Autonomous Waste Collecting Boat

Group 1 - Systems Design and Engineering

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1 Introduction

1.1 Group information

We have decided to name our project "Plactor" as a shortened word for "Plastic Collector". The reason why we thought of this group name was because the assignment was based on collecting plastic from lakes and rivers, so we combined "Plastic Collector" into "Plactor" and went along with it. Later on we decided to collect all kind of waste, and not just specifically plastic. Even though we updated the concept of operation, we kept the same name because it sounds reasonable and we grew fond of it.

Plactor consists of six members from different engineering disciplines at USN Kongsberg, with different work background and experience. We have four students from computer engineering, one electrical engineering student and one mechanical engineering student. The reason why we went towards a multidisciplinary approach was because of the ability to combine our different views on topics that involve software, electrical and mechanical engineering. The fact that we are very different from each other is a huge benefit to the project, because then we can think from different perspectives and portrait problems from different angles.

There are a lot of things that students from these three engineering disciplines can do, and when you combine these three and form a multidisciplinary group, amazing things can happen.

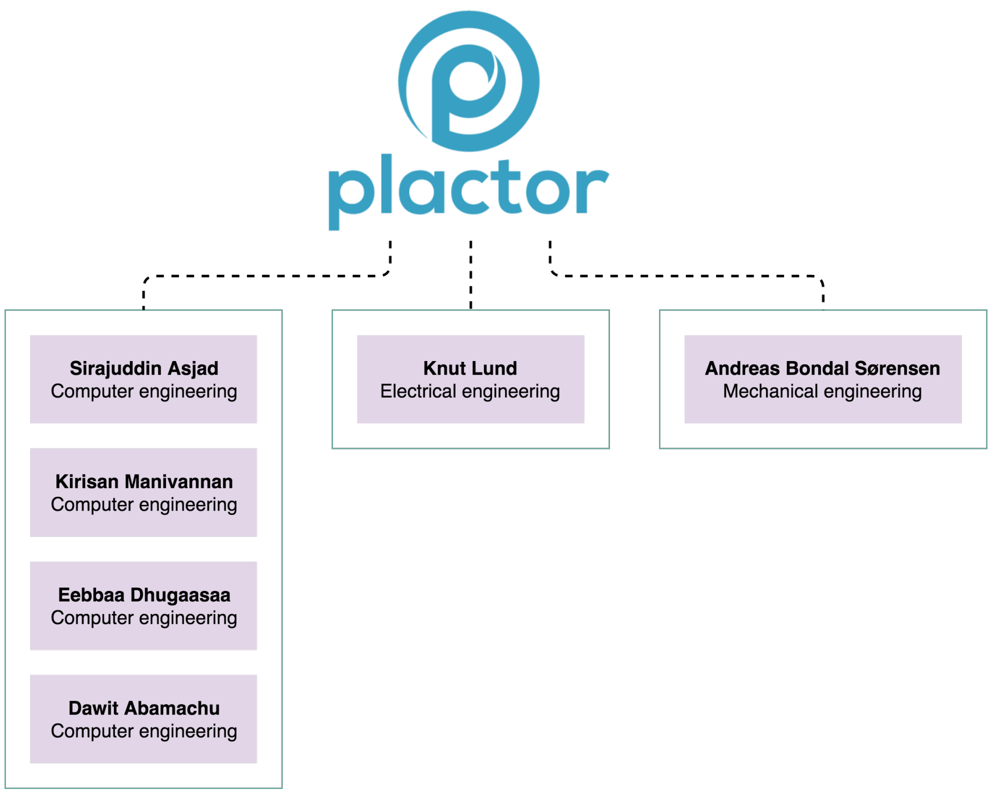
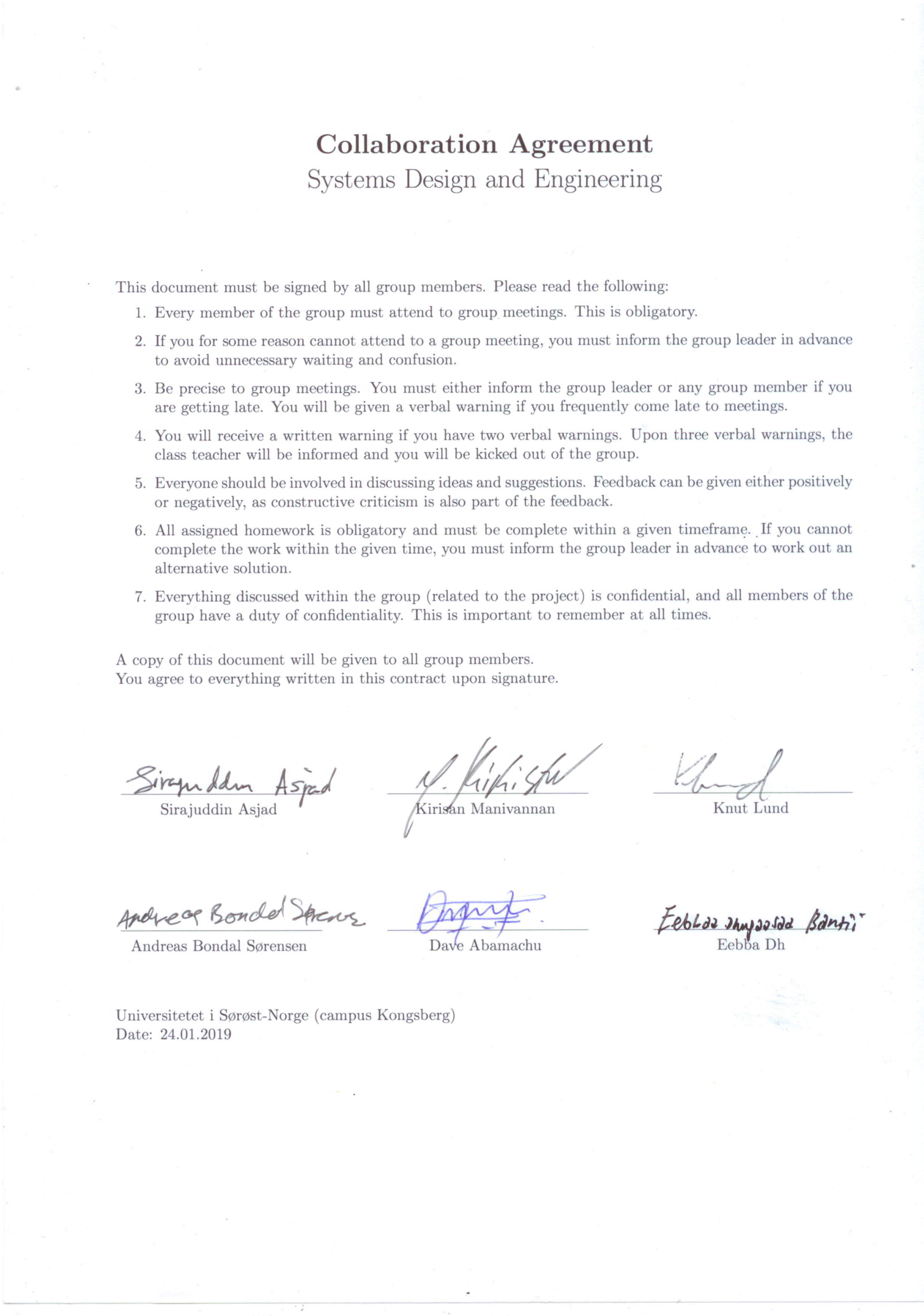


Figure 1: Group members structure

1.2 Contract of Collaboration

One of the very first things we established during the planning phase was a contract of collaboration. Every group needs some sort of agreement in order to function properly, and it can be difficult to cooperate and work in larger groups. That is why we decided to agree upon a contract, which every group member signed as well. This is just a formal way of building a railway for the group in order for the project to prosper.



Collaboration Agreement

Systems Design and Engineering

This document must be signed by all group members. Please read the following:

1. Every member of the group must attend to group meetings. This is obligatory.
2. If you for some reason cannot attend to a group meeting, you must inform the group leader in advance to avoid unnecessary waiting and confusion.
3. Be precise to group meetings. You must either inform the group leader or any group member if you are getting late. You will be given a verbal warning if you frequently come late to meetings.
4. You will receive a written warning if you have two verbal warnings. Upon three verbal warnings, the class teacher will be informed and you will be kicked out of the group.
5. Everyone should be involved in discussing ideas and suggestions. Feedback can be given either positively or negatively, as constructive criticism is also part of the feedback.
6. All assigned homework is obligatory and must be complete within a given timeframe. If you cannot complete the work within the given time, you must inform the group leader in advance to work out an alternative solution.
7. Everything discussed within the group (related to the project) is confidential, and all members of the group have a duty of confidentiality. This is important to remember at all times.

A copy of this document will be given to all group members.
You agree to everything written in this contract upon signature.

Sirajuddin Asjad | Kirisan Manivannan | Knut Lund

Andreas Bondal Sørensen | Dave Abamachu | Eebba Dh

Universitetet i Sørøst-Norge (campus Kongsberg)
Date: 24.01.2019

Figure 2: Contract of Collaboration

1.3 Pre-project planning

In order to work together as a group and to plan the entire project, we had a pre-project planning session where we planned the development phases ahead, along with the project structure and development methods. It is very important to have a good workflow through the entire project, which depends on a reliable system development life cycle model and strict planning throughout the entire process.

1.3.1 SDLC Model

We have decided to follow the V-model as our System Development Life Cycle (SDLC) model. The main reason why we chose to follow this model is simply because it is easier to look back and do some changes if needed. In Systems Engineering there are different approaches for project management, and there are lots of different approaches that one can follow. One approach that is often discussed is the waterfall model, which is a specific approach that some follow during a project. Waterfall is basically a method of locking down requirements, design, implementing it and then finally testing it.

The reason why this method still is attractive today is because it's quite efficient. The only reason why someone would prefer the waterfall approach over anything else would be if there is absolutely no need for change during the development process, such as changes in requirements or changes during the implementation phase. But that's never the case, because there will always be change. Change is in fact good, we should welcome change because it's an improvement from the last state. We often see companies pivoting, where they start with one concept in the beginning and then end up with a completely different concept by the end of the development phase, which is something we did with our concept as well. That is because they often realize another use case scenario that most likely is more beneficial, so they decide to pivot the whole concept into something entirely divergent.

We have modified our V-model in order to match our working process as well. We have added three more sub-phases under System Specification and Design; technical research, risk management and the final prototype. These sub-phases are marked in red in the figures below, and in Figure 4 you can see how far we came during the entire development process of our system.

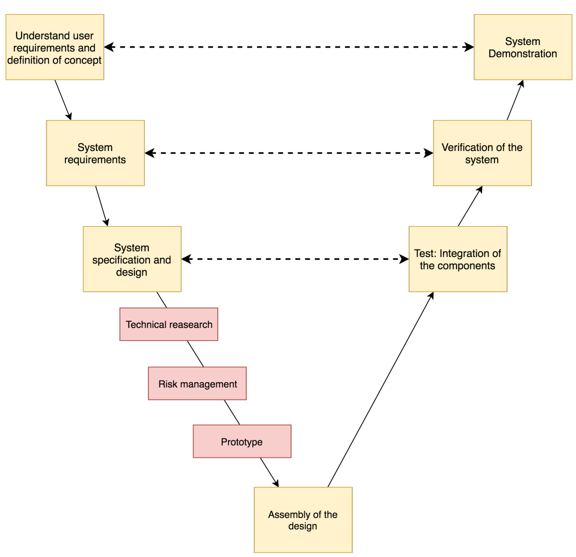


Figure 3: Our SDLC model

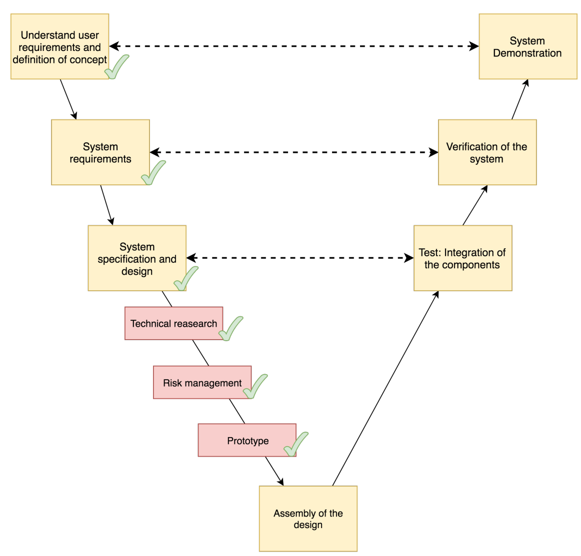


Figure 4: Our SDLC model at finished stage

1.3.2 Project Management

We have used Scrum as a project management tool during the entire development process. Scrum is an agile project management framework that helps teams work together, and we are very satisfied with the tool. We have all the tasks in a product backlog, and then we pick out a few elements from this backlog and move it to the sprint backlog. A sprint is a work session, so for example a week. During this sprint, we work together as a group and the goal is to complete all the tasks from the sprint backlog. When we are done with the sprint, we make a proper documentation of the work session, and then we start a new sprint. By using Scrum we have improved the group workflow exponentially and we are quite satisfied with it.

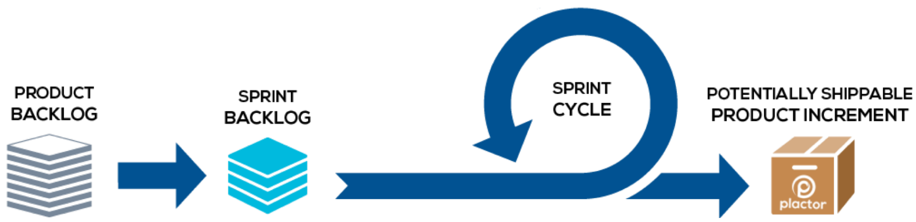


Figure 5: Our agile project management tool

In order to achieve all this greatness, we have been using a web application called Trello for managing tasks in the group. There are different columns for each step in the Scrum process, and we have been using this web application on a daily basis, as it is a perfect workplace for groups.

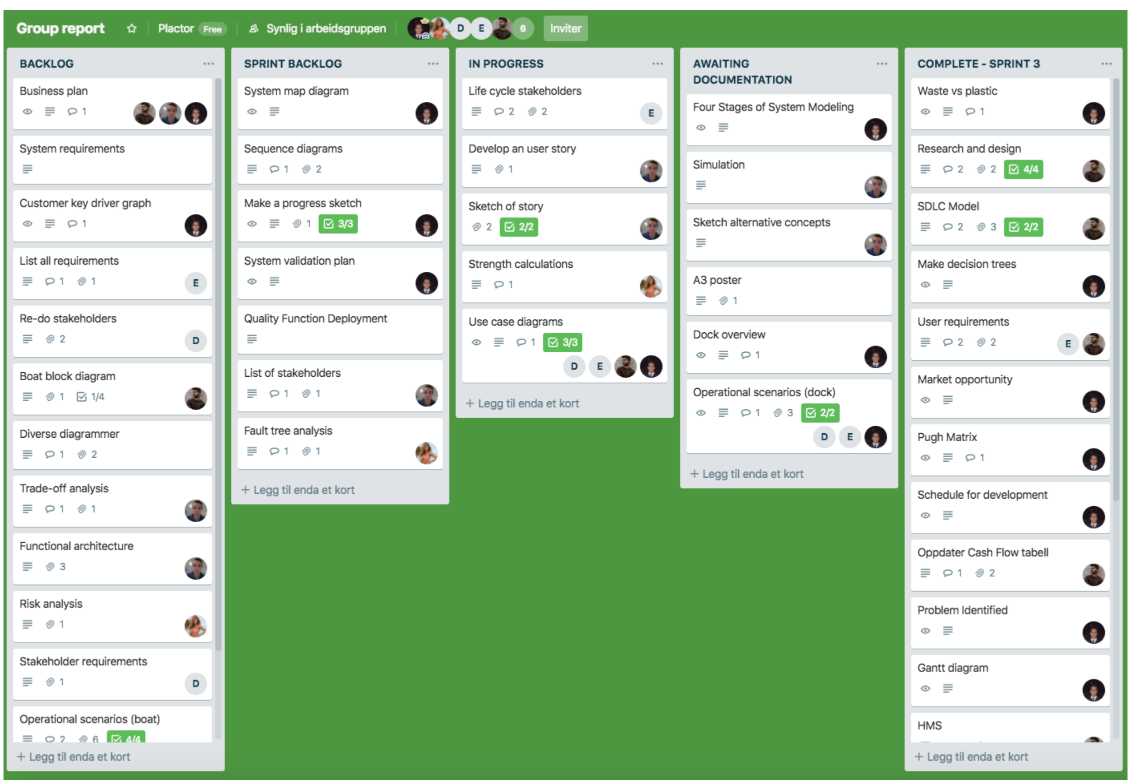
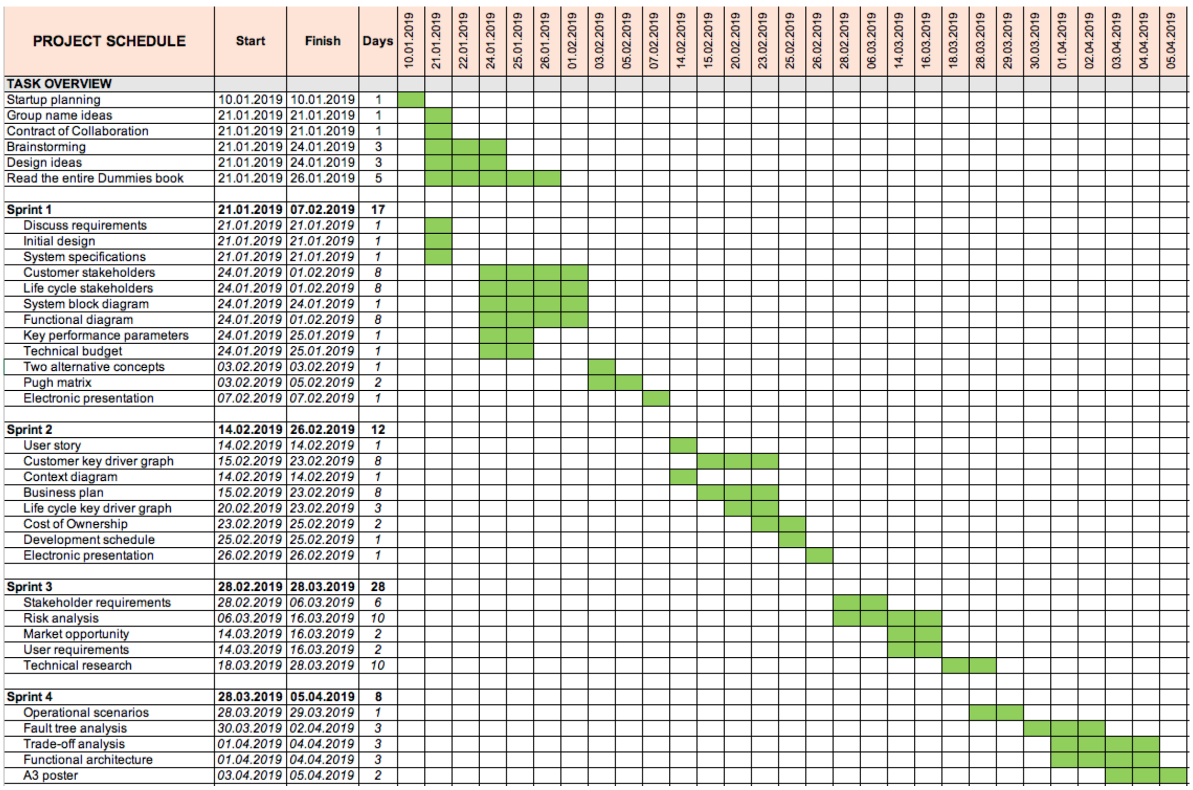


Figure 6: Overview of Trello web application

1.3.3 Time planning

Along with Scrum, we have been using a Gantt-chart for planning and to keep track of all the tasks and deadlines. We figured it would be nice to use a Gantt-chart in order to have a full overview of the entire project life cycle and to see the full picture, along with Scrum as our project management tool.

By using this Gantt-chart we can plan tasks ahead and know how much time we have left, and based on this information we can plan the duration of our next sprint. This has been a really nice approach and we have learned how important it is to structure and organize time during a project, in order to achieve a common goal. We had to continuously update this Gantt-chart in order to keep it up to date with our development, especially after each sprint in the Scrum process.



PROJECT SCHEDULE	Start	Finish	Days
TASK OVERVIEW			
Startup planning	10.01.2019	10.01.2019	1
Group name ideas	21.01.2019	21.01.2019	1
Contract of Collaboration	21.01.2019	21.01.2019	1
Brainstorming	21.01.2019	24.01.2019	3
Design ideas	21.01.2019	24.01.2019	3
Read the entire Dummies book	21.01.2019	26.01.2019	5
Sprint 1	**21.01.2019**	**07.02.2019**	**17**
Discuss requirements	*21.01.2019*	*21.01.2019*	*1*
Initial design	*21.01.2019*	*21.01.2019*	*1*
System specifications	*21.01.2019*	*21.01.2019*	*1*
Customer stakeholders	*24.01.2019*	*01.02.2019*	*8*
Life cycle stakeholders	*24.01.2019*	*01.02.2019*	*8*
System block diagram	*24.01.2019*	*24.01.2019*	*1*
Functional diagram	*24.01.2019*	*01.02.2019*	*8*
Key performance parameters	*24.01.2019*	*25.01.2019*	*1*
Technical budget	*24.01.2019*	*25.01.2019*	*1*
Two alternative concepts	*03.02.2019*	*03.02.2019*	*1*
Pugh matrix	*03.02.2019*	*05.02.2019*	*2*
Electronic presentation	*07.02.2019*	*07.02.2019*	*1*
Sprint 2	**14.02.2019**	**26.02.2019**	**12**
User story	*14.02.2019*	*14.02.2019*	*1*
Customer key driver graph	*15.02.2019*	*23.02.2019*	*8*
Context diagram	*14.02.2019*	*14.02.2019*	*1*
Business plan	*15.02.2019*	*23.02.2019*	*8*
Life cycle key driver graph	*20.02.2019*	*23.02.2019*	*3*
Cost of Ownership	*23.02.2019*	*25.02.2019*	*2*
Development schedule	*25.02.2019*	*25.02.2019*	*1*
Electronic presentation	*26.02.2019*	*26.02.2019*	*1*
Sprint 3	**28.02.2019**	**28.03.2019**	**28**
Stakeholder requirements	*28.02.2019*	*06.03.2019*	*6*
Risk analysis	*06.03.2019*	*16.03.2019*	*10*
Market opportunity	*14.03.2019*	*16.03.2019*	*2*
User requirements	*14.03.2019*	*16.03.2019*	*2*
Technical research	*18.03.2019*	*28.03.2019*	*10*
Sprint 4	**28.03.2019**	**05.04.2019**	**8**
Operational scenarios	*28.03.2019*	*29.03.2019*	*1*
Fault tree analysis	*30.03.2019*	*02.04.2019*	*3*
Trade-off analysis	*01.04.2019*	*04.04.2019*	*3*
Functional architecture	*01.04.2019*	*04.04.2019*	*3*
A3 poster	*03.04.2019*	*05.04.2019*	*2*

Figure 7: Gantt chart for time management

Since the traditional Scrum model does not involve a Gantt-chart, we have basically created our own hybrid project management model, where we have combined both Scrum and Gantt-chart during the development phase of our project. We used the benefit of Scrum to work together in an agile way, and a Gantt-chart to plan the entire development process and to set deadlines on each task that needs to be accomplished throughout the project. This hybrid approach has worked exceptionally well for the group, and we learned incredibly much by following these methods.

1.4 The problem domain

Waste and plastic ending up in the ocean is a huge problem all over the world. Large portions of plastic are coming from us polluting our lakes and rivers far inland and letting the rivers carry it out to the ocean. Its effect on the environment is tremendously huge. It has been estimated that about eight million tons of plastic debris, such as food packaging and plastic bottles, are being washed into the ocean each year. The plastic pollution is adversely affecting the nature, particularly the marine life.

Since plastic does not decompose easily, this problem is alarming and harmful and therefore it must be taken serious. One approach to solve the problem is to get the trash out of the rivers and lakes before it ends up in ocean. Therefore by taking this into consideration, we have tried to figure out what we can do in order to attack the problem domain and how we can contribute to solve this important problem.

1.4.1 Understanding the problem

Before we come up with a solution, we need to understand the problem. There are actually many problems, such as the fact that polluted rivers will escalate the plastic build up in the ocean and make them unsafe to wildlife. In addition to this the accumulation of plastic waste in the river hinder the people around from swimming, fishing and enjoying the river. The pollution will also instigate the area to become less attractive to both people who wants to live there and for the visitors. This is one of the reasons why we are dedicated to design an autonomous boat to collect waste from rivers and lakes in an environmental-friendly approach.

We started by making a user story to visualize and understand the problem as a real life scenario, as this helped us understand the problem domain from a specific perspective. Shifting towards our stakeholders, we have categorized them into active and passive stakeholders based on their connection either direct or indirect with the system that is going to be designed. This approach has helped us to perceive the depth of our problems and to let us know the right direction in designing the right system for our customer.

Along with attacking the problem domain, it is important to keep up with the standards and regulations as well, particularly the Norwegians law. We must be in position to follow the regulations in order to deploy a product to the market, and there may be consequences if we cannot keep up with these regulations.

It is also significantly important to inspect the entire system to see which external entities our system interacts with, and to comprehend the relationships between these entities. A practical way to do this is using a context diagram to describe and connect our system to every external factor that interacts with it. Systems engineering is all about describing things, it's about describing the complexity of a system and how it interacts with other external entities.

There are however multiple ways to describe a system and its sub-systems. It all depends on perspective and viewpoint, because the system description depends on who describes it and where this particular person stands. A simple rule is that you cannot fully describe a system without knowing its context, so basically if you are an user or a customer, you will describe the system entirely different compared to the description of a system engineer or a developer with more knowledge of context. So upon understanding the scope of our problems, we were able to grasp and comprehend the requirements of our customer better.

