several boats crossing safety zone. Drones catching hostile drones with net.	5	5	4	E	M	M	H
4	Incorrect assembly and/or use of the system.	Not thorough enough work. Missing parts or something that has been overlooked. Incorrect use.	Thorough and regular inspection and maintenance of material. Assembly is controlled by qualified workers. Continuous course/training. Easy to understand user manual, in several languages.	3	2	5	C	H	H	L
5	Using laser.	Use of laser to shoot down hostile drone.	Security measures close to platform. Safety zone for use of laser. Alarm on platform. Drones catching with net.	5	3	5	D	L	H	L

Figure 57: Rapid risk ranking.

With this analysis, we find various risks that may arise. Further we decide whether it is important to make preventive measures or not. There is a limitation which means that safety must be assessed. Out of this risk assessments we found some factors that were important to cover for the safety on the platform.

One of the things this made us aware of, was the risk of using laser above the platform. If the drone flies above the radius of where we can use laser, and then drops down right above the platform, shooting it down by laser may cause a big risk for the civilians on the platform. The risk would be both if the drone falls down, or using laser close to the platform. Knowing this we decided to use drones with nets in this scenario instead. This way we lower the risk of damage to the platform and the civilians on it. Additionally there will be a system that receives notification on the platform, which gives the workers a warning.

A.11.2 Drone Catcher Sequence

The sequence diagram found in the report [Fig. 17] illustrates the preceding steps that activate our drone-catcher subsystem and the communications between all the relevant subsystems. The sequence of events is initialized by an anomaly that our boats have identified as an enemy drone. Once identified as an enemy, the boat then analyzes the weather and the enemy's position relative to the protected oil platform.

If "AnalyzeRadius" or "AnalyzeWeather" return "negative results", the boat will signal the Hub that the drone-catcher must be responsible for neutralization instead of itself. The boat then continuously sends updated coordinates to the Hub, which then forwards it to the drone-catcher and the MDS until the drone-catcher has the enemy in sight.

Once within reach, the drone-catcher captures the drone with a net and transfers it far away from the platform. If the drone-catcher is hit/damaged or exposed to a lot of wind, it will stabilize itself using hardware and software. Once neutralized, everyone on the platform is assured that it is safe to go outside.

A.12 Appendix 12: Classifying friendly drones

When designing our detection subsystem we found out we needed the capabilities to classify "friendly" drones. For now we cannot find any references for oil platform using drones as a tool, but since the use of drones are rising we wanted to take this into consideration for the future.

For separating "friendly" and "enemy" drones we first decided to use machine learning to train an algorithm for separating them. We found out that this would be difficult since what classifies as an enemy drone has no concrete distinguishing factors between friendly drones. Visual distinguishing factors could be used, but this could also easily be replicated by a threat actor. We decided drones permitted to fly would need a transmitter (TX) installed. The boats will have an receiver (RX) installed. The TX would send out a number identifying that this drone is friendly. The RX will receive the number and check it against a database.

To avoid threat actors being able to replicate another drones number, the number is supposed to be a rolling number that works like a Multi factor Authentication (MFA) token. The transmitter contains a clock that generates a random number at a given time interval, with a personalised seed (a number used for psudo-random number generation). This number would be unique for that drone. The RX receives the number transmitted by the TX and checks the number against a local database.

Before drones will be able to operate in the area around our system. The need to be registered in our database. The database will have drones and their unique seed. The boats will be pushed with a copy of drones that are scheduled to fly. The boats can then use this list to generate the same number for each drones scheduled to fly and check it against the received number. Drones not located in this database will be classified as non-friendly.

A.13 Appendix 13: Network and Communication

A.13.1 Network Topology

Our system consist of a network of multiple boats that all need to be able to update each other about incoming threats and work together towards eliminating the danger. We have mainly looked at two options for handling and arranging the communication between these boats.

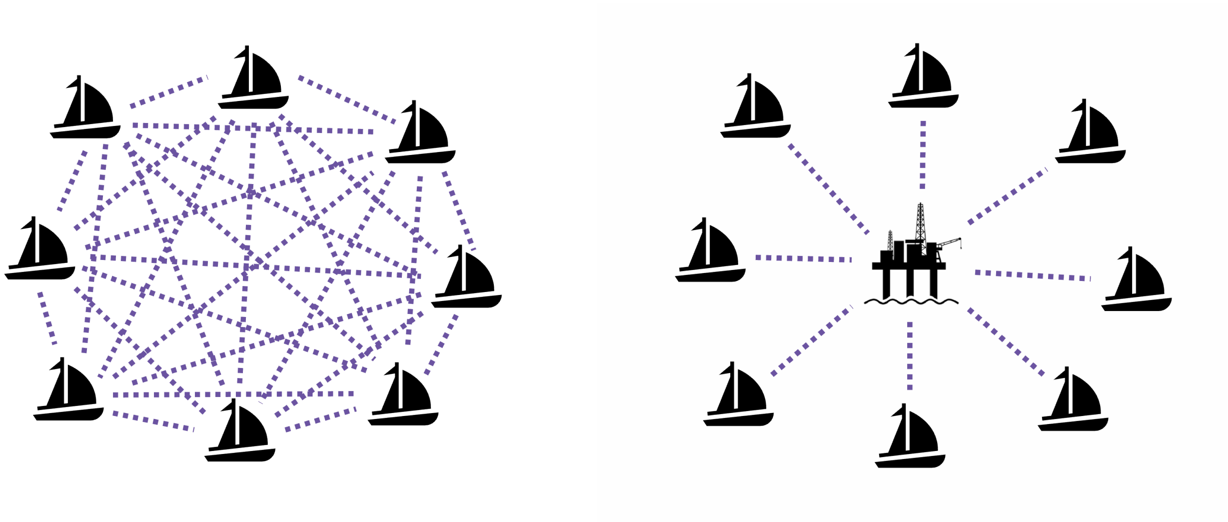
Mesh topology

One of the first arrangements we looked at was the mesh topology. In this technology all the boats communicate directly with each other, and everyone keeps track of the boats' placement at all times. One issue we found with this type of technology was that it consumed a lot of processing power and therefore would need heavier system specs. This also meant that it would consume a lot of power, which directly goes against one of our requirements regarding maintenance, *“The system should be easy to handle by the operator and installation- and maintenance crew.”* [Section 2.3, stakeholder requirements, bullet point nr. 2]. Not only would the batteries need changing more often than hoped for, but the boats themselves would need regularly maintenance due to heavily switching between them caused by low battery. This power consumption problem would in addition not be too good for the environment, so we decided to look for other options.

