# Redesigning a Tracking Device for Researching Waterway Plastic Pollution

Client: Noria Sustainable Innovators

Supervisors: Bas Flipsen & Freerk Wilbers

Client Mentor: Parshva Mehta

Student: Stijn Wiltingh – 50170486

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TU Delft

NORIA SUSTAINABLE INNOVATORS

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# Abstract

Plastic pollution in Dutch waterways is a growing environmental challenge, contributing to ecological damage, public health risks, and increased operational costs for maintenance and cleanup. This report focuses on the redesign of Noria's floating litter tracker, the TrashTracer, to address key limitations in the original design, including water ingress, insufficient durability, and high production costs. By employing a user-centered design process, the project incorporated modularity, improved waterproofing, better signal reliability, easier recovery, lower chances of losing the tracker and extended battery life, resulting in a more effective research tool.

Through iterative prototyping, stakeholder feedback, and technical analysis, the redesigned tracker enhances operational efficiency and creates added value. The project also ensures the tracker aligns with Noria's mission to research and mitigate plastic pollution, contributing to broader efforts to improve the quality of aquatic ecosystems in the Netherlands. The report concludes with an evaluation of the project's results and recommendations for implementation.

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# 1. Introduction

## 1.1 Background

Plastic pollution in Dutch waterways poses significant environmental, health, and logistical challenges. The Netherlands' extensive network of canals, rivers, and other water bodies is increasingly contaminated with plastic waste, highlighting the need for urgent action.

### Scale of the Problem

Plastic pollution in Dutch waters has reached alarming levels:

- Less than 1% of Dutch surface water meets the European standards for water quality (Natuurmonumenten, n.d.).
- In Amsterdam alone, approximately 3500 kilograms of waste is removed from canals daily (Lopes, 2021).

These figures reflect only a fraction of the pollution, as much of the plastic waste continues to flow from urban waterways into rivers and oceans.

### Sources and Transport of Plastic Pollution

Plastic waste enters Dutch waterways from various sources:

- Industrial Activities: Approximately 40% of plastic waste originates from industries such as construction, shipping, and fishing (NL Times, 2023).
- Consumer Litter: Around 35% of waste comes from improperly discarded packaging, plastic drink containers, and cigarette filters (NL Times, 2023).
- Direct Dumping: An estimated 19% results from deliberate dumping into waterways (NL Times, 2023).

Once in the water, plastics are transported by rivers, acting as conduits that carry waste from urban areas to seas and oceans.

### The Urgency of Plastic Removal

The removal of plastic waste from waterways is critical due to its rapid degradation into microplastics and its broader environmental impact:

- Fragmentation into Microplastics: Macroplastics in rivers break down into microplastics, which are nearly impossible to remove (Noria Sustainable Innovators, 2024).
- Sinking of Fragments: Smaller fragments sink over time, making cleanup efforts more challenging (Noria Sustainable Innovators, 2024).
- Environmental Impact: Rivers act as conduits, transporting plastic waste from land to the ocean, where it further pollutes marine ecosystems (Noria Sustainable Innovators, 2024)

## Health Concerns

Microplastics have been detected in human tissues, including the liver, kidneys, and placenta, raising serious concerns about their health implications (US Environmental Protection Agency, 2024). Research indicates potential links between microplastics and:

- Developmental disorders
- Reproductive and immune issues:
- Neurological effects
- Endocrine disruption

## Conclusion

In summary, plastic pollution in Dutch waterways represents a pressing environmental and health challenge. Its widespread impacts underscore the need for immediate and effective solutions to mitigate its consequences for ecosystems and human well-being.

## 1.2 Client

Noria Sustainable Innovators (or Noria for short) is a company addressing the plastic pollution problem in Dutch waterways. Their approach to tackling this issue is what they call the "3R method", where the three R's stand for Research, Remove and Reduce.

The "**Research**" part of Noria's approach focuses on understanding the problem so that it can be addressed more effectively. Noria identifies the sources, transport routes and hotspots of floating litter through geographical analysis (GIS) combined with mathematical models, monitoring using cameras and AI, and simulating the behaviour of floating waste using **GPS trackers** (see Figure 1). In addition to this they also research the distribution of plastic in the water column using sonar and sampling of microplastics.



*Figure 1: Noria's original GPS tracker during use.*

Using insights from the research phase, Noria works to "**Remove**" floating (plastic) litter from waterways using their CirCleaner (Figure 2) and CanalCleaner (Figure 3) devices to clean waterways from pollution. Although focused on plastic pollution, Noria also cleans the water of other litter types like glass bottles and aluminum cans.




*Figure 2: CirCleaner (Noria Sustainable Innovators, n.d.).*



*Figure 3: CanalCleaner (Noria Sustainable Innovators, n.d.).*

Lastly, with the "**Reduce**" part of their approach, Noria addresses the issue through preventive measures such as using their data and insight to help form policies to combat littering.

This graduation project takes place in the **Research domain** of Noria's approach, and concerns redesigning the GPS tracker they use to simulate the behaviour of floating waste. The GPS tracker that has been used thus far is lacking in functional and aesthetic aspects which is detailed in the following section.

## 1.3 Problem Statement

Noria currently uses a floating tracker consisting of a PVC tube casing and a Lightbug Pro GPS tracker (see Figure 4). They are however experiencing several issues and limitations with this design that they want to improve through this graduation project.




*Figure 4: PVC casing and Lightbug Pro GPS tracker*

The problem statement can be summarized in several **pain points** that were identified from a project briefing with Parshva Mehta, Noria's mentor for this project:

- **Water** regularly **leaks into the casing**, leading to tracker **damage and loss**.
- Frequent **data transmission failures** lead to **incomplete data**, **recovery challenges**, and **losing trackers**.
- The trackers are sometimes **removed** from the water, disrupting research. This can happen because they are mistaken for waste or out of curiosity.
- Trackers can be **difficult to locate and retrieve**, especially in vegetation or around structures that obscure them from sight. This costs Noria a lot of time and therefore money
- Loss of trackers results in **environmental pollution** and costs associated to **replacing trackers**.
- The current **three-week battery life** restricts research duration, Noria aims to **double** this.
- The current or "original" tracker **lacks a professional aesthetic**. Noria fears this might diminish the perceived quality of their work and expects a more professional and marketable aesthetic to possibly bring in more clients.

## 1.4 Design Assignment

Following these issues, the assignment for this graduation project was defined as follows:

**“Redesign a GPS tracker for Noria Sustainable innovators that is used for researching plastic pollution in waterways such as rivers and canals to improve functionality and professional image, and to increase the value it has for its stakeholders”.**

## 1.5 Objectives

This graduation project aims to **address existing issues** and **identify other potential challenges** in the design and use of the GPS tracker. The project explores potential solutions and proposes a redesign of the tracker to ensure it appears **professional** and aligns with the research environment in which it will be used. Additionally, it seeks to **add value** to the product for key stakeholders **outside of the pain points** identified in the problem statement.

The aim of this project was to design something that **contributes positively to the world**, in this case by **improving the aquatic environment**. The design proposal should be put to use after this project has finished and should therefore reach a **Technology Readiness Level of 7** (TRL 7).

The project places a **focus on embodiment design**, allowing for the demonstration of current skills and the development of new ones, particularly in prototyping, testing, knowledge on materials and production methods, and advancing the product as far as possible within the project scope. The design proposal is intended to **contribute positively to the world** by tackling sustainability issues, in this case improving the aquatic environment. To achieve this, the product should reach a **Technology Readiness Level of 7** (TRL 7), enabling its practical implementation post-project.

Finally, the project seeks to **deepen understanding of the plastic pollution problem**, reflecting a potential ambition to address this issue in future work. By combining these objectives, the project aims to showcase a holistic approach to product design while creating a **meaningful and impactful outcome**.

## 1.6 Project Scope

Since there are limits in terms of what can be achieved within the boundaries of a graduation project, some aspects that could potentially be included in the redesign of Noria’s GPS tracker were left out of scope (*see Figure 5*). These are addressed below:

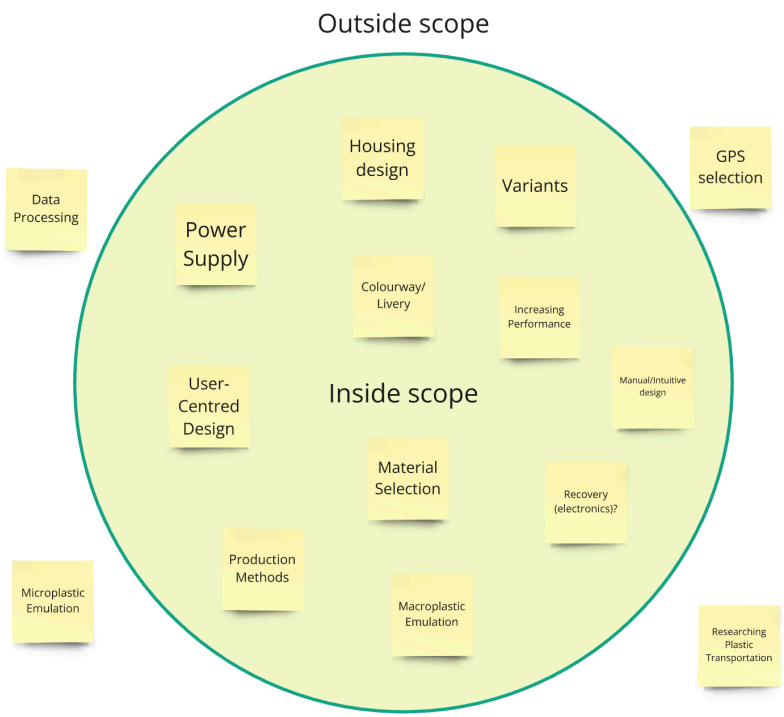



*Figure 5: Project Scoping*

## Exploration of GPS hardware

It was decided early in the project to continue using the **Lightbug Pro** as the GPS hardware for the redesigned version of the floating tracker, leaving the exploration of alternatives out of scope.

The Lightbug Pro tracker is a standalone commercial tracker connected to a portal where the trackers can be managed and where data can be collected. Noria currently uses it in their floating trackers and has indicated that this tracker, unlike other trackers they tried before, serves their needs well. The problems they are experiencing which motivated this graduation assignment to be initiated are caused by the PVC casing they use, not with the GPS device.

## Data Processing

Processing the data that is generated by the trackers is also left out of scope for this project. Lightbug already offers a well-functioning portal where the trackers can be managed and Noria offers the ForSea dashboard which provides insight into their client's pollution problem and the process that is being made (LightBug - IoT & Tracking Portal, n.d.; Noria Sustainable Innovators, n.d.). This project will focus on the issue at hand which is the functional design of the tracker housing, without delving too deep in the specifics of the data the tracker will collect.

## Microplastic Emulation

Representing the transport of microplastics (particles <0.5 cm (Schwarz et al., 2019)) is also left out of scope as this cannot realistically be done with a tracker that requires certain electronics, and thus has a certain minimum size.

Additionally, **Noria** builds **machines** that **remove** floating **macroplastics** (the "CirCleaner" and "CanalCleaner"). One of the main purposes of the floating tracking devices is to help inform where these machines can most strategically be placed, so designing a tracker to simulate microplastics, which are not removed by Noria's machines is not a logical direction to take.

### Researching Plastic Transportation

During this project, it became clear that there is a knowledge gap regarding the transport behavior of specific types of floating litter, for example based on shapes. Understanding these variations would help determine which types of debris the trackers best represent. However, researching this in depth would require a dedicated project, and is beyond the scope of this thesis. For this project, exploration of this topic will be limited to a review of existing studies.

### Material Sustainability

Although the project addresses an environmental issue, sustainability of the redesign did not receive priority. Because a **limited number of 20-25 will be produced**, sustainable choices in materials have limited impact. It is more effective to focus on performance to make sure the tracker can be used for a long time and is unlikely to sink or be lost during use, as this will cause significant pollution, especially because the tracker contains batteries.

## 1.7 Report Structure

The structure of this report adheres to the **pyramid principle** (Minto, 2008). After providing the necessary background information in this chapter the final design of this project, the TrashTracer, is presented first in the chapter hereafter to place **focus on the outcome** of the project. The development of the design is then discussed in *chapters 4 to 7* which cover an **analysis** of Noria's original tracker and its context, and *chapters 8 to 15* which discuss the **embodiment** design of the redesigned version.

The pyramid principle is also applied in writing. Each passage of text **leads** with stating the **main point**, **answer to a question** or **decision**, is then **supported** by (high level) **insights**, which are then **backed up** by **evidence.**

## 1.8 Terminology

- **Floating Litter**: Waste materials, primarily plastics, that are found on the surface of water bodies.
- **Original Tracker**: The GPS tracking device initially used by Noria, consisting of a PVC casing and Lightbug Pro GPS hardware.
- **Redesigned Tracker**: The newly designed tracking device (TrashTracer).
- **Lightbug Pro**: A GPS tracking device used in the trackers for collecting and transmitting location data.
- **Biofouling**: The accumulation of microorganisms, plants, algae, or animals on surfaces submerged in water, affecting the tracker's performance and appearance.
- **Microplastics**: Tiny plastic particles resulting from the degradation of larger plastics, less than 5 millimeters in size.