1.4.2 User scenario

In the beginning of summer 2017 the local kids in Drammen wanted to enjoy the swimming area of Drammens Elva. However the place they used to swim was littered with lots of floating plastic, so the kids had to travel 40 minutes to go swimming in another place called Eikern, where the water was unpolluted. This made the parents of the local kids in Drammen unhappy so they complained to Drammen Commune and demanded them to clean it up somehow. This made the mayor of Drammen start looking for solutions which led him to Plactor.

After contacting the Plactor team and discussing the situation with us, he was instantly pleased with what the autonomous Plactor boat promised to provide. The mayor then came out with a statement that before mid-summer the river in Drammen would be clean of floating garbage and ready for anyone to enjoy. The Plactor team with it's easy setup started the work on the docking station where the boat would charge. This was done quickly due to our simple design with the almost finished docks in warehouse and ready to be fitted on a river bank, the biggest problem only being the cabling needed to connect it to the grid and the ability to have a recycling truck access it. As soon as the dock was finished Plactor was set in operation. Conveniently it was placed a bit upstream from the public swimming areas as it will catch the plastic before it floats downstream, and the location upstream was away from the public as to be as little intrusive as possible. As a result the local kids in Drammen went back to enjoying the newly cleaned river and the parents were happy they did not have to waste time traveling far to different swimming places.

Some other children living near the docking station found it fun to look at the autonomous boat while it worked. Ducks liked to enjoy the area as well, so the kids were betting on the boat to one time "eat" one of the ducks. To their disappointment this never happened as Plactor was designed with detection technology and smart software to protect all wildlife. This made the children very annoyed so one of them decided to test Plactor to the limits and swim right up to touch it. Plactor was familiar with with situation as well and simply avoided the child by driving away and not ever letting him get close. In the end the children were unhappy that they never saw Plactor eating a duck, but after a few weeks one child thought it would be fun to say he did see it "eat" a duck. This became a big rumour and eventually led to an environmental friendly reporter from Drammens Tidene to stake out Plactor to catch a photo of it harming the wildlife, and to this day he is still waiting and the ducks quacking.

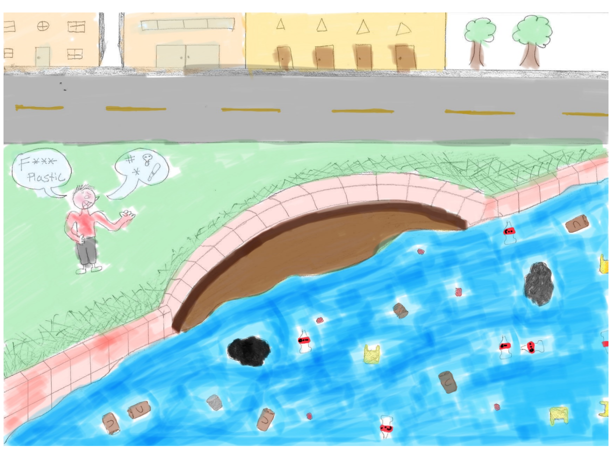


Figure 8: Illustration of a polluted river

Figure 9: Illustration of a clean river

1.5 Market demand and opportunity

When we started working on the project, we immediately did some research on existing products in the market with the same concept of operation as ours. There are different organizations, environmentalists, governmental organizations and researchers who have invested a lot of money and resources in building a better product to clean waste in rivers and lakes in an environmental-friendly way. Different products are currently operating in different areas to minimize the problem, which is waste pollution of rivers and lakes.

As a group of Systems Engineering students, it is our responsibility to do proper research on different existing products in the market in order to help us figure out which technology that is being used today, operational mechanisms, usage costs, advantages and disadvantages in each existing concept. By doing this approach we are prepared for building a better product, which can dominate the current market.

1.5.1 Identifying our competitors

There are many projects available out there with many different solutions, but we did proper research on some of the most popular projects with the same concept of operation as ours. The following three products are currently dominating the market as of today:

- Manta's Waste Collector
- Baltimore Trashwheel
- The Water Shark

1.5.2 Market research: Manta's Waste Collector

Manta's Waste Collector is a giant waste collection system built with a main target to clean the ocean. The system is very large and it is about 70 meters long, 49 meters wide, 61 meters high and it operates with clean energy production. It is autonomous and has excellent maneuverability, enabling it to rapidly intervene in the most polluted areas. The reason why this system is not the greatest available and one big disadvantage is the fact that it's very huge and it takes a lot of space when it is deployed. The waste collector cannot be used to clean small rivers and lakes, because it simply cannot fit in such areas. As a result of its massive size, the waste collector is relatively challenging to maintain as well.

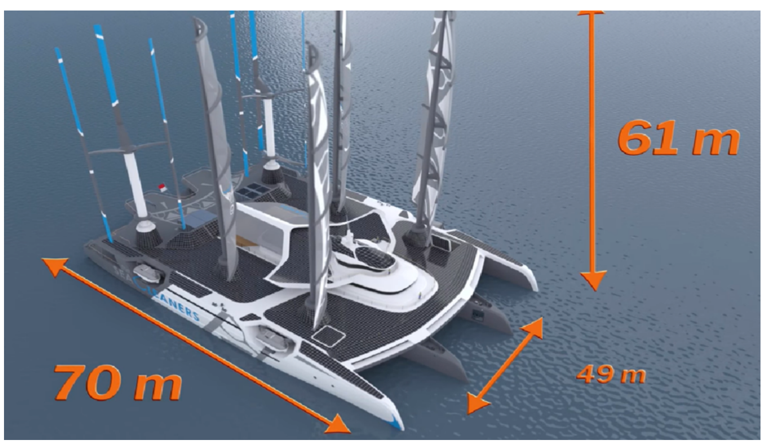


Figure 10: Manta's Waste Collector

1.5.3 Market research: Baltimore Trashwheel

Baltimore Trashwheel, officially called the Inner Harbor Water Wheel, is a vessel that removes trash from the Jones Falls river in Baltimore. It is powered by water wheels and solar panels, and places trash from the harbor onto an onboard conveyor belt which routes it into dumpsters on the vessel. This system has gained a lot of popularity as well, but its biggest disadvantage is that the system is stationary, which means it cannot move around and clean specific areas of the river.

Figure 11: Baltimore Trashwheel

1.5.4 Market research: The Waste Shark

The Waste Shark is an electric boat that collects waste by driving around in lakes and rivers with an open mouth, and is great for small areas where large systems cannot fit. The main disadvantage of this system is that it collects anything that comes across its navigation. It has no efficient localization and collection mechanism and it collects anything that is in front of the boat. It can also grasp small fishes during the operation, since it doesn't detect and avoid animals, which also is a huge drawback of the system.

Figure 12: The Waste Shark

1.5.5 Identifying product opportunity

Identifying product opportunity is actually one of the most important steps in order to successfully manufacture products and drive a company in our modern society. An opportunity for a product exists when there is a gap between what is currently available on the market, and the possibility for a significantly improved or new product that result from emerging trends. If our team can design and produce a system that fills a product opportunity gap that fulfills the customer need, expectation and concerns, it will be much more desirable in the existing market, rather than all the the currently existing products.

The three products we mentioned above can also be potential competitors for our product, as they serve the same concept of operation and we aim towards the same goal. It is however a good approach to take good features from all these products and add some advanced features which makes our product more preferable. The product that we currently are building should be more flexible during operation, compared to our competitors. It should have some advanced functionality, along with a fair price relatively with all those products we have today in the market. So we are expected to design our product with the latest available technology. To make our product unique and operational efficient, we need to consider better options during the design process to fill the existing product opportunity gap.

For starters we are focusing on the domestic customers here in Norway, with Drammen Commune as our first customer. The demand for our product will hopefully increase within the next couple years across other communes in Norway. Since plastic and general waste pollution is an international problem and the problem is getting some serious attention globally, we strongly believe that we can use the market opportunity in an international level as well, since there are many countries that might benefit considerably from our solution and product. This is however something we need to discuss in the future, as our current main goal is to deploy the autonomous waste-collecting boat in Norway.

1.6 System Context and Boundaries

When starting a project, it is important to set the boundaries for your design. The boundaries will tell where your system starts and ends. It reduces supervision and makes it easier for an individual or a group working on a sub-system without exceeding what is already decided. Stakeholders should review a drafted project boundaries statement to decide whether a particular product, service or requirement should be included in the project or not. In our case, we have set our own boundaries from what our task says and how far into the subject we can dive. A big factor for us is time, so this will be considered slightly higher than other factors.

Project scope is the planning phase that involves determining a list of project goals, deliverables, tasks and deadlines. The project scope must be documented to assure that everyone working on the case understands the task and keeps focused. The scope will give project members guidelines for making changes and decisions about the project. The better documentation we have on the project scope from early in the design process, the easier it will be to manage changes made to the design. When making a design scope, stakeholders should be as specific as possible. This is to avoid so-called “scope creeps”, complications and misunderstandings which leads to loss of time, money and other resources.

An example of design scope with an ATM is that everything inside the box, which is an ATM, is in our design scope, but the internet it communicates with and everything outside the box is not our design, and therefore not in our scope.

1.6.1 Internal and external interfaces

Our relationship and connection to the rest of the world can be summarized as our external interfaces. We have several examples of this in our system, where we communicate with the outside world, such as internet, electricity, third party manufacturers, collaborators and so on. Most of these interfaces have a big part in our product, but our influence on them is limited. Things that happen within an external interface is not in our control, so if something happens to for example the data center where we host our web interface, there is not much we can do about it.

With internal interfaces we control both endpoints of the connection. If we stumble on a problem, we can quickly look at all involved parts and sub-systems to find out where the problem is. Problems of this kind is often within our own systems or design and therefore is easy to maintain and control. External interfaces however is often run by a second or third part of the connection and it's often connected to a different system, which makes it harder to control. Therefore the more control you need, the more it makes sense to run the interface internally within our system.

1.6.2 System context diagram

This system context diagram is the highest level view of our system, similar to block diagram, which shows our system as a whole and its inputs and outputs from external entities. It involves every factor that interacts with our system, and every activity is divided into sub-groups and organized under what part of our system it belongs to. Every sub-group is on level zero, so it only shows the activity and not the process behind it. In this way, the person reading the diagram will get an immediate understanding of where our system operates, and on a lower level what it does as well.

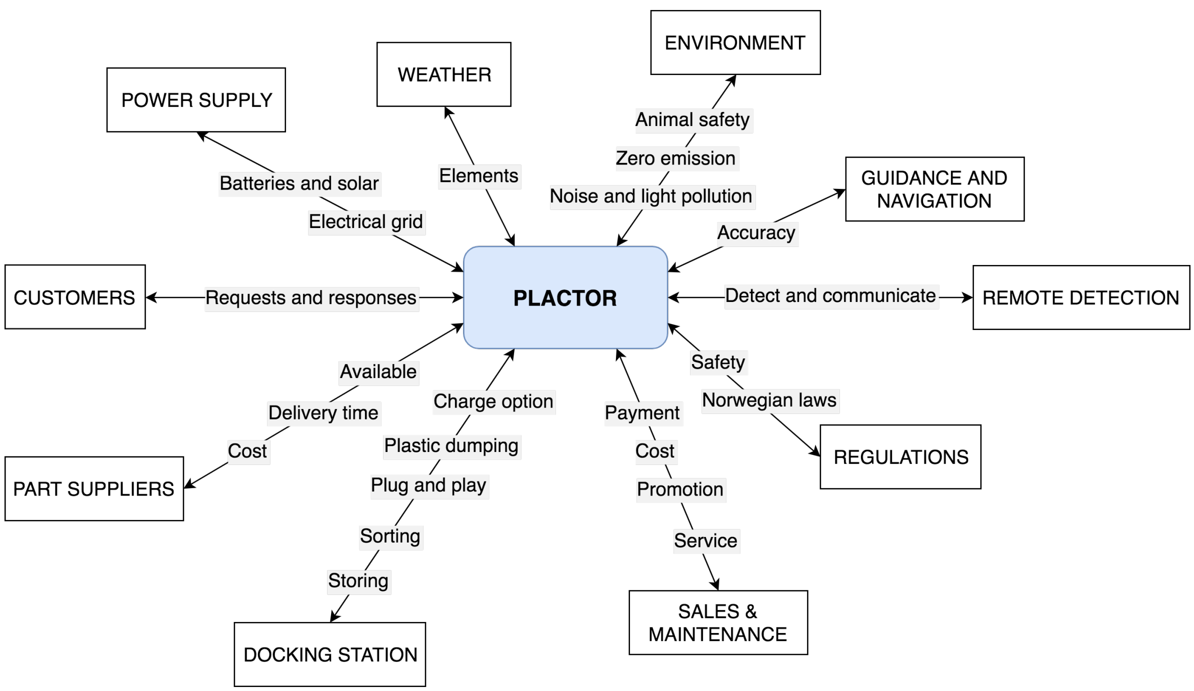


Figure 13: System context diagram

The context diagram also displays how the system relates to its environment. It includes stakeholders, both active and passive, habitat and its habitants, conditions, in addition to laws and regulations.

2 Stakeholders

2.1 Active stakeholders

Active stakeholders are the ones that are directly involved with the organization activities. Usually they are a part of the company's formal structure as employees. Some of the concerns these stakeholders may have are: organization of components, price, performance and quality on supplied components, when the product is available, the cost of constructing and the price of the product. Our suppliers might also be concerned about the continuation of Plactor since we could become a big customer of parts and therefore have serious contracts with a suppliers which of course they would hope lasts for as long as possible. We have divided our stakeholders into active and passive, where some of our active stakeholders are staff members, customers, maintenance crew, suppliers, commune and partners.

2.2 Passive stakeholders

Passive stakeholders are not less interested but they do not actively participate in the company's decision making or developing. One of the bigger concerns here are the laws and regulations that the government might have that our system must oblige for us to be able to sell it. Another concern from a passive stakeholder are light and sound pollution as the local residents would like to continue living in peace, this includes animals. Some other concerns might include being environmental friendly, as in using recycled materials for construction or batteries to operate with zero emissions. Some of our passive stakeholders are government, investors, media, other competitors, neighbors, local habitants and the general public.

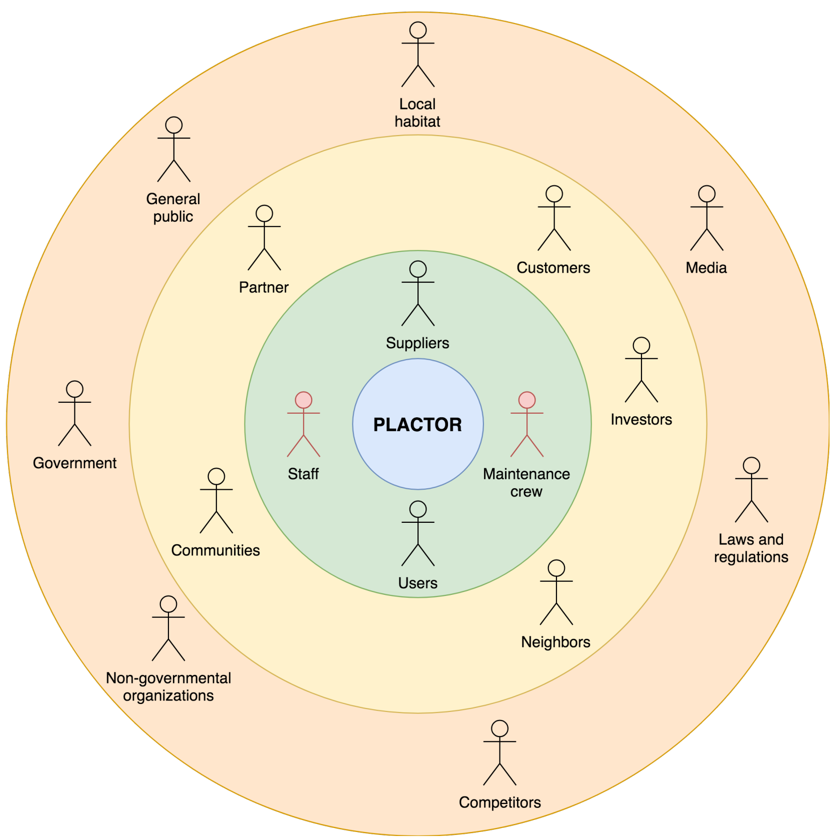


Figure 14: Stakeholder onion diagram

2.3 Life cycle stakeholders

In order to fully understand our system and to see which internal and external entities our product interacts with, we made a list of stakeholders, including life cycle stakeholders for our system. This means all groups, individuals and other systems that interact with our autonomous boat in one way or another. A system's life cycle begins from the system definition and design and passes through construction, production, operation, maintenance, support and phase-out. We listed all possible requirements from these stakeholders which helped us understand the system that we are going to build and to understand the problem domain more clearly. It helped also us to consider all the possible issues we may face later such as maintenance issues, component supplier issues, material selection issues, along with what we have to do after the product is retired and many more concerns. The following is a list of our life cycle stakeholders with their concerns.

Maintenance crew:
The maintenance crew is responsible for checking, repairing, and servicing our system during the operation life time and the maintenance crew should conduct periodic maintenance checks, planning equipment upgrades, identifying faults, investigating equipment breakdowns and monitoring the performance of equipment after repairs have been carried out and some of their main concerns are easy access to replace any components, components surveillance to make sure that all the components work as they should, how much time they have used on repair and what the cost of repair is. Is anything happens within the warranty time line, which usually are 2 years, the warranty will cover the cost.

Environment:
We are responsible for improving and to protect the quality of the natural environment, and this is something we need to focus on as it is a major concern for the government as well. In order to have a clean environment and to keep it like this, there are some concerns and requirements that needs to be followed. Some of them are zero emission, no harm to inhabitants or external factors and noise and light pollution.

Recycling:
The recycling group is responsible for converting materials into new materials and objects. During the end of life period of our system, this group will be responsible for disassembling of the entire system and they take care of the components accordingly. Their main concerns are special waste like batteries, electrical components and etc. One other concern is the recycling cost that depends on the municipality and the company which belongs to this municipality.

Installation:
To install a system, we need different type of equipments. System installation refers to the systematic process of setting up a system and all its interfaces to carry out certain tasks. The main concerns of installation is for example easy to assemble and install. The installation has to be time-effective.

Power management:
The power management system allocates enough power to the different electrical components, so they work as they should. It controls the amount of electrical power consumed by system and subsystem, with minimal impact on performance. Some of the main concerns of power management are the cost of replacing the batteries. These batteries are costly high quality batteries. The cost can be covered as long as the customer has valid warranty. The charging time depends very much on how much waste there are to collect. But since Plactor has a high quality solar panel on the top, it will charge all the time. In case if it is using more power than what it can afford from the solar panel, it can simply drive to the dock and make a quick super-charge. The power consumption and battery lifetime are also a part of the main concerns.

Safety:
Safe operational environment and preventing injury is important, in case that may arise due to our system. Safety issues should be considered during the system design by considering how system will interact with other systems.It should do it by considering the possible system failure during operation. The main concerns are for example battery failures, motor failures or maybe any type of electrical difficulties. Even the web interface is a concern. Since this is about safety, HSE (Health, Safety and Environment) is important. Safety of other external factors are also important, like other boats or swimmers and etc.

Logistics: One of the concerns in logistics is spare parts and other equipment. It is important to always have spare parts, equipments and extra materials. The shipping can also be a concern since the cost and everything that has with shipping to do, depends on weight, size and destination.

Production: Concerns in production can be many different things. One main concern is the production time. It has to be time-effective production. Even the parts can be a concern, since the parts has to be economical but still be high quality. Quality control, Laws and regulations are other concerns.

2.4 Life cycle key drivers

The life cycle key driver graph gives a general overview of the life cycle stakeholders and their main concern as application drivers. The graph lists all the requirements derived from these application drives and the technology that will be used for accomplishing the applications at component level. We have listed some of our key drivers in Figure 15, with the requirements that are necessary to accomplish these key drivers.

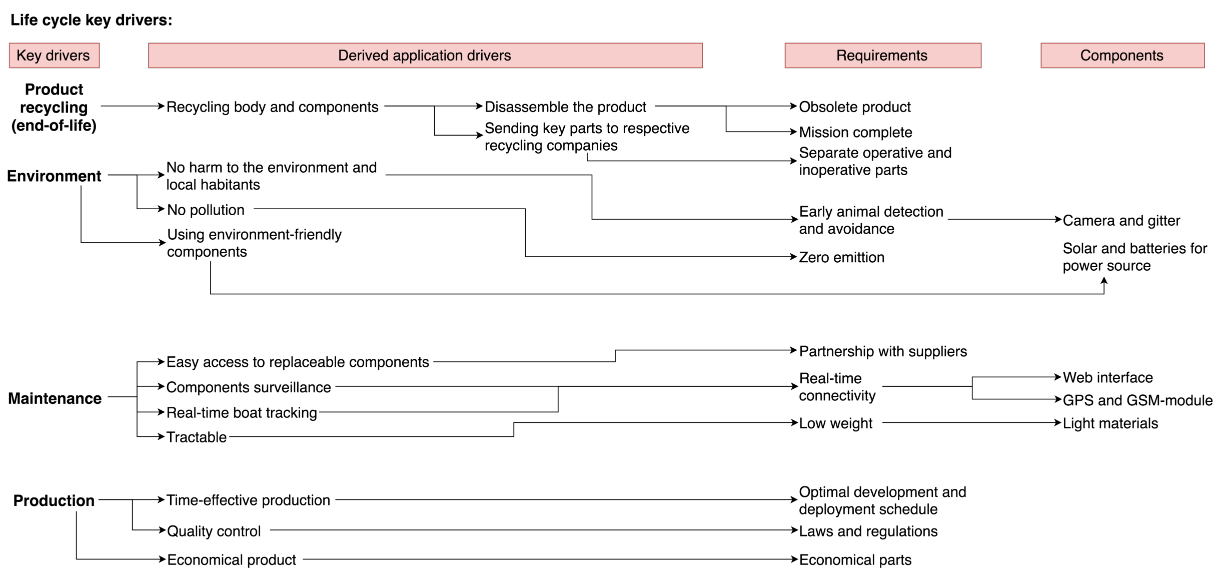


Figure 15: Life cycle key driver graph

2.5 Customer key drivers

The customer key driver graph gives a general overview of the main concerns of our customer as application drivers, and is used to dive into and gauge the most significance of our customer requirements. The correlation between the customer understanding and the value assessed makes the graph into a tool which is used for creating the right system.

As shown in Figure 16, the customer key drivers in our system are safety, waste collection, and operational concerns. Safety is one of the parameters in the customer key drivers graph which provides information about how our system provides safety in scenarios where there might be accidents and how to prevent these scenarios as well. For example if Plactor is in operation and is driving in a lake or river somewhere, and then suddenly another boat comes too close to our autonomous boat. Our safety systems will trigger an early hazard detection and recognize the boat through object detection by using our remote camera. This will prevent collisions and save both our own boat and the nearby boats as well. Moreover the remote detection will help our boat so that the boat does not harm animals in the water, by using sound emitting technology to scare away the animals without hurting them of course.

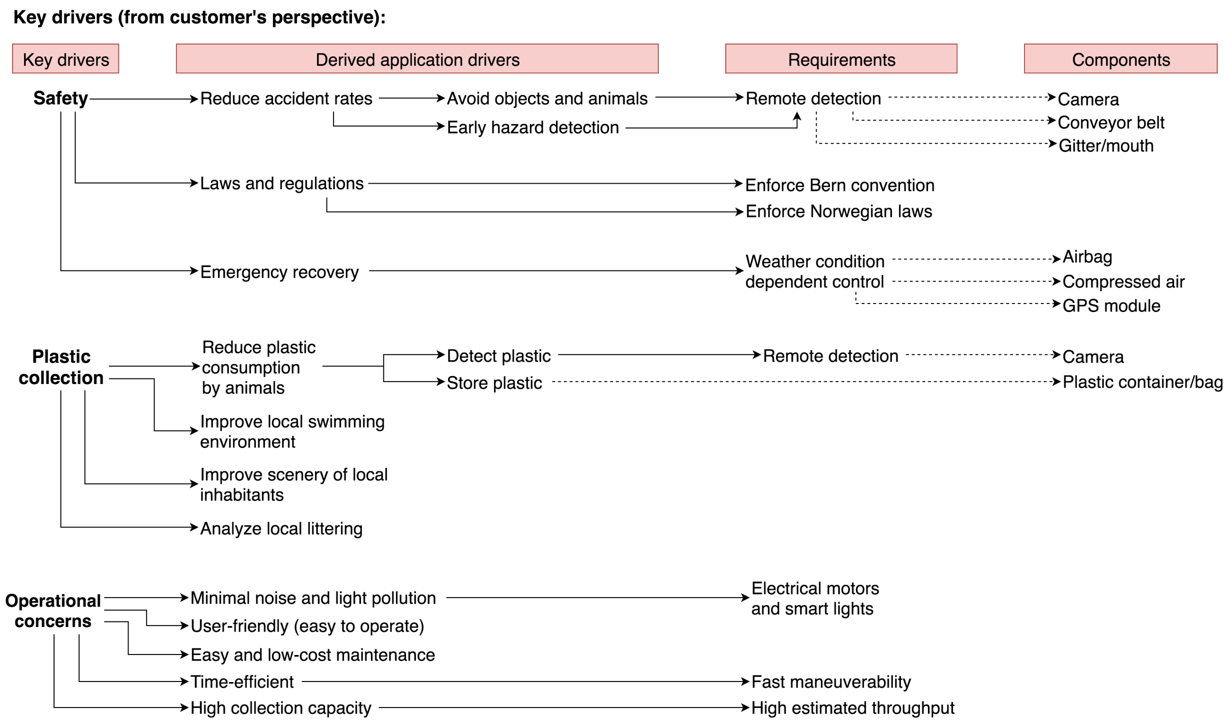


Figure 16: Customer key driver graph

2.6 Primary customers

The primary customer for Plactor is the communes that has a body of water which they would like to be cleaned. Mainly rivers but Plactor works seamlessly in any body of water. The reason for the commune to be our main customer is that it is responsible for its local environment and therefore has to take care of any polluting that locally occurs, especially in their rivers which can carry their waste to other communes or in the worst case to the ocean. Plactor will help greatly with doing this without having to hire any new personnel. It is also a great way for the commune to show that they care about the ocean, more specifically the garbage that ends up in the ocean. Other main customers are companies or organizations that are situated by water and that would like their body of water to be clean at all times. Mainly this would be private ports or the likes of yacht clubs.