Star topology

The star topology was an idea from early on, but needed investigation. The idea here is that none of the boats communicate directly with each other, but all will send their messages to a central, which either passes them along or makes decisions based on the input given. The star topology turned out to be just what we needed for our system. The power consumption was lower, so this was already a plus, but we also noticed some strengths that we had not though of with the mesh. Security was a big plus with the star network as the central is the ”owner and distributor”, while the boats only would be slaves. This meant that if one were to hack into the system and take control over one boat, you would only have access to that boat, and not the entire system. Another plus was regarding troubleshooting, as a star network is cleaner and it is easier to understand where the problem derives from, whereas in a mesh everyone sits on the same code and data and it would be difficult to figure out which boat started it.

An assumption was that a star topology would be slower than a mesh network. This turned out to be the complete opposite, as mesh networks would need to pass messages between all nodes in the mesh network, while the star always could just send it to the central, and the central would pass it along to the correct boat. We found that this central could also be practical for other reasons, and began developing on this thought. The central quickly turned into our position planner and later become what we know of as the Hub.



(a) (b)

Figure 58: (a) Mesh network topology. (b) Star network topology.

A.13.2 FileCatalyst

All of our subsystems need to continuously communicate with each other with short latency. A high latency would lengthen our response time for warning and neutralization so much that our entire system would be powerless. High data transfer rates are easy on land, but on an offshore oil platform with moving vessels, there is a heightened risk of signal loss. In addition, high data transfer speeds often come with the cost of reduced security, which is unacceptable for us due to the context that S.W.I.M operates in.

Fortunately for us, excellent solutions already exist in the marketplace, especially by FileCatalyst. FileCatalyst is a well-established firm recognized for Fast File Transfer (FFT); a solution that allows for transfer speeds up to 10 Gbps, regardless of weather and location. For reference, 10 Gbps is so fast that a computer can download a 4K movie in 30 seconds or less. FileCatalyst achieves this by acting as a centralized hub (which in our case would be installed on the oil platform as it is stationary when in operation). This technology has been tried and tested offshore. For instance, Petroleum Geo-Services (PGS); a marine geophysics company, uses FileCatalyst to transfer data from moving ships [14].

> "The first benefit we noticed after implementing FileCatalyst was the enhanced control over our transfers and a dramatic speed improvement—we are finally able to use our 10 Gbps line speed to its full extent." – Petroleum Geo-Services [14].

To achieve this, FFT uses User Datagram Protocol (UDP), a networking protocol that is responsible for how data packets are transported from destination to source. UDP is fast, but it does not check if the packets have reached their destination or if they are sent in the correct order, compromising security. To rectify, FFT also recovers lost packets has data flow mechanisms such as using algorithms to prevent congestion of data traffic. In addition to industry-standard encryption and authentication built-in, FileCatalyst's solution results in both consistently fast and secure data transfers.

A.14 Appendix 14: Calculations

A.14.1 Response time calculations

For our *Response time* key performance parameters we needed to have a upper bound limit for neutralizing. Our first system requirement is that we want to protect against drones up to 120 km/h. Since the safety zone of an Norwegian oil platform is 500 m. That means a drone traveling 120 km/h or 33.33 m/s [eq. 2] from the start of the safety zone to the edge of the platform takes 15 seconds [eq. 3] to reach the edge.
We opted to find the needed response time for drones traveling 250 km/h or 69.5 m/s [eq. 4]. After an internal discussion we concluded with drones that are capable of these speeds are low risk to our stakeholders, since the surveillance and payload capabilities are limited for these types of drones (e.g. racing drones). We made an assumption that if our system is able to neutralize drones capable of these speeds, the system is able to neutralize slower drones. After these calculations we wanted our response time for neutralization to be 7 seconds [eq. 5]

$$\frac{120km/h}{\frac{1000m}{3600s}} = 33.33m/s \tag{2}$$

$$\frac{500m}{33.33ms} = 15.001 \tag{3}$$

$$\frac{250km/h}{\frac{1000m}{3600s}} = 69.5m/s \tag{4}$$

$$\frac{500m}{69.5m/s} = 7.2s \approx \underline{\underline{7}} \tag{5}$$

A.14.2 Position calculations

The requirements discussed in [Section 7.1] can be divided into sub-requirements as follows:

1. The cumulative area of all boats A_i should cover the entire horizontal and vertical circumference of the spherical A_{safe}. This ensures that for every point in the safety zone, a drone will be discovered and engaged by our system.

2. When possible, adjust boat positions to increase overlap between areas A_i. This will contribute to lower neutralization time which in turn lowers response time by increasing the likelihood that multiple boats can engage the same targets and increase the weapons' damage output.

When tackling the first sub-requirement, we need to deal with blind zones - for any point in the safety zone, there are no positions a boat can take where it single-handedly has line of sight on the entire safety zone. Blind zones triggered by the platform is visualized in [Fig. 59]

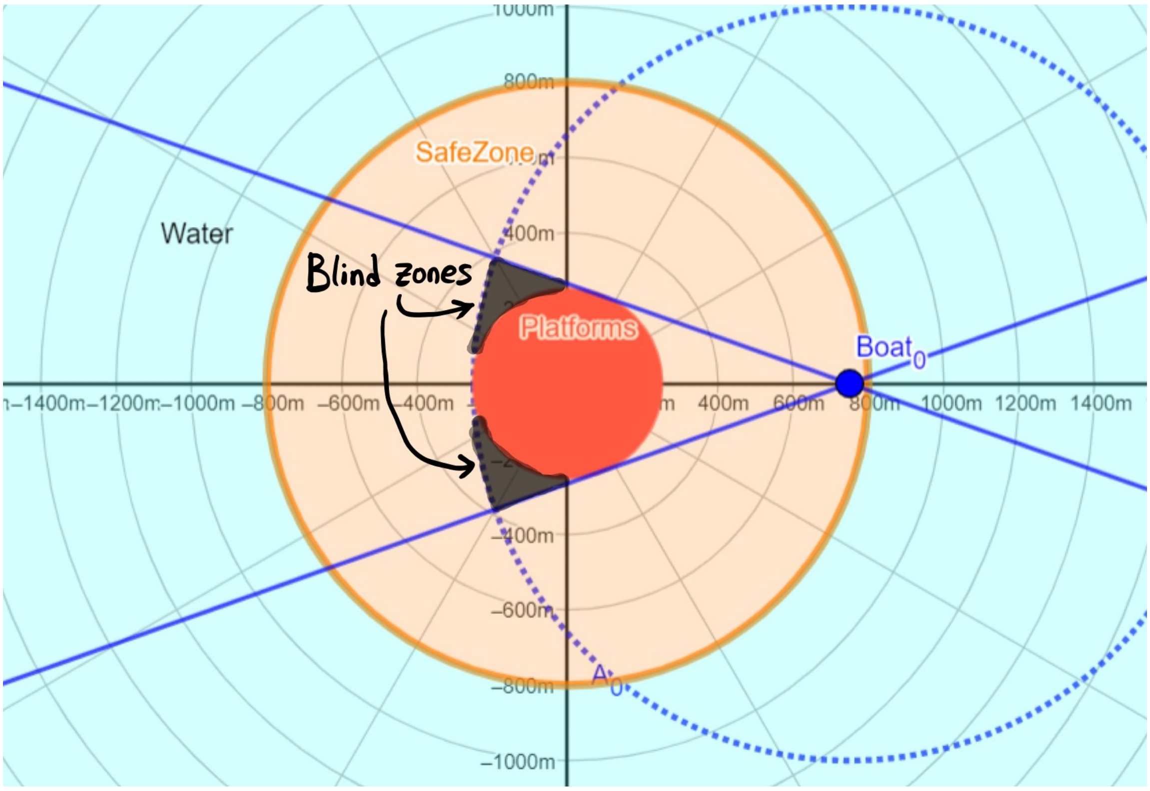


Figure 59: Blind zones triggered by platform visualized.