# 2. Design Showcase

The outcome of the project is highlighted in this chapter, discussing the name, features, the value it creates and problems it mitigates, and a summary of the viability aspects.



## 2.1 Name Considerations

The name **TrashTracer** was determined with Noria's product portfolio in mind. The products they sell, the CirCleaner and CanalCleaner, incorporate double letters (CC). The TrashTracer's name adheres to this, but with the letter T as it exists in a different area of Noria's approach to tackling plastic pollution. The name also aims to communicate the function of the device.

## 2.2 Features

- **Robust waterproofing design,** tested to **IP67**, but possibly able to withstand more extreme conditions.
- **Self-righting** properties, combined with **optimized antenna placement** to ensure a reliable signal.
- **Flexible battery configuration**, giving control over research duration (Figure 6).
- **Adjustable transportation behaviour,** through adjustable buoyancy and wind – and current influence (Figure 7).
- **Integrated AirTag** for easier and faster recovery (Figure 8).
- **Comprehensible information** through large font and simple wording (in Dutch, targeted at expected users).
- **Tamper-resistant** closing method requiring tools to open (Figure 9).

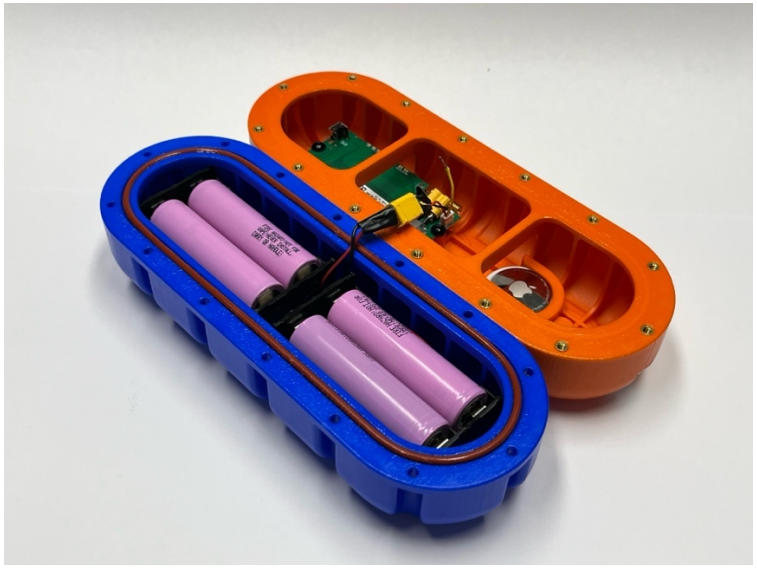


*Figure 6: Flexible battery configuration*




*Figure 7: Optional attachments allow adjustable transportation behaviour.*




*Figure 8: Integrated AirTag*




*Figure 9: Bolted closing methods prevents tampering.*

## 2.3 Value Creation & Problem mitigation

The TrashTracer created value for Noria and other stakeholders. This is listed in the sections below:

### Functional Value

- **Improved Waterproofing**: Enhanced waterproof casing design reduces water ingress, minimizing damage and loss of trackers.
- **Increased Battery Life**: Battery life is doubled, allowing for longer research periods without interruptions.
- **Reliable Data Transmission**: Higher signal reliability ensures more consistent and usable data for analysis.
- **Easier Tracker Recovery**: Improved visibility and recovery technology reduce retrieval time, cutting down operational costs.
- **Reduced Loss**: The points mentioned above result in a lower chance of losing trackers.

### Financial Value

- **Added profit margin: (**Expectedly) **l**ower operational costs increase the profit over the lifetime of the TrashTracer compared to Noria's original tracker.
- **Increased clientele:** The more professional aesthetic and better research results could increase how many assignments using trackers Noria receives.

### Stakeholder Value

- **Professional Appearance**: Redesign improves the aesthetic appeal, enhancing Noria's reputation and client confidence.
- **Reduced Removals**: Clearer information on trackers can prevent removals, reducing disruptions in research.
- **Tamper Resistance**: Design mitigates unauthorized opening of the tracker casing, making it less prone to tampering by individuals who encounter the trackers..

## 2.4 Viability Summary

The TrashTracer can be expected to bring **financial gain** for Noria. **One tracker, over its lifetime** is expected to increase profits **up to €500, -** compared to the original tracker Noria has used so far. This is achieved by:

- Expectedly **losing fewer** trackers
  - Higher signal reliability (*chapter 11*)
  - Easier recovery (*chapter 12*)
  - Better waterproofing (*chapter 10*)
- **Shorter recovery** times (*chapter 12*)
- Possibly **fewer unplanned removals** (*chapter 9*).

Figure 10 provides an overview of the expected profit margins that are expected with the TrashTracer for different scenarios (described in *chapter 15.4*). It is expected (based off test results) that **a realistic scenario is in-between the Medium-case – and Best-case scenario** displayed in the figures. The financial gain presented above is based off this. Since the TrashTracer can be used at least up to 6 weeks (likely longer, as discussed in in *chapter 11*), this was also included.

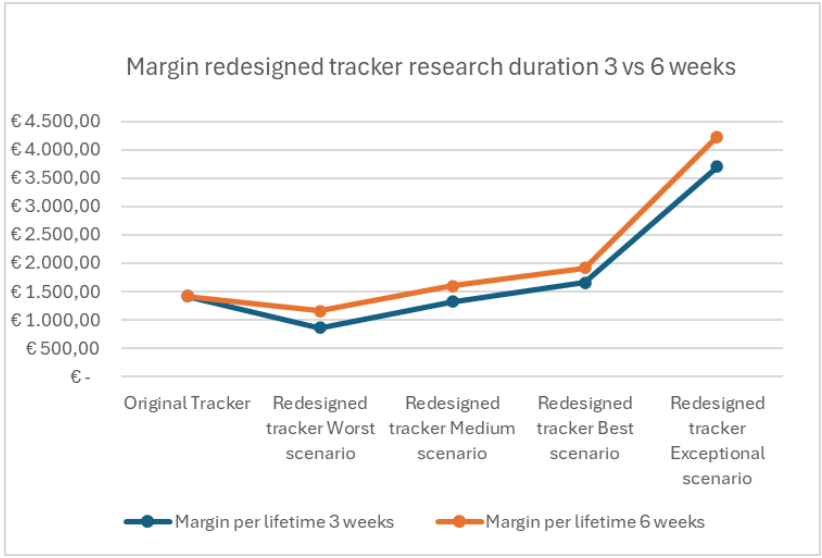



*Figure 10: Expected margin for different scenarios, for 3/6 week periods.*

# 3. Methodology

## 3.1 Approach

The approach taken for this project is mostly similar to the **Double Diamond approach**, but incorporates **some aspects from an Agile approach**, namely extensive prototyping and solving issues separately in an iterative manner. Solutions to the various problems were combined into the final product.

Similar to how the Double Diamond approach has two cycles, this project is divided in two main phases: an **analysis** phase and an **embodiment** phase.

### Analysis

The analysis phase focuses on studying the issues with the current design to understand how they can be addressed and how value can be created through this project. It involves examining both the existing product and its context, with the goal of identifying a clear set of problems (or failure modes) that can be tackled in the project.

### Embodiment

The embodiment phase is dedicated to determining how the redesign can be practically implemented and includes both design and validation activities. This phase involves systematically addressing the problems identified in the analysis phase through an iterative process, where assumptions and ideas are frequently tested with prototypes and feedback. By combining these solutions into a final product, this should in theory result in a solution to the problem and all its complexities.

## 3.2 Design & Research Methods

Design – and Research methods applied in this graduation project are listed below, many of which found in Van Boeijen et al. (2020):

- Literature Research
- Benchmarking
- Harris Profile
- Prototyping
- Prototype Reflection Cards
- Interviews
- Feedback Sessions
- Analysis
    - Stakeholder Analysis
    - Product Life Cycle Analysis (PLCA)
    - Economic Feasibility Analysis
    - Environmental Context Analysis
    - Failure Modes and Effects Analysis (FMEA):
- “5 times Why?” method
- List of Requirements
- Design Drawing
- Morphological Chart
- Datum Method
- Usability Testing
- Performance Testing
- Cost Price Estimation
- 3D Physical Models

# Analysis Phase

The analysis phase of this report includes a **product analysis** that examines the original tracker, and an **analysis of the context** in which it is used. This is followed by a synthesis of the analysis that identifies **failure modes (***Chapter 6***)**. After this a **list of requirements** is presented in *Chapter 7* (Van Boeijen et al., 2020). These requirements were developed progressively throughout the analysis phase, with references in the text indicating which insights contributed to each specific requirement.

The analysis phase encapsulates the first diamond of the Double Diamond approach that was used for this project, which includes the **discover** and **define** steps in the process.

# 4. Context Analysis

In order to generate a fitting (re)design, it is important to understand the environment, stakeholders, constraints, and other factors that will influence the product. A context analysis was conducted **to identify user needs, practical limitations and other factors** to ensure that the redesigned tracker will be **desirable, feasible**, and **viable** to use. The context analysis was also used to help formulate design requirements for this project. All requirements identified in the context analysis are compiled under “4.8 Context Conclusions Summary”

The context analysis covers the following topics:

- Related Works
- Stakeholder Analysis
- Market Analysis
- Environmental Analysis
- Regulatory and Legal Context
- Ethical Considerations
- Economic Factors



## 4.1. Related Works

This section discusses other existing tracker devices used for monitoring floating plastic transportation in riverine environments, as well as the gaps they leave in performance, aesthetics, etc. Devices used to physically remove floating litter (e.g. Noria's CirCleaner and CanalCleaner) from waterways are excluded as they serve a different purpose.

### Existing trackers & learning points

Two notable examples include the **"Message in a Bottle"** project by Duncan et al. (2020) and a study involving **The Ocean Cleanup** project (Mani et al., 2023).

Information from these papers regarding the design of these devices that was useful for the development of the TrashTracer is noted below:

#### "Message in a Bottle"

- The GPS antenna must be above the water level and exposed to the sky (*Requirement #15*) (Duncan et al, 2020).
- Batteries were placed down below in the housing for a low-center of gravity, ensuring it self-rights when capsized (Duncan et al, 2020).
- An O-ring in combination with screws was used for waterproofing (Duncan et al, 2020).
- The design looked like a plastic bottle and this likely caused it to be removed by bystanders since there exists an informal waste trade in the Ganges river area where the trackers were used (Duncan et al, 2020).

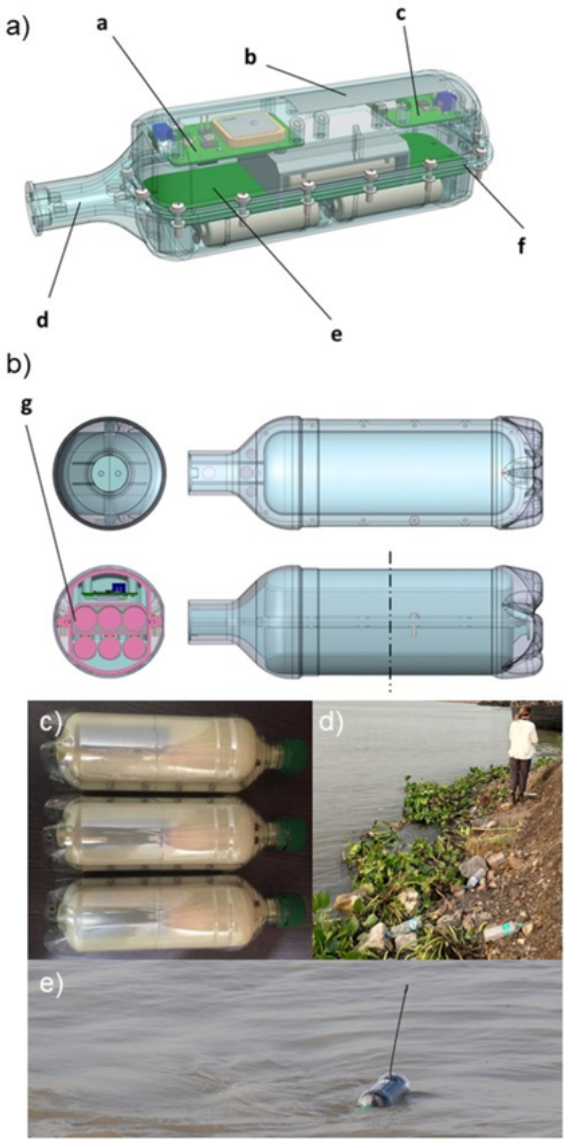



*Figure 11: "Message in a Bottle" GPS Tracker from Duncan et al. (2020).*

### Ocean Cleanup paper

- The same Lightbug Pro trackers were used in this tracker design, but with a 20.000 mAh battery pack, giving it a maximum battery life of 48 days.
- Batteries and PCB (including antenna) were positioned such that the tracker had a low centre of gravity and the PCB reached above the water level (*Requirement #15*)
- A screw-top container with thread seal was used for waterproofing.
- The container was a grapefruit-sized cylinder, and compact, homogenous shapes decrease the likelihood of entrapment.