3 Requirements

3.1 Understanding the requirements

To fulfill one important and probably the main requirement of the system and to serve its main purpose, which is to clean rivers and lakes, we had to conscientiously discuss a few technical dilemmas in the beginning of the project. One of the first dilemmas we encountered was deciding if the autonomous boat should only collect plastic or all types of waste. There are both pros and cons if we decide to focus on plastic only, so we made a comparison list to decide whether we should pick the one or another.

ALL WASTE:

Pros	Cons
We pick up more than just plastic, so the river gets cleaner.	We have to sort the waste into different categories for recycling.
We do more than what Jamal requires in his assignment. Thinking outside the box.	We need a larger garbage bag inside the boat to be able to collect all the waste.
The boat doesn't continuously have to check what it's collecting (except animals of course).	

ONLY PLASTIC:

Pros	Cons
There is less garbage to sort if we only allow and collect plastic in the boat.	We don't clean the entire river, there is still other garbage out there, such as metal etc.
	If the boat collects other kind of waste, we have to throw it out again.
	We don't solve the problem according to our user story. Even if we collect all the plastic, there is still a lot of waste out there that needs cleaning.

Figure 17: Waste versus plastic comparison list

After many discussions, we decided to pick all kind of waste and not only plastic, because then we can expand our system and implement a garbage sorting and recycling system to separate the waste. This is something we wanted to do all along, but it wouldn't be practical if we only collected plastic, because if we are building a recycling system in the first place, we should fully use its potential and it should do more than just separating plastic by its type of material. Upon this conclusion, we started working on the autonomous boat with an aspect towards all kind of waste.

3.2 Stakeholder requirements

Some of the stakeholder requirements are based on the stakeholder concerns. These requirements and concerns will be different between the stakeholders. It all depends on what focus these stakeholders have. Some of the stakeholder concerns are for example that we need to meet the customer needs in terms of performance and quality. And for the customer, it must be easy to use and operate. The system must be time-effective and cannot harm the natural environment, such as the animals. One important concern is that we function according to the rules and laws from the government, because that's something we cannot avoid. We have many more concerns that we need think about, and we need solutions in order to satisfy each and every stakeholder. One example for a stakeholder concern is not causing any harm, and a requirement to extend this concern is not causing any harm to any living organisms, such as animals.

We have chosen a few stakeholder concerns and requirements that we have explained in depth in order to understand the stakeholders properly. Some of the most important concerns and requirements are:

Low noise and light pollution:
Noise and light pollution are major problems which creates disturbance for the people whom live nearby the lakes and rivers. Our product cannot disturb the locals in any way and we have to make sure to keep the noise level at a minimum in order to avoid complaints or any annoyance. Our solution to solve this matter is to keep the autonomous boat parked at the docking station at night time, so it is charging the batteries and getting prepared for the next day. While it is in operation, the autonomous boat is using very few lights in terms of saving battery and to avoid light pollution in the area. There are however some laws that require us to use lights for security purposes, which is something we cannot avoid. We must respect the local neighbors and therefore operate the autonomous boat according to them. Some of the stakeholders that require low noise and light pollution are for example neighbors, commune, general public and the government.

Zero emission:
The issue of zero emission is a crucial issue today, which has been paid attention globally. This is because zero emission will have a positive effect on climate and is environmental-friendly as well. For that matter our autonomous boat is designed to be a zero emission product. This is because the boat is driven by powered batteries and is charged by solar panels as well. In other words, the autonomous boat is not driven by fuel of any kind. This also means that the boat will have a relatively low noise level, compared to normal automobiles which are driven by a fuel engine. This indicates that the boat is environmental-friendly, as it meets the demand of law and regulations on the environment, which limits the release of Co2 in the air. There are some stakeholders that share this requirement, such as the commune, the government and of course the local neighbors that live in that area.

No harm to inhabitants:
Any machine that operates in lakes and rivers may harm the inhabitants in that area, both animals and human beings. In order to avoid this, there must be some kind of object or animal avoidance system in order to prevent this situation from happening. This is a very important requirement that we have taken very seriously as well. We have equipped multiple sensors and used modern technologies in our autonomous boat to detect both objects and animals. This is a very important requirement for almost all stakeholders, specifically for the customers, which in our case is the commune. This requirement is important to other stakeholders as well, such as the government, general public, media and the local neighbors.

No harm to external factors:
This requirement is equally as important as the requirement above, which is not harming the local inhabitants. Not harming external factors, such as boats, while the boat is in operation is a key focus point and is something we must prevent. Since our product is autonomous, it is critical to have a feature where the boat can avoid external objects and prevent itself from harming other factors in the lakes and rivers. If such a catastrophe happens, it may cost us a lot and it will cause major consequences as well. That is why this is a requirement we must keep in mind at all times.

Easy use and fair price:
Today in the current market, it is not so easy to find machines that are easy to use and operate, along with a fair price as well. That is why we are providing our autonomous boat to the customer to solve this criteria, which also fills the need of multiple stakeholders. It is designed in such a way that it is easy to operate the autonomous boat, where everything can be controlled from a web interface. If the boat is very complex and complicated to use, it might not be in interest for the customer and we might lose the market because of this. This requirement comes from the staff itself, along with the main customers that are interested in purchasing our product.

Quality production and easy to transport:
Production and easy transportation are both important for many stakeholders as well. We must deliver a high quality product and it should be produced with high quality materials as well. Along with these criterias, the boat must be relatively easy to transport and it should be able to move the boat from one place to another. This is solved by reducing the total weight of the boat into a smaller amount, and to implement transportation solutions for the customer. This requirement is important to the maintenance crew, along with the system developers and customers as well.

Up-to-date with all laws, regulations and standards:
Considering law and regulations up to date is a critical requirement for some stakeholders. If for the example the staff team forgets to keep this requirement, it may lead to major consequences. That is why we are constantly keeping ourselves updated with the laws and regulations, in order to avoid any unnecessary problems with the government. This requirement is mostly aimed towards the staff team, and is something we share in common with the commune.

3.3 Customer requirements

Listing customer requirements is the most important part of the design process for defining a system of interest. The system we are going to build should satisfy the end customer or user. As system developers we should express user requirements clearly and we need to drive them by having interviews and arranging meetings with customer to know more about their needs and concerns. Some of the most common and major user requirements that we need to focus on are:

- The system will be used for collecting waste from lakes and rivers.
- The system should be autonomous.
- The system cannot harm living organism in any way.
- The system should have minimum or zero noise pollution.
- The system should be environmentally friendly (zero emission).
- The system should be very efficient in collecting waste.
- The system should be easy to use.
- The system should have low maintenance cost.
- The system should have low running cost.
- The system should have a fair price relatively with the current market.
- The system should have good durability.

We have picked out a few important customer requirements and explained them in depth.

Collect waste from rivers and lakes:
One requirement that all the customers have in common is that they want the product to collect waste from lakes and rivers, as this is our problem domain. To fulfill this requirement we must follow some rules and regulations. But there are several things that should be on point. Plactor will have many different type of sensors to avoid problems and any issues that will show up in the middle of the collection process.

It can sometimes be difficult to collect colossal waste in terms of size. So in order to only allow collectable waste, the autonomous boat needs to detect the object first. By detecting the object, the autonomous boat will immediately know if the given object is waste or something else. If it detects something that is collectable, but too colossal, it simply will not allow the object inside the boat and will reject it subsequently. With advanced technology implemented on the boat, it is able to separate waste from animals during the object detection as well. This is critical in terms of animal avoidance and protection.

There is a camera mounted on top of the boat with a real-time object detection processor running, so it can detect objects and animals and avoid these as well. If any animal starts swimming into the boat's mouth, the camera will register this immediately and simultaneously close the gate in front of the mouth. This will hinder the animal from entering the boat. This feature is for security reasons, so the animals do not get harmed in any way. There is a SONAR sensor implemented under the boat as well, which will detect fishes that appear under the boat. It will adjust the height of the conveyor belt accordingly, in order to make it difficult for fishes to swim into the boat.

Easy to use (plug and play):
Plactor is very easy to use, simply because it is autonomous, which means it will think and work by itself. The customer is not supposed to worry about the usage of the autonomous boat, along with installing it. Everything will he handled by the Plactor crew, in order to make it as simple as possible for the customer. Plactor will also bring the collected waste to the docking station and sort it out there, which means that the customer does not need to think about sorting the waste. This requirement is very attractive for the customer who does not want to use much time on supervising the boat and especially on sorting the collected waste. In other words, everything will function by itself without needing a human being to interfere.

It is also important that the boat is not very heavy as well. We have tried to make the boat as light as possible in order to make it easier to handle, so we made a strict weight budget to set some boundaries. So instead of making this machine heavy, we have decided that Plactor will be maximum 100 kg. 100 kg for a big machine is actually very low. The reason for a maximum weight limit is to make sure that the weight is not exaggerated.

Safe to use:
Safety is a major priority and is something we have to prioritize throughout the entire life cycle of the product. In order to raise the security of the system, we have implemented multiple high quality components and many smart systems to avoid unauthorized individuals from accessing the boat, or even trying to steal it. There are also smart systems to detect and prevent water leaks, high boat temperature and to prevent collisions.

To keep an eye on the autonomous boat at all times, there is a surveillance system which is running all the time. It is possible to watch it over web and on the user's phone. With this system it is possible to make sure that Plactor is safe and not getting disturbed. Plactor will be built with fire-resistant parts to make sure that it will survive if it starts burning. All the parts will also be water-resistant, so no water is getting in to the components.

Time-efficient:
To get the best result in a small timeline, time-efficiency is one another requirement for the user. There is no reason to waste any time, espesially if the boat is available and is able to collect more waste. It is also important to collect a big amount of waste during collection operations. If it doesn't have the capacity to collect a big amount of waste, it is not so efficient as it should be. In other words, this is a high-performance machine.

Plactor got the ability to move fast, so it can fulfill this user requirement. But it will not move faster than what the laws in Norway are letting boats to move. To stay within the law, Plactor will have the ability to move fast enough to collect waste on different places on the water. It has to follow the general speed limit which is 5 knots (9km/h). And to avoid the make of big waves, it has maximum estimated power on 10hp.

3.4 System requirements

Most of the requirements for our project are decided by or together with stakeholders. However, we have some requirements of our own to ensure our costumer‘s happiness. These requirements are based on what we want out of our system to make it as good as possible for both us and our customers. In difference to customer requirements, the system requirements is not for what our product can deliver, but what we can deliver as an addition to the product.

Replaceable and upgradable parts:
To reassure a good and reliable product, we have decided to put extra weight on making replaceable and easy upgradable parts for Plactor. This makes it easier for us to help customers that struggle with replacing parts or if they want to upgrade their purchase. Replaceable parts would also make the design process and development process a whole lot easier for us. Both producing and servicing of parts will be much easier if this is focused on from the start.

Always have spare parts in inventory:
As every good store or company should, we will always have spare parts in our inventory. We will have extra parts and components for everything needed on our product. Customers that have bought our system will also be able to buy certain components to keep in their own inventory.

Proper component surveillance:
Implemented to our software, we will have component surveillance on certain parts. Some of the parts on Plactor is more exposed for wear than others, therefore we will be extra cautious. An example is the battery, it will have surveillance in conjunction with battery percentage, but also on how much it is capable to perform. The battery will wear of when doing cycles of charging and discharging, so it won‘t last forever.

Time-effective production:
To assure our customers that their purchase will be delivered in time, we will make our production as effective as possible. This will make our customers happy and save us both time and money by keeping the manufacturing process as short as possible.

Thorough product testing and quality control:
Even though we will have a time-effective production, we will test our product thoroughly. This is an important part of a manufacturing process and a major part of the final product. Without proper testing, we will never know how Plactor will work in real life. Of course, testing will only be testing, but we will be more prepared for what Plactor will experience in the “real world”.

Testing will also help selling our product in the first phase our project. If the customers can see what type of testing we have done and how our product did, they will be more likely to buy one from us.

Follow laws and regulations:
Before we can start producing anything, we have to make sure that we work within laws and regulations. We need to know that our product is safe for what environment we are putting it in, that the pollution is within the law and that the boat functions within what is allowed in terms of speed and size. If we don‘t follow these rules, we might not be able to sell our product.

4 Concept Selection

4.1 Comparison of concepts

We had a brainstorming session in the early design process, where we came up with different solutions in order to solve the problem. We had to compare the solutions and pick one concept that would function according to our customer and system requirements. This concept selection was quite important, because we had to thoroughly compare each and every aspect of the different concepts in order to pick the best one.

4.1.1 The First Concept: Bridge with an extendable arm

There are tails mounted underneath the bridge in Kongsberg, where an extendable arm or crane is attached. Using this rail, the arm can move across the whole bridge and therefore cover the whole river. The extendable arm is then used to drop down from the bridge and onto the plastic floating beneath the river. The tip of the arm has a claw for grabbing pieces of plastic, as it hoists it back up afterwards. The arm will then travel along the rail to either one of the sides, where it will drop the waste into the collection bin. To detect waste in the river, it uses several cameras to analyze the river and then make an action plan for the arm to follow.

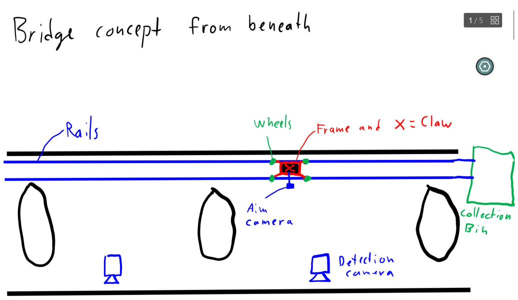


Figure 18: Bridge with an extendable arm

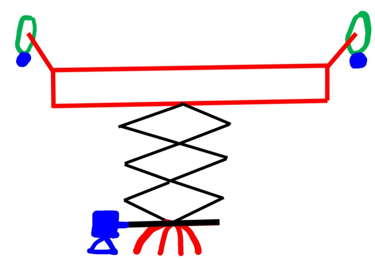


Figure 19: Crane attached to the bridge

4.1.2 The Second Concept: Floating tube

There is a tube floating out in the river where the plastic tends to float by. This tube has plenty of holes large enough to suck in large bits of plastic. However the suction will not be too strong so the fishes will be able to swim away from the tube. At the end of the tube there is a filter system that lets out any excess water and lets it back into the river. Even though this is an easy concept to execute, it has several problems. The biggest problem is that it will permanently block a large part of the river since it is a stationary floating tube, which leads to other boats not being able to drive through the floating tube.

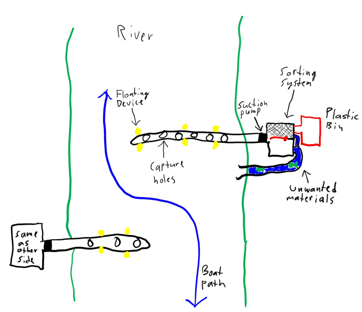


Figure 20: Floating tube concept

4.1.3 The Final Concept: Autonomous waste-collecting boat

The third concept is an autonomous waste-collecting boat that detects and collects waste in rivers and lakes. This boat is mobile and is not stationary, like the extendable arm and the floating tube. Compared to the two previous concepts, this autonomous waste-collecting boat is more advanced and smarter in many ways. It has much more focus on security and reliability, as it satisfies the customer needs.

The extendable arm and the floating tube concept can be useful, but might be a disturbance to other factors in that environment. The extendable arm might disturb other boats that are driving along the river, which might lead to multiple complications. This means that the extendable arm need to stop collecting waste when a boat is crossing the bridge where the extendable arm is installed. If the waste collection stops as a result of this, it means that there is a big chance for the waste to float back together with the boat. This is just a tiny flaw, along with many other issues that relate to this concept.

This autonomous boat on the other hand is much more flexible. Since it is a floating machine, it will make space for crossing boats, as it will pick up any waste that comes along with the boat. The autonomous boat is very user-friendly, and it is much more attractive to the customer as well, compared to the previous concepts. With a lot of advanced technology, it is able to separate waste from animals and other objects during detection, which certainly is an important feature that needs to be implemented.

The autonomous boat is fully powered by batteries and solar panels, which means it is economically friendly and has zero emission as well. The boat contains many sub-systems for different scenarios, such as an emergency recovery system in case something happens to the boat and it needs to be rescued by a maintenance crew. It has other important features as well, such as a real-time web interface for the customer, which is very useful for surveillance and maintenance. The boat is fully autonomous during operation, and does not need any manual maneuvering in order to function properly. This is an important feature that the other two concepts do not possess, which is why we believe this autonomous boat is greater and more reliable.

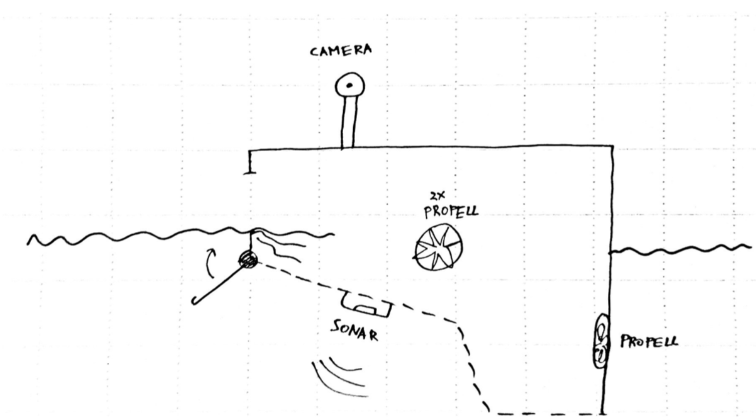


Figure 21: Our initial boat design

The illustration shown in Figure 21 was our very first design of the boat, and this is how we planned the autonomous boat would look. This is just a light sketch of our very first thought of the concept, and we have made many changes afterwards. At this point we only discussed the concept from an abstract level, just enough to have something we can compare the other two concepts with. Even though we liked this concept much more than the previous ones, it was too early to pick a favorite and decide once for all. We had to compare the solutions in terms of quality and functionality, and we had to compare the solutions according to what the customer needs. If the customer was not satisfied with either one of the concepts, we had to continue brainstorming for more ideal concepts in order to satisfy the customer.

4.2 Selection of a preferred concept

In order to select the best and most suitable concept for our customer, we had to compare the three concepts thoroughly. We decided to use Pugh's Concept Selection Matrix to compare the concepts, which is a method where we compare different qualities of the concepts separately. The comparisons are marked with score, and the resulting concept with highest total score is selected as our preferred concept.

Parameters	Autonomous waste-collecting boat	Extendable arm concept	Floating tube concept
Cost	2	3	5
Energy	3	4	5
Installation	4	2	5
Robustness	4	2	2
Operations	5	1	3
Disturbance	4	3	1
Maintance	4	2	1
Safety	5	4	2
Plastic collection	4	3	4
Total:	**35**	**24**	**28**

Figure 22: Pugh's concept selection matrix

It is important to keep in mind that a preferred concept cannot be selected by only using a Pugh Matrix diagram. Along with this method, we had multiple iterations and discussions where we thoroughly went through the positive and negative qualities of each concept. Based on these discussions, we concluded which concept we should take to the next phase and which concept we should select in order to satisfy the customer.

4.3 Key performance parameters

Technical requirements are factors required to deliver a desired function or behavior from a system to satisfy customer requirements and needs. These factors include performance, reliability, usability, maintainability and adaptability. To effectively meet the needs of our customers requirements, we need to consider the combination of these factors, which are key system capabilities that our system should meet in order for the system to meet its operational goals. We have chosen these parameters for Plactor by analyzing our system behavior, functionality and system context, as in our operating environment. These parameters describe our system generally, so we have been using them in the entire design process as a reference.

4.4 Technical budget

Along with the key performance parameters, we have a technical budget as well, where we make sure all the components are within the weight limit of our system. The technical budget is based on the key performance parameters, and since one of our parameter is maximum 100 kg, we have to make sure we stay below this amount in order to successfully build our system.

Key Performance Parameters	Estimated amount
Size	0,5m x 1,0m x 1,5m (h, l, w)
Weight	100 kg
Bag volume	0,3 m^3
Reliability	2 years
Power consumption	1-10 kWh
Maximum throughput	0,15 m^3/hour (150 L/hour)
Maximum speed	5 knots (9 km/h)
Maximum power	10 hp

Figure 23: Key performance parameters

Component	Weight
Battery	10 kg
Camera	0,2 kg
Motors	5 kg
Sonar	1 kg
Solar panel	20 kg
Conveyor belt	5 kg
Sound emitter	0,1 kg
Net bag	5 kg
Frame	15 kg
Chassis in plastic	5 kg
Compressed airbag	5 kg
Anemometer	0,2 kg
Electricals	2 kg
Miscellaneous	5 kg
Total weight:	**78,5 kg**
Weight not in use:	**21,5 kg**

Figure 24: Technical budget

4.5 Conceptual design

When we had decided which concept to proceed with, we shifted into an early design phase of the system, also called conceptual design, where we came up with potential designs to meet the customer requirements. Conceptual design is the very first step and process when designing a product. In this step we use drawings and other illustrations to model the design. Its purpose is to describe the system we are building and this phase usually starts when the requirements are set and when we have a somewhat idea of the product we are designing. The whole phase starts with requirements, where we need to know the system needs and define them properly. When we know what the customer wants, we start a conceptual design and do proper research and development to support this design.

4.5.1 The first prototype design

With the customer requirements and needs in mind, we started designing a simple boat with some of the main components that we planned to implement. This first and initial prototype design was a great place to start, but it had multiple issues and it was quite complicated to make this design work with the requirements. The main concern was that there was no space for the solar panel on top of the boat, as birds could easily fly into the waste container and pick out the waste. This is something we absolutely had to prevent, because this is very harmful and health concerning to the birds.

Because of lack of space on top of the boat, there was no good location to place the camera as well. It needs to be positioned properly in order to detect objects in front of the boat from a good angle, and this was hard to implement on this conceptual design. The conveyor belt was unprotected as well, there was no chassis around it to protect it from birds and other animals that might eat the waste while it's being dragged up from the water surface.

This first prototype design was all right, but it had many liabilities and there was a lot of small issues that we had to think about. So instead of spending a lot of time fixing these liabilities and trying to solve these issues, we decided to change the entire design instead and we iterated with a new sketch, which was a huge improvement from this current design.

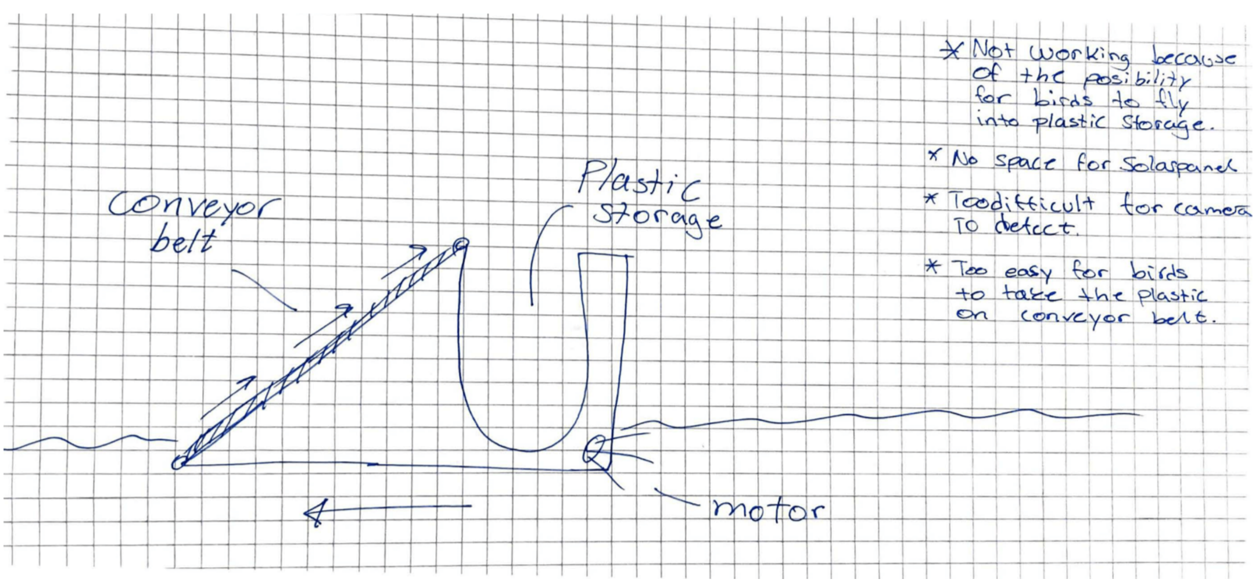


Figure 25: The first prototype design

4.5.2 The second prototype design

This new concept was a complete upgrade from the previous design, and we have implemented a lot of new features to improve the previous liabilities. The backside of the boat is below the water surface, so all the plastic floats into the front side. This time we did manage to implement a solar panel on the roof of the boat, along with cameras, but the main problem was that if the boat gets filled up with too much waste, it might actually sink.

There are some laws of physics that we must keep in mind, since the boat is floating on water. If the buoyant force is less than the weight of the boat, it will not be able to float on the water and the boat will sink. That is why we had to make sure to keep the boat weight under a certain limit. This is especially a difficult task if the boat is already tilted under the water surface, because then the chance of sinking is even higher.

Another problem that occurred is that it is difficult to filter out the water inside the boat. Since the boat is driving with an open mouth, we expect water to pass through the conveyor belt and that is why we need some kind of system to filter out this water, otherwise the boat will get too heavy and sink. We could implement a vacuum filter to push out the water, but this was too complicated to implement in such a small boat and it would need a lot of power resources as well. So instead of changing the entire concept, we decided to keep it and make improvements to it instead. We noted all the liabilities of this current prototype design and found solutions to them in the next design.