We also have an issue with the vertical reach of our weapons. As visible on [Fig. 60], if seen as a side-view, we can see that the weapons radius in this case does not reach the top of the safety zone. This is an issue that occurs when $r_{laser} < \sqrt{2}r_{safe}$. This means there's a blind zone that drones can exploit where the distance to the platforms is shorter than on any other angle. We must therefore ensure that the boats always cover the top of the safety zone.

To solve for these blind zones we will first add another boat to the system that compensates for the first boat's blind zone caused by the platform. We will then adjust the "offset" - how far the boats are placed from the center of the safety zone. Valid values for offset can by any number in the range of $< r_{platforms}, r_{safe} >$. Within this range, the offset is calculated like this and its results visualized below:

$$offset(r_{laser}, r_{safe}) = \begin{cases} \sqrt{r_{laser}^2 - r_{safe}^2} & , r_{safe} > \sqrt{(r_{laser}^2)/2} \\ r_{safe} & , r_{safe} < \sqrt{(r_{laser}^2)/2} \end{cases} \tag{6}$$

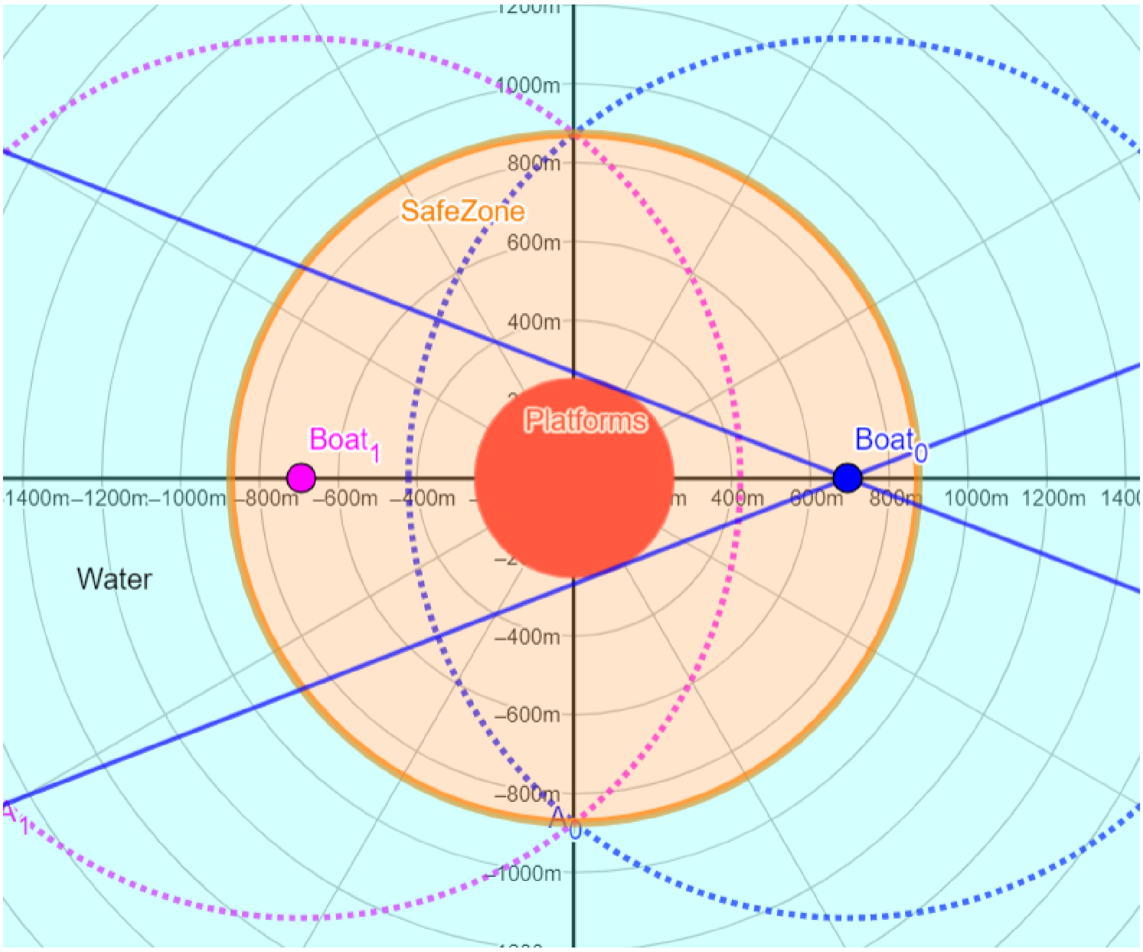


Figure 60: Blind zones solved by adding a boat and offset.

To solve for the second sub-requirement, we will add more boats to our system so that their areas overlap and we have 2 or more overlaps for every point in the safety zone. By having areas overlap we ensure that multiple boats can engage the same drones which will greatly reduce the neutralize time and help us guarantee a time lower than 7 seconds. A birds-eye-view of the system of 4 boats and their overlapping areas are visualized below. Note that "3-4" indicates that there are volumes in this area where 4 zones overlap, but other volumes where 3 overlap:

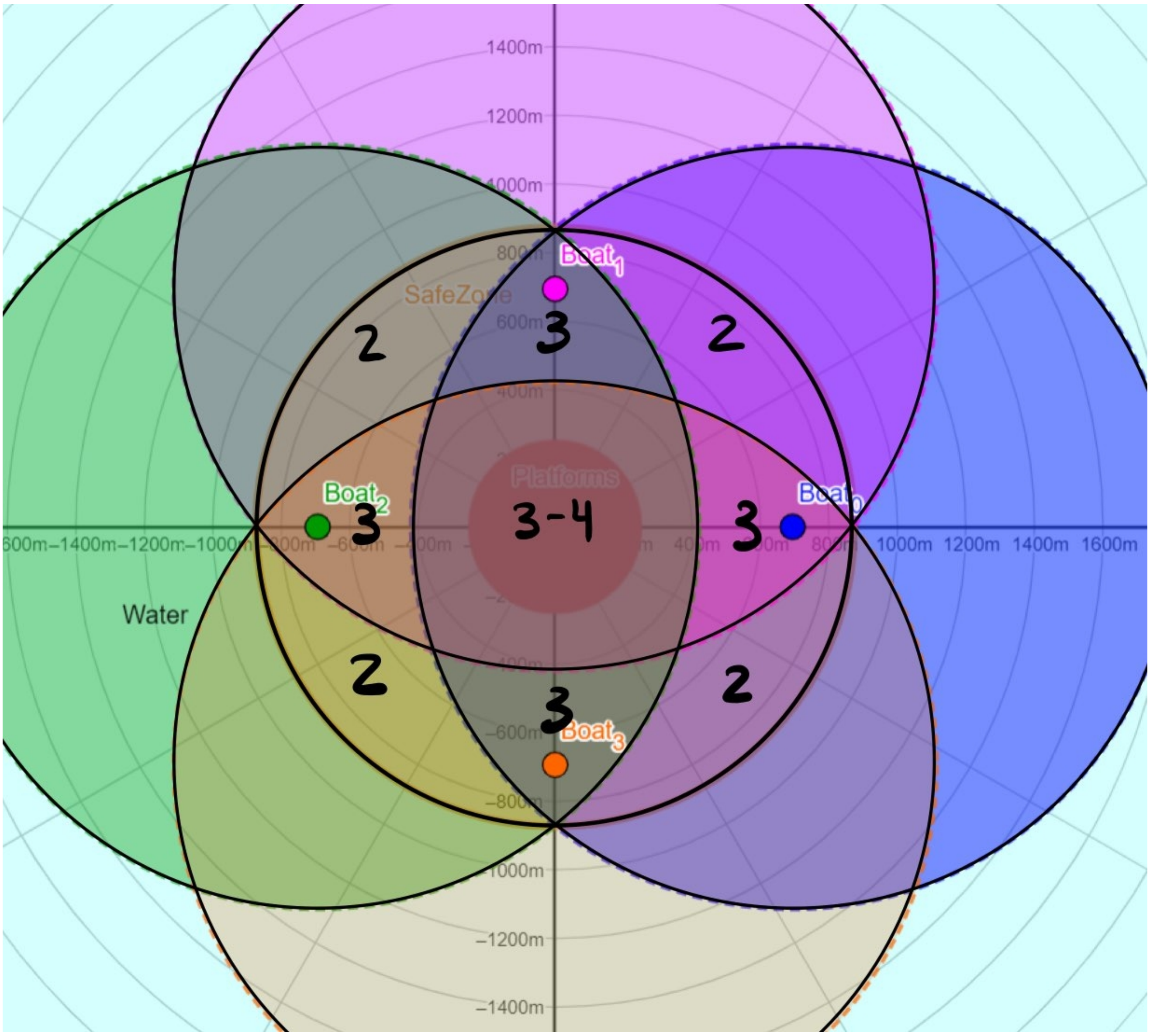


Figure 61: Overlapping boat weapon areas.

A.15 Appendix 15: Future Development

Picking up the drones

Early on we saw that our system would not be completely recyclable and environmentally sustainable if the drones we shoot down is not picked up again. We had a few discussions about this, some including a capturing net, or using the drone-catcher system. However, we came to the conclusion that this was beyond our scope, and that we could either outsource this problem, or work on it later on. This problem would have to be solved for our system to be optimal.

Drone catcher

As we saw from the conclusion after the rapid risk analyses in [Appendix A.11.1], we ended up outsourcing a drone cathcer to use above the platforms. For further development, this would be one of the things we would like to look more into. Maybe designing a drone cathcer system of our own, and figuring out where to place, and what to do with the captured drones

Placement of the Hub

The Hub will be placed in contact with the platform for power supply. Initially we designed it to lay on the water below the platform, but because of extreme weather conditions that often occurs out in the open sea, like 5-10 meter tall waves, we got skeptical to the placement. This will not be suitable for a relatively small Hub. An alternative we have looked a bit into is to put the Hub up under the platform with a crane that can lift the H ub up and down autonomously when we need to switch boats. [Fig. 62] shows a quick illustration of this.