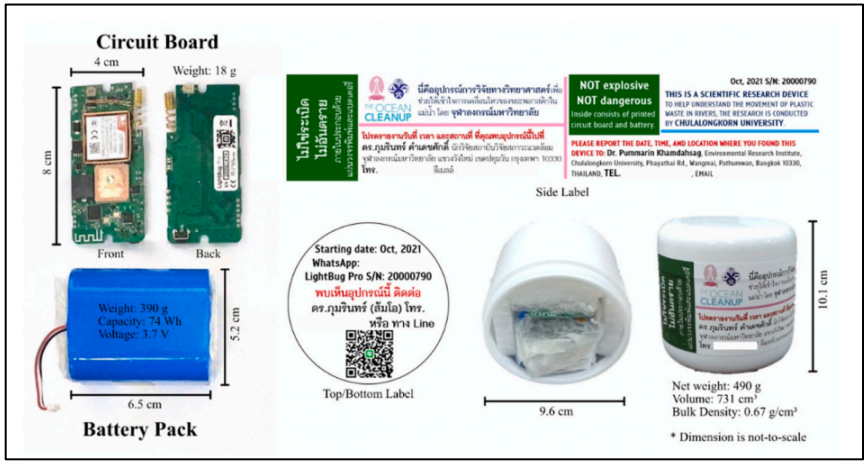



*Figure 12: Floating tracking device used in Mani et al. (2023).*

## Gap Analysis

- Most appear to be **one-time research devices** that are not designed for repeated use.
- They **lack a professional Aesthetic**.
- There is **no easy way to recover them outside of GPS**.
- **No adjustable properties** relating to buoyancy or wind – or current influence.

## 4.2 Stakeholder Analysis

To identify the various stakeholders to consider for this redesign project, an (extended) stakeholder map was made (*see Figure 13*). This subchapter will focus on the key stakeholders that will influence the outcome of this project the most by exploring their needs, influence and interests with regards to the tracker.

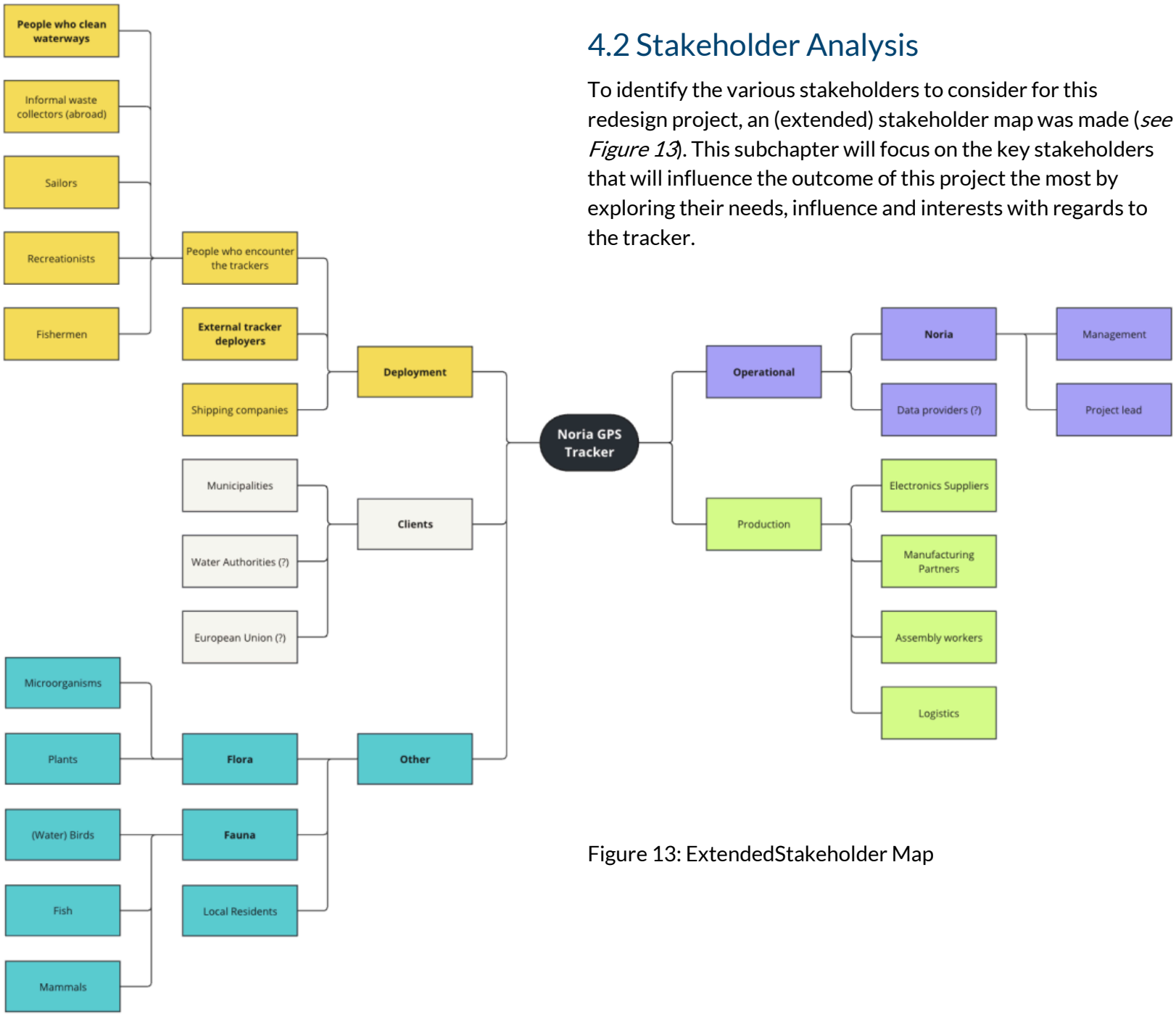



Figure 13: ExtendedStakeholder Map

## Key Stakeholders

Stakeholders most relevant to this design process are listed below including a short description. These stakeholders are also mapped in Figure 14.

- **Noria Sustainable Innovators:** The direct client of this graduation project.
- **Noria's clients:** Parties for whom Noria conducts research projects with their trackers. These are often municipalities, water boards, environmental funds, etc.
- **Canal cleaning crews:** Canals in Dutch cities, like for example Delft, are often cleaned from (plastic) litter to maintain clean water and a more pleasant street scene. This is done from the shore or from boats using grippers and nets. Parties who carry out this work are usually managed by municipalities.
- **Bystanders (who encounter trackers):** People who encounter the tracker, who can be anyone from kayakers, fishermen, or houseboat residents, are also key stakeholders. They may come across the trackers floating in the water or stuck on land.
- **Flora/Fauna:** Organisms like plants and animals that live in the environment where the trackers are used. They are somewhat influenced by the trackers themselves, but more so by the purpose for which they are used: reducing the amount of floating litter in waterways.
- **Production partners:** Companies that will be involved in the realization of the redesign. This includes part suppliers and partners who can manufacture custom parts.
- **Lightbug:** The tracking hardware is supplied by Lightbug. In addition to the hardware their service also includes a portal where trackers can be followed and where data can be collected.
- **External tracker deployers:** This stakeholder role does not yet exist but is planned for the future. Since deploying or retrieving trackers is a straightforward task, outsourcing it to e.g. students could save money compared to having highly educated employees perform it, as is currently done.

Stakeholders that are **users** of the tracker **include Noria**, **bystanders** and **canal cleaning crews**, with **external tracker deployers** as a projected **user in the future**. How current users interact with the original trackers is further elaborated in "*5.5 Usability*" in the Product Analysis (*Chapter 5*).

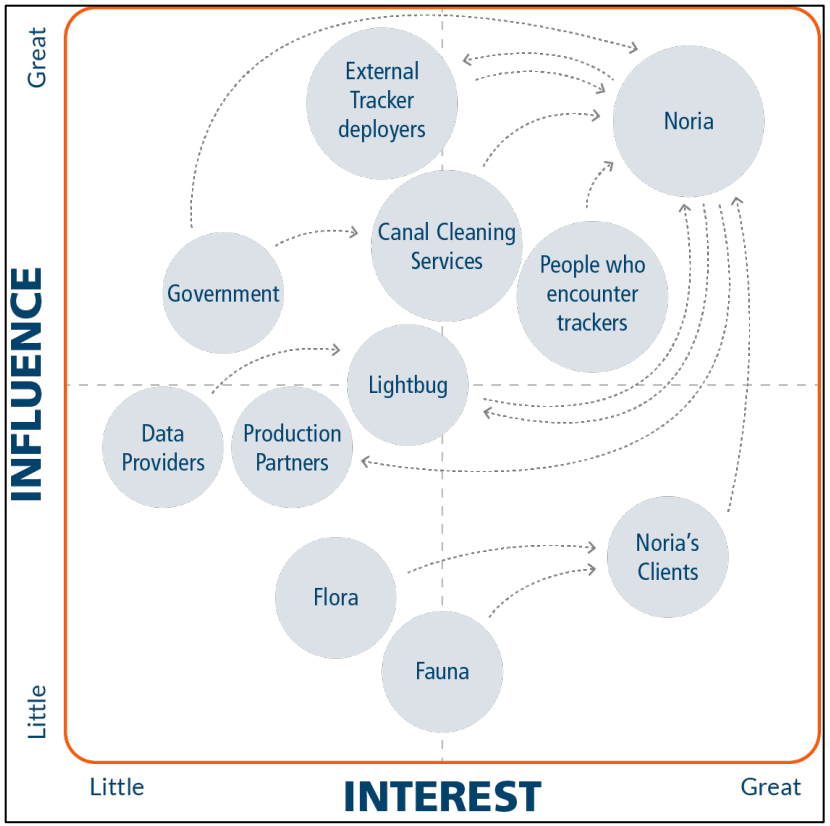



*Figure 14: Stakeholder analysis matrix.*

## Stakeholder Needs, Influence, and Interests

These key stakeholder's needs, as well as their influence on - and interest in the tracker, are noted below. Table 1 provides a summary, with levels of influence, interest and thereby importance of the stakeholder indicated with shades of blue (darker equals higher).

### Noria Sustainable Innovators:

Noria's **needs** are to receive a (re)design proposal at the end of this project and to be updated about the project's progress. Their **influence** is **high** as they provide regular feedback, determine things like budget, and the design should match their company identity. Noria's **interest** is also **high** as they initiated this project because they want to improve their current design.

### Noria's Clients:

Noria's Clients' **needs** are to be confident in the quality of Noria's research and therefore their trackers. Their **influence is low** but concerns the aesthetic design of the tracker. Their **interest is medium** as they are the stakeholder who initiates assignments for which trackers are used, but interest lies mainly with research results than the tracker itself.

### Canal Cleaning Crews:

This stakeholder **needs** to be aware of the presence of the tracker and be able to recognize it (*Requirement #9*). This way accidental removals can be prevented. Their **influence is high** as they actively remove litter from the water where trackers are used and can remove trackers which disrupts research. Their **interest is medium** as they share a common goal with the tracker (cleaning waterways), although it does not personally affect them. Interviews with representatives of cleaning crews from Canal Hopper (Delft), Municipality of The Hague and Municipality of Rotterdam all stated that the best way to prevent removals was to contact them so that they can inform their colleagues to leave the trackers alone. This has already been done to great effect with Canal Hopper for the original tracker.

### Bystanders (who encounter trackers):

Bystanders have no real **needs** with the tracker as it does not directly affect them. It would be advantageous for Noria if bystanders left the trackers in the water, but the way to achieve this can vary between individuals, making it hard to design for this stakeholder group. Whereas one person might read the text on the tracker and return it to the water, another might intentionally take it to sell the electronics. Their **influence is high** (although lower than cleaning crews) because they can disrupt research which needs to be prevented. Their **interest is low** in the sense that trackers do not directly affect them, but interest can be what moves some individuals to remove and investigate a tracker they encounter.

### Flora/Fauna:

This stakeholder group **needs** the tracker to be an effective tool in addressing the floating litter to improve the quality of the environment they live in. Trackers should also not unnecessarily disturb wildlife (for example through loud noises or flashing lights) (*Requirement #24*). Their **influence is medium** as they cannot directly affect the design but they are taken into account to minimize disturbance and cause biofouling. Their **interest is medium** because the tracker's aim is to address the pollution problem that negatively influences the environment where they live, yet they are likely unaware of the trackers' existence or purpose.

### Production Partners:

A production partner **needs** the design of the tracker to be manufacturable. Their **influence is medium** as they will have certain manufacturing limitations and design guidelines, but they work for Noria, and cater to their needs. Their **interest is low** as the order quantities are limited at 20-25 (initially). There might however be some marketing opportunities where they can boast that they helped make Noria's trackers, if these were to gain publicity.

### Lightbug:

Lightbug has no clear **needs** as they only supply the electronics used in the trackers but do not come into contact with the trackers, especially considering they are based in the U.K. Their **influence is high** as the performance of their device directly influences the performance of Noria's floating tracker and the specs, dimensions, etc. influence the design of the tracker housing (*Requirement #25).* Their **interest is low** as Noria only plans to produce 20-25 units of the redesigned tracker (initially) so order quantities will not be high. Again, there might be marketing opportunities.

### (External) Tracker Deployers:

This stakeholder **needs** the process of deploying and recovering trackers to be straightforward (*Requirement #23*). This way, failed deployments, that could result in losing trackers can be prevented. Their **influence is high** as they need to perform their job correctly to collect data properly and prevent losing trackers Their **interest is low** as their main motivation would be some financial compensation (or high if it is performed by Noria employees).