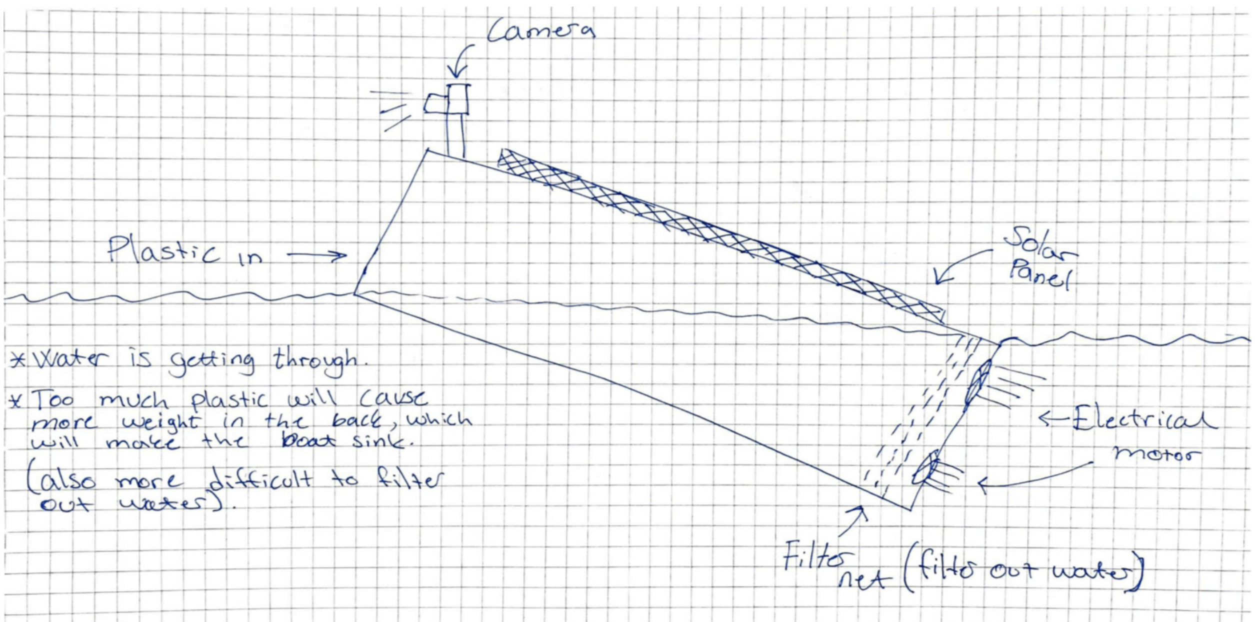


Figure 26: The second prototype design

4.5.3 The final prototype design

We finally came up with a final solution that functions according to our needs. We improved a lot of features from the previous prototype design and changed many performance parameters to match the customer needs and requirements. We managed to implement a gate in front of the boat to cover the mouth as a component in the animal avoidance system, as it plays an important role in our emergency recovery system as well. We finally had enough space on the roof to implement a solar panel to deliver enough power to the batteries, and we managed to place batteries inside the chassis. The conveyor belt is now properly adjusted according to the mouth and is able to drag the waste into the waste container.

We implemented a small electrical pump to filter out the water that manages to get into the boat, as this is quite important to balance the boat weight. We placed a Sonar sensor with a built-in sound emitter underneath the boat, which is a major component in our animal avoidance system as well. Some of these sub-systems are quite complicated with a lot of details, and will be explained in depth later in this report. We are very satisfied with this final prototype design and we decided to keep this design for numerous reasons. We have plenty of room for adjustments and this design fits the needs of our customer as well.

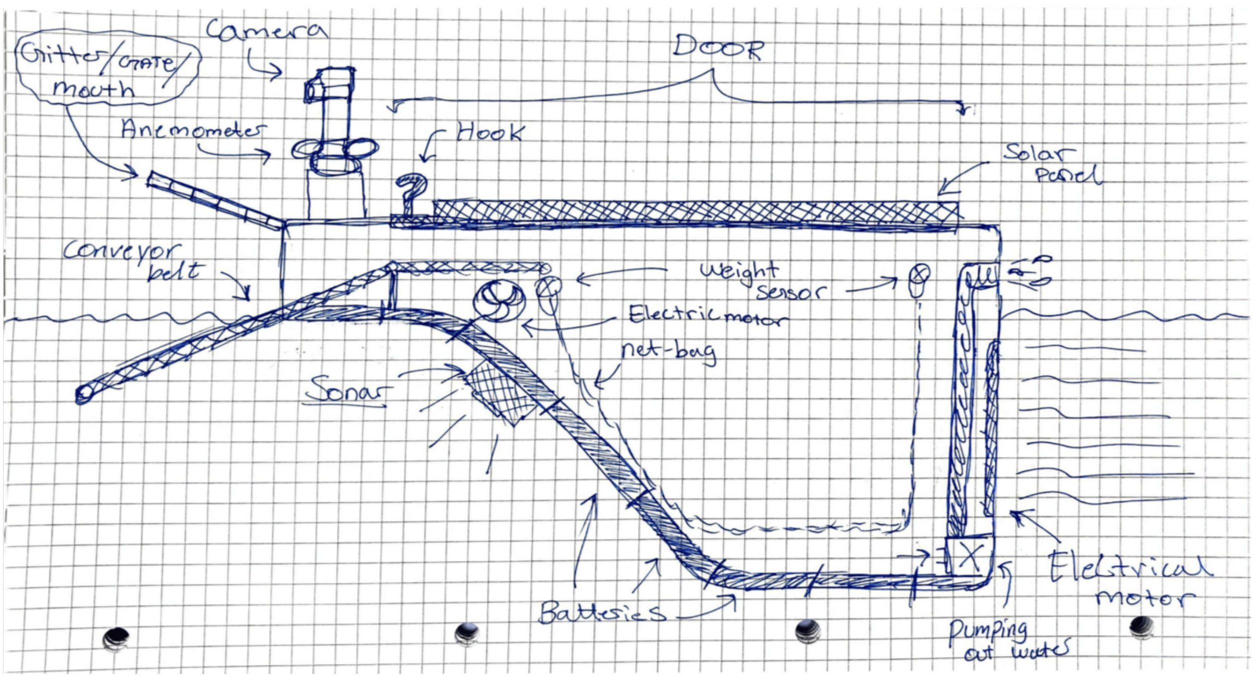


Figure 27: The final prototype design

4.6 Quality Function Deployment

We have used House of Quality in this project to asses how well we have understood our costumers' requirements and how well we have transferred them into engineering. With a weighting option to different aspects in the house of quality diagram, we can together with the customers decide what is important for them and figure out what we have had to focused on, and how well we have executed our project.

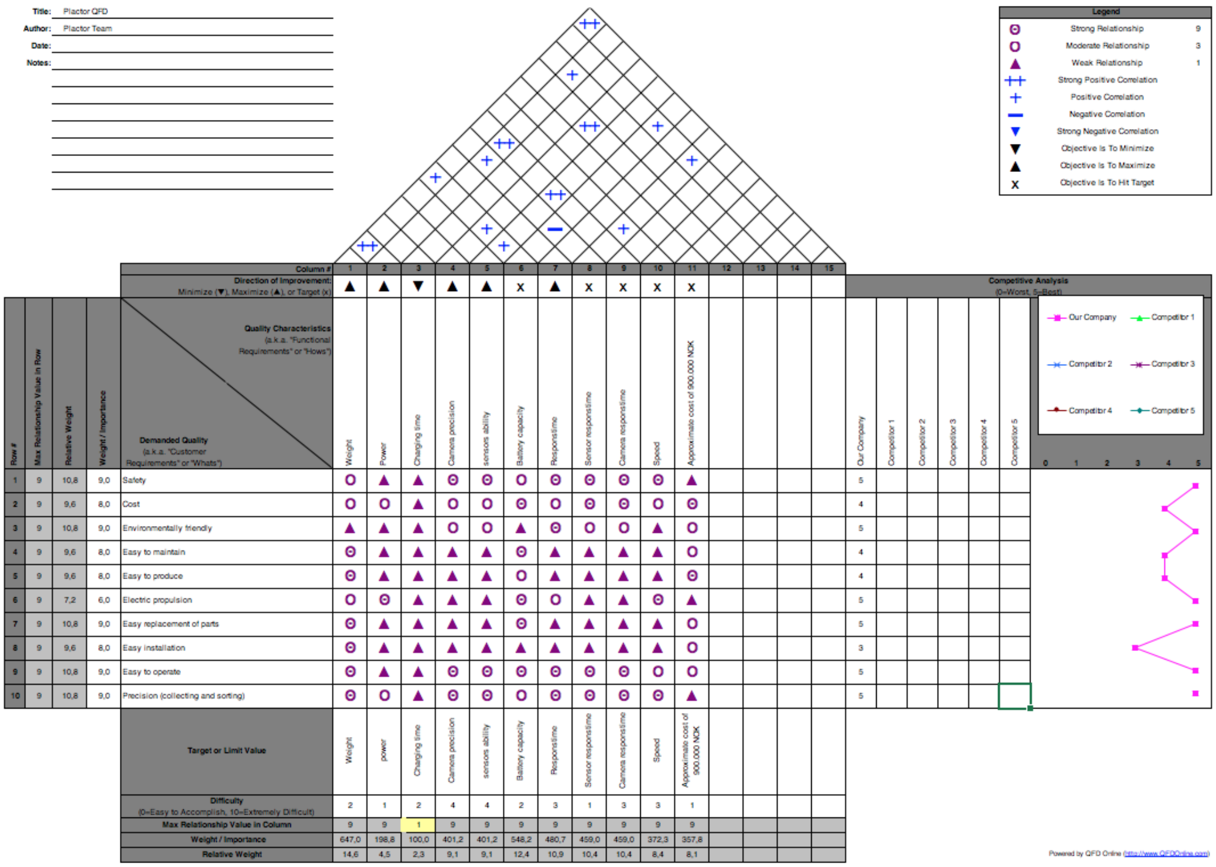


Figure 28: Quality Function Deployment

5 Functional Analysis and Allocation

Functional Analysis and Allocation is the process of translating system requirements into detailed functional design, and the result of this process is a defined functional architecture that can be used to trace each function of the system. This process bridges the gap between the system requirements and the detailed functional analysis that is necessary in order to fully understand and develop the system.

5.1 Functional architecture

The functional architecture diagram shows all major functions of our entire system from different levels. This portrays a good overlook of the system as a whole and is great for keeping organized when further designing our systems. It also gives a clear understanding of how our system interacts with its different functions. Therefore by using this architecture we can see how to start designing its subsystems as the collective of those subsystems must operate together to do everything we set our functions to do. When we have designed each function (all their subsystems that make them work) and made them properly communicate, we can start seeing a complete system that is able to complete all the tasks we require from it.

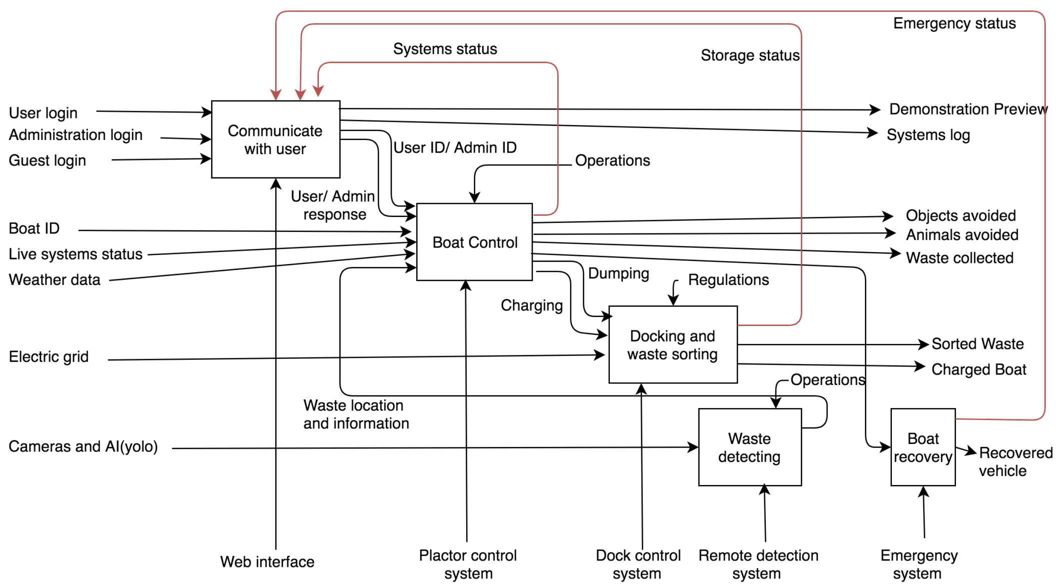


Figure 29: Functional architecture (level 1)

Now that we have a great functional overlook of our system, we can dive deeper to all the functions our subsystems need in order to complete all parts of each of the level 1 functions. As you can see in Figure 30, we are focusing on the docking and waste sorting system. We know all the desired inputs and outputs from the previous diagram but we have to add all the functions to handle these inputs and come up with the correct outputs. From this diagram we also see that we need to go to the next level as waste sorting needs several different functions to fully operate.

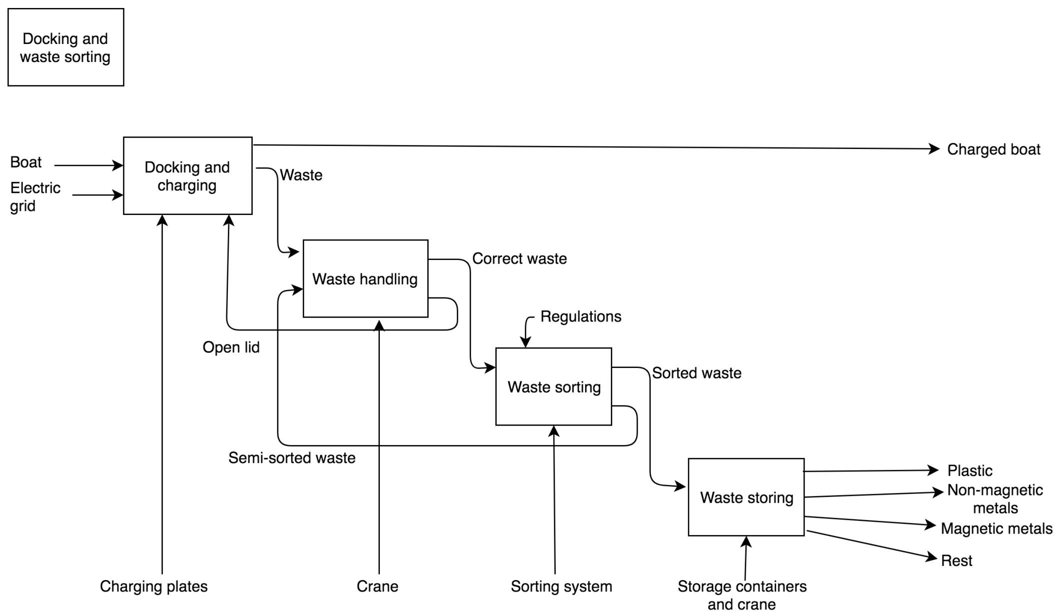


Figure 30: Functional architecture (level 2)

Diving even deeper into the functional architecture, the diagram shown in Figure 31 is a level 3 diagram that is only focusing on the waste sorting function of the previous level. Again we know the inputs and desired outputs so we started our designing with this in mind and came up with the functions needed to sort the waste correctly. In this architecture we also notice that all the functions used are constructed with components and not any further subsystems. This means we have reached the bottom level of this specific subsystem, and that docking and waste sorting have been fully designed in perspective to functionality.

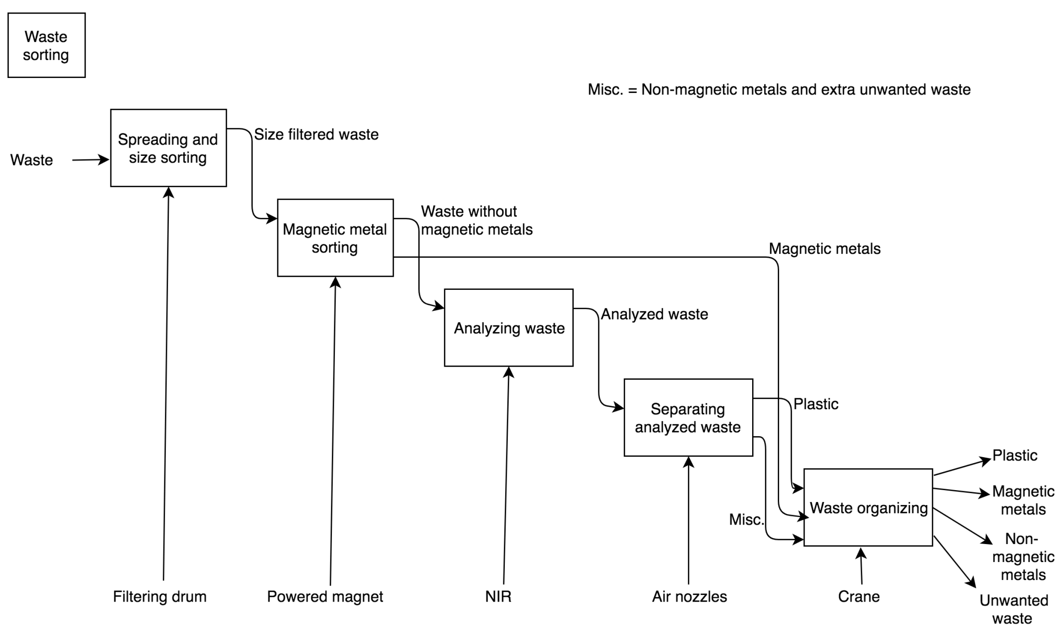


Figure 31: Functional architecture (level 3)

5.2 Functional block diagram

In systems engineering, a functional block diagram is block diagram that describes the interrelationships and functions of a system. A functional block diagram can picture several things. Like for example, functions of a system, the relationships between functions, functional paths and sequences for signals and input and output elements of a block.

This functional block diagram has been divided into different levels as well. The boat works in specific steps: the remote camera sends a signal to the boat, the boat then moves to that specific location and collects the waste. When it is complete, the boat drives back to the dock where it dumps the waste container if it is full. One important sub-function is the "Check bag capacity" system, which is marked in red in Figure 32. This particular sub-system will be explained in depth later in the report. We have decided to stop this functional block diagram at three levels, but we could expand the depth and add even more levels to portrait the sub-functions with even more details. But the purpose of this functional block diagram is to describe the main functions of our boat, which is why we only mentioned the functions from an abstract view.

By using the functional block diagram to describe the system in different levels, our team and other persons will understand how this system works. Instead of describe it with words and sentences, they can just see the diagram and get an abstract view of the whole system, which makes it much easier for the customers. Anyone can easily understand the whole process since everything is happening in step by step. As mentioned, it is possible to make this one much more detailed by having more levels, but we decided to have only three levels so the functions can be viewed from an abstract view.

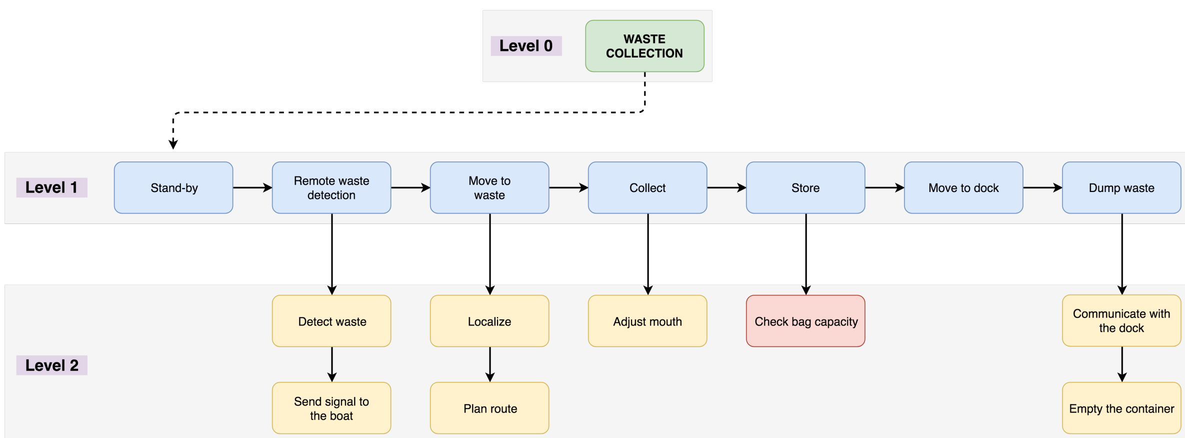


Figure 32: Functional block diagram

5.3 Systems architecture design

Our systems architecture design has been illustrated as a block diagram for all our systems and sub-systems. We have multiple systems, there are on-board systems and off-board systems, where Plactor is the on-board system. As you can see in Figure 33, the boat has a Central Processing Unit (CPU) that communicates with the dock and remote cameras by using wireless transceiver. There are many different components that are doing different type of tasks. This is a very detailed diagram of the whole system. For example in the "Propulsion Control System" we have a motor controller (PCB) that is controlling four motors, GPS module and gyroscope sensor which is stabilizing the boat while it is on the water.

The emergency recovery system contains a gyroscope sensor as well. This means that several sub-systems are using the same components, or with other words, one component is used by several sub-systems. By letting several sub-systems use the same component for the same task, we can save a lot of weight, space and cost. We don't need to buy one component per sub-system. But in the emergency recovery system, we need to have a backup GPS. Emergency recovery system cannot use the same GPS module as the Propulsion Control System, because if this GPS dies Plactor has a backup one which can show where it is. This backup GPS will only turn on when emergency mode kicks in. But the Propulsion Control System and the Surveillance System are using the same GPS module. The systems architecture block diagram is shown in Figure 33.

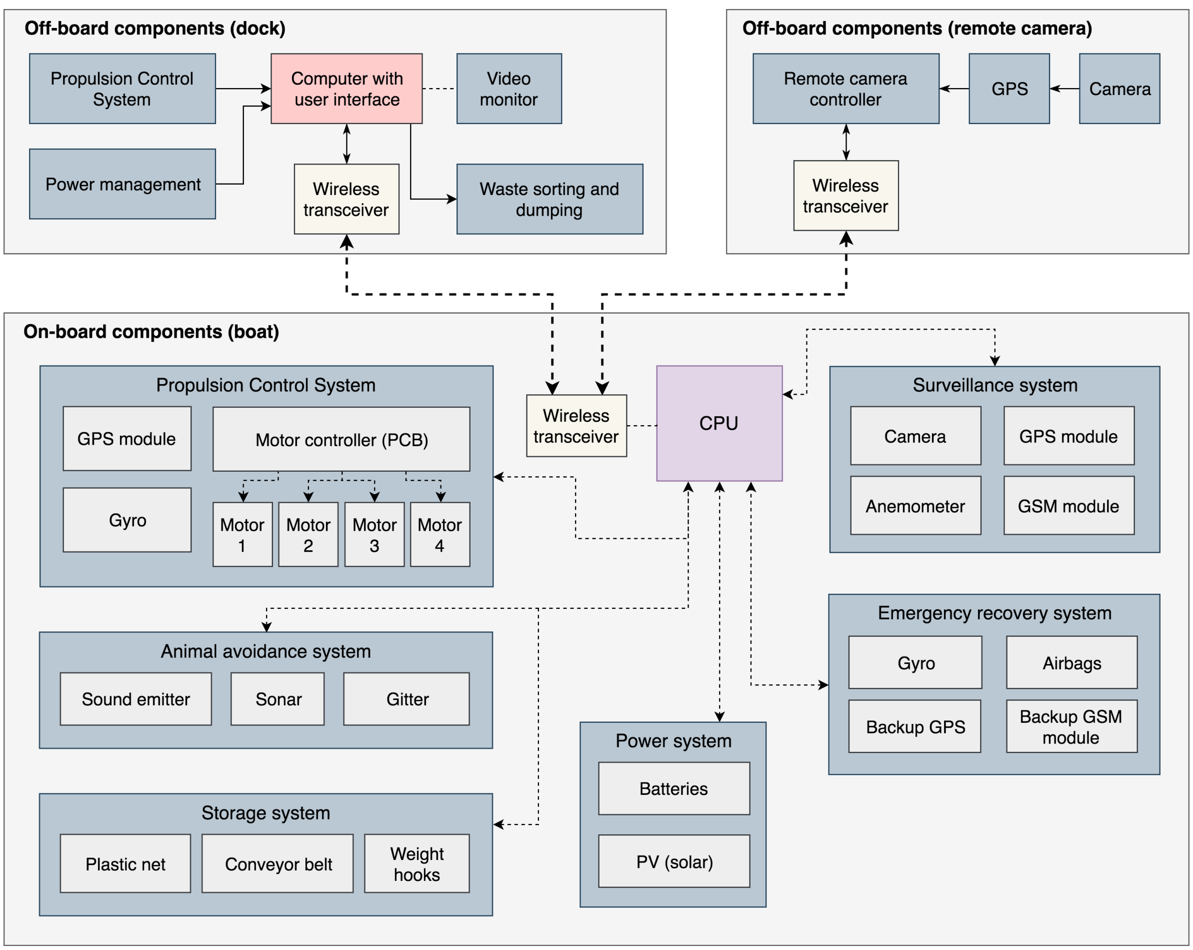


Figure 33: Systems architecture block diagram

5.3.1 Sub-system: Check Bag Capacity

Plactor contains many sub-systems for different scenarios, and there is one sub-system of the entire waste-collection process is that is called "Check Bag Capacity". This function gets called every time the boat drives towards waste before picking it up. A simple way to describe this sub-system is by using a condition diagram to portrait the following steps within the sub-system.

So whenever the function gets called, the boat first checks if the waste container bag is full. This is a boolean condition, so it can either be true or false. If it is true and the container bag is actually full, the boat returns back to the docking station to empty the waste container. If the boolean condition is false, it triggers a sub-function within this same sub-system that checks another condition, which is the battery level. If the battery level is critical, the boat returns back to the docking station immediately for charging, while if the boolean condition is false, it continues to drive around, detect and collect waste. This function gets called in a loop, so basically it stops whenever the boat gets triggered to return back to the docking station for either emptying the waste container or for charging the boat batteries.