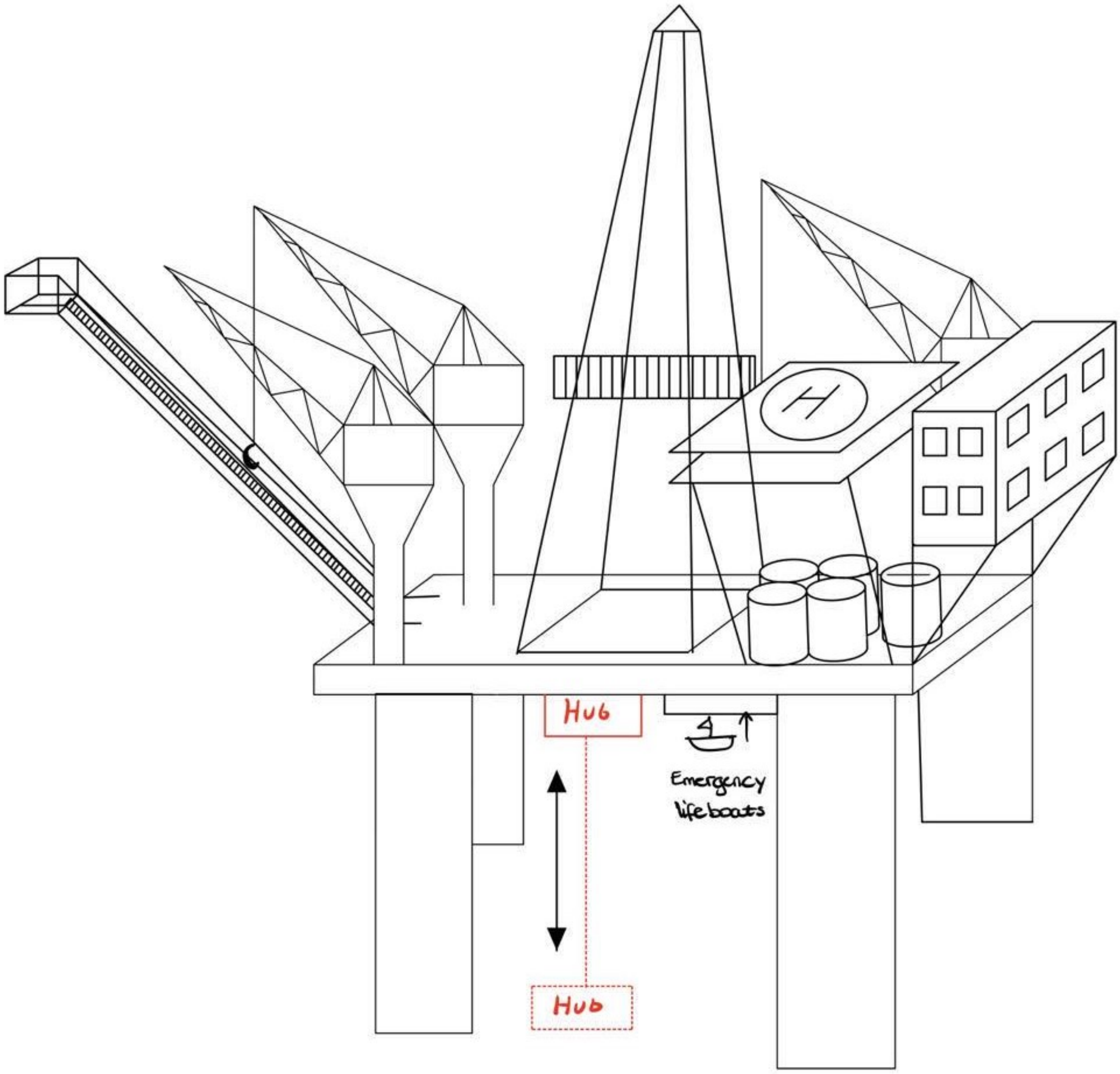


Figure 62: Hub placement.

A.16 Appendix 16: Finances

Cost of Ownership Model			
Purchase of system	Product	$	1,520,000
	Installation	$	100,000
	Training	$	144,000
	Upkeep	$	5,000,000
Total system cost		$	6,764,000
After sales	Extra boat	$	200,000
	Recalibration	$	10,000
Total aftersales cost		$	210,000
Total life cycle cost		**$**	**6,974,000**

Figure 63: Cost of Ownership Model.

Activity	**Cost/Price per unit**	
System price	$	7,000.00
System after sales price	$	210.00
Base salary	$	(50.00)
System manufacturing	$	(1,200.00)
System deployment	$	(1,000.00)
Marketing	$	(5.00)
Operations	$	(75.00)
Warranty	$	(250.00)
GROSS PROFIT	$	4,630.00
GROSS MARGIN (%)		64.22%
Tax cut (30%)	$	(1,389.00)
NET PROFIT	**$**	**3,241.00**
NET MARGIN		**44.95%**

Figure 64: Profit margins.

Activity	Year 1	Year 2	Year 3	Year 4	Year 5
Manufacturing volume	0	1	2	4	8
Sales volume (units)	0	0	1	2	4
Systems in operation	0	0	1	3	7
Number of Employees	12	15	20	25	30
Research & Development	$ (500)	$ (500)	$ (250)	$ (125)	$ (63)
System development	$ (750)	$ (750)	$ (375)	$ (188)	$ (94)
System manufacturing	$ -	$ (1,200)	$ (2,400)	$ (4,800)	$ (9,600)
System deployment	$ -	$ -	$ (1,000)	$ (2,000)	$ (4,000)
Marketing	$ (60)	$ (75)	$ (100)	$ (125)	$ (150)
Salaries	$ (600)	$ (750)	$ (1,000)	$ (1,250)	$ (1,500)
Operations	$ (195)	$ (263)	$ (350)	$ (475)	$ (675)
Maintenance	$ -	$ -	$ (188)	$ (563)	$ (1,313)
Sales	$ -	$ -	$ 7,000	$ 14,000	$ 28,000
After sales	$ -	$ -	$ 210	$ 630	$ 1,470
Gross result	$ (2,105)	$ (3,538)	$ 1,548	$ 5,105	$ 12,076
Tax cut (30%)	$ -	$ -	$ (464)	$ (1,532)	$ (3,623)
Net result	**$ (2,105)**	**$ (3,538)**	**$ 1,083**	**$ 3,574**	**$ 8,453**
Ingoing balance	0	$ (2,105)	$ (5,643)	$ (4,559)	$ (986)
Outgoing balance	$ (2,105)	$ (5,643)	$ (4,559)	$ (986)	$ 7,468

Figure 65: Finances under ideal circumstances.

Activity	Year 1	Year 2	Year 3	Year 4	Year 5
Manufacturing volume	0	0	1	2	4
Sales volume (units)	0	0	0	1	2
Systems in operation	0	0	0	1	3
Number of Employees	12	15	20	25	30
Research & Development	$ (500)	$ (500)	$ (500)	$ (250)	$ (125)
System development	$ (750)	$ (750)	$ (750)	$ (375)	$ (188)
System manufacturing	$ -	$ -	$ (1,200)	$ (2,400)	$ (4,800)
System deployment	$ -	$ -	$ -	$ (1,000)	$ (2,000)
Marketing	$ (60)	$ (75)	$ (100)	$ (125)	$ (150)
Salaries	$ (600)	$ (750)	$ (1,000)	$ (1,250)	$ (1,500)
Operations	$ (195)	$ (225)	$ (313)	$ (400)	$ (525)
Maintenance	$ -	$ -	$ -	$ (188)	$ (563)
Sales	$ -	$ -	$ -	$ 7,000	$ 14,000
After sales	$ -	$ -	$ -	$ 210	$ 630
Gross result	$ (2,105)	$ (2,300)	$ (3,863)	$ 1,223	$ 4,780
Tax cut (30%)	$ -	$ -	$ -	$ (367)	$ (1,434)
Net result	**$ (2,105)**	**$ (2,300)**	**$ (3,863)**	**$ 856**	**$ 3,346**
Ingoing balance	0	-2105	-2300	-3862.5	855.75
Outgoing balance	$ (2,105)	$ (2,300)	$ (3,863)	$ 856	$ 3,346

Figure 66: Finances if production is delayed by 1 year.