*Table 1: Summary of key stakeholders*

| Stakeholder | Needs | Influence | → Reasoning | Interest | → Reasoning |
|---|---|---|---|---|---|
| Noria Sustainable Innovators | • Stay updated on the progress.<br>• Receive a (re)design proposal | HIGH | • Provide regular feedback<br>• Determine things like budget<br>• Designed to match company identity | HIGH | • Initiator of the project<br>• Want an improved design |
| Noria's clients | • Confidence in the quality of research | LOW | • Mainly that the design should look more professional | MID | • They initiate research assignments<br>• Interest is rather in research than tracker |
| Canal cleaning crews | • Awareness of the trackers' existence and purpose<br>• Recognize trackers to avoid accidental removal | HIGH | • Their removals disrupt research<br>• Tracker is designed to prevent this. | MID | • Share common goal (cleaning waterways)<br>• Does not personally affect them |
| Bystanders (who encounter trackers) | • No direct needs<br>• (Noria needs) a way to prevent them from removing trackers | HIGH | • Their removals disrupt research<br>• Tracker is designed to prevent this. | MID | • Not directly affected by the tracker<br>• Some people can be curious |
| Flora/Fauna | • Effective litter monitoring to improve their habitat.<br>• Minimal disturbance | MID | • Cannot directly affect the design<br>• Are taken into account (minimize disturbance)<br>• Biofouling affects design | MID | • Are unaware of the tracker's purpose<br>• Tracker addresses pollution affecting their habitat. |
| Production partners | • The design needs to be manufacturable | MID | • Manufacturing requirements/limitations<br>• They work for Noria | LOW | • Limited order quantities (initially 20-25) |
| Lightbug | • No real needs, Noria is a customer of them | HIGH | • Performance directly affects the tracker<br>• Specs influence the housing design | LOW | • Limited order quantities (initially 20-25) |
| (External) tracker deployers | • Streamlined deployment and recovery process | HIGH | • Responsible for tracker deployment and recovery | LOW | • Only financial compensation<br>• No personal motivation |

## 4.3 Market Analysis

A market analysis was conducted to define the tracker's target audience, identify competitors and evaluate their strengths and weaknesses, and to clarify the tracker's role in the industry.

### Target Audience

The **primary target audience** for this project **is Noria**, as they will directly use the redesigned tracker. Functional improvements are mainly targeted at them, as they will be the main users.

However, **Noria's clients need to be convinced to commission Noria for projects** utilizing these trackers. Noria has expressed a desire for the trackers to have a more professional appearance. This is discussed further in "*5.4 Aesthetics and Design*".

### Competitors/Benchmarking

Within the Netherlands, **Noria is the only organization offering plastic pollution research using floating trackers**. There are also no known competitors offering an off-the-shelf floating tracker as a product.

While there is competition in the removal of floating plastic, for example the WasteShark (RanMarine Technology, 2024) or the Bubble Barrier (The Great Bubble Barrier®, 2024), **Noria experiences little competition** in **researching** the pollution problem in general.

In offering research with floating trackers, Noria is unique (in the Netherlands). Therefore, there is **no** direct **pressure from competitors** to improve the design of the tracker.

### Role of Floating Trackers in the Industry

The role of a floating tracker in the domain of waterway plastic pollution research (which is dominated by Noria in the Netherlands), lies in its ability to gather **real-time data**.

Noria also conducts geographical analysis (GIS) combined with mathematic models, and visual counting using cameras and AI (Noria Sustainable Innovators, n.d.).

While **mathematical models** only offer **predictions** of plastic movement and accumulation, and **visual counts** capture **static snapshots**, the data from trackers is "real" and continuous. This allows the tracker data to validate and "feed" mathematical models and to work in conjunction with visual counting to create a better understanding of the transportation behaviour of floating litter.

## 4.4 Environmental Analysis

### Physical Environment

The tracker will be deployed in waterways such as **canals** and **rivers** to study floating litter (*see Figure 15*). It will be exposed to **outdoor conditions** for up to **six weeks**. Therefore, it must meet the following requirements:

- Since the tracker can be submerged at times, it should meet the requirements for **IP67 rated** enclosures

meaning it can resist being submerged under water for **30 minutes** at a depth of **15 cm to 1 meter** (*Requirement #7*).

- The tracker housing must be **UV-resistant** (*Requirement #33*), to prevent discolouration and degradation of material properties.
- All parts must be able to **withstand temperatures between -20°C and 60°C** (*Requirement #26*). This temperature range aligns with the operating limits of the Lightbug GPS device (Lightbug Ltd, n.d.-b), and all other tracker components should be able to withstand this.
- The tracker should **stand out visually** (*Requirement #27*). The tracker will encounter water vegetation, particularly in summer, and artificial structures like jetties, which can make it harder to see. Additionally, trackers often get stuck between docked boats and the embankment (see *Figure 16*).
- The tracker housing should **not** be **prone to biofouling** (*Requirement #31*). Biofouling is the process of a film growing on objects in the water due to microorganism build-up (*see Figure 17*) (Noria Sustainable Innovators, 2024). This can increase wear and influence buoyancy (Schwarz et al, 2019). It can also make the tracker look more like waste and make it harder to spot.
- Furthermore, trackers need to be able to **resist impacts** (*Requirement #11*) **and mechanical loads**. It is however complex to quantify this as many situations could arise (e.g. squishing between objects in the water, a boat running into it, etc.), making it hard to determine what mechanical forces would apply.



*Figure 15: A typical location where trackers are used, including vegetation and man-made structures.*



*Figure 16: Noria's original tracker (unlike most, this one has a white sticker) stuck between a docked boat and the embankment.*



*Figure 17: Biofouling on Noria's original tracker after 48 hours in the water.*

### Ecological Impact

Given that only 20-25 units are planned for an initial production run, the **ecological impact** is rather **minimal**. Nonetheless, it remains important to **avoid** unnecessarily **materials and processes** to ensure it aligns with the image of a sustainable startup (*Requirement #17*).

## 4.5 Regulatory and Legal Context

As long as **trackers are removed** from the water after a research period, there should be **no legal issues**. Concerns may arise as littering is obviously illegal, but this would require the trackers to be left in the environment.

**Clients of Noria** are often **governmental bodies** such as municipalities and waterboards **who** generally **determine rules and regulations** around topics of this sort. Considering that these parties are paying Noria to conduct research with floating trackers, it is **highly unlikely** that **there are any legal concerns** with the way trackers are currently used. Nonetheless, trackers should be compliant with rules and regulations set by authorities such as waterboards (*Requirement #32).*

There is a slight gray area if trackers are lost during use. As this is not intentional, it should not lead to legal implications, yet it is obviously bad for the environment. **Losing trackers should therefore be minimized**. This is discussed further in chapter "*5.3 Performance Analysis and Pain Points*".

## 4.6 Ethical Considerations

### Environmental Impact

As previously discussed, the device should minimize its environmental impact. This involves reducing the use of polluting and toxic materials and **ensuring that trackers do not remain in the natural environment** post-research.

### Privacy of Data

Privacy concerns may arise regarding individuals who come into proximity with the tracker. Depending on available signals, the Lightbug Pro can determine its position using WiFi, Bluetooth, or GPS (Lightbug Ltd, n.d.-b). The use of WiFi and Bluetooth could be concerning as it involves **local networks** and signals from devices like smartphones. However, Lightbug states that **all data transmission is encrypted** (Lightbug Ltd, n.d.-a). For this reason, incorporating their products should not cause concerns.

Additionally, as shown in *Chapter 2*, technology was added in the redesigned tracker to aid tracker recovery at the end of a research period. It is essential that this technology respects individuals' privacy (*Requirement #29*).

### Transparency to bystanders

Since the trackers are **deployed in public waterways**, there is an **ethical obligation** to **inform the public** about their purpose and data usage. The original tracker already addresses this with an informational sticker, which includes a QR code linking to Noria's webpage explaining the research (https://www.noria.earth/aanpak/). The redesigned tracker

should also adhere to this moral obligation and **communicate its purpose** to bystanders who encounter it (*Requirement #12*).

### Potential for Misuse

Concerns may exist about the misuse of the Lightbug Pro's data collection capabilities if it falls into the wrong hands. However, the **trackers can be deactivated** remotely via the portal, mitigating this risk.

### Methods of Preventing Unplanned Removal

Trackers should **not be likely to startle or scare people** who encounter them (*Requirement #30*). One potential method to prevent bystanders from removing the tracker could be to include deterring symbols (e.g., toxic, hazardous, radioactive) or to trigger an alarm if it is touched. However, these methods are **ethically questionable** and could cause authorities to intervene, leading to **legal issues**. For these reasons, such methods are considered unsuitable.

## 4.7 Economic Factors

### Cost Constraints

Cost-wise, the most important thing for this redesign is ensuring it remains **cost-effective** for Noria. This is further explored in the Viability chapter of this report. However, to provide a guideline for the project, a **rough budget of €400 per tracker** has been set in consultation with Noria (*Requirement #20*).

### Economic Trends

According to the latest Central Economic Plan, wages are expected to grow by 6% (Centraal Planbureau, 2024). This wage growth **affects the labor costs** for both Noria employees, and any production partners involved in manufacturing. For this reason, the assembly duration should be limited to a maximum of 20 minutes (*Requirement #28*). Additionally, higher labor costs influence the expenses associated with deploying and recovering the trackers, making it advantageous to reduce these operational costs where possible through the redesign of the tracker.

## 4.8 Context Conclusions Summary

To summarize, the following requirements were identified in the context analysis:

- The GPS antenna must be above the water level and exposed to the sky (Requirement #15, Duncan et al., 2020).
- The tracker must be compliant with IP67-rated enclosures, resisting submersion for 30 minutes at a depth of 15 cm to 1 meter (Requirement #7).
- The tracker housing must be UV-resistant to prevent discoloration and degradation of material properties (Requirement #33).
- All parts must be able to withstand temperatures between -20°C and 60°C (Requirement #26).
- The tracker should visually stand out in environments with vegetation and artificial structures (Requirement #27).

- The tracker housing should not be prone to biofouling (Requirement #31).
- Trackers need to resist impacts and mechanical loads (e.g., squishing between objects in the water or collisions with boats) (Requirement #11).
- Trackers should not unnecessarily disturb wildlife, such as through loud noises or flashing lights (Requirement #24).
- The redesigned tracker must respect individuals' privacy, ensuring any recovery-assisting technology does not cause privacy breaches (Requirement #29).
- The redesigned tracker must communicate its purpose to bystanders who encounter it (Requirement #12).
- Trackers should not be likely to startle or scare people who encounter them (Requirement #30).
- Assembly duration must be limited to a maximum of 20 minutes to reduce labor costs (Requirement #28).
- The budget per tracker must not exceed €400 (Requirement #20).

# 5. Product Analysis

To identify limitations and formulate design requirements for the project, an analysis of the original tracker was conducted. This chapter examines the tracker's components, functions, and other relevant aspects to provide a thorough understanding of its performance and challenges. The analysis primarily focuses on the **PVC casing** used by Noria, as the Lightbug Pro GPS tracking device was predetermined to remain part of the redesigned tracker (as discussed in *Chapter 1.6)*. Since the main issues experienced by Noria are related to the casing, it received the most attention during this analysis.

The product analysis covers the following topics:

- Components and Materials
- Functions
- Performance
- Aesthetics
- Usability
- Durability
- Manufacturing
- Costs
- Sustainability



## 5.1 Components and Materials

Components and materials used in the original tracker were identified to help **understand the product and its limitations**. Knowledge of this is used in various aspects of the product analysis such as “Aesthetics and Design”, “Durability and Build Quality”, and “Sustainability” which are discussed later in this chapter. The **components** of the tracker are displayed on the next page.

Table 2 provides an overview of the materials of the components

*Table 2: Bill of Materials for the original tracker.*

| Subassembly | Component | Subcomponent | Material |
|---|---|---|---|
| PVC Casing | Construction | Tube | PVC |
| | | Glue | PVC Cement |
| | | Bottom Cap | PVC |
| | Opening Mechanism | Screw Cap | PVC |
| | | Waterproofing seal | Rubber (likely Nitrile) |
| | Stickers | Screw cap sticker | Paper, Ink, Adhesive, Plastic |
| | | Bottom Sticker | Paper, Ink, Adhesive, Plastic |
| | | Side sticker | Paper, Ink, Adhesive, Plastic |
| Lightbug Pro | Outer Casing | Plastic Case | Hard Plastic |
| | | Charging Contact | Copper |
| | | (Machine) Screws | Steel (stainless) |
| | | Threaded Inserts | Brass |
| | Electronics | Battery Pack | Li-Ion |
| | | PCB | Copper, Gold, Plastic |
| | | Cables | Copper, Plastic |

## PVC Casing

## Lightbug Pro



## 5.2 Functionality Analysis

To understand what base functions the redesigned version of the tracker must fulfill, the functions performed by the original tracker were identified with the help of a **Product Life Cycle Analysis** (PLCA) (Van Boeijen et al., 2020). With this methodology, different stages that the tracker goes through in its life are identified, which were linked to the functions it must perform, as well as design requirements that must be met by the redesigned tracker. The most important functions, or **core functions**, are listed below, including an explanation:

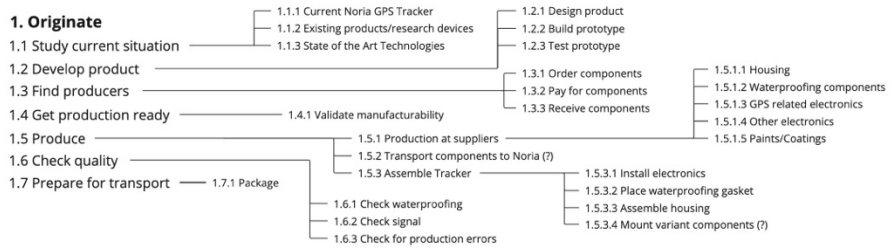
- **Waterproofing:** to keep it afloat and prevent damage to the electronics, the PVC casing has a rubber seal aimed at keeping out water.
- **Data Collection and Transmission:** It collects and transmits GPS data to give insight into the transportation of floating (plastic) litter and to identify hotspots where it is most efficient to remove litter from the water. This data is available in a portal provided by Lightbug.
- **Prevent Removal:** If the tracker is removed from the water (by bystanders or cleaning crews), this can disrupt research if it is not returned. Trackers have stickers on them with information stating that it is a research device which should be left in the water.
- **Allow for recovery:** After research is completed, Noria recovers the trackers so that they can be used for future research. Noria uses their last-known GPS location and looks for the bright orange stickers to find them.