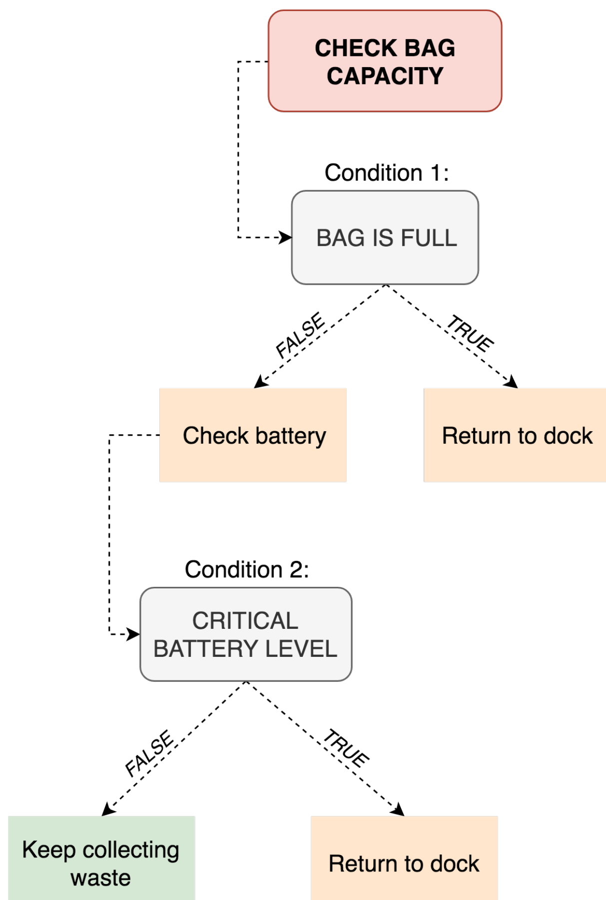


Figure 34: Check Bag Capacity

5.3.2 Sub-system: Emergency Recovery System

Since security is a common requirement for multiple stakeholders, it is something we need to prioritize during the entire product life cycle. We have implemented an emergency recovery system in the autonomous boat, which ensures security to the boat itself, along with its surroundings. The recovery system is a separate sub-system of the boat, and it contains backup GPS and GSM modules along with backup power supply to function in scenarios where the entire system is dead and the main GPS and GSM modules do not function properly. The purpose of these backup components is to continuously log events to the web interface, such as real-time geographic location. This is a huge benefit for the maintenance crew, because of the ability to track the boat upon emergency scenarios.

There are three main sensors monitoring at all times in case something happens. The pressure sensors will trigger emergency mode if the boat goes beneath the surface. The gyroscope will trigger the emergency mode if the boat is tilted above the minimum tilt angle. Lastly the GPS signal will trigger emergency mode if the boat goes outside the location where it is programmed to operate. When emergency mode is triggered the "rescue" operations start. This starts with activating the backup battery, GPS module and GSM module. These are to ensure communications and the whereabouts of the boat. During this mode the boat will also close the mouth so that no captured waste can escape and re-pollute the water. In case it's dark the user can also activate lights from the web-interface so that it is easier to locate. The boat will stay in emergency mode until the user resets it for operations, which can be done both on site or from the web interface.

In the figure below you can see a use case scenario of the emergency recovery system. You can see how the actors interact with each other, and how the system works from an abstract level.

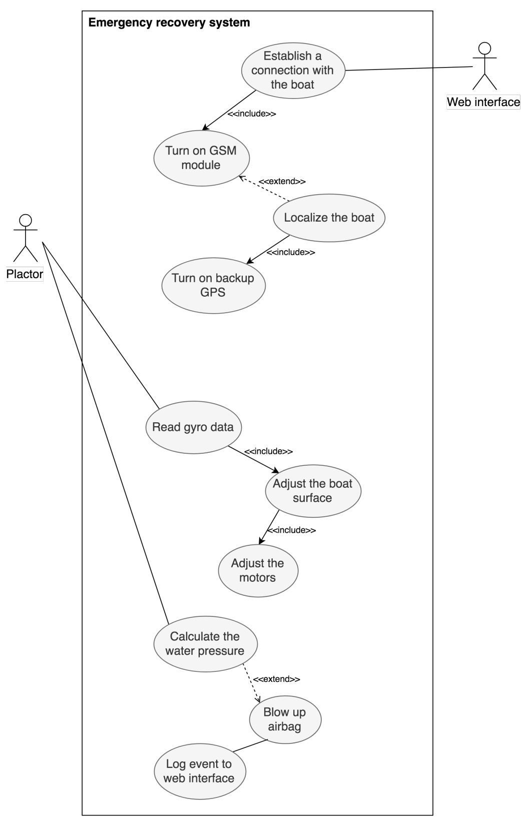


Figure 35: Use case diagram for ERS

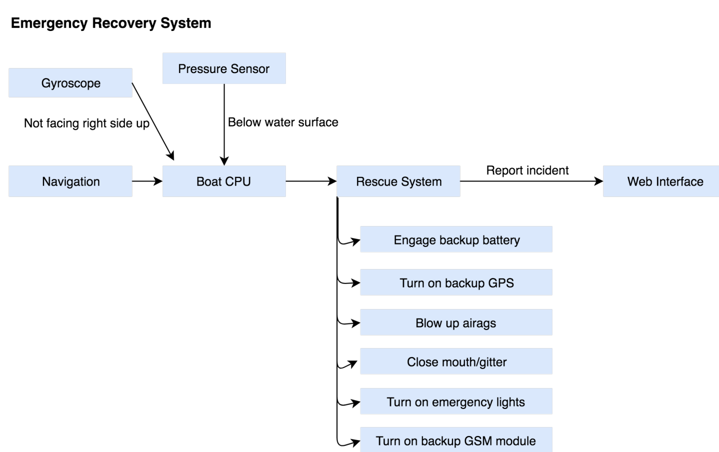


Figure 36: Functional diagram for ERS

6 Problem Identified: Waste Sorting

When we were trying to only use the autonomous boat as our whole system, we noticed that it was lacking in a big way. It was simply too complicated to properly sort the collected waste inside our boat, and since no recycling company in Norway would want to pick up unsorted waste, we saw this as new problem to figure out. We had already designed a dock to charge our boat and a way to collect the waste from the boat. But we had no idea of how to sort the waste, so this became our new focus. A sorting system that would fit right inside the docking station. Collecting only plastic would be easier but also not address all the aspects of the problem, since in reality there are lots of different types of waste in a river, not only plastic.

We did a lot of research on sorting to learn more about this process, NIR (near infrared detection) is a way to analyze the molecular structure of the waste and categorize them out of what molecules they are built from. Then we needed a way to separate the different types of waste and that is when we learned of air nozzles to separate the categorized waste into their right place. Since we have made many functionality diagrams for the boat, we applied our new knowledge and started our functionality diagram for the sorting system, with this diagram we can easily see that we start with general waste and at the end of the run the waste is sorted into their respective categories: plastic, magnetic metals, non-magnetic metals and the rest.

We also believe that many other people that have tackled the same problem as us did not elaborate on the sorting aspect, so we made sure to think of everything when it came to sorting. Therefore, anyone collecting general waste in a river can use our sorting system to make their concept complete as we have designed it to not only work with our autonomous boat but adaptable to any type of boat.

6.1 The Docking Station

The diagram shown in Figure 37 is an overview of our docking station. The station consists of a garage, a crane, sorting station, charging station for Plactor and an area for container drop-off. Just like Plactor, the docking station will be fully autonomous. The docking station contains many sub-systems for different scenarios, where two important functions are charging Plactor and to collect garbage that the boat turns in.

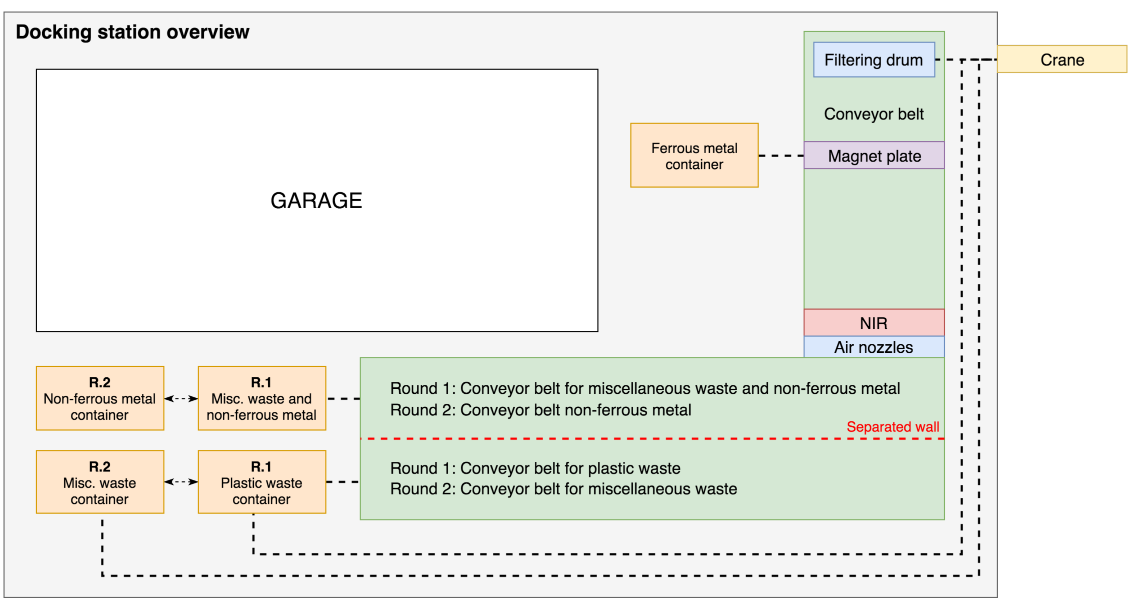


Figure 37: Block diagram of the docking station

6.1.1 Sorting station

Since Plactor will be picking up all sorts of waste from the river, we need some type of way to sort it. As shown in Figure 37, the sorting process starts with a crane picking up a container of garbage from Plactor. The crane will drop the garbage into a filtering drum, sorting the waste into bigger types on one side, ranging down to smaller types on the other side. This is to make the further process easier. The filtering drum will drop the waste onto a conveyor belt where in the next step ferrous metal will be picked up by a strong magnet and dropped into a container. The rest of the waste will continue along the conveyor belt and go under a NIR-scanner where the waste will be scanned and put into different categories. NIR-scanners can scan down to molecules, so it will be very precise.

As you can see on the diagram, the process will now be divided into two parts or rounds. On the first round, plastic will be separated from the rest of the waste. This will be done with the knowledge from the NIR-scanner and air nozzles to “shoot” the plastic over to a separated conveyor belt. The waste that is left (misc. and nonferrous metal) will continue on the first conveyor belt (closest to the garage) and be transported back to the filtering drum.

The unsorted waste from the first round will now go through the same process one more time. However after it has gone under the NIR-scanner, the air nozzles will now “shoot” the miscellaneous waste over to the separated conveyor belt, leaving the non-ferrous metal on the first conveyor belt. During the process, the containers will be switched out and every type of garbage will have their own container.

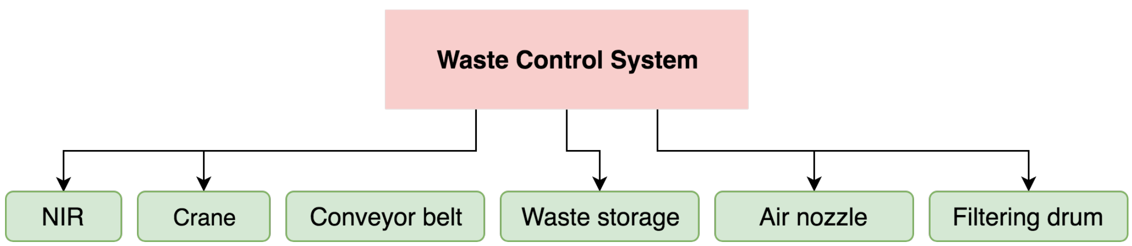


Figure 38: Components used in the sorting process

6.1.2 Garage and charging

The docking station will have charging for Plactor and will also have a garage for storing Plactor during winter. Every time Plactor comes to deliver off waste for sorting, it will be connected for charging. This will happen with an own slot that Plactor will park in, enabling the crane to pick up the garbage container. The garage will be for storing Plactor during winter time or for servicing and changing of parts. The garage can be equipped with tools and special equipment needed for servicing Plactor.

6.1.3 Container drop-off

The last area of the docking station is for containers. The only part of the dock that is not autonomous is the picking up of containers for delivery to recycling center. Once the containers are full, staff will be noticed on the web interface that the waste is ready for delivery. Staff from the commune will then have to pick it up and deliver it. This is the last process of the sorting station and the process can start over again.

7 Operational Scenarios

7.1 Remote waste detection

In this operational scenario we describe how the boat receives a signal from the remote camera and starts moving the specific area of the river. This operational scenario is very important to the overall system, and it plays a big role for the autonomous boat to work efficiently with high accuracy.

In our concept we have remote cameras placed further up the river from where the boat is working. The cameras will pick up movement from objects passing by, identify it and check if the boat is able to collect it. Once it has done this procedure, it will give signals and commands to the boat, telling it to move to the part of the river where the garbage was spotted. An example is that the cameras sees an item floating on the right side of the river. The camera will quickly find out what it is. In this case, a piece of plastic. The cameras will send a message to the boat telling it to move to the right side of the river, and once the boat is done with its ongoing task, it will move over and be ready to collect the plastic bit. In this way, the boat will be more effective, saving both time and power. Instead of going back to the dock, it will combine tasks and create its path from what the remote cameras tells it.

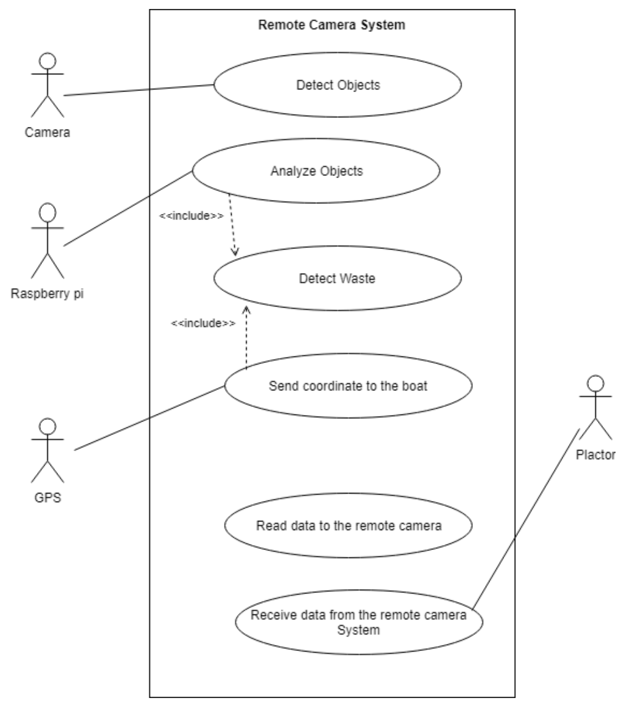


Figure 39: Remote waste detection (use case)

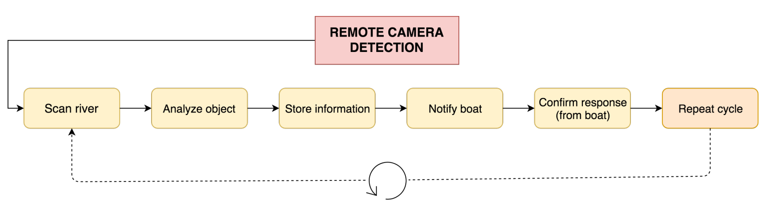


Figure 40: Remote detection process

7.2 Waste collection process

The operational scenario starts with all the remote cameras that are mounted alongside the river or lake. The job of the remote camera is to detect all the waste that floats on the water. When the waste is detected and the boat has driven to the waste to collect it, it will detect the waste once again to make sure that it is not collecting something else. If it is waste, it will gladly collect. But in case if there are animals, or a bigger size of materials, Plactor will close its mouth immediately so no animals gets harmed. After collecting big amount of waste, it will check the bag capacity, and take a decision of what the next step is.

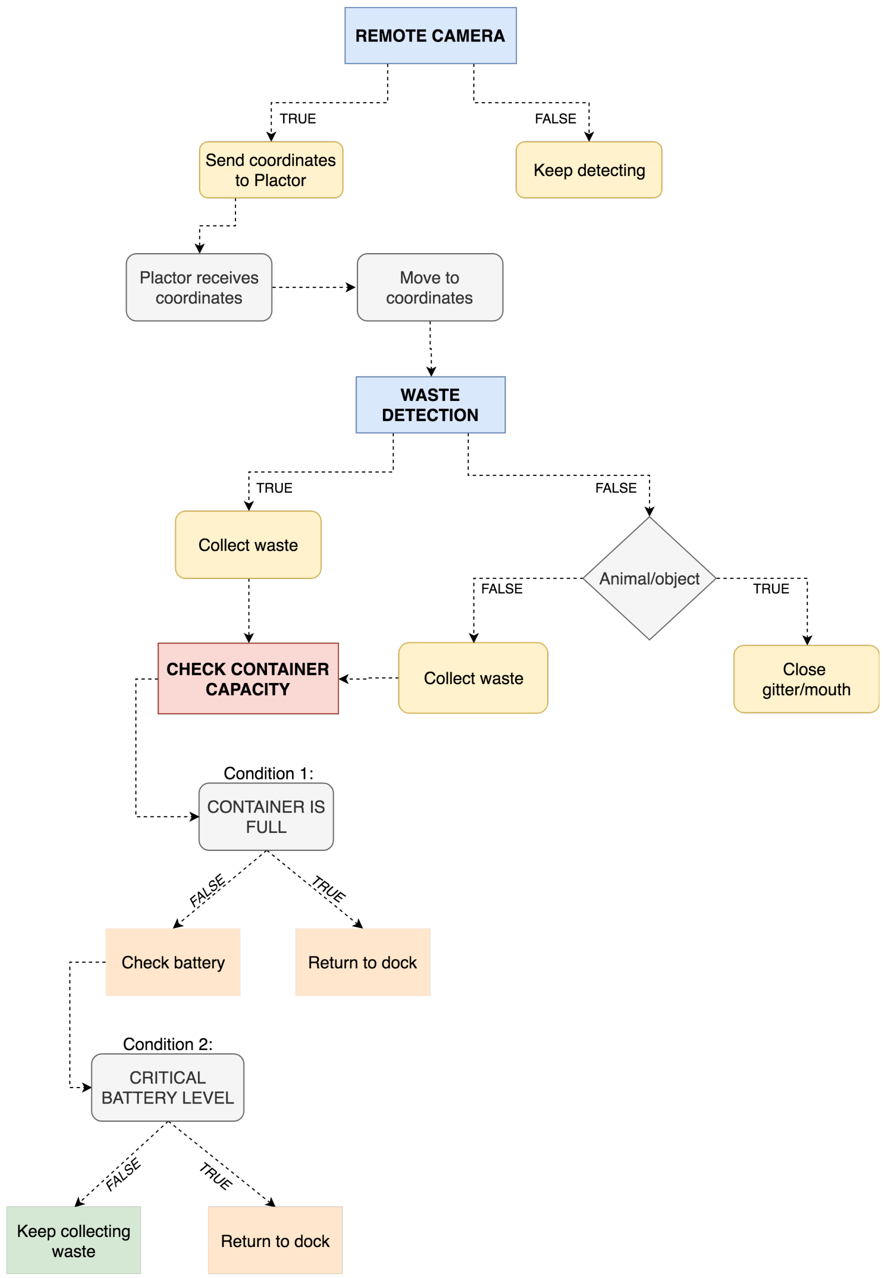


Figure 41: Waste collection process

7.3 Waste sorting process

In this operational scenario we describe how the waste sorting process works in the docking station. There are four different actors present and all these actors interact with the system. The actors are components of the dock sorting process, because they all perform different tasks and operate differently. For example the crane only has one task, while the NIR sensor handles multiple operations at once.

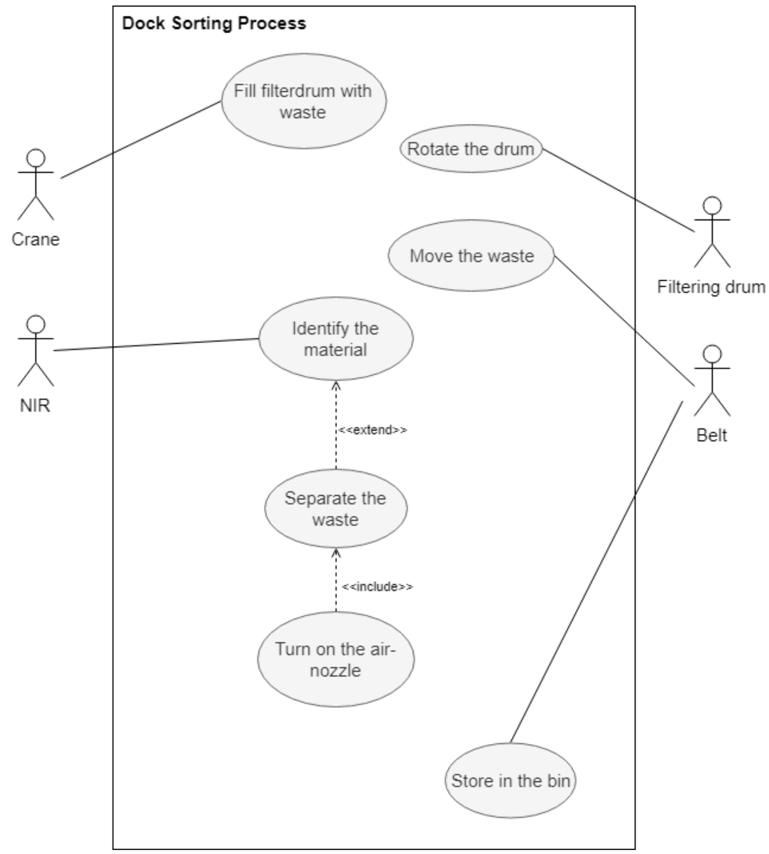


Figure 42: The waste sorting process (use case)

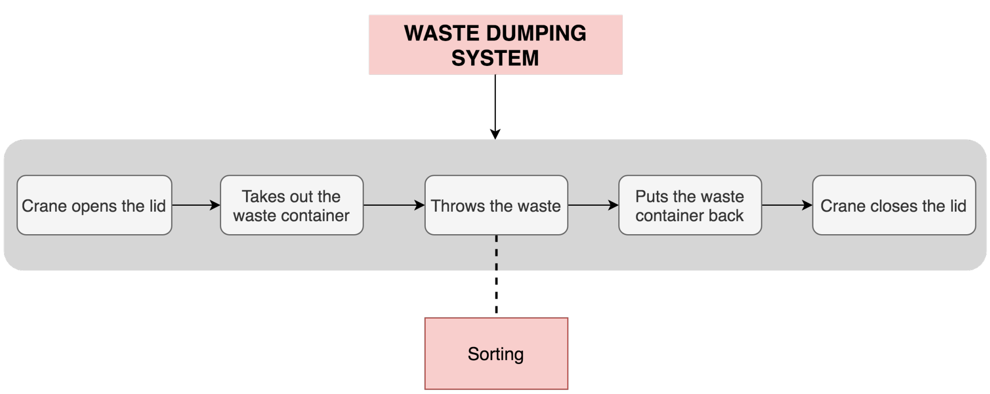


Figure 43: Waste dumping process

7.4 Boat charging process

Sequence diagrams shows how the objects interacts with one another to achieve some high-level functionality that individual objects cannot achieve on their own. It also emphasizes the order of the messages over time. The implication is that it is the interaction among our system, sub-systems or components in order to achieve some high-level functionality.

In the sequence diagram shown in Figure 44, our boat is an actor, the web interface is a user interface, the Power Management System is a controller and the charging status is a data element. In this diagram it is explained how our autonomous boat is communicating with the dock station in need of charge. In this case there is a controller which control messages between the boat and dock station. When the request from the boat is sent to the user interface, it will direct the request to the controller and the controller will send the request to the charging status if there may be charging availability. If the controller gets the respond with the station availability for charging, the boat is driven to the dock station and then start charging.

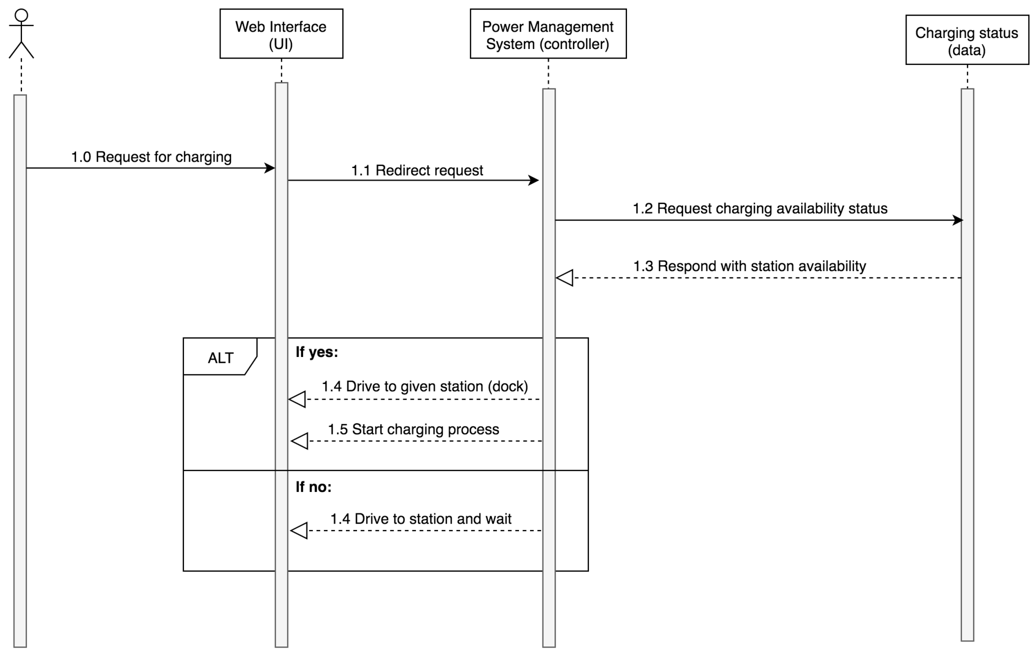


Figure 44: Boat charging process (sequence diagram)

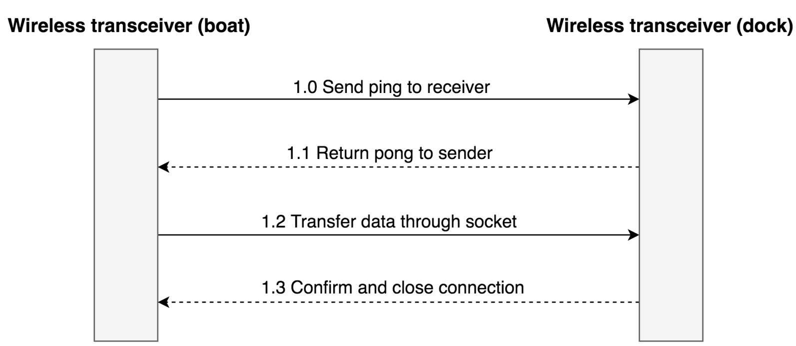


Figure 45: Wireless communication using transceivers

8 The Final Design

After going through multiple brainstorming sessions and iterations, along with many different previous concept alternatives, we finally managed to assemble a final design by working with the customer requirements, key drivers and performance parameters to finalize the design.