A.17 Appendix 17: Other diagrams

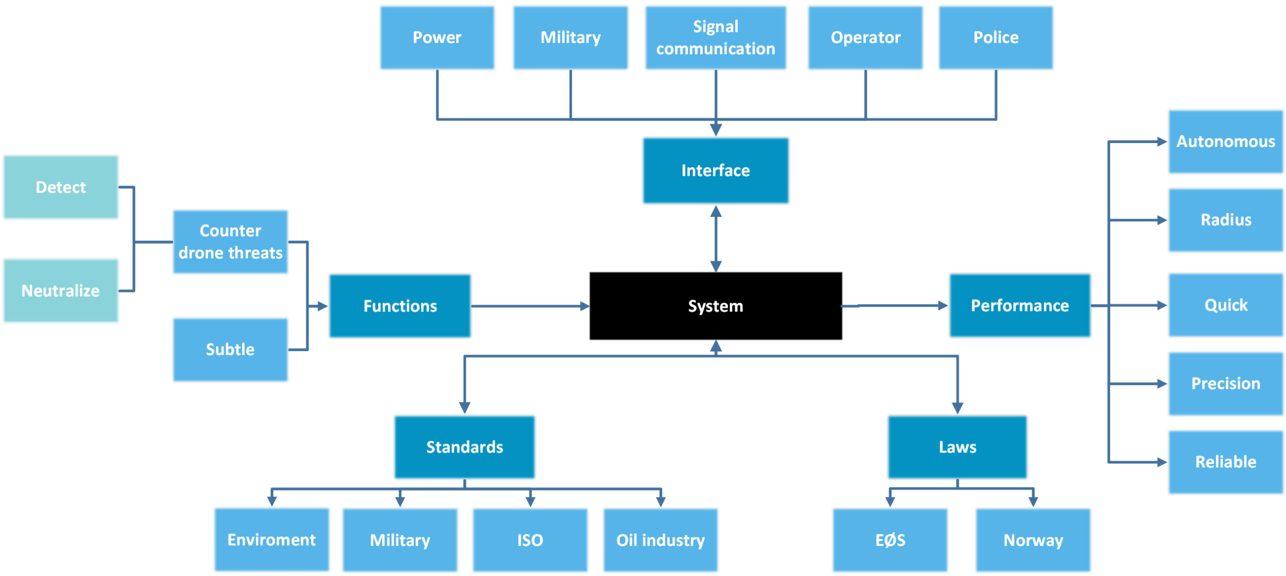


Figure 67: Blackbox diagram.

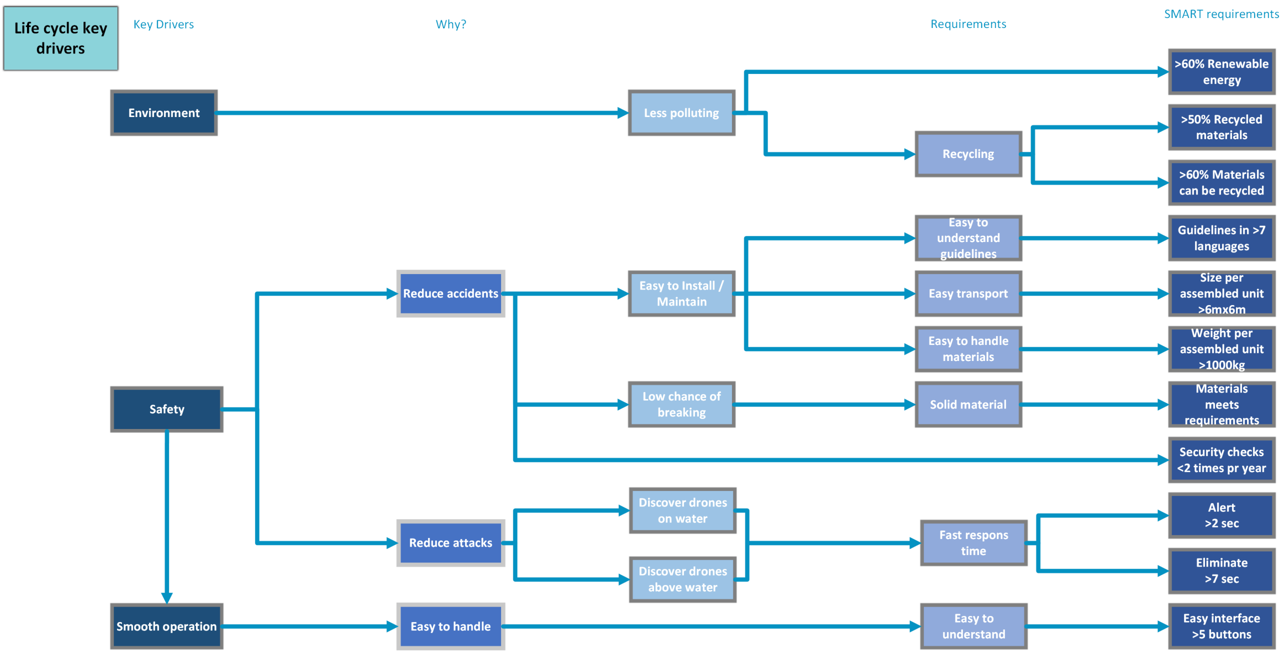


Figure 68: Life Cycle Key driver graph.

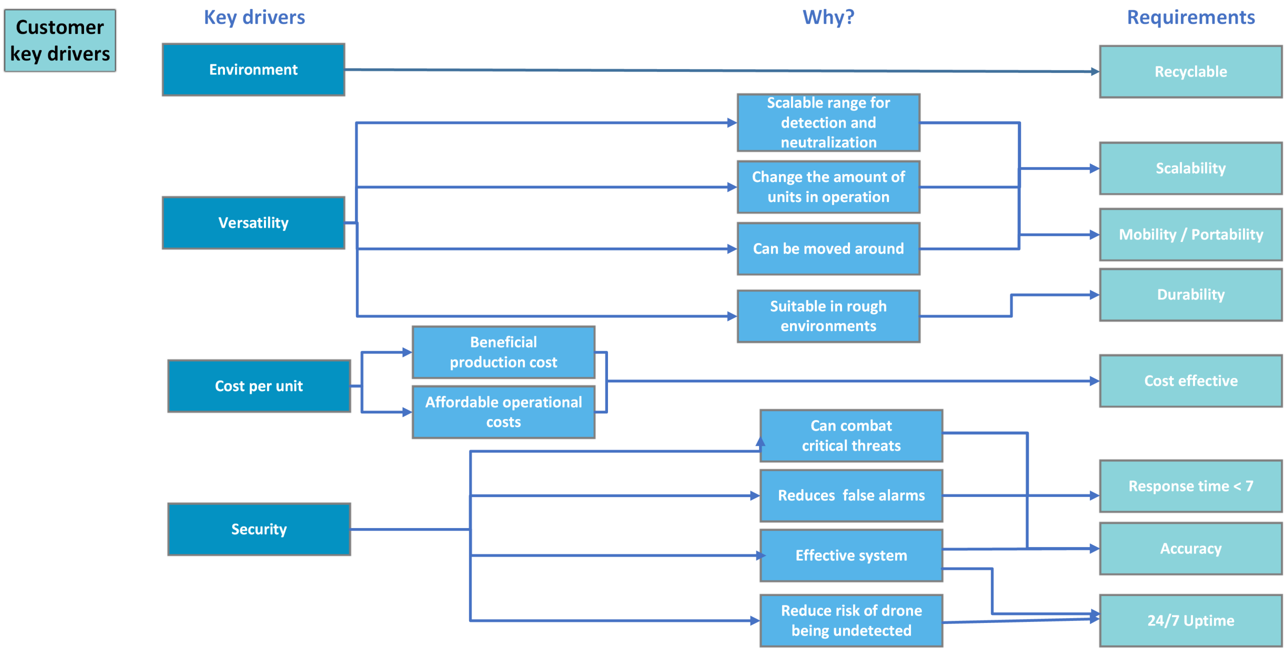


Figure 69: Customer Key driver graph.