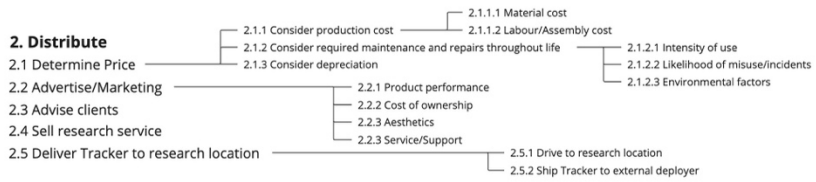
### Product Life Cycle Analysis

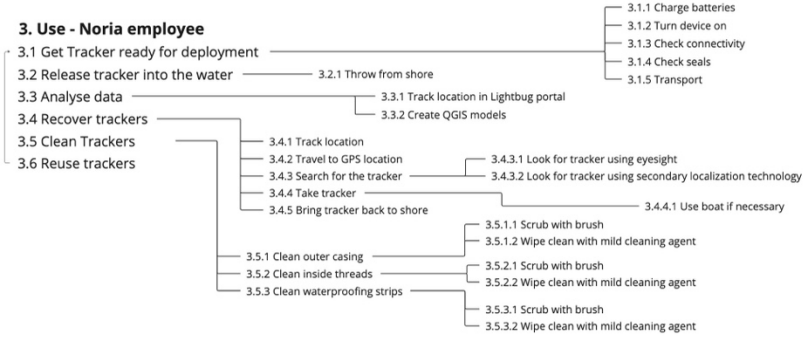
User identification, as described in "*4.1 Stakeholder Analysis*", as well as a project briefing with Parshva Mehta (Noria's coach involved with this project) and interviews with Noria employees were used as information sources to complete the Product Life Cycle Analysis. The "Use stage" was analysed for all **four anticipated users**.

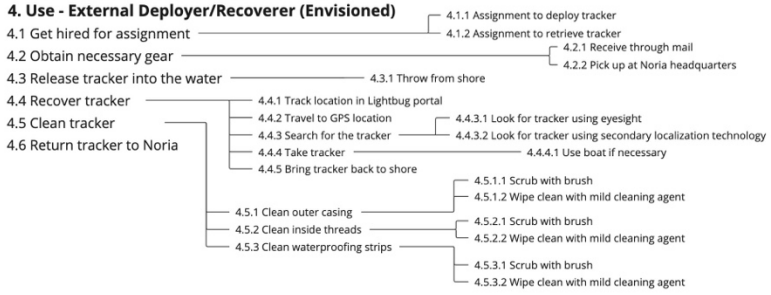
While focused on the current situation, envisioned steps for a future scenario with the redesigned tracker are also incorporated (e.g. "4*. Use- External deployer/recoverer*") to help form requirements. The Product Life Cycle Analysis is visualized in *Figure 18*.

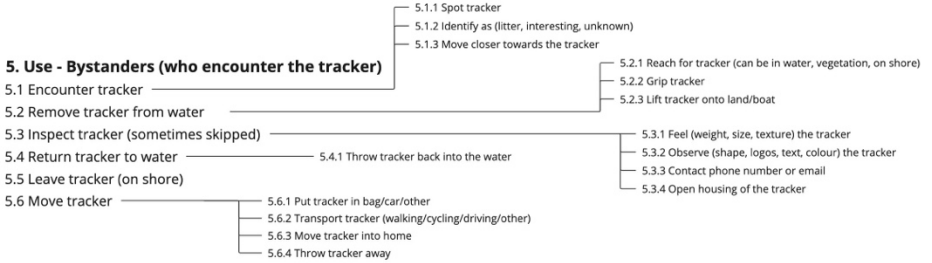
Numbers assigned to steps in the figure correspond to the second column in the List of Requirements at the end of the analysis part of this report. Requirements derived from the Product Life Cycle Analysis are linked to the stage where they were identified.

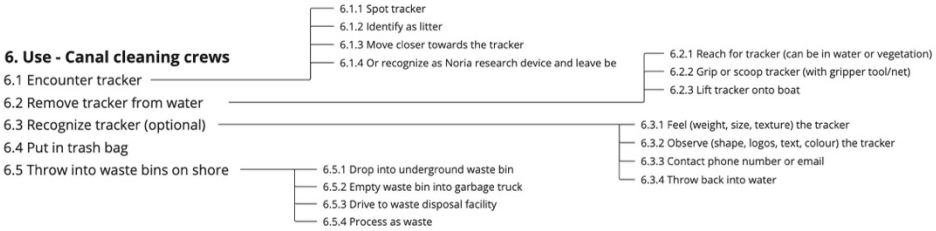


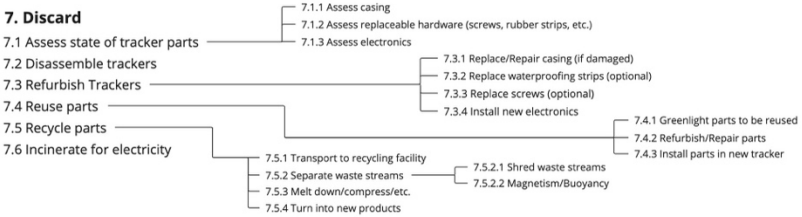




*Figure 18: Product Life Cycle Analysis*

### Conclusions

Requirements that were formed from this PLCA are listed below:

- The tracker should discourage people to remove it from the water, and if they still do, encourage them to return it (*Requirement #4*). During the employment, bystanders and canal cleaning services can encounter the trackers. If they remove the tracker from the water and don't return it, this can disrupt the research.
- Tracker is thrown in the water from the embankment which can be significantly higher than the water. The tracker should survive being dropped in the water from 3 meters height (*Requirement #8*).
- Batteries require charging after every use. For this reason, charging or replacing batteries must be an easy process (*Requirement #34*).
- The casing and waterproofing strip should resist light abrasion (*Requirement #36*) and mild chemical cleaning agents (*Requirement #37*). Trackers require cleaning after use to maintain aesthetic qualities and reduce wear caused by biofouling.
- To refurbish parts of used-up trackers, all internal components should be replaceable (*Requirement #39*). This does not apply to the tracker casing as this part is expected to wear the most since it is exposed to the elements, and therefore not suited to be refurbished at the end-of-life.

More requirements were identified with the help of the PLCA but have already been discussed previously in the report or fit better elsewhere and are therefore not repeated here. These requirements can be identified by the presence of a "PLCA #" in the List of Requirements.

## 5.3 Performance Analysis and Pain Points

After identifying the tracker's core functions, its **performance** in fulfilling those functions was assessed. The performance analysis is related to the "**pain points**" experienced by Noria which were discussed in "*1.3 Problem Statement*". This is done because **for each core function**, **there was at least one pain point** for Noria.

There was one additional performance-related finding with regards to the tracker's ability to represent different types of litter.

### Waterproofing

**Pain Point:** Water ingress leads to tracker damage and loss.

**Performance Analysis:** The true effectiveness of the waterproofing seal is unclear. Of 50 tests, 6 trackers were lost, but the cause (which can be sinking, signal failure or simply not being found) cannot be determined.

Noria employees have however noted that waterproofing is an issue, especially after trackers have been in the water for extended durations. During early performance testing (Appendix B), one of the tracker casings leaked water on both occasions it was used (see Figure 19).



*Figure 19: water ingress after two days of use.*

The Lightbug Pro trackers that are used inside the tracker casing are IP66 rated (Lightbug Ltd, n.d.-b). While this means they are resistant to waterjets and dust, they cannot handle submersion. Noria usually protects the Lightbug Tracker by putting it in a plastic bag inside the PVC tube.

## Data Collection and Transmission

**Pain Point:** Frequent signal failures lead to data loss and recovery challenges.

**Performance Analysis:** Signal reliability is only at around 40% (*Appendix B*). This means that only 40% of the time the tracker tries to transmit a signal, it manages to do so. As a result, many data points are missed, making the data less complete and usable.

A plus is that the Lightbug Pro collects data such as temperature, acceleration and orientation which could be used to create more insight into what occurs during use.

## Recovery

**Pain Point:** Trackers are difficult to locate and retrieve, especially in vegetation or around structures that obscure them from sight.

**Performance Analysis:** Recovery of the trackers (when multiple are retrieved simultaneously) often takes several hours according to Noria employees. If a tracker cannot be located, it remains in the environment and will eventually sink. Finding a tracker should not take more than 10 minutes after arriving on the location (*Requirement #3*).

The trackers are equipped with **highly visible orange stickers** which help Noria spot trackers during recovery. Additionally, the **last known GPS location** is used.

## Prevent Removals

**Pain Point:** Bystanders and cleaning crews sometimes remove trackers, disrupting research. This can happen because they are mistaken for waste or out of curiosity.

**Performance Analysis:** On 3 occasions (out of 50 tests conducted) a tracker has been removed from the water (once by a cleaning crew, twice by bystanders) and required to be picked up by a Noria employee, which costs Noria time and money (see

Appendix H). Information is provided (i.e. that it is a research device and should be returned to the water, as well as a QR-code to Noria's website) in a small font size (*see Figure 20*).




*Figure 20: Excessive text and a small font used on the sticker, QR code leading to Noria's website.*

## Loss of Trackers

**Pain Point:** Loss of trackers results in environmental pollution and costs associated for replacing trackers.

**Performance Analysis:** Out of 50 tests, 6 trackers have been lost. There is a 12% chance of losing a tracker per deployment, which is much too high. This should be reduced to <5% (*Requirement #5).*

The stickers on the casing contain **Noria's contact information** so that it can be returned if someone finds it.

## Battery Life

**Pain Point:** The current three-week battery life restricts research duration, Noria aims to double this to 6 weeks (*Requirement #6).*

**Performance Analysis:** While Lightbug estimates a battery life of approximately 7.6 months with a 6600 mAh battery at an hourly update rate, the longest duration Noria has observed in practice is around **three weeks** ((Lightbug Ltd, n.d.-b).

## Additional Finding – Litter Representativity

**Finding**: To simulate plastic pollution transportation, the tracker should be representative of floating plastic litter (*Requirement #*10). The tracker only closely represents a limited amount of floating litter.

**Performance Analysis:** It has a certain size, weight, and shape, and therefore is affected differently by the wind and waterflow than other waste items (Schwarz et al., 2019). For this reason, it can only be closely representative to a specific type of floating litter. Its size is similar to (larger) plastic bottles, which are a relatively common type of litter (Noria Sustainable Innovators, unpublished). Its density is around 0.59 grams/$cm^3$, causing it to be approximately 60% submerged in water.

While this was not indicated by Noria to be a pain point, it was identified as a functional limitation of the tracker.

## Summary

This performance analysis highlights areas where the tracker underperforms, generally aligning with Noria's pain points. An additional functional limitation was identified in that the tracker can only closely simulate a small group of litter types.

Table 3 summarizes the issues, the supporting data, and positive and negative attributes of the design.

*Table 3: Performance issues, supporting data, and potential solutions.*

| Issue | Supporting Data | Positive Attributes | Negative attributes |
|---|---|---|---|
| **Waterproofing** | Frequent leakage observed | + closing method is easy to use<br>+ seal is cheap to replace | - Noria experienced leakage in the past<br>- Lightbug Pro tracker is only IP66 waterproof |
| **Data Transmission** | ≈40% signal reliability | + Lightbug Pro collects more than just GPS data | - Trackers often fail to transmit signals, making the data less complete and usable |
| **Prevent Removals** | 3 removals in 50 tests; once by a cleaning crew and twice by a bystander | + contains text for communication<br>+ QR-code to Noria's website | - Small font is unlikely to be read |
| **Recovery** | Several hours required to recover trackers | + bright orange color helps visual localization<br>+ GPS is used to locate trackers | - Recovery takes a long time to do |
| **Loss of Trackers** | 6 trackers lost in 50 tests | + trackers have a strong construction | - A 12% chance of losing a tracker per deployment is much too high |
| **Battery Life** | Max. 3 weeks was observed (with a 6600 mAh battery pack) | + Lightbug Pro uses WiFi and Bluetooth to save power | - Battery life is much shorter than advertised. |
| **Litter Representativity** | Tracker properties are similar to a limited number of litter types | + Size is similar to plastic bottles, which are relatively common. | - properties of the tracker cannot be adjusted to be similar to a larger range of litter |

## 5.4 Aesthetic and Design

One **additional** (not performance related) **pain point** that Noria has with the original tracker is its **appearance** (indicated during the project briefing and conversations with Noria employees).