So now we are introducing Plactor: a small autonomous boat with a conveyor belt to pick up waste. The boat will be fully autonomous with help from cameras and sensors. However, you will be able to control the boat from the docking station or an integrated web interface. The boat will, in addition to batteries, be powered by solar panels. The solar panel is attached to the hatch on top of the boat, this is to get the best effect out of it. The boat is also equipped with a 360-camera, anemometer and a hatch with a hook.

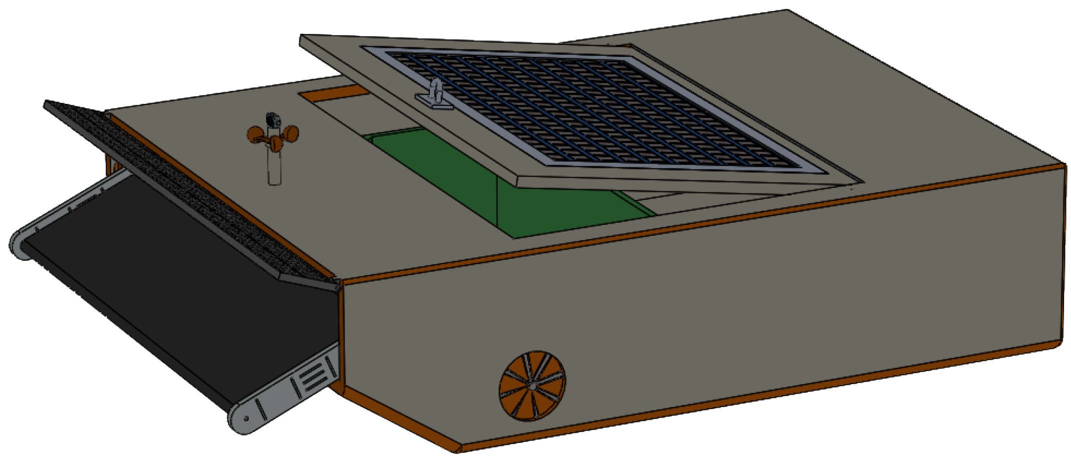


Figure 46: Projected view of the boat

The boat will be controlled with the help of four propellers. One on each side and two in the back. The main propulsion will be from the to propellers in the back, while the ones on each side will mainly be used for steering. The propellers on the side will also play a part in the emergency system using thrust to stabilize in cases of bad weather.

8.1 Collect and drop-off

The boat will collect garbage using the conveyor belt in the front. The conveyor belt will drop the waste into a container, which will be collected and emptied on a docking station. Since the boat is of a rather small size, it must know what it is about to collect. It also has to avoid collecting animals. To accomplish this, it will use the camera mounted on top of the boat and advanced software to identify objects. In this way, it will know if it is an old soda can or a duck it is approaching. Since the boat is not equipped with any type of sorting technology, all garbage will be collected and dropped of on the docking station. After this, the garbage will be sorted there.

8.2 Anemometer and solar panel

On the top of our boat there will be an anemometer. This is to help the boat maneuver across the river. An anemometer measures wind speed. We will use the information from the wind speed to choose the right path for the boat to take and where the garbage is most likely to float. Doing this, we can save a lot of power. Instead of the boat driving around blind, it will have information that will make it more intelligent.

As mentioned, the boat will be equipped with a solar panel on the hatch on top of the boat. The panel will be used to charge our boat, not as a main source of power, but to increase the time the boat can be out in the river. This will mean greater collection of garbage, as the boat will be on the river for longer, and it will do less damage to the battery with fewer cycles of discharging.

8.3 Camera, sonar and sound emitter

The most important part of controlling our boat is the camera. The camera will be used to everything from moving around to identifying objects. We will also use a remote camera to detect garbage coming down the river. When it comes to the grating, that will be used as a small emergency protection against our boat collecting animals. Using the camera, the boat will avoid animals as a “standard”, but if it fails to do so, the grating will stop the animals from entering the boat.

Sonar and sound emitter is attached under the boat. The sonar will be used to map the bottom of the river to stop the boat from hitting it. It will also detect any steams of fish. If the fish comes to close to the boat, the sound emitter ill be turned o and stats sending sound waves into the water and scaring the fish away. This technology is very mature and will not hurt the fish or other animals in any way.

8.4 Propellers and power

As mentioned, the boat will have four propellers, two in the back and one on each side. The main propulsion will come from the two propellers in the back and the ones on each side will mainly be for steering and emergency cases. The propellers will each have an individual electric engine, powered by batteries and of course to solar panel. This is to keep the boat as agile as possible and environmentally friendly using electricity as our power source. The boat will charge on the docking station, both when emptying the garbage box and when the remote camera no the camera on the boat don‘t detect any garbage in the river.

8.5 More pictures

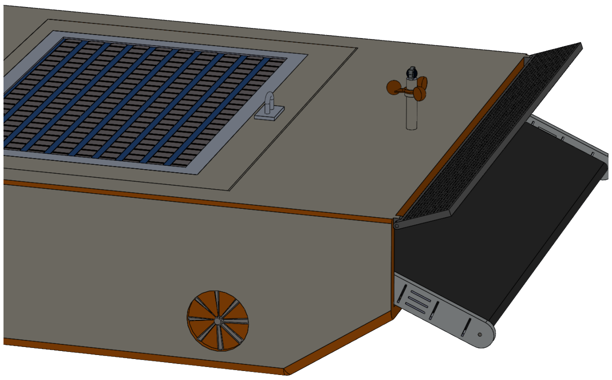


Figure 47: Top view of the boat

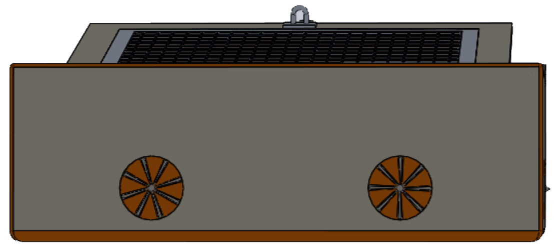


Figure 48: Back side of the boat

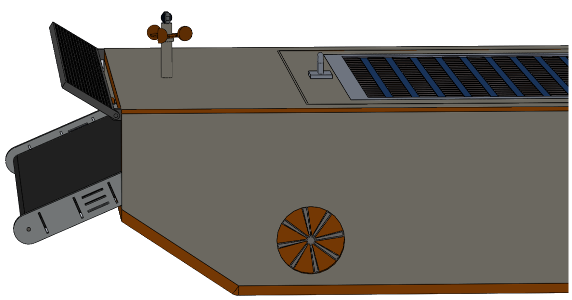


Figure 49: Left side of the boat

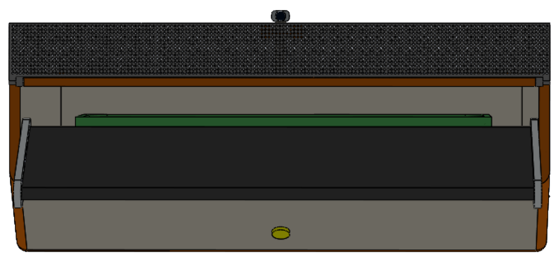


Figure 50: Front view of the boat

9 Technical Research

We have done a lot of technical research throughout the entire project, and we have been looking at different technologies to use for the autonomous boat. While doing research, we have found several different solutions for the same operations, so we have decided to use Pugh Matrix diagrams in order to compare these.

9.1 Chassis material

The autonomous boat must have a chassis made by high quality material, since it is going to face some waves while driving. However the chassis cannot be heavy, because it might sink under water if it gets filled up with a lot of waste. So in order to fulfill this requirement, we need to use some light material that is also strong. Carbon fiber is perfect for this type of criteria, but it's not the best solution because it costs a lot. That's why we decided to compare multiple chassis materials in order to pick the best one available for our case, and with the use of Pugh Matrix we can easily see that aluminum is the best material available.

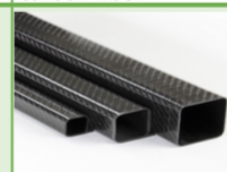
Criteria	**Weight**	**Aluminium**	**Plastic**	**Carbon fiber**
Material				
Cost	20	4	5	1
Material Weight	30	2	3	5
Robustness	20	3	4	5
Installation *Molding/Welding modification*	20	4	2	3
Repair/service *Repairing broken parts*	10	5	2	3
Total score:	**100**	**18**	**16**	**17**
Posistion:		1	3	2

Figure 51: Chassis material selection using Pugh Matrix

9.2 Object detection software

There are many solutions available for object detection, and in order to pick the right software for our concept, we used a Pugh Matrix diagram to compare and separate the most popular open-source software that are currently available. We compared NIR, YOLO and TensorFlow. NIR is an object identifying technology which is used in numerous sorting stations around the world. YOLO on the other hand is a very precise object detection framework, built on top of TensorFlow which is better for machine learning.

As you can see in Figure 52, both NIR and YOLO score pretty similarly and they are both close to each other. TensorFlow did not score so high compared to YOLO, because it has a few known issues and it is quite complicated to install and deploy. It is known for not being precise as well, which is very important in our case. YOLO is much better than TensorFlow in this criteria, because it has been heavily optimized for precise object detection, and it is very popular as well. And at last, NIR is used a lot in waste sorting and recycling stations and is pretty known for its functionality.

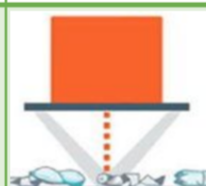
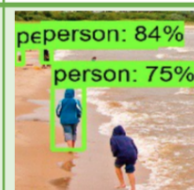
Criteria	**Weight**	**NIR**	**YOLO**	**TensorFlow**
				
Cost	20	1	4	3
Robustness	20	5	4	2
Installation *Software availability*	30	4	3	3
Updates *Software availability*	30	4	2	2
Total score:	**100**	**14**	**13**	**10**
Posistion:		1	2	3

Figure 52: Comparing object detection software using Pugh Matrix

Since NIR and YOLO both score similarly, we decided to implement both technologies in our system, but on different places and for different scenarios. YOLO will be integrated into the remote camera, which is detecting waste very early in the lakes and rivers. It is also integrated in the camera which will be positioned on top of the autonomous boat. NIR on the other hand will be used inside of the docking station, where it will function to identify waste on the conveyor belt.

9.3 Battery selection

Battery selection is a major decision and we had to do a lot of research on this specific technology. To find the most suitable battery for our boat, we compared three type of batteries: Tesla batteries, Lithium-Ion batteries and the classical Lead-acid battery.

Before the comparison we were very clear about that we are not going to use the classical lead-acid battery, since it is huge and very heavy for our boat. But we still included it in the Pugh Matrix diagram to compare and to see the differences. All of these batteries score very differently, and Tesla battery is scoring highest. Even though they score quite differently, we had three important criterias according to our system requirements, which was material weight, quality and performance. Tesla batteries are perfect as well, because they are famous for super-charging and they deliver at a really high performance level as well. So this decision was pretty clear after the Pugh Matrix comparison.

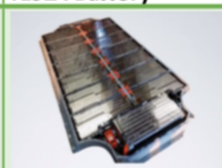
Criteria	Weight	TESLA Battery	Lithium-Ion Battery	Lead-Acid
Material				
Cost	15	1	4	3
Material Weight	15	2	4	1
Robustness	10	4	2	3
Installation *Molding/Welding modification*	15	4	2	1
Performance	25	4	2	2
Charging	20	5	2	2
Total score:	**100**	**20**	**16**	**12**
Posistion:		1	2	3

Figure 53: Battery selection using Pugh Matrix

9.4 Solar panel

In today's market there are many different types of solar panels available. We have compared four different types of solar panels in terms of different design, cost and efficiency. We can see in Figure 54 that they score very close to each other. This is because they are very good in different scenarios.
As we can see the Mono-SI solar panel is scoring very even on every criteria. There is one negative side of Mono-SI though, which is the cost. It is quite expensive compared to the other three. But again, there are other criteria that we also need to have focus on, such as robustness.

It is critically important that the solar panel does not get damaged by the weather or something else that might damage the panel. It must be fair in weight as well, it cannot be very heavy, such as the CVP solar panel, which is scoring quite bad at weight and is therefore not suitable for our project.

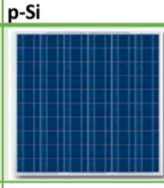
Criteria	Weight	Mono-SI	p-Si	A-SI	CVP
					
Cost	20	1	3	3	2
Robustness	20	5	2	2	5
Weight	20	4	4	4	2
Installation	20	3	2	4	2
Efficency and performance	20	3	2	1	4
Total score:	**100**	**16**	**13**	**14**	**15**
Posistion:		1	4	3	2

Figure 54: Solar panel selection using Pugh Matrix

9.5 Sonar and sound emitter

Plactor has one component which is unique compared to other existing systems. This component is called sonar, and is one of the most important components of Plactor. This component makes sure that the boat is not floating into a shallow or anything else which is under the boat. The sonar sensor is a perfect component to keep an eye under the water, because this is not something we can do as human beings. Sonar is not delivering any images or live streaming videos, it shows a heatwave picture of the ground instead.

So in the case of Plactor driving towards a shallow groundwater, you will be able to see on the screen that some of the area is yellow and red colored. Red color means that the shallow is too high and can hit the boat if it drives near or over it. As your can see in Figure 55, the color changes from green to yellow to red, based on how critical the are is. Since Plactor is autonomous, it means that Plactor will understand these color references and take action out of it.

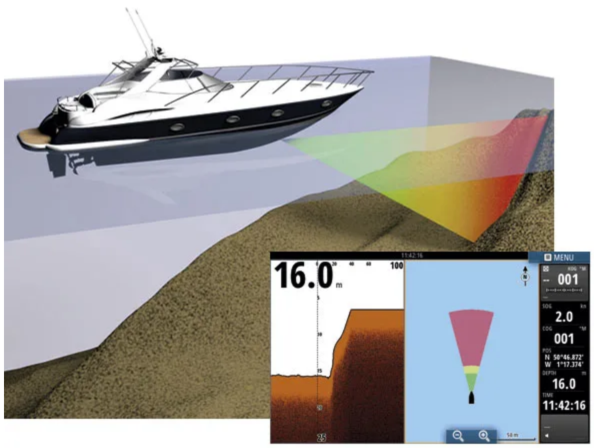


Figure 55: Sonar ground detection

Figure 56: Sonar fish detection

One of our goals is to not harm any fishes, and avoid collecting them with the conveyor belt. So to make sure that the conveyor belt is not collecting any fishes, the sonar will have an integrated function where it can detect fishes too, and not only the ground. This function exist on many boats these days, especially on fishing boats. But those boats use it to detect and catch fishes, while Plactor will use it to avoid them.

When the sonar sensor detects a fish, it will trigger a sound emitter which is also inside the sonar. This sound emitter is specially made for fishes, and helps Plactor to scare the fishes away. Fishes can be scared at high intensity, with low frequency and the frequencies are normally lower than 10Hz.

This sound emitter combined with sonar is the perfect component to make sure that no fishes are getting harmed, and none of them are getting inside Plactor. And since Plactor is autonomous all these functions and detections will be understood by Plactor, and then it will take its own decisions. But from the interface as you can see in Figure 56, the customer and the maintenance crew can easily watch the the heatwaves.

10 Trade-off Analysis

10.1 Battery comparison

When trying to figure out what batteries we should use, we had to do a lot of research and we used a Pugh Matrix to also compare the batteries. Important features we needed was having it very compact and to be able to charge it a huge amount of times. From the start we knew that a lead-acid battery would most likely be too bulky and heavy. Therefore we thought of using a lithium ion battery, which has proved to last a long time with a lot of charging.

The battle would be against Panasonic 18650 cells vs Tesla's new 2170 cells (numbers here represents the size, 2170 = 21mm diameter and 70mm tall. "The 18650 cell delivers 3,000 mA and the 2170 cell delivers 5,750-6,000 mA". From here we can see that the Tesla 2170 cell can deliver about twice the current of the 18650 cell with only being about 50% larger. Meaning that energy per volume is roughly 50% better in the 2170 cell.

According to Elon Musk himself the 2170 cell is "the highest energy density cell in the world, and also the cheapest." Since the Tesla cell is also designed with electric vehicles in mind they are also superior at handling larger currents which means that it can be charged quicker with using the right equipment.

Property	Value	Unit	S
Length	70	mm	k
Diameter	21	mm	k
Volume	24.250	mm^3	c
Weight	66	gram	e
Voltage	3,7	V	e
Charge	5.750	mAh	k
Capacity	21,275	Wh	c
Energy density	877,5	Wh/L	c
Specific energy	322,3	Wh/kg	c
Density	2,72	kg/L	c

Figure 57: A 2170 battery cell

Property	Value	Unit	S
Length	65	mm	k
Diameter	18	mm	k
Volume	16.540	mm^3	c
Weight	45	gram	e
Voltage	3,7	V	e
Charge	3.400	mAh	k
Capacity	12,58	Wh	c
Energy density	760,6	Wh/L	c
Specific energy	279,6	Wh/kg	c
Density	2,72	kg/L	c

Figure 58: A 1850 battery cell

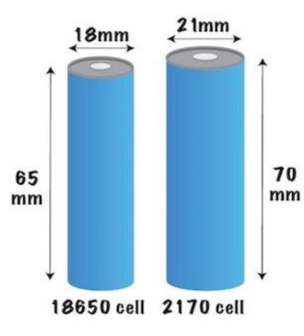


Figure 59: Battery size comparison

10.2 NIR technology

In our sorting system in our dock, we will use NIR-technology to identify different types of waste. NIR is short for near infrared and operates around wavelengths between 760-2500 nm. To compare, visible light is 380-760 nm and infrared light is 2500-25000 nm. With this system, we will be able to sort waste in separate categories down to the molecules. NIR is often used in sorting-systems, mainly because of its accuracy and high speed. This technology will boost both quality and effectiveness in our production.

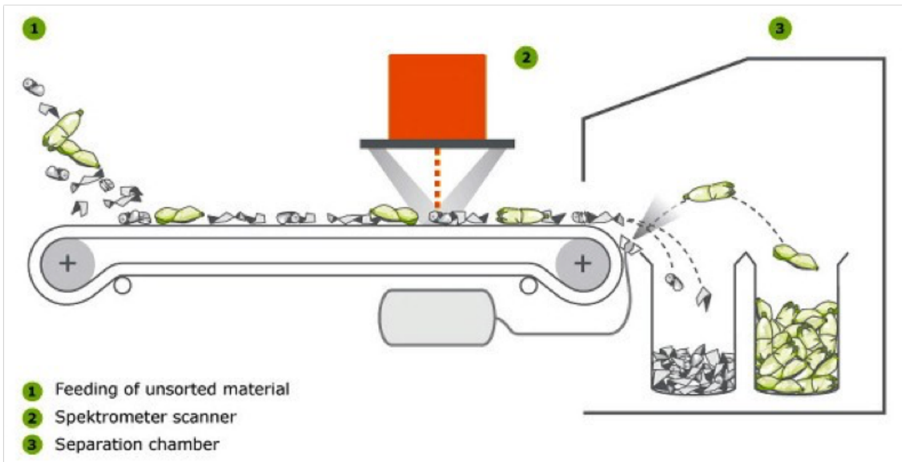


Figure 60: NIR-technology used for sorting

There are several different types of NIR technologies available. We can sort them into five different groups according to how they generate spectra:

10.2.1 FT-Nir

A Fourier Transform Nir-instrument uses an interferometer to collect a spectrum. It consists of a source, beam splitter, two mirrors, a laser and a detector. Energy goes from the source, via the beam splitter who splits the beam into two. One part is transmitted to a moving mirror and the other to a fixed mirror. A precise laser is used to control the moving mirror in addition to act as an internal wavelength calibration. The laser is then reflected to the beam splitter.

Since the beams have travelled different distances, they create an interference pattern. This pattern is also known as an interferogram. The beam is transmitted to a detector, where the detector reads every wavelength from the beam. An algorithm called Fourier transform is performed on the interferogram to create a spectrum. A major benefit with this FT-NIR is very precise due to its internal laser.

10.2.2 Dispersive Infrared Instruments

A dispersive infrared instrument also has a source and mirrors. Energy is sent through a sample and a reference path, through a chopper to control energy going to the detector, and directed to a diffraction grating. The grating is similar to prism, it separates wavelengths of light in the spectral range and directs individually each wavelength through a slit to the detector.

Each wavelength is then measured, going through the spectral bandwidth and the grating, with the detector selecting wich wavelength to measure. This is used to construct the spectrum. Dispersive infrared instruments is the most common NIR as it has been around for a long time.

10.2.3 Diode Array

In a diode array spectrophotometer, a light source illuminates the sample with white light. Some of the light is absorbed and the rest is reflected. The reflected light hits a stationary grating, which separates it by wavelength, converting it to a spectrum. A benefit of diode array is the speed of measurement. Each wavelength is measured by a dedicated diode detector, measuring every wavelength simultaneously.

10.2.4 LVF

A Linear Variable Filter is a bandpass filter that has been intentionally wedged in one direction, creating a dispersive optical element depended on position. LVF is suited for compact instruments requiring high spectral resolution and benefits from the ability to make it small size.

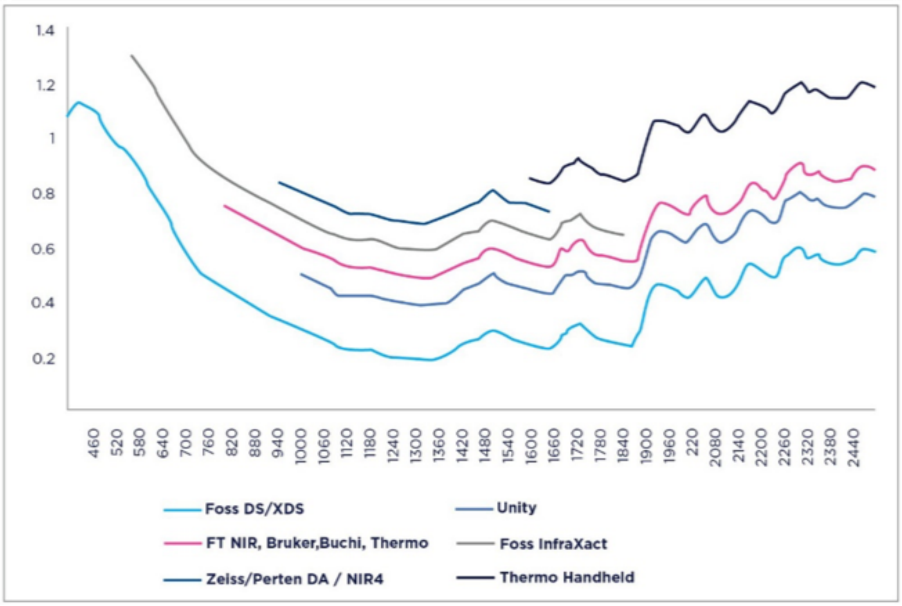


Figure 61: Graph of NIR wavelengths

10.2.5 Software and Cost of Ownership

Every type of NIR-instrument comes with their own software for a proper readout of the scanning. The instruments vary in purchase price, but all of them will have to replace certain parts after a while, such as source lamp (1000-5000 NOK) and consumables like NIR cups. Some of the instruments have moving parts that will need replacing during their period of life. Glass components used in NIR-instruments can be costly, but rarely fail. It is recommended to have a yearly service on the device though.

10.2.6 Which type fits us?

The type of NIR most suitable for us is Diode Array. Since we will be dealing with all sorts of garbage, we need a system with great range in reading wavelengths. This is also the most used for sorting systems, as it is fast and precise. With this technology we can use Norwegian manufacturers such as Tomra. Tomra has their expertise in waste and metal recycling and their technology is perfect for our system.

11 Simulations

11.1 Motor and gate simulation

Instead of creating an animation that demonstrates some parts of the system by simulation, we decided to make an actual prototype instead. Prototyping is an excellent approach for demonstration and shows a better understanding of the overall system, compared to an animated simulation. In this prototype we only focused on two specific parts of the system: the gate in front of the boat and the motors behind the boat.

The gate is definitely one of the most important parts of the entire system, because that is where all the waste goes in, as it plays a major role in our animal avoidance system. The opening and closing of the gate was relatively easy to design and build, however the conveyor belt that is supposed to drag the waste into the boat was quite difficult to implement. Therefore it did not get included in our prototype, as we had very limited amount of time. Even though the prototype was made to only simulate the gate and the motors of the boat, it also taught us a tremendous amount about how we would have to organize the insides of our boat with regard to wiring, CPU placement and best places to attach the battery in order to help keep our stable in the water.