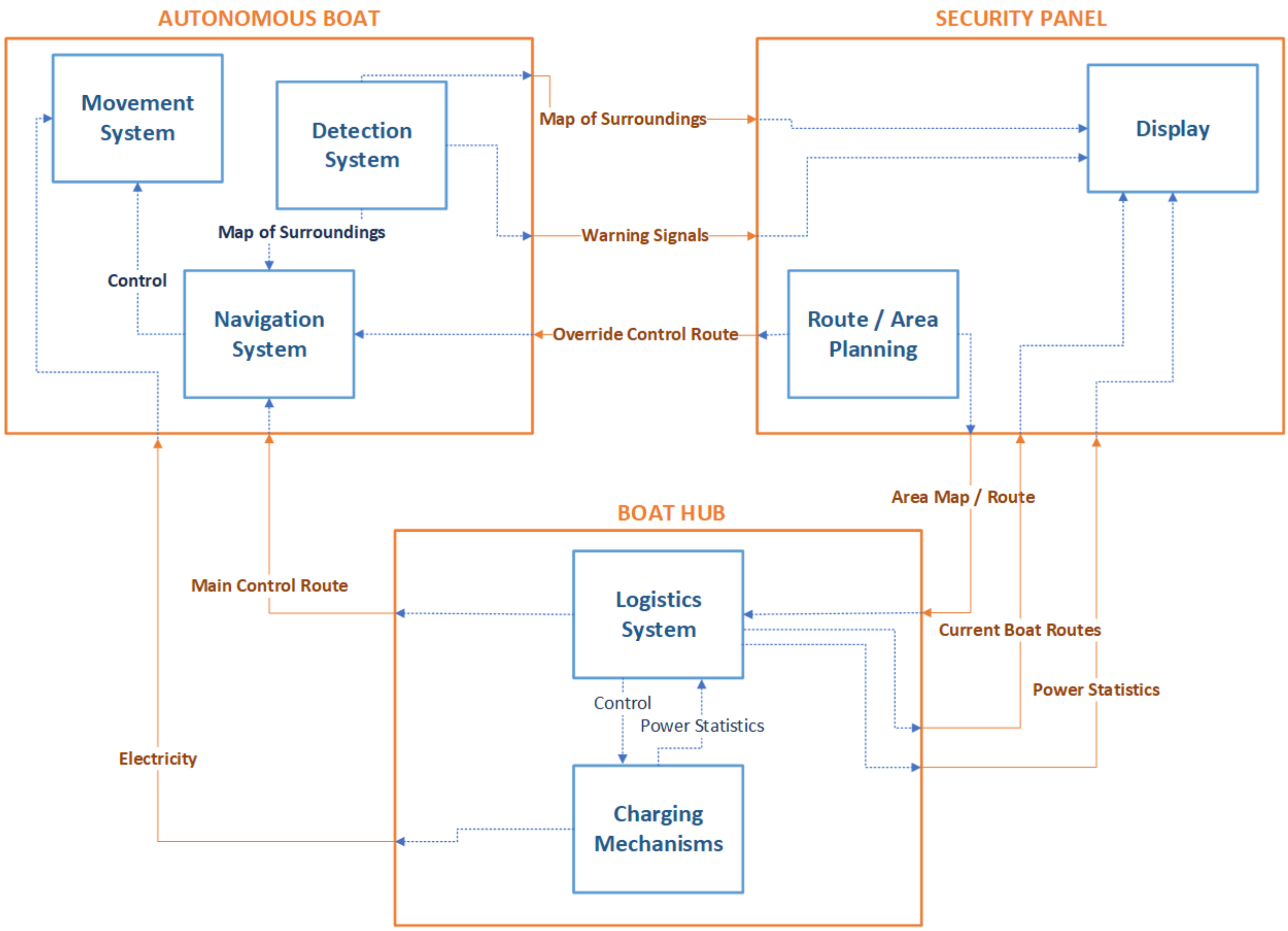


Figure 70: Block Diagram

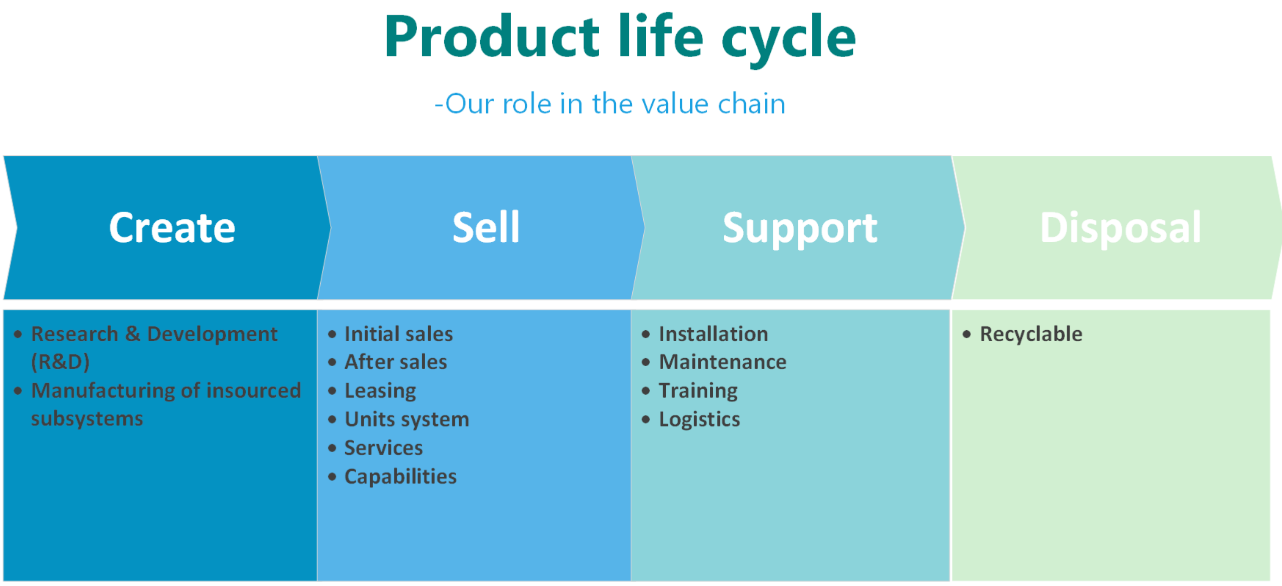


Figure 71: Life Cycle - our role in the value chain