Noria worries that it looks **unprofessional** and that this affects the trust that potential clients have in the quality of work carried out with the trackers, which in turn could **reduce the number of assignments** Noria receives. For this reason, Noria expressed a **desire for a tracker with a more professional appearance.** To make this quantifiable, 80% of people should think the redesigned tracker looks more professional than the original (*Requirement #1*).

To help identify elements that cause this unprofessional appearance, the original tracker was assessed on its aesthetics.

### Aesthetic Perception

Feedback sessions with different people throughout this project involved asking participants to compare the aesthetics of the original tracker to prototypes at varying stages and levels of development. Participants often described the original tracker (see Figure 21) as looking **cheap, thrown together** and **resembling construction waste**, while all **prototypes were deemed more professional** in appearance. This was mainly caused by the **standardized PVC components** that were recognized from hardware stores and construction sites, but also due to **glue residue** and **wear on stickers** (discussed in the next subchapter).




*Figure 21: Aesthetic of the original tracker housing.*

## 5.5 Usability

The usability of the tracker was analyzed to understand whether it meets user needs and to identify ways to improve this. This subchapter is divided in two parts covering two groups of users: “Usability for Noria Employees”, and “Usability for Finders”.

### Usability for Noria Employees

For Noria, there are three main uses phases with the tracker that each include several actions:

1. **Preparation for Research**
    a. Charge tracker

    b. Activate tracker
    c. Open/Close PVC casing
    d. Deploy tracker
2. **Monitoring During Research**
    a. Check data and battery percentages
3. **Recovery after Research**
    a. Check location
    b. Look for trackers (visually)
    c. Remove trackers
    - Prepare for future use

Each phase, and corresponding actions are discussed in more detail hereafter:

## Preparation for Research

### *Charge Tracker*

The Lightbug Pro is charged in a **docking station**, via a charging contact present on the outer casing, making this convenient (see Figure 22). The battery pack can however not be easily replaced, especially since the casing appears to not open.



*Figure 22: Lightbug Pro in its docking station*

### *Activate Tracker*

The trackers are activated in Lightbug's **online portal**. To check whether they work, the data they collect can be monitored in this portal, but this is delayed by several minutes.

### *Open/Close PVC casing*

As stated before, there is **no indication** of how much tightening is required. Overtightening may result in deformation of the waterproofing seal which can compromise it. The method of assembling/closing for the redesigned tracker must ensure a waterproof seal and include an indication. (*Requirement #13*).

*Deployment*

Trackers are thrown into the water from the embankment which can be done comfortably without the need to crouch or reach down.

## Monitoring During Research

During research, the trackers can be monitored in Lightbug's portal to check their **location**, **signal transmissions** and the **battery percentages** (this last one is monitored to ensure trackers are retrieved before their batteries run out) (see Figure 23). Most data will however be analyzed after a research period is completed.




*Figure 23: Lightbug Portal displaying location, battery percentage, and various data.*

## Recovery after Research

*Check location*

The first step in recovering a tracker is to check its **last-known location** in the Lightbug portal, and to travel to this location.

*Look for trackers (visually)*

The **orange** color **helps spot** trackers, but this can be challenging if the trackers are obscured from sight.

*Recover trackers*

Noria uses handheld **fishing nets** to remove trackers from the water, making this process much easier (see Figure 24). The tracker therefore does not need a handle or other feature so that it can be grabbed more easily.

*Prepare for future use*

To prevent water ingress and to keep the trackers looking properly, the casings are **cleaned** and **dried**. The tracker is then removed and can be charged for future use.



*Figure 24: Recovery of a tracker using a fishing net.*

### Usability for Finders

"Finders" sometimes remove trackers from the water, hindering research.

With "**finders**", anybody not associated to Noria who may encounter the tracker during its use is meant, including random **bystanders** and **canal cleaning crews**.

Cleaning crews generally **remove** all **floating litter** they encounter, **without paying** too much **mind** to what it exactly is, as indicated by representatives from both the municipality of The Hague, and the municipality of Rotterdam, and the fact that a tracker was brought to a waste treatment facility by cleaning crews in Delft (which likely meant the information on the stickers was not read).

Interaction of bystanders *typically* consists of the following steps (formulated based off an interview with someone who found a tracker and contacted Noria):

1. **Spotting the tracker.**
2. **Grabbing the tracker.**
    a. Can be challenging because the trackers are round and can become slippery due to biofouling (which can be a good thing to reduce likelihood of removals).
3. **Reading the text on the stickers.**
    a. This is sometimes skipped as there is a surplus of information in a small font.
    b. This sometimes leads to contacting Noria or visiting the website using the QR-code.
4. **Opening the tracker.**
    a. Unknown how often this happens, but the casing can easily be opened by hand. This can cause issues with waterproofing (if it is not closed tightly afterward) and may increase the chance of theft (particularly the electronics). The redesigned tracker should resist being opened or tampered with (*Requirement #38*).
5. **Returning the tracker to the water.**
    a. In one known occasion a tracker was taken home by someone who found it.

## 5.6 Durability and Build Quality

To assess the tracker's suitability for extended use in demanding environments, its durability and build quality were evaluated, focusing on its materials, construction, and ability to withstand wear and tear. This helped identify areas for improvement.

### Materials and Construction

The tracker housing is **durable and can withstand significant damage,** thanks to its strong construction. It is made of a PVC tube with a PVC cap glued to the bottom and a screw-cap on the top, with a consistent wall thickness of approximately 4 mm.

### Sticker Wear

The stickers, or rather the **transparent tape applied over the stickers** on the side surface of the tracker housing show **significant wear**. While this was applied to reduce wear, the majority of the trackers that Noria owns have damage to this tape which causes it to rip and peel off, only enlarging the

problem (*see Figure 25*). It is evident that this results in pieces of **plastic** being **released in the water** during the use of the tracker. Additionally, the damage makes it **harder to read** the **text**.




*Figure 25: The plastic coating on the sticker flakes off.*

What is interesting to note however, is that the **sticker on the screwcap wears significantly less**. This sticker is not covered by transparent tape and is embedded into the surface of the cap, making it less likely to peel of or come into contact with other objects which can cause damage (see Figure 26).



*Figure 26: Less wear on stickers not covered by transparent tape and embedded into the surface.*

Noria has indicated that the stickers they used were low-cost, which might cause them to wear more easily.

Higher-quality stickers that are **resistant to water and UV**, that are **embedded** into the surface of the tracker housing, can be expected to display less wear.

### Maintenance and Repairability

The stickers on the housing, as well as the waterproofing strip can be replaced with relative ease, however, due to the rate of wear for the stickers, these require frequent replacing to maintain aesthetics and readability. This can be time-intensive and somewhat wasteful. The redesigned tracker should be designed to be **wear-resistant** and require **minimal maintenance** (*Requirement #16).*

If parts of the construction break, it is hard to service or replace them as a lot of glue is used in the design. When considerable damage occurs during use, the tracker is however likely to be lost, making this less relevant.

## 5.7 Manufacturing and Sourcing

How the tracker was manufactured and where parts were sourced was analyzed to identify strong points and aspects that can be improved.

### Manufacturing Process

The manufacturing process of the casing involves three main steps:

- **Glueing** the **bottom cap** to the PVC tube.
- **Installing** the screw-on **lid** which will be used to open and close the casing.
- **Applying stickers** to the bottom, top and side.

After this, a Lightbug Pro tracker can be put inside, and the devices can be used.

While the process is quite simple and not very time-consuming, it was carried out by a Noria employee. **Outsourcing manufacturing** can **save costs** (Noria employees are highly educated and have relatively high wages) and would allow employees to be allocated to other tasks (*Requirement #21).*

### Sourcing

The PVC components and the glue are sourced from local hardware stores. The informational stickers were ordered online. Where exactly the components were produced and where the raw materials originate from is hard to tell. The components are **standardized** and **readily available** which makes it low-cost and easier to repair or reproduce the trackers. Mostly standardized components should be used in the redesigned tracker for these reasons (*Requirement #22).*

## 5.8 Cost Analysis

Aside from costs associated to parts and manufacturing, there are also costs of using the tracker. How these compare to the revenue that the trackers generate is discussed in this subchapter.

### Production Cost

The total production cost is **€200**, -. This consist of the Lightbug Pro tracker, which is roughly €150, - and the construction of the PVC housing which is €50, -, according to a work package provided by Noria. The construction costs consist of materials and wages for a Noria employee.

### Revenue and Profit Margins

Noria charges clients **€172, -** per tracker that is used. They estimate that a tracker can be used **16 times** during its life which entails a total revenue of **€2752, -** over the life of one tracker. There are however numerous costs like deploying and recovering the trackers, the costs for losing trackers, and unplanned removals (when someone who encounters a tracker removes it from the water).

With these costs deducted, an estimated profit margin over the lifetime of one tracker is around **€1400, -** The redesigned version of the tracker should be expected to at least match the amount of uses and the expected profit number (*Requirement #18 & #19*). The viability chapter of this report further discusses the cost-structure, and more details can be found in Appendix H.

## 5.9 Sustainability

Although material sustainability of the trackers does not have priority (as explained earlier in the "Project Scope" section of this report), it is still interesting to evaluate considering that **Noria is a sustainability-focused company**. The use of particularly unsustainable materials does not match well with a sustainable identity.

This subchapter is divided in the **environmental impact** of the casing, and the **energy consumption** of the tracking device. Materials used in the tracking device are left out of scope as they are limited in amounts, and because omitting electronics is not feasible.

### Environmental Impact

**PVC** is one of the **most harmful plastics** throughout its lifecycle. Toxic, chlorine-based chemicals are released during its production, use, and disposal. These chemicals accumulate in water, air, and the food chain (Greenpeace, 2003). Although the carbon footprint of PVC is relatively low compared to other plastics (Vogtländer, 2024), its major issue lies in the release of these toxic substances.

Since the tracker is used in water, there is a **risk of leaching harmful substances** into the environment. These toxins primarily include plasticizers, such as bisphenols and phthalates, which can contaminate the water and bioaccumulate through the food chain (Kudzin et al., 2023). A study by Lithner et al. (2011) found that among the plastic types PP, HDPE, PVC, ABS, and Epoxy, **PVC** and Epoxy **leached the highest levels of toxic substances** into water. However, "**rigid PVC**," commonly used for pipes and **used in the tracker housing**, contains fewer or no plasticizers, making it **significantly less toxic** than more flexible types of PVC (National Sanitation Foundation, 2022). Lithner et al.'s study (2023) also stated that a rigid PVC sample did not release toxins into the water. Nevertheless, **PVC's production and disposal remain highly damaging to the environment**.

One could argue that the tracker contributes to litter cleanup during its use, which offsets its own environmental impact. However, f**or a sustainability-focused company**, the use of materials with a **high environmental impact**, even when less harmful variants are chosen, is **conflicting** and needs to be **avoided** (*Requirement #17*).

## Energy Efficiency

As stated in the performance analysis, Lightbug estimates a much more optimistic battery life than has been realized for Noria.

Despite this considerable difference in practice, the **energy consumption remains reasonable**. Charging a Lightbug Pro tracker consumes about twice as much energy as charging an average smartphone in 2024, which gives it a three-week long charge. Considering that most people charge their phones daily, the **energy requirements** of these trackers are **not concerning**.

## 5.10 Product Conclusions Summary

Various requirements were formulated through the product analysis. These are compiled below:

- The tracker should discourage people to remove it from the water, and if they still do, encourage them to return it (*Requirement #4*). During the employment, bystanders and canal cleaning services can encounter the trackers. If they remove the tracker from the water and don't return it, this can disrupt the research.
- Tracker is thrown in the water from the embankment which can be significantly higher than the water. The tracker should survive being dropped in the water from 3 meters height (*Requirement #8*).
- Batteries require charging after every use. For this reason, charging or replacing batteries must be an easy process (*Requirement #34*).
- The casing and waterproofing strip should resist light abrasion (*Requirement #36*) and mild chemical cleaning agents (*Requirement #37*). Trackers require cleaning after use to maintain aesthetic qualities and reduce wear caused by biofouling.
- To refurbish parts of used-up trackers, all internal components should be replaceable (*Requirement #39*). This does not apply to the tracker casing as this part is expected to wear the most since it is exposed to the elements, and therefore not suited to be refurbished at the end-of-life.
- Trackers should communicate to users more effectively to reduce unplanned removals (*Requirements #4 & #12).*
- Recovering trackers should be less time consuming. Finding a tracker should not take more than 10 minutes after arriving on the location (*Requirement #3*).
- Too many trackers are lost with a chance of 12% per deployment. This should be reduced to <5% (*Requirement #5).*
- The battery life is insufficient for Noria's needs and should be doubled to 6 weeks (*Requirement #6)*.
- Noria desires a tracker with a more professional appearance. 80% of people should think the redesigned tracker looks more professional than the original (*Requirement #1*).
- There is no indication of how tight the casing should be closed. Assembly should be straightforward and there should be an indication for closing the casing (*Requirement #13*).
- Bystanders should not be able to easily open (or otherwise tamper with) the tracker, as this can cause problems with waterproofing and may increase the chance of theft (*Requirement #38*).
- The redesigned tracker should be designed to be wear-resistant and require minimal maintenance (*Requirement #16).*
- Manufacturing could be made more affordable if it is outsourced and executed at a lower hourly rate (*Requirement #21).*
- To reduce cost and improve repairability and availability of parts, the redesigned tracker should incorporate mostly standardized parts (*Requirement #22*).