Figure 62: Prototype left view

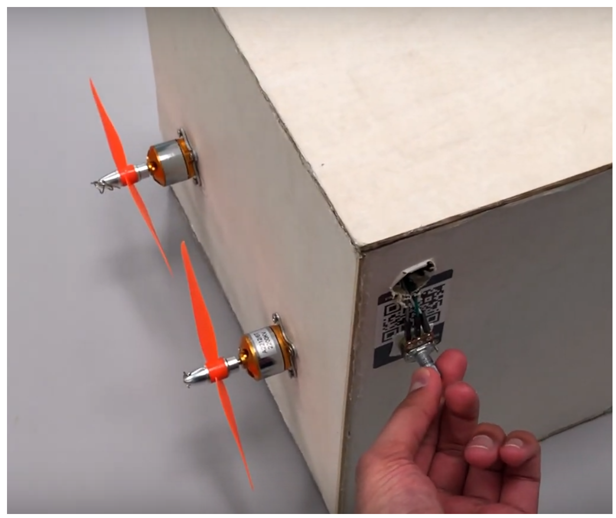


Figure 63: Prototype back view

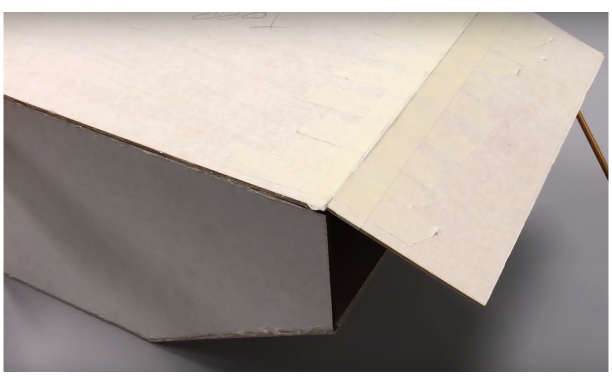


Figure 64: Prototype top view

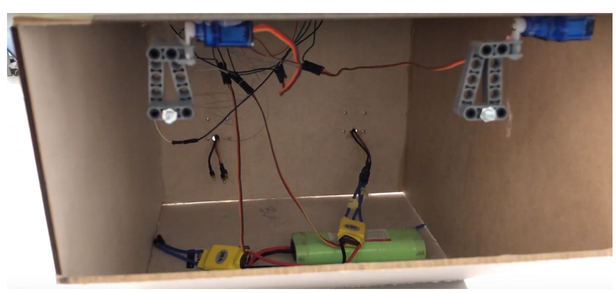


Figure 65: Prototype front view

11.2 Buoyancy force calculation

We have used Archimedes principle for calculating the boat buoyancy in order to check if the boat will float or sink during operations. His principle says that in order to float the weight has to be less than the the volume displaced multiplied by the density of water, as seen in the formula below. With this formula we can calculate how much buoyancy the boat has with its respective size.

We customized the formula in a way where the variables that matter, like the height, width, and length are easily manipulated. Using this function we created a Python code that generates the different buoyancies for different boat sizes. The code is set up in two parts, an increasing loop that gives us the buoyancy when we make the boat bigger and a decreasing loop for a boat that gets smaller.

The code is also well organized and flexible, which means that we can easily change a few variables to get a different buoyancy output for different boat dimensions. For the final output we render graphs that simulate the increasing or decreasing changes that we have specified. By using our simulation code we can get a much better understanding of how to size our boats respectively to its weight, and to create a product that is stable in the lakes and rivers without sinking the boat due to miscalculations.

$$W < \rho H2O \cdot Vd$$

$$W \ < \left(\left((h-0.2)\cdot\frac{2}{3}l\cdot w\right)+\frac{1}{2}\left((h-0.2)\cdot\frac{1}{3}l\cdot w\right)\right)\cdot \rho H2O$$

where h, w, l are boat dimensions, W is boat weight, $\rho H2O$ is water density and Vd is volume displacement.

The final graphs shows how the max allowed weight increases and decreases as we raise the boat dimensions, as you can see in Figure 66 and Figure 67. In both examples we increase the height, width and length for demonstration, but we can choose to only increase one size unit, such as width, due to the very flexible simulation code.

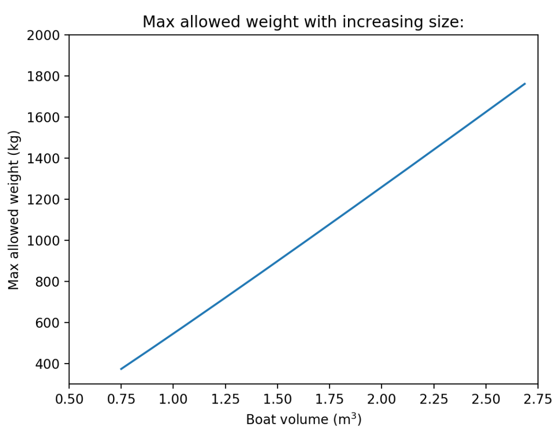


Figure 66: Buoyancy with increasing size

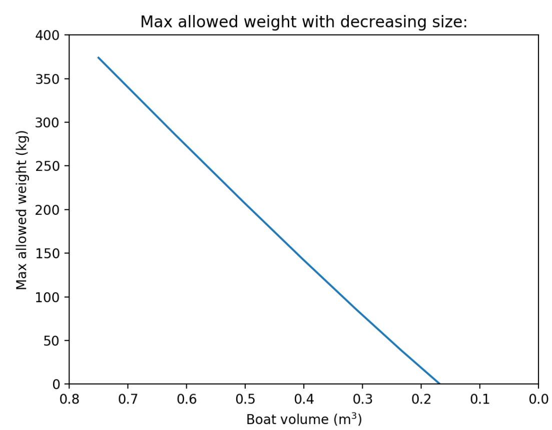


Figure 67: Buoyancy with decreasing size

We made the loop run ten times, so it would do ten calculations. The results are printed in Figure 68. The amount of loop rounds is just a variable in the Python code, so it could easily be changed to something else if we wanted to increase or decrease the amount of calculations.

```
Increasing size:
Boat volume: 0.75 m^3 - Max allowed weight: 373.88 kg
Boat volume: 0.9 m^3 - Max allowed weight: 473.26 kg
Boat volume: 1.06 m^3 - Max allowed weight: 584.91 kg
Boat volume: 1.23 m^3 - Max allowed weight: 709.43 kg
Boat volume: 1.43 m^3 - Max allowed weight: 847.45 kg
Boat volume: 1.64 m^3 - Max allowed weight: 999.6 kg
Boat volume: 1.87 m^3 - Max allowed weight: 1166.49 kg
Boat volume: 2.12 m^3 - Max allowed weight: 1348.75 kg
Boat volume: 2.39 m^3 - Max allowed weight: 1547.01 kg
Boat volume: 2.69 m^3 - Max allowed weight: 1761.89 kg

Decreasing size:
Boat volume: 0.75 m^3 - Max allowed weight: 373.88 kg
Boat volume: 0.62 m^3 - Max allowed weight: 286.12 kg
Boat volume: 0.5 m^3 - Max allowed weight: 209.37 kg
Boat volume: 0.4 m^3 - Max allowed weight: 143.01 kg
Boat volume: 0.31 m^3 - Max allowed weight: 86.41 kg
Boat volume: 0.23 m^3 - Max allowed weight: 38.95 kg
Boat volume: 0.17 m^3 - Max allowed weight: 0.0 kg
```

Figure 68: Weight limits based on boat volume

11.3 Stress calculation of propeller

On the pictures below you can see a calculation on water pressure impact on the propellers on our boat. In Figure 69 we have used alloy steel as our chosen metal. We have chosen this because it has a high strength to weight ratio and therefore fitting good on our boat. Alloy steel is not resistant to water and very prone to corrosion. This means we would have to treat with a protective layer after manufacturing.

In the other test we have used a 6000-series aluminium. This is because aluminium is very light-weight and cheap and would be a good fit for us. Also aluminium does not corrode. And since the propellers will be under water, that is a great plus. However, as you can see in the test, the aluminium is not strong enough for the pressure it will encounter.

In the calculation we have a couple of red areas on the propeller. However from the yield strength being a fair amount higher than the highest level of stress the propeller gets, we are working within safe areas. The propeller is being applied 1,5 psi of pressure. The amount has been over dimensioned to be extra safe that the propeller will not fail. The propeller will be around 0,5 meter under water, however in the test, we have used pressure at 1 meter under water. The test shows that it is safe to use steel alloy for our propeller.

Pictures of both tests are on the next page.

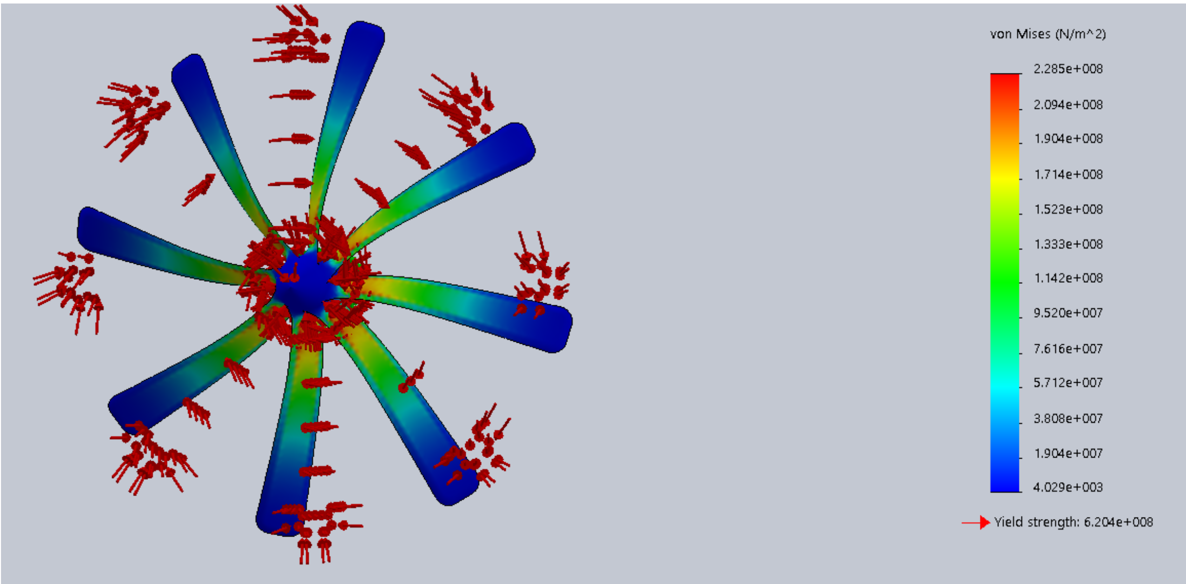


Figure 69: Alloy steel test

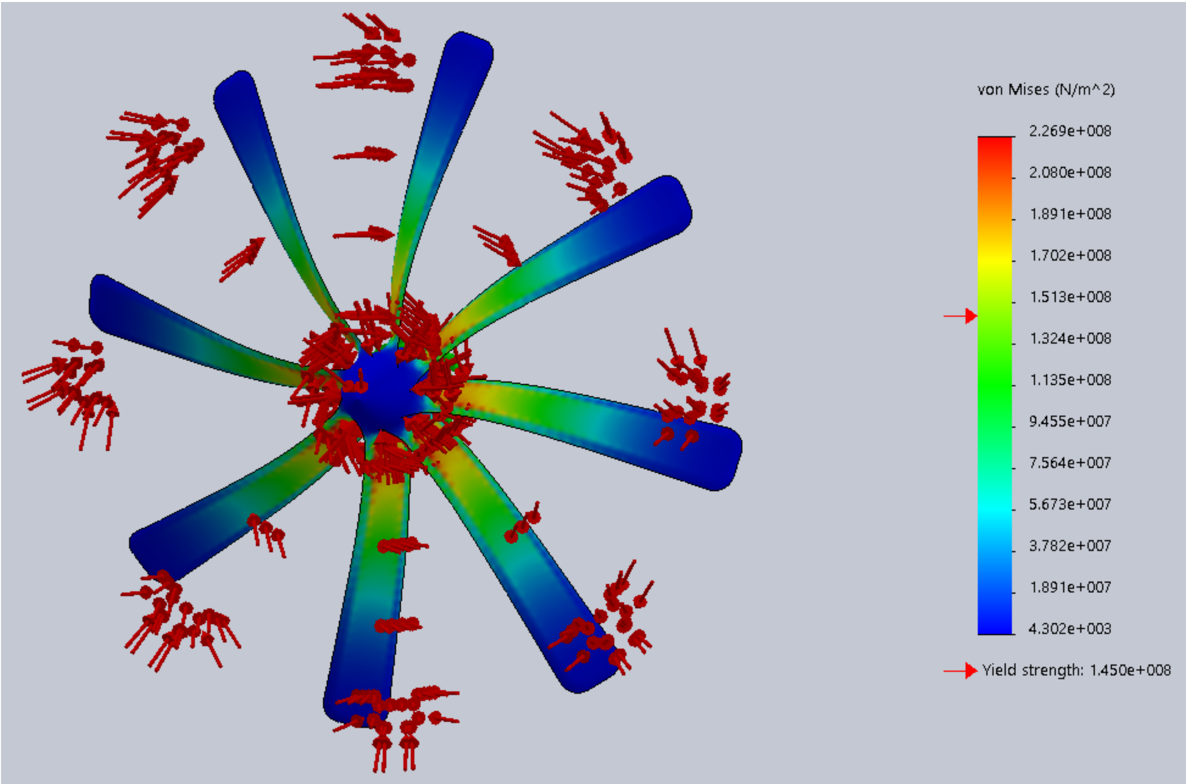


Figure 70: Aluminium test

12 Risk Assessment

Risk will always be in the back of our heads. There is no way of getting rid of it, but we are always working on minimizing it. There are many risks to consider when working on such a complex system as an autonomous boat, and with little to no experience, most of them can end up pretty costly. And we don't want to spend all our money and resources on solving complications that could have been avoided. With every part or subsystem that is designed, risk analysis follows. Not always as an own process, but with every suggestion we come up with, we think of what problems we might encounter and how we can solve them.

Often we can accept some risk on an idea, but other times we have to kill the idea and come up with another one because the probability of the risk is too high. But at the same time, we come up with a solution for that risk if it is possible to do something with it. For example drowning is a big risk. The boat could be overloaded with a lot of water, and it will sink. If this happens, Plactor will be waste too.

So for not turning the waste cleaning machine Plactor into waste, we came up with an idea which is a part of the emergency system. The water pressure will understand that the boat is sinking because of the pressure, and then it will trigger the sensor, and the compressed air will be blown into several airbags, which will make Plactor float. Then the customer or the maintenance crew can go and get it. The risk of drowning can be high at some points. If there are many big waves, or someone push it down with force, it will drown.

Understanding risk is in many cases just as important as understanding the main problem. The first impression you get from the risks of your design might not be what the risk really is about. Sometimes, the risk will have greater consequences than you first thought, other times the consequences can be smaller than you thought. In both situations, resources must be used right to accomplish deadlines and budgets.

The risk assessment table is on the next page (Figure 71).

1. Fire due to battery overheating	Fire would cause great damage to the boat, components and surroundings. Battery management and surveillance is implemented to control overheating.
2. Drowning	Being underwater for a long time, can cause damage to all the electronic components. When water-pressure sensor detect pressure, the emergency mode kicks in. Airbags will be filled with compressed-air, and the boat will immediately start floating.
3. Collision	The boat colliding with either the river bottom or other vessels could lead to the boat sinking or spillage of waste and industrial fluids. Emergency mode would be the solution.
4. Power loss	Loss of power would make Emergency mode kick in. GPS and airbags will have backup power source, but boat must manually be recovered.
5. Communication loss	The boat depends on connection via GSM. A connection failure could lead to information loss, which again could mean wrongful decision-making by the boat`s "brain".
6. Damage to wildlife	Situations where animals or birds could be harmed by the boat. Supervision and surveillance by both Plactor itself and people working with Plactor as a tool must handle the situation.
7. Failure on remote cameras	Remote cameras contribute to lower power consumption. A failure on these could lead to more frequent charging cycles.
8. Sabotage	Sabotage by a person or group of persons. Worst case scenario is for Emergency mode to kick in

Large consequence

Medium consequence

Minor consequence

Figure 71: Risk assessment

12.1 Fault Tree Analysis

Fault tree analysis is mainly used to help identifying potential systems failures or anything that can cause systems failures before the failure actually happens.

Plactor will possibly after many months or years start failing to identify objects. The reason for that can be lack of YOLO knowledge. Maybe the structure of a product made my plastic has changed, or something new material has been created that YOLO didn't know about. YOLO can only develop its intelligence by train it. It needs to be updated. If this not happens there are chances for failure.

The camera can also fail by having too much dirt on the lens, which makes Plactor blind. The chances are very low for that since the camera is placed very high compared with the water surface. Without the camera, there are no use of YOLO. Both of these needs to work together, and are only useable if they work together.

If the system gets hacked somehow, the coordinates can be changed and the whole process will be damaged. This can cause Plactor to get stuck. If it is very bad weather one day, Plactor should work and survive this day. But at one point the weather can be too bad. Waves will be much more bigger, thunder, lightning and lots of rain. At this point Plactor will maybe not survive.

So it is important that Plactor understand what it is capable of to handle by reading and understanding the data from YOLO and Anemometer. In case if it can't survive since the waves are taking over and Plactor is drowning, the emergency system will kicks in to save Plactor from drowning and getting more damaged. As you can see in Figure 72 there are different reasons for different faults.

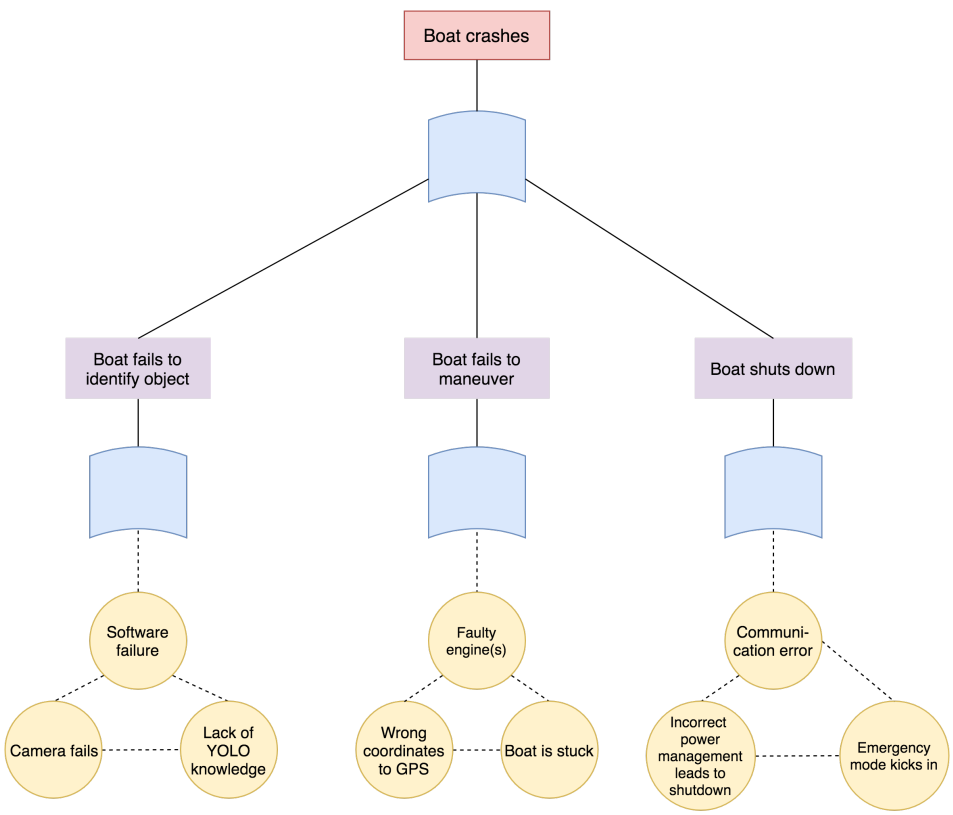


Figure 72: Fault tree analysis

12.2 HSE - Health, Safety and Environment

HSE stands for Health, Safety and Environment and can be separated into two parts. One for the employer and one for the employee. The employer is responsible for the employee to have a fully sufficient environment. This means that you will not maintain any mental or physical illness or injuries because of work. In our Plactor team, we need to have focus on HSE to not break any rules. Security in our team is important, in case there are any emergencies like fire or anything else.

Everybody will be attending an HSE course to be certified in HSE. Before doing anything, the employer must regularly check the work risks, make a plan for how to prevent any risks and implement reinforcements. This is another reason for why risk managements are important in this kind of projects. Before someone starts a task, a risk assessment needs to be carried out. Then the safety instructions, protective equipment and training must be included. Everybody in the team needs to have respect for each other, and not discriminate on behalf of anything.

Figure 73: Health, Safety and Environment

13 System Validation and Verification

13.1 Verification

To begin systems testing we organize the systems requirements and verify their functionality in order to meet the customers needs. Below is a matrix constructed of our most important requirements and the process of how it will be tested and verified. Also included is a letter grade which states how important each requirement is. H being high, M being medium, and L being low. When completing the verification process with the use of this matrix we get a clear understanding on how to move forward and be ready for the validation process.

RQ ID	Description	Criticality	Related subsystems	Test Cases	Test Method
02.1	No noise pollution	M	Motor system	Verify noise from motors is low enough to not be heard next to the river	Throttle motors to full speed while underwater and measure decibels from a 2 meter range
02.1.1	Minimal light pollution	L	Emergency system, navigation system	Verify that light is low enough to not disturb locals during operations at night	Turn on all lights in a dark room and measure the lumen strength, also use volunteers to check their annoyance
02.2	Zero emissions	H	Power system	Not part of systems testing as batteries do not emit emissions	
02.3	Replaceable and upgradeable components	H	All hardware systems	Verify that each important component can be easily replaced after product is fully built	Replace all important components on a finished built product
02.4	Charging capabilities	M	Power system, charging system, dock system	Verify that the boat charges as specified, and that there are no charging complications whilst emptying waste	Connect charger to depleted batteries and measure average charging speed. Connect boat to dock and monitor charging whilst waste is being dumped
02.5	Component surveillance	M	Component surveillance code	Verify that a faulty component will alert us and the user of the failure	Attach faulty components to different systems and make sure the alert is received to both user and Plactor team
01.2	Easy to operate	H	Entire system	Verify that any user is able to operate the Plactor system	Assemble a group of volunteers to operate the system and monitor their experience
01.1	Effective waste collection	H	Mouth system, waste storing system, navigation system, dumping system	Verify that the mouth is able to collect most types of waste and that the storing space is sufficient and dumping works as intended	Feed the mouth all types of waste. Fill the storage space and analyze its operations while full of waste. Run through dumping with minimal waste and maximum waste

13.2 Validation

Here we have our specific validation cases that we are using in order to verify the deployment of our system and that all our users needs are being met. For the validation testing we will only be using a complete operational system and a system where all components have met their requirements and passed their verification's. The validations process will be conducted in a Pass or Fail criteria and in order to move to the next stage the previous one must have passed. In case a stage is failed it must be re-worked and then a new validation must be done and passed before moving on to the next stages. Out process is split up into four different stages.

1. Validation of training: Users access to manuals and the control interface (web-interface) to monitor and learn everything about the whole system.

2. Validation of autonomous operations: Validation of Plactors ability to get correct information from remote cameras, maneuver autonomously, collect waste autonomously and lastly dump the collected waste autonomously.

3. Validation of data communications: User and administration able to collect data logs by using web-interface. Ability to command Plactor with the web-interface from anywhere.

4. Validation of full systems operations: Validation of the users ability to operate all parts of the system and for all out sub-systems to work together in order to meet our main system requirement that is cleaning the river.

After completing the entire validation process we will write a validation report that will ensure all our future customers that our system is ready to be used. The validation report will include all details of the performed validations. It will also include any part where a validation failed but with the new and improved design that made it eventually pass.

14 Business Plan and Marketing

Our business plan portraits multiple plans and views about how we are going to run this business. We are following the Value Chain, where all the parts are divided into five different sections: Inbound logistics, Operations, Outbound logistics, Marketing and sales and Service. Our role within the value chain is Operations. We need to make sure that parts are ordered, assembled and to keep the product up to date. We also need to take care of inbound logistics, such as ordering raw materials and components, storing these items in a warehouse and keeping track of the inventory. After assembling the developing the autonomous boat, we also need to take care of outbound logistics, such as storing the product in a warehouse, keeping track of inventory and simultaneously make sure we fulfill our orders.

Each department within our team have different tasks, such as:

- Mechanical team: make sure parts are up to standards.
- Electrical team: make sure wires and circuit boards are up to standards.
- Software team: make sure the software development is up to date.

We have two types of income. The one is through customer sales and the second one is through project investors. There are a few expenses, as we need to manufacture the product before selling it to the customer. We have separated the expenses detailed under the sections in the value chain where they belongs.

Inbound and Outbound logistics:
In inbound and outbound logistics, we have different type of expenses. One major expense is to order raw materials and components from suppliers. These materials and components need to be shipped from the suppliers to our factory. Then it needs to be placed in a warehouse, so another expense is the warehouse rent and electricity. We need equipment to store the materials on,product insurance and money to cover office expenses. It is also smart to have some money left over, so it can cover additional taxes.

Operations:
Since our part of the value chain is operation, we need equipment for manufacturing and development. That means we need employees for manufacturing and development, which again means we need employee insurance. We also needs to give these employees salary, and pay taxes for these. To have the best knowledge and being up-to-date, we need to train our employees and give them different type of courses, which all are expenses we need to include in the business plan.

Marketing and sales:
In the marketing and sales part, we need to give salary to the team. Apart from the salary there are other expenses like advertisements, sales equipment and professional fees. The professional fees are like lawyers, accountants and etc. Just like the inbound and outbound logistics, we need to have money left over for additional costs.

Service:
The maintenance crew is a part of the Service, and we need to give salary to this team. Just like the operation part, these employees need training and courses to be up-to-date. Additional costs is also a part of service, since the maintenance crew need to travel and get to place where Plactor is.

14.1 Business model

We followed a step-based business model, as you can see in Figure 74. You can also look at the business model as a timeline, as it starts from the left side and goes to right.

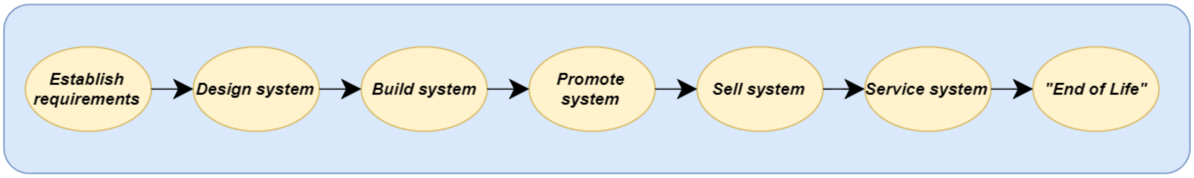


Figure 74: Step-based business model

Establish requirements:
The first step of our project is to establish requirements. This would be done together with our costumers and buyers. Partners and investors would also play a role here, handling some of the economic parts. After all requirements have been decided, we will move on to the next part our model.