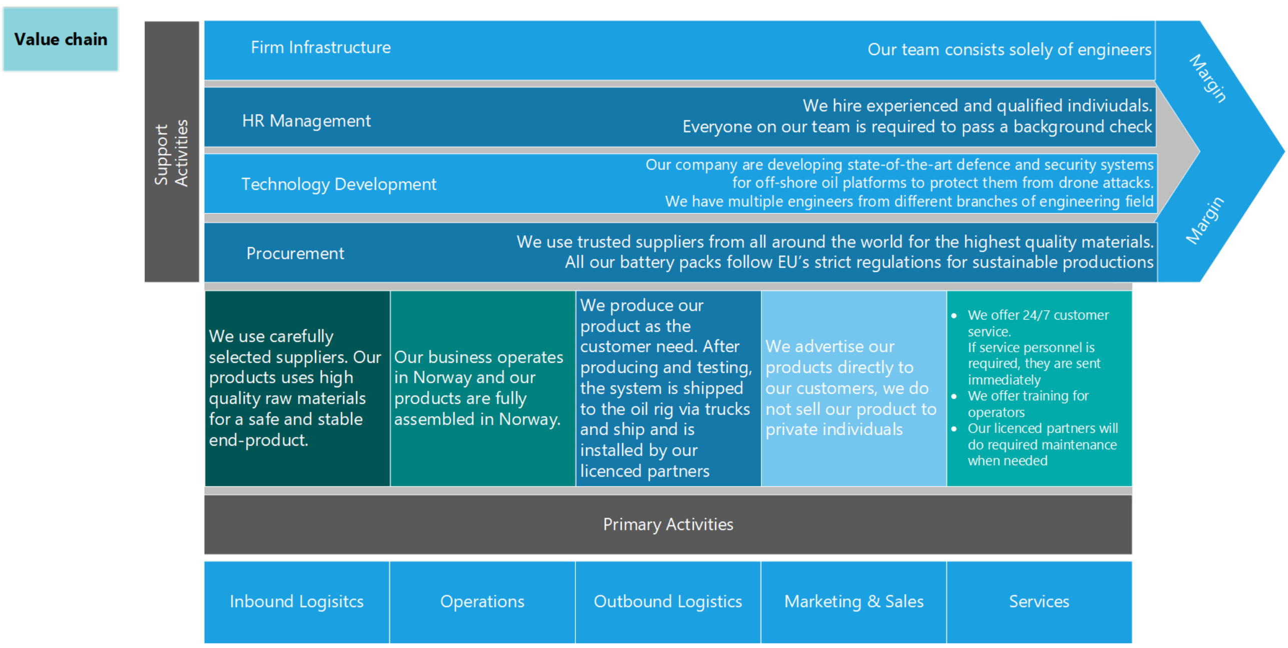


Figure 72: Value Chain

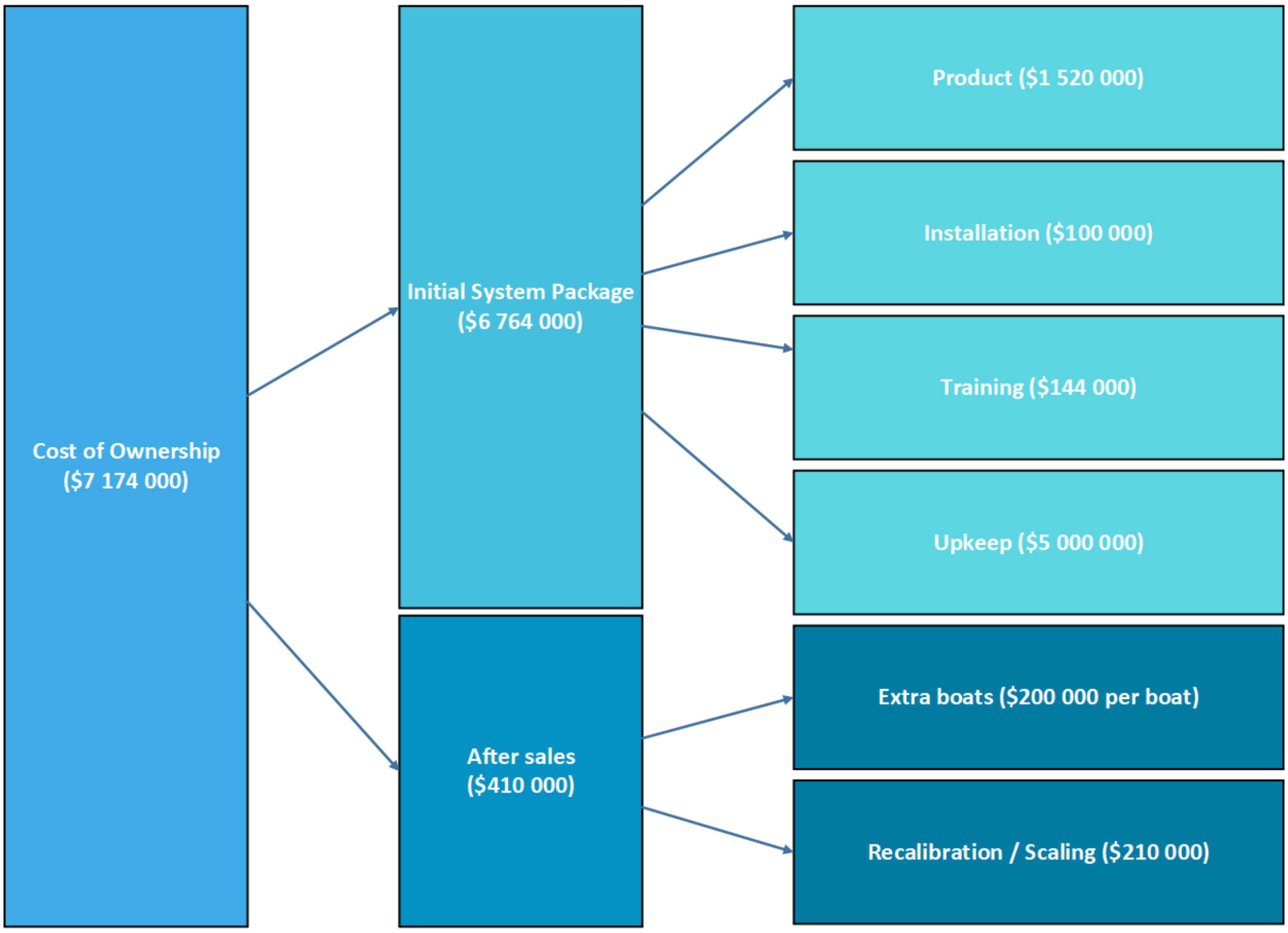


Figure 73: Cost of ownership

63