- The original tracker is expected to last 16 uses, the redesigned tracker should match this (*Requirement #18*).
- To be financially viable, the redesigned tracker should be expected to return at least **€1400, -** of profit over its lifetime (*Requirement #19*).
- While the reality is more nuanced, Noria uses material with a very unsustainable reputation, which does not match with their identity as a company. This should be prevented in the redesigned tracker (*Requirement #17)*

# 6. Synthesis of Analysis

This chapter compiles findings from the context – and product analysis. Failure modes and design opportunities to be addressed are discussed, as well as a vision for carrying out the embodiment phase of the project.

## 6.1 Failure Modes and Root Causes

In the context – and product analysis, various problems occurring during use, were identified, mostly relating to tracker performance. From these problems, the most important **failure modes** (ways in which a service, product or process can fail (Six Sigma, n.d.)) were identified:

- **Water ingress**.
- **Unreliable signal** causes failed transmissions.
- **Tracker removal** from the water during its deployment.
- **Loss of tracker** during deployment.
- **Excessive recovery time** at the end of a research period.
- **Battery has run out** before the end of a research period

To address these failure modes properly, they first need to be understood thoroughly. While the context - and product analysis helped to identify the problems that exist, they did not necessarily identify the **root causes** behind them. These root causes were identified using the "5 times Why?" method (see Figure 27). The root causes corresponding to each failure mode, as well as potential solutions are discussed below.

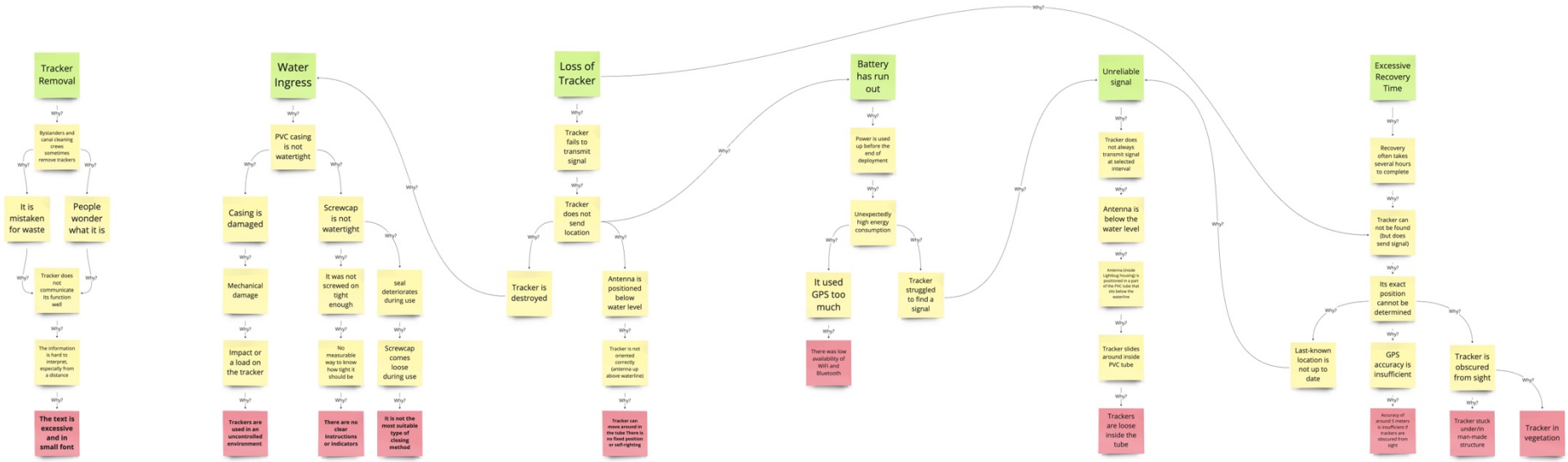



*Figure 27: "5 times Why?" method applied for each Failure Mode (green), to identify the Root Causes (red).*

## Water Ingress

### Root Cause(s)

The screwcap sealing method **lacks tightening indicators**, reducing reliability of the seal due to a potential for insufficient compression of the rubber seal. Additionally, a **screwcap is not the most suitable type of closing mechanism** when it comes to **preventing loosening**

Furthermore, the **handmade glue connections** are not always watertight.

Water ingress can also occur if the **casing is damaged** by external factors (boats, built structures, floating objects, etc.) as trackers are used in **uncontrolled environments**. It is however unclear whether this has happened as lost trackers are never found again.

### Potential Solution(s)

An **improved seal**, with a **reliable assembly method** is essential to prevent waterproofing issues for the redesigned version of the tracker. **IP67** was chosen as this encapsulates the most extreme type of waterproofing challenge the trackers are expected to experience.

Furthermore, a **strong and impact resistant casing design** is necessary to prevent damage as much as feasibly possible.

## Unreliable Signal

### Root Cause(s)

The problems with transmitting data are largely due to the **antenna** being **submerged below the water level** during use, as wireless signals have trouble moving through water. This is caused by the **trackers** being **loose inside the PVC tube**, which means they slide to one side which will become more submerged, resulting in the antenna being positioned below the water level. *Figure 28* illustrates how the tracker is positioned inside the PVC tube. Tests conducted early in the project showed that lifting the antenna (slightly) above the water level and giving the tracker self-righting capabilities, resulted in roughly 80% signal reliability (Appendix B).

### Potential Solution(s)

**Ensure** that the **antenna remains above the water level** during use by giving it a fixed position. This can expectedly be improved further than during the tests described in Appendix B by increasing the clearance between the antenna and the water level. The redesigned version should achieve at least 80% transmission reliability (*Requirement #2*).

**To** be able to **achieve sufficient clearance**, the tracker should have a **maximum density of 0,7g/cm$^3$** (*Requirement #14*).

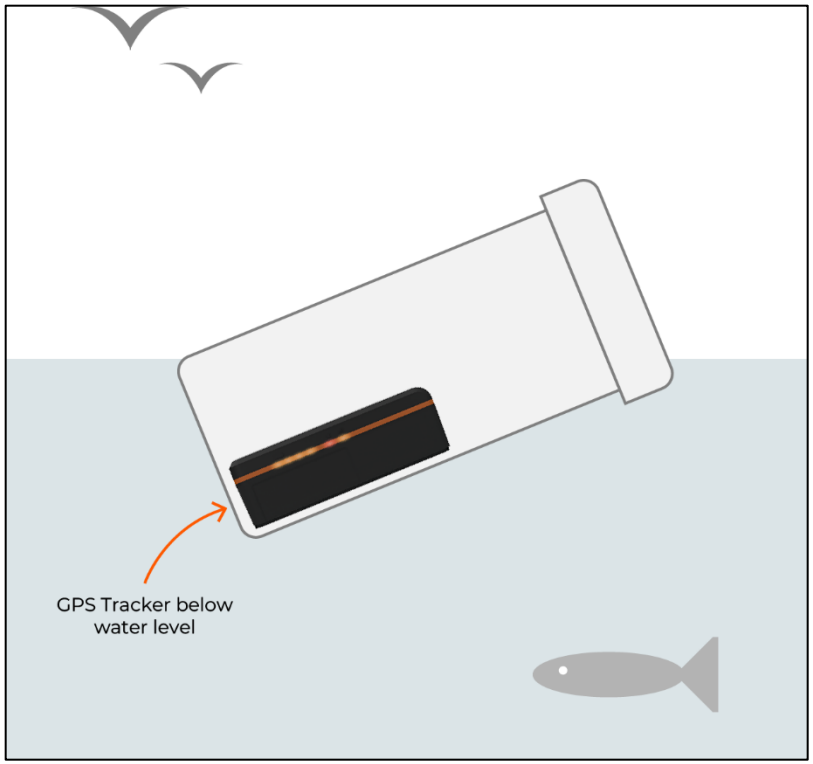



*Figure 28: Position of the Lightbug Pro inside the PVC tube, causing an unreliable signal.*

## Tracker Removal

### Root Cause(s)

As stated before in chapter 6.3, the text on the tracker housing is **excessive** and in a **small font size**. This makes it less likely that someone is going to read (all of) it and understand the tracker's purpose. Furthermore, because the font is so small, it is also challenging to read from a distance and requires the tracker to be removed from the water to be read properly, which increases the chance of disrupting research.

### Potential Solution(s)

**Larger font**, **less text**, and **clear symbols** could reduce unintended removals as it helps communicate to users. The design should discourage removal and encourage returning the tracker to the water.

A "stealthy" design that is unlikely to be seen could be implemented, but this makes it hard for Noria to visually locate trackers during recovery, and it makes it harder to recognize for cleaning crews, expectedly increasing removals.

## Loss of Tracker

### Root Cause(s)

Trackers can be lost due to several reasons including loss of signal, water ingress, or because they can simply not be found during recovery. When trackers are lost it is **not possible to determine the exact cause**.

### Potential Solution(s)

**Addressing all anticipated causes** in the redesign of the tracker, making losing trackers less likely.

## Excessive Recovery Time

### Root Cause(s)

While the bright orange stickers aid in **visual identification**, they are **ineffective when trackers are obscured from sight** by vegetation or man-made structures.

Locating the tracker relies on its last-known GPS location, but **GPS accuracy**, typically around 5 meters (with Lightbug

claiming 0.5-5 meters accuracy), is **insufficient in environments with many "hiding places".**

This challenge is enlarged by **signal reliability issues**, leading to periods without location updates that **make the last-known location inaccurate**.

#### Potential Solution(s)

Additional technology that aids in **more accurately locating trackers** could reduce the time required to find trackers and the number of trackers that are lost. Finding a tracker after arriving at the last-known GPS location should not take more than 10 minutes on average. To achieve this, additional localization technology should determine the tracker's location to an accuracy of 1 meter or less (*Requirement #35*).

### Battery Runs Out

#### Root Cause(s)

This considerable difference between the advertised battery life (7.6 months) and how it has performed for Noria (three weeks) is unclear but **might be caused by the tracker struggling to transmit a signal**, which causes it to "search" for a signal, **which increases power consumption**. The tracker can connect using Bluetooth or WiFi which consumes less power than GPS. This is likely what Lightbug's estimation is based off.

#### Potential Solution(s)

**Doubling the battery capacity to 13200 mAh** can increase the maximum research duration to the desired six weeks.

A **better signal reliability** might also improve battery life.

## 6.2 Failure Modes and Effects Analysis

Having identified the root causes of each failure mode, the **priority of** addressing **failure modes** was determined in consultation with Noria and with the help of a **Failure Modes and Effects Analysis** (FMEA). The frequency and severity rating (and thereby priority) are estimates as insufficient data was available. These estimates were given by a Noria employee responsible for all tracker projects, who is therefore best positioned to make these estimations.

*Table 4: Failure modes and their occurrence, severity and priority*

| Failure Mode | Effect | Root Cause | Frequency (1-10) | Severity (1-10) | Priority |
|---|---|---|---|---|---|
| Water Ingress | Water enters the casing which can result in loss of the tracker | There is no indication of how to tighten or assemble the trackers.<br>A screwcap is not the most suitable closing method | 2 | 10 | 20 |
| Unreliable signal | Data is missing which makes results from research less useful | Lightbug Pro tracker is used loose inside the PVC tube, causing the antenna to be below the water level. | 5 | 4 | 20 |
| Tracker Removal | Research is disrupted as the expected data is not gathered. | Information on the tracker is excessive and in a small font, making the design ineffective at communicating its purpose. | 3 | 6 | 18 |
| Losing Tracker – Antenna below water level | Costs money and pollutes the environment. Also results in the loss of data. Noria won't be able to analyse the context they are researching as expected. | Lightbug Pro tracker is used loose inside the PVC tube, causing the antenna to be below the water level. | 5 | 10 | 50 |
| Losing Tracker – Mechanical damage | Costs money and pollutes the environment. Also results in the loss of data. Noria won't be able to analyse the context they are researching as expected. | Trackers are used in an uncontrolled environment where external forces can be applied on the trackers. | 1 | 10 | 10 |
| Excessive Recovery Time | A lot of time and money is spent on trying to recover the trackers at the end of a research. | Trackers are obscured from sight by vegetation and man-made structures. The accuracy of the GPS is insufficient if there are any places to "hide" for the trackers | 4 | 4 | 16 |
| Battery has run out | Tracker needs to be recovered early. If not, the tracker will likely be lost. | Higher power-consumption due to no or too little availability of WiFi or BlueTooth during deployment. | 1 | 10 | 10 |

The higher the priority rating, the more important it is to address the failure mode in the redesign of the tracker. As can clearly be seen from Table 4, **losing the tracker because the antenna is below the water level** is considered to be the **most problematic failure mode** of the tracker.