Design system:
Now that the requirements are decided, we can start to come up with a few designs. This is a time demanding process and many things have to be considered. We have to find a solution that meets all of our costumer‘s requirements and do it within reason relative to spending money and resources. Since we are a start-up company, resources will be limited. Keeping it within reason is therefore very important. When we have reached a final design, building and assembly of our system can start.

Build system:
Just as in the designing process, we will stand for all building and assembly of our boat. However, we would still be depending on third party firms that could provide us with technology and solutions. Building our system will be one of the most expensive parts of our project. We would have to provide spaces for offices, a workshop, testing facilities etc. After testing, our system is ready for the market.

Promote system:
Our system is developed with costumers‘ requirements in mind. However, we would like for others to show interest in our solution. Therefore, we would do campaigns to promote and try and sell our system. We would travel around to pitch our idea for environmental organizations, stately owned firms and other targets. We believe this would help us sell more units.

Selling and servicing our system:
After developing, building and promoting our system, we will hopefully be able to sell it. In addition to selling our boat, we will also sell service deals. Teams of a few people would have responsibility of several costumers and travel around to service our system.

End of Life:
When our system is finished with it‘s work, too damaged to continue to work or unable to be upgraded anymore, we must dispose it. We have arranged a deal for our costumers to dispose their system through us. We will charge a small fee for disposal and transport, and then take care of everything else.

14.2 Cost of Ownership

The description of what cost of ownership is is very self explanatory. Simply said, the cost of ownership describes how much it costs for the customer to buy Plactor and to own it. Even before purchasing Plactor, the customer can see all the estimated costs of ownership, which makes it much easier for the customer to get an image of all the costs.

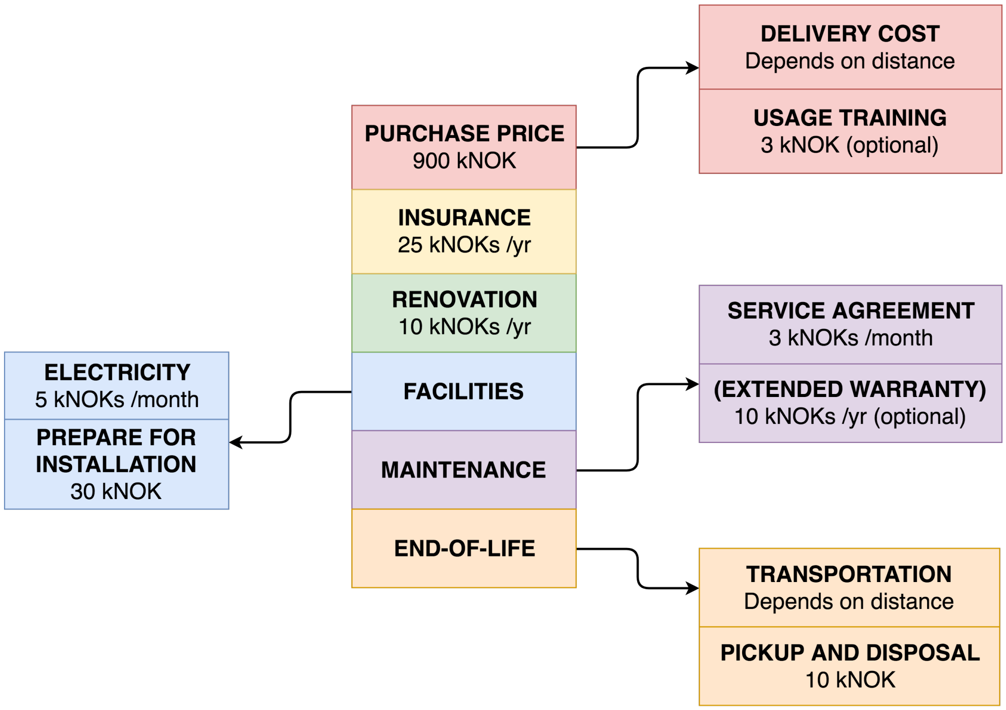


Figure 75: Cost of Ownership

Electricity: Estimated cost is 5000 NOK per month. Plactor will charge most of its time at the night, in case that the prices are lower than at the daytime. This cost may be lower, if there are no plastic to collect over a long time.

Prepare for deployment: Estimated cost is 30.000 NOK. It is a one-time payment for dig a space along the river, so the Plactor team can install the dock. The installation price is included in the purchase price.

Service agreement: Estimated cost is 3000 NOK per month. This agreement includes customer support, camera-battery replacements, component surveillance and docking security. Docking security is a security system which is directly connected to Plactor's maintenance crew. Which means, if there are any persons who tries to damage the docking or tries to steal anything from the dock, the sensors will be triggered and will send an emergency signal to the maintenance crew. Among that there will be taken photos and videos of the docking area, so the evidences can be collected. In reason of GDPR, the photos and videos will only be taken, if the sensors are triggered.

Extended Warranty: 2 years guarantee is included. This warranty is the normal warranty which has to be on products in Norway. But there is a way to extend the warranty for some years by paying 10.000 NOK per year. This is optional. By extending the warrenty, the customer can feel much more secured and less worry, in case anything happens with Plactor.

Renovation: Estimated cost is 10.000 NOK per year. This cost includes a container and emptying of the container. This is just an estimated price, which means that there are possibilities to make a good and cheaper deal with the renovation company. The price again differentiate between municipalities and companies. Since this is a long-term concept, the renovation company can maybe agree on a cheaper deal, but until that the estimated cost is 10.000 NOK per year.

Delivery cost: The delivery cost depends on where we are going to deliver Plactor. The cost can be discussed with the customer, and then come to agreement. If the delivery is nearby our factory, we can even deliver it for free, if the deal is fair. If not, a small fee can be charged.

Transportation: Just like the delivery cost, the transportation cost depends on where we are heading to. But when we talk about transportation for the maintenance crew, we can take a look at the Norwegian kilometer rates. Because this kilometer rate is fixed by the goverment. A solution could be that the customer can pay this rates to us, so we can cover the lowest transportation cost. For the Plactor team it could be smart to have a overview of this kilometer rates in Norway. It can maybe give us money back on the taxes.

Usage training: Fixed price on 3.000 NOK. When buying Plactor, a usage training program will be offered. This training program is optional, but highly recommended. To use the performance of Plactor to the fullest, a usage training is the best way to learn how to do it.

Insurance: Insurance is very important on products that cost alot. In case if anything happens with Plactor, the customer needs an insurance that can cover the loss. There are different costs on insurance in Norway, where different companies offer different prices. So to give the customer a aproximately price, we sat the estimated cost on 25.000 NOK per year.

Pickup and disposal: In Norway there are strict rules of how things should be disposed. When Plactors end-of-life has become, it has to be disposed in the right way. Plactor is made by different type of matierals, components, electronics and etc. So, it is a big job to dismantle Plactor, sort it an then recycle it. So, to not to put our customer into a responible posistion of dispose Plactor, we do the job for a fixed price on 10.000 NOK. The customer doesn't need to worry about the disposal, we fix. A machine like Plactor cannot just be throwed away, since this will cause the customer problems from the Norwegian goverment for dispose it in a very bad and wrong way.

14.3 Cash flow

As a part of our business plan, we made an estimated cash flow table to plan our income and expenses for each quarter of the year. As you can see in Figure 76, we are in loss the first three quarters. There are many expenses that needs to be covered, and at this point we haven't earned any profitable money yet. But then in the fourth quarter, we start making some profit. All estimated numbers are in Norwegian Krones (NOK), since this is related to our user scenario which is taking place in Drammen.

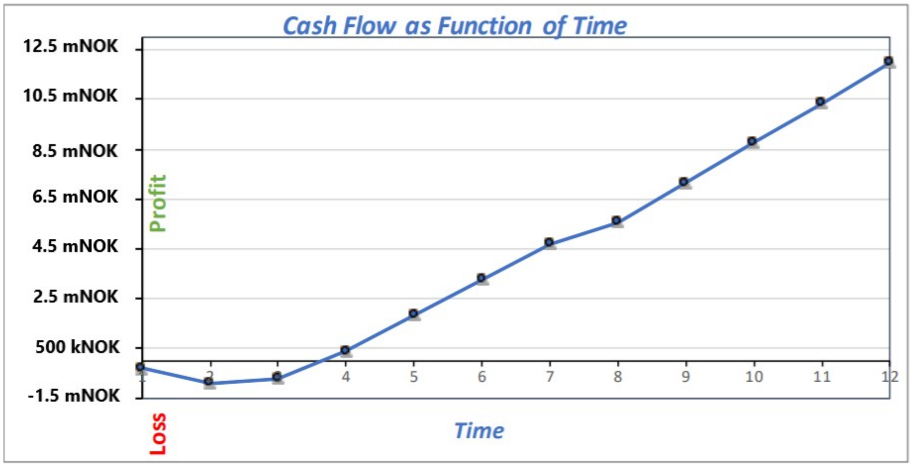


Figure 76: Cash flow graph

As we start earning more and as we make more profit, we increase the amount of units in production as well. This is because of the fact that we can afford more employees and more units to be produced per quarter. In Figure 77, all profit is marked in green and loss is marked in red color.

	YEAR 1				YEAR 2				YEAR 3			
	Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**	**Quarter 1**	**Quarter 2**	**Quarter 3**	**Quarter 4**
Investments	300 kNOK	600 kNOK	200 kNOK	200 kNOK	50 kNOK	20 kNOK	20 kNOK	20 kNoK	20 kNOK	20 kNOK	20 kNOK	20 kNOK
Sales units	0	0	1	2	3	3	3	3	4	4	4	4
Income	0	0	900 kNOK	1.8 mNOK	2.7 mNOK	2.7 mNOK	2.7 mNOK	2.7 mNOK	3.6 mNOK	3.6 mNOK	3.6 mNOK	3.6 mNOK
Expenses	300 kNOK	600 kNOK	900 kNOK	900 kNOK	1.3 mNOK	1.3 mNOK	1.3 mNOK	1.84 mNOK	2.02 mNOK	2.02 mNOK	2.02 mNOK	2.02 mNOK
salary	*270 kNOK*	*270 kNOK*	*270 kNOK*	*270 kNOK*	*360 kNOK*	*360 kNOK*	*360 kNOK*	*900 kNOK*	*900 kNOK*	*900 kNOK*	*900 kNOK*	*900 kNOK*
materials	*0*	*300 kNOK*	*600 kNOK*	*600 kNOK*	*900 kNOK*	*900 kNOK*	*900 kNOK*	*900 kNOK*	*1.08 mNOK*	*1.08 mNOK*	*1.08 mNOK*	*1.08 mNOK*
other	*30 kNOK*	*30 kNOK*	*30 kNOK*	*30 kNOK*	*40 kNOK*	*40 kNOK*	*40 kNOK*	*40 kNOK*	*40 kNOK*	*40 kNOK*	*40 kNOK*	*40 kNOK*
Quarter profit	300 kNOK	600 kNOK	200 kNOK	1.1 mNOK	1.45 mNOK	1.42 mNOK	1.42 mNOK	880 kNOK	1.6 mNOK	1.6 mNOK	1.6 mNOK	1.6 mNOK
Cumulative profit	**300 kNOK**	**900 kNOK**	**700 kNOK**	**400 kNOK**	**1.85 mNOK**	**3.27 mNOK**	**4.69 mNOK**	**5.57 mNOK**	**7.17 mNOK**	**8.77 mNOK**	**10.37 mNOK**	**11.97 mNOK**

Figure 77: Cash flow table

14.4 Schedule for deployment

We have a development and deployment schedule for the next 4 quarters, from january to december. We will go through four main stages: planning phase, development phase, stabilization phase and deployment phase. We have a continuous iteration between the planning phase and the development phase. That means that while we are developing the system, we will keep going forth and back between these phases while doing research and discovering new requirements.

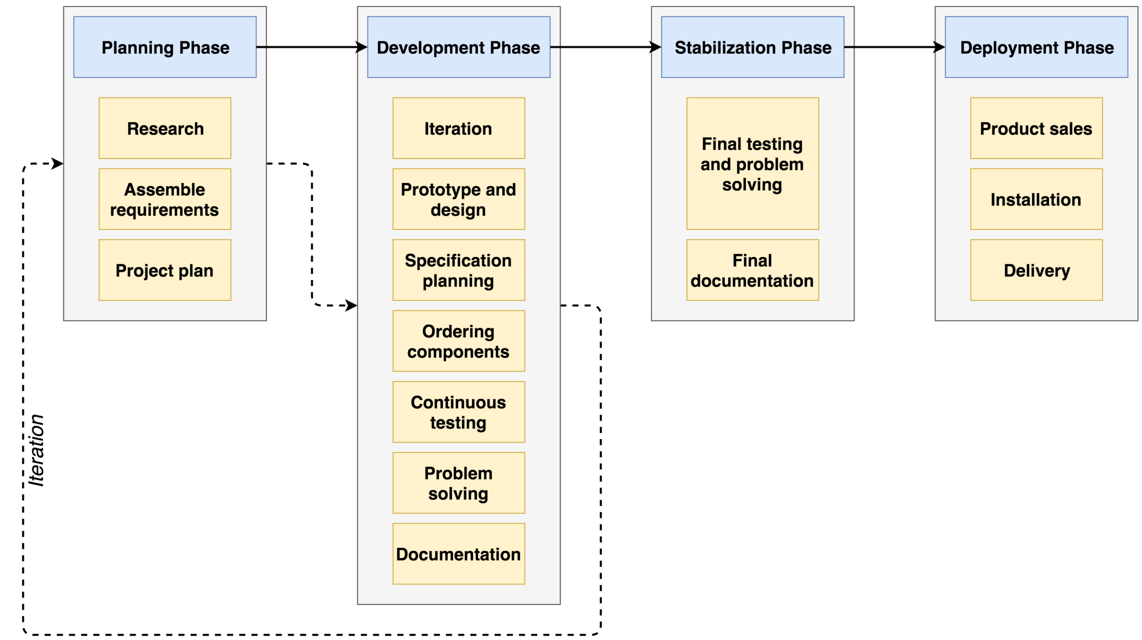


Figure 78: Four main stages of the project

QUARTER 1			QUARTER 2			QUARTER 3			QUARTER 4		
JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Research	Development	Development	Development	Development	Development	Production	Production	Production	Production	Production	Production
			Ordering parts	Ordering parts	Ordering parts	Ordering parts		Deployment			Deployment

Figure 79: Schedule for deployment

In the first quarter, we will not sell any units as this and the second quarter is for research and developing. As we don‘t sell any units our income will be nothing. We will only use money that we get from investors and work on a small salary the first period of time. We will be doing the same process in the second quarter of the year but start to spend some money on a place to be, office supplies and some materials to start manufacturing the first boat.

By the third quarter, we will be selling our first unit. We will start slow by only selling one unit, but we will increase already by the fourth quarter. By starting slow, we will be able to finetune every part of our business so that it will be ready for bigger challenges. Since we are not making our own money, we will decrease the amount we are asking for from our investors. By doing this, we show them that we can carry on with our plan and start making them some money. And in the fourth quarter that is the result, our first quarter with profit is a fact.

15 A3 Architecture Overview

An A3 architecture overview is a representation of system architecture to give a manageable view of a given system. This architectural overview helps to capture architectural knowledge and facilitates decision making process when a team is working together for designing or evolving a complex system. A3 architectural overview reduces large amount of information about a system and presents the information in an easy way by including all the important details in the design process. This representation helps the stakeholders to understand more about the system, and it makes the acceptance process easier.

For our project we made an A3 architectural overview that summarizes our system functionalities and some of our most important sub-systems as well. We have visualized all the information about our system in a way that our stakeholders understand the entire system easily.

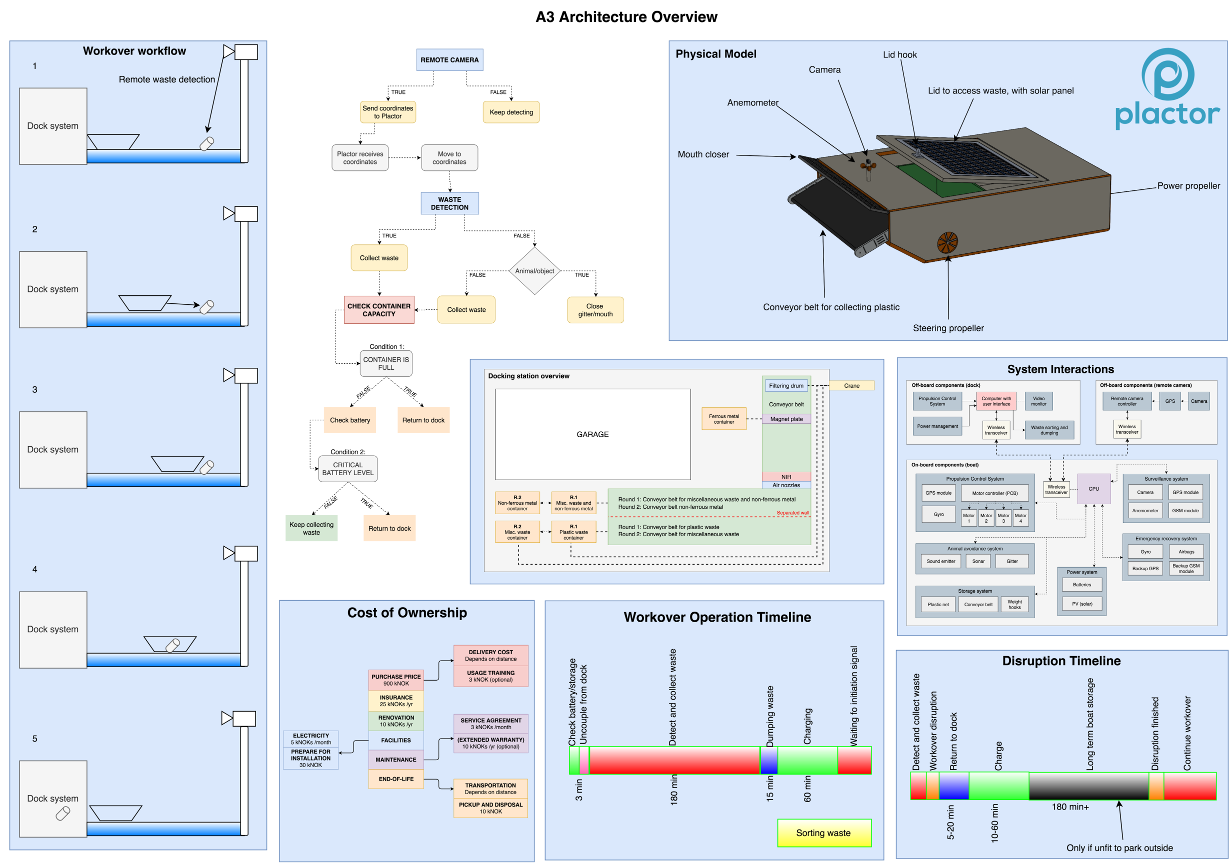


Figure 80: A3 architecture overview

16 Source code

16.1 Buoyancy force calculation

Our buoyancy force simulation was developed with the following Python code:

```
import matplotlib.pyplot as plt
class Buoyancy:
   h = 0.5            # Total boat height (m)
   w = 1.0            # Total boat width (m)
   l = 1.5            # Total boat length (m)
   p = 997            # Water density (kg/m3)
   volume = []
   maxweight = []

   def __init__(self):
      print("Increasing size:")
      self.increaseSize(self.h, self.w, self.l)
      self.printArray()
      self.plotGraph("Max allowed weight with increasing size:", 0.5, 0.25*11, 300, 2000)
      self.resetArray()

      print("Decreasing size:")
      self.decreaseSize(self.h, self.w, self.l)
      self.printArray()
      self.plotGraph("Max allowed weight with decreasing size:", 0.8, 0, 0, 400)
      self.resetArray()

   def printArray(self):
      for i in range(len(self.volume)):
         print("Boat volume:", round(self.volume[i], 2), "m^3", "-", "Max allowed weight:",
             round(self.maxweight[i], 2), "kg")

   def resetArray(self):
      self.volume.clear()
      self.maxweight.clear()

   def increaseSize(self, h, w, l):
      for i in range(10):
         # Volume displaced:
         v1 = (h - 0.2) * (2/3)*l * w
         v2 = (1/2)*((h - 0.2) * (1/3)*l * w)

         # Max allowed weight:
         vd = (v1+v2) * self.p

         self.volume.append(h * w * l)
         self.maxweight.append(vd)
         h = h + 0.05
         w = w + 0.05
         l = l + 0.05
```

```python
    def decreaseSize(self, h, w, l):
        for i in range(10):
            # Volume displaced:
            v1 = (h - 0.2) * (2/3)*l * w
            v2 = (1/2)*((h - 0.2) * (1/3)*l * w)

            # Max allowed weight:
            vd = (v1+v2) * self.p

            if(vd > 0):
                self.volume.append(h * w * l)
                self.maxweight.append(vd)
                h = h - 0.05
                w = w - 0.05
                l = l - 0.05

    def plotGraph(self, title, x1, x2, y1, y2):
        plt.title(title)
        plt.xlabel('Boat volume ($\mathregular{m^3}$)');
        plt.ylabel('Max allowed weight (kg)');
        plt.xlim(x1, x2)
        plt.ylim(y1, y2)
        plt.plot(self.volume, self.maxweight)
        plt.show()

Buoyancy()
```

16.2 Motor and gate simulation

Our prototype was developed with the following Arduino code:

```
#include <Servo.h>
Servo esc;
Servo servo1;
Servo servo2;

const int servoPin1 = 6;
const int servoPin2 = 7;
const int buttonPin = 2;

volatile int buttonState = 0;
volatile unsigned long lastInterrupt = 0;

void setup() {
    esc.attach(8);
    esc.writeMicroseconds(1000);
    servo1.attach(servoPin1);
    servo2.attach(servoPin2);
    pinMode(buttonPin, INPUT_PULLUP);
    attachInterrupt(digitalPinToInterrupt(buttonPin), setGitterPosition, RISING);
}

void loop() {
    int val;
    val = analogRead(A0);
    val = map(val, 0, 1023, 1000, 2000);
    esc.writeMicroseconds(val);
}

void setGitterPosition(){
    if((millis() - lastInterrupt) > 500){
        switch(buttonState){
            case 0:{
                Serial.println("Opening gate!");
                for(int pos = 0; pos < 110; pos++){
                    servo1.write(pos);
                    servo2.write(pos);
                }
            } break;
            case 1:{
                Serial.println("Closing gate!");
                for(int pos = 110; pos > 30; pos--) {
                    servo1.write(pos);
                    servo2.write(pos);
                }
            } break;
        }
        buttonState = !buttonState;
        lastInterrupt = millis();
    }
}
```

17 References

[1] ScienceDaily: "Deep Sounds Scare Fish Away From Turbines That Could Kill Them"
https://www.sciencedaily.com/releases/2007/05/070514154055.htm

[2] Power Motoryacht: "How to Avoid Obstacles with Your Boat"
https://www.powerandmotoryacht.com/electronics/how-avoid-obstacles-your-boat

[3] Advanced Marine Innovation: "Fish Scaring System"
http://www.advancedmarineinnovation.com/Fish_Scare.htm

[4] Baltimore Water Front: "Trash Wheel Project"
https://www.baltimorewaterfront.com/healthy-harbor/water-wheel

[5] Burge Hughes Walsh: "Systems Engineering Tools and Techniques"
https://www.baltimorewaterfront.com/healthy-harbor/water-wheel

[6] Greenmatch: "7 Different Types of Solar Panels"
https://www.greenmatch.co.uk/blog/2015/09/types-of-solar-panels

[7] Theseacleaners: "The Manta"
https://www.theseacleaners.org/fr/the-manta/

[8] WYPR: "Baltimore's Trash-Eating Machine"
https://www.wypr.org/post/baltimores-trash-eating-machine-may-multiply-other-cities

[9] CEN: "Baltimore's trash-eating waterwheel"
https://cen.acs.org/environment/pollution/Baltimores-trash-eating-waterwheel/96/i16

[10] GlobalCitizen: "The Waste Shark"
https://www.globalcitizen.org/en/content/wasteshark-plastic-pollution-robot/

[11] CNN: "The Waste Shark"
https://edition.cnn.com/2018/10/30/middleeast/wasteshark-drone-dubai-marina

[12] InformIT: "External Interfaces"
http://www.informit.com/articles/article.aspx?p=328170&seqNum=4

[13] AcqNotes: "Functional Analysis and Allocation"
http://acqnotes.com/acqnote/careerfields/functional-analysis-and-allocation

[14] AcqNotes: "System Scope and Boundaries"
http://www.testablerequirements.com/testablerequirements/def_sys_scope_bound.htm

[15] Sciencestruck: "Alloy Steel"
https://sciencestruck.com/difference-between-alloy-steel-stainless-steel

[16] Abvista: "Understanding the differences between NIR machines"
https://www.abvista.com/news/June-2018/Differences-between-NIR-machines.aspx

[17] IVAR: "IVAR ettersorteringsanlegg Forus"
https://www.ivar.no/ivar-ettersorteringsanlegg-forus/category926.html

[18] TU: "Slik fungerer NIR-spektroskopi"
https://www.tu.no/artikler/vaeskeanalyse-nir-spektroskopi/218194

[19] TOMRA: "TOMRA Sorting Explained"
https://www.tomra.com/en/sorting/recycling/why-tomra

[20] Tam villmark: "Kompass, kart og GPS"
http://tam-villmark.blogspot.com/p/kart.html

[21] ILAInstruments: "Analysis of plastics, electronic plastics"
https://www.lla-instruments.com/process-analysis/waste-sorting-recycling.html

[22] Sortere: "Plastemballasje og sortering"
https://sortere.no/privat/avfallstype/104/Plastemballasje

[23] Kongsberg Kommune: "Priser og gebyrer 2019"
https://www.kongsberg.kommune.no/innhold/mest-sokt/priser-og-gebyrer2/

[24] ScienceDirect: "Quality Function Deployment"
https://www.sciencedirect.com/topics/engineering/quality-function-deployment

[25] Systems Design and Engineering: "Facilitating Multidisciplinary Development Projects"
G. Maarten Bonnema, Karel Veenvliet, Jan Broenink (2016)