## 6.3 Design Opportunities

Aside from problems to solve, there are also opportunities to explore which can add value to the redesigned floating tracker device. While these opportunities will certainly add value to the redesign, they receive a lower priority compared to the failure modes mentioned above. The opportunities are explained below.

### Design for use by external parties

Trackers are now being deployed by Noria's employees, which is rather expensive as they are all highly educated workers. If the redesigned tracker could be reliably deployed and recovered by external people, who are assigned to deploy or recover trackers as a stand-alone assignment, this could save Noria money. To achieve this, the design should be foolproof to prevent failed deployments or retrievals. Aside from having external people use the trackers for Noria, it might even be interesting to have clients use trackers themselves.

### Litter Representativeness

The current tracker has a specific size, weight, and buoyancy, allowing it to simulate only one type of floating debris accurately. Different types of debris are transported at varying speeds and end up in different locations due to differences in how they are influenced by wind and water flow (Corcoran et al., 2015; Faure et al., 2015, as cited in Schwarz et al., 2019). It is known that wind influence is the most significant factor in the transportation of floating debris (Noria Sustainable Innovators, 2024). While this feature is not essential to the basic functionality of the tracker, it would be valuable to explore ways to modify the tracker's properties affecting its movement, allowing it to simulate a broader range of floating debris types.

### Professional Aesthetic

The Aesthetics of the tracker can also be improved on. As discussed before, Noria has indicated a desire for a tracker with a more professional aesthetic.

## 6.4 Design Vision

To help give direction to this project and to set a goal for the outcome of the project, a design vision was formulated. This design vision for this project is expressed in the following sentence:

**"To restore the riverine environment (in the Netherlands) by redesigning a floating GPS tracker to be an effective research tool as a part of Noria's system of tackling plastic pollution in Dutch waterways by eliminating known failure modes, exploiting opportunities, and creating added value".**

# 7. List of Requirements

Below, the List of Requirements is shown that was informed by the analysis phase of this project (*Table 5*). The requirements are grouped by themes for clarity. Original numbering has been retained across this report.

Requirement numbers as are referred to in the text, are noted in the second column. “PLCA #” refers to the Product Life Cycle Analysis as was discussed before.

To give priority to the different requirements, the MoSCoW method was used.

The (sub)chapter in which the requirements are introduced is noted in the far-right column.

*Table 5: List of Requirements*

| Theme | Req. # | Requirement | MoSCoW | Chapter # |
|---|---|---|---|---|
| **Design and Appearance** | 1 | Design of the tracker is found to look more professional compared to the original by >80% of people. | Should | 5.4 |
| | 9 | Tracker has a recognizable design. | Must | 4.2 |
| | 12 | Tracker communicates its purpose to bystanders who encounter it. | Should | 4.6 |
| | 4 | Tracker discourages people from removing it from the water and encourages them to return it. | Should | 5.2 |
| **Functionality and Features** | 2 | Signal reliability is at least 80%. | Must | 6.1 |
| | 3 | Finding a tracker (during recovery) after arriving at the last-known GPS location should not take more than 10 minutes on average. | Should | 5.3 |
| | 5 | Trackers are lost <5% of the times they are used. | Must | 5.3 |
| | 14 | Tracker has a maximum density of 0.7g/cm3. | Must | 6.1 |
| | 15 | The antenna has to maintain its position above the water level during use. | Must | 4.1 |
| | 18 | The tracker can be expected to last at least 16 uses (three-week periods). | Should | 5.8 |
| | 35 | Tracker location can be determined to 1 meter or less. | Should | 6.1 |
| **Hardware and Durability** | 6 | Tracker has a 6-week battery life. | Must | 6.1 |
| | 7 | Tracker housing is waterproof (IP67). | Must | 4.4 |
| | 8 | Tracker can survive being thrown in the water from 3 meters height. | Should | 5.2 |
| | 11 | Tracker is impact resistant. | Could | 4.4 |
| | 16 | Tracker housing is designed to be wear-resistant and require minimal maintenance. | Should | 5.6 |
| | 26 | All tracker components can operate between -20°C and 60°C. | Should | 4.4 |
| | 31 | Housing is not prone to biofouling. | Should | 4.4 |
| | 33 | Tracker housing can withstand exposure to Sunlight (UV). | Must | 4.4 |
| | 36 | Casing and waterproofing strips withstand light abrasion. | Should | 5.2 |
| | 37 | Casing and waterproofing strips are chemically resistant to mild cleaning agents. | Should | 5.2 |

| | | | | |
|---|---|---|---|---|
| | 32 | Tracker is compliant with rules and regulations in the environment of use (e.g. water boards). | Must | 4.5 |
| **Manufacturing and Assembly** | 13 | The method of assembling/closing the tracker ensures a waterproof seal and includes an indication. | Must | 5.5 |
| | 17 | Tracker does not contain unnecessarily polluting or toxic materials and processes. | Should | 4.4 |
| | 21 | Manufacturing and assembly are outsourced. | Could | 5.7 |
| | 22 | (Standard) components are readily available. | Should | 5.7 |
| | 25 | The design of the tracker housing accommodates the integration of Lightbug Pro hardware. | Must | 4.2 |
| | 28 | Assembly of the trackers takes a maximum of 20 minutes to reduce costs. | Should | 4.7 |
| | 39 | All internal tracker components are replaceable. | Should | 5.2 |
| **Stakeholder Considerations** | 24 | Tracker does not unnecessarily disturb wildlife. | Should | 4.2 |
| | 29 | Technology used in the tracker cannot lead to privacy breaches of individuals who interact with it. | Must | 4.6 |
| | 30 | Tracker is unlikely to startle or scare bystanders who encounter it. | Should | 4.6 |
| | 38 | Tracker resists being opened or tampered with. | Should | 5.5 |
| **Recovery and Deployment** | 10 | Tracker is representative of floating plastic litter. | Should | 5.3 |
| | 23 | The process of deploying and recovering trackers is straightforward and can be executed by externals. | Should | 4.2 |
| | 27 | Tracker stands out visually in vegetation. | Could | 4.4 |
| | 34 | Batteries can be recharged or replaced with ease. | Should | 5.2 |
| **Costs** | 19 | The tracker should generate a profit margin of > €1400, - over its lifetime to add value for Noria. | Should | 5.8 |
| | 20 | Production cost does not exceed €400, -. | Should | 4.7 |

# Embodiment Phase

The embodiment phase focuses on turning the insights and requirements from the analysis phase into a concrete and feasible design. This phase includes all the steps necessary to refine the concept, validate its functionality, and prepare it for production. From generating initial ideas to addressing key design challenges like waterproofing and signal reliability, the embodiment phase ensures that the final design meets the requirements set earlier in the project. The following chapters are part of this phase:

- **Conceptualization**
- **Aesthetic Design and Removal Prevention**
- **Waterproofing**
- **Signal Raliability**
- **Recovery**
- **Litter Representativity**
- **Implementation**
- **Viability**

This phase ensures the design is not only functional but also desirable, viable, and ready for implementation.



# 8. Conceptualization

The conceptualization phase was the first step in the embodiment phase, aimed at generating, exploring, and refining ideas to address the failure modes and user needs identified during the analysis phase. Several concepts were generated and evaluated through the datum method and feedback from Noria's design team.

The outcome of this phase was a revised concept, which integrates the best aspects of the initial ideas and feedback to create a refined design ready for further development.

## 8.1 Revised Concept

Based on the results from both the Datum Method and the feedback provided by Noria's design team, the "Intuition" and "Modular" concepts were merged into a revised design featuring the following key elements:

- **Horizontal Parting Line:** This design feature allows for easier access to electronics, keeps the waterproofing seal above the waterline, and offers greater design flexibility.
- **Self-Righting Mechanism:** clever weight distribution which ensures that the device remains upright in the water, maintaining reliable signal transmission.
- **Status Light:** A visible status indicator aids in deployment and recovery and helps prevent the tracker from being mistaken for floating pollution. It has to be determined whether this is feasible with the Lightbug tracker.
- **Ultra-Wideband Technology:** This technology is integrated to facilitate faster and easier recovery of the tracker.
- **Bolts and Threads:** These will be used to secure the two halves of the design, preventing wear due to opening and closing of the tracker, and tampering by people who find the trackers (adhering to *Requirement #38*).
- **Adjustable Wind and Flow Influence:** Optional casing attachments will allow users to modify the tracker's response to wind and water currents. Allowing it to mimic different types of floating pollution.

This revised concept is aimed at creating a balance between cost-efficiency and increased functionality. A sketch of this concept is shown in *Figure 29*.

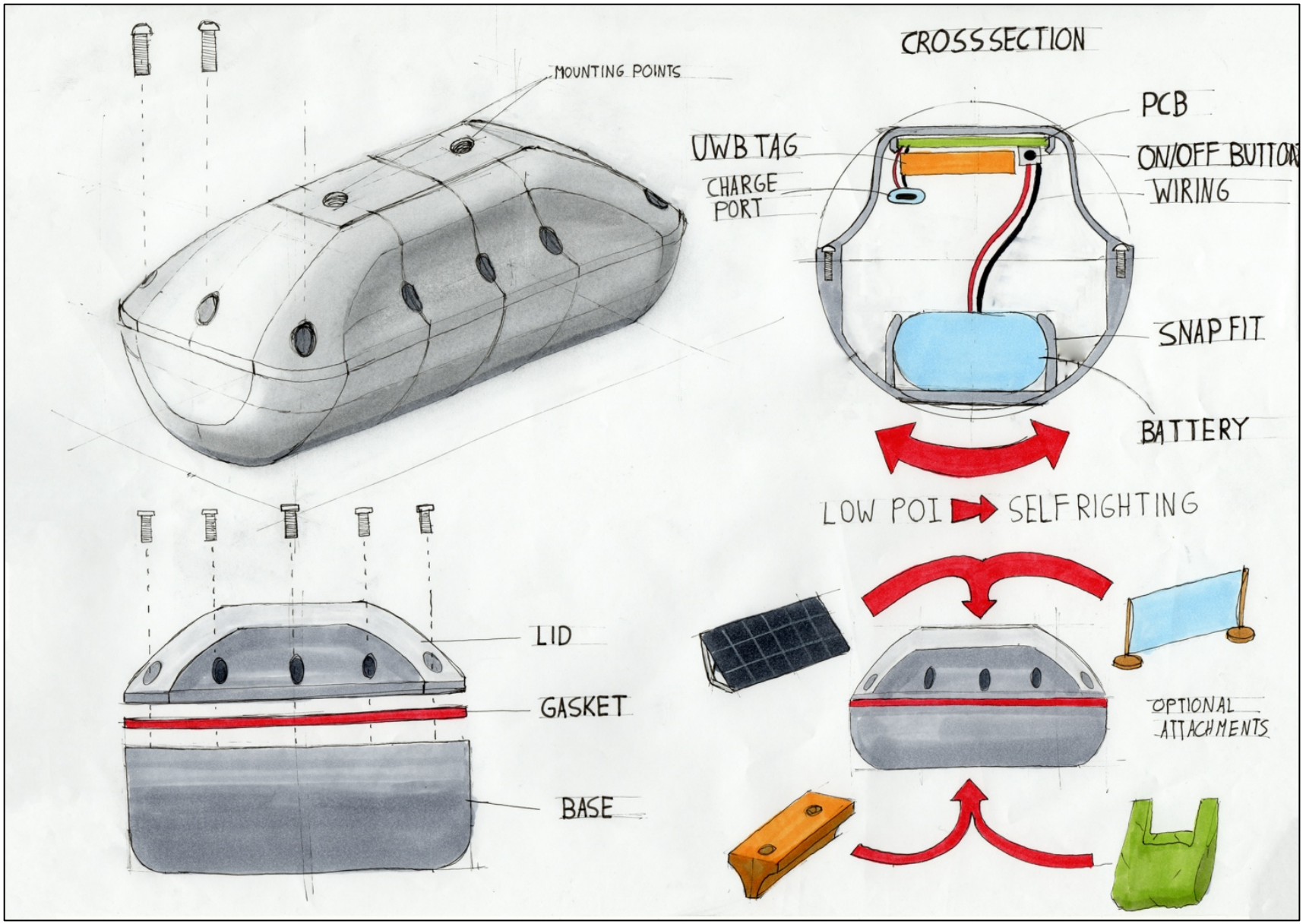



*Figure 29: Sketch of chosen concept*

## 8.2 Concept Design Strategy

To guide the conceptualization process, two design methodologies were used. To foster creativity, generate ideas, and develop concepts, a **Morphological Chart** was utilized (Van Boeijen et al., 2020). This method was selected because it helps mitigate the risk of tunnel vision that can occur when a designer becomes too focused on a specific approach, encouraging a broader exploration of ideas. An example of a Morphological chart filled is shown in Figure 30, others that were created can be found in Appendix C.

After generating the concepts with the assistance of the Morphological Chart, the **Datum method** was applied to compare the concepts to one another. The Datum Method was chosen for its structured and objective way to compare concepts and to simplify the decision-making process.

In addition to the Datum method, the concepts were presented to members of the **design team at Noria for feedback**. As they are the client of this project, it is important to ensure they are on-board with the direction this project will take.

These steps are discussed further in the following paragraphs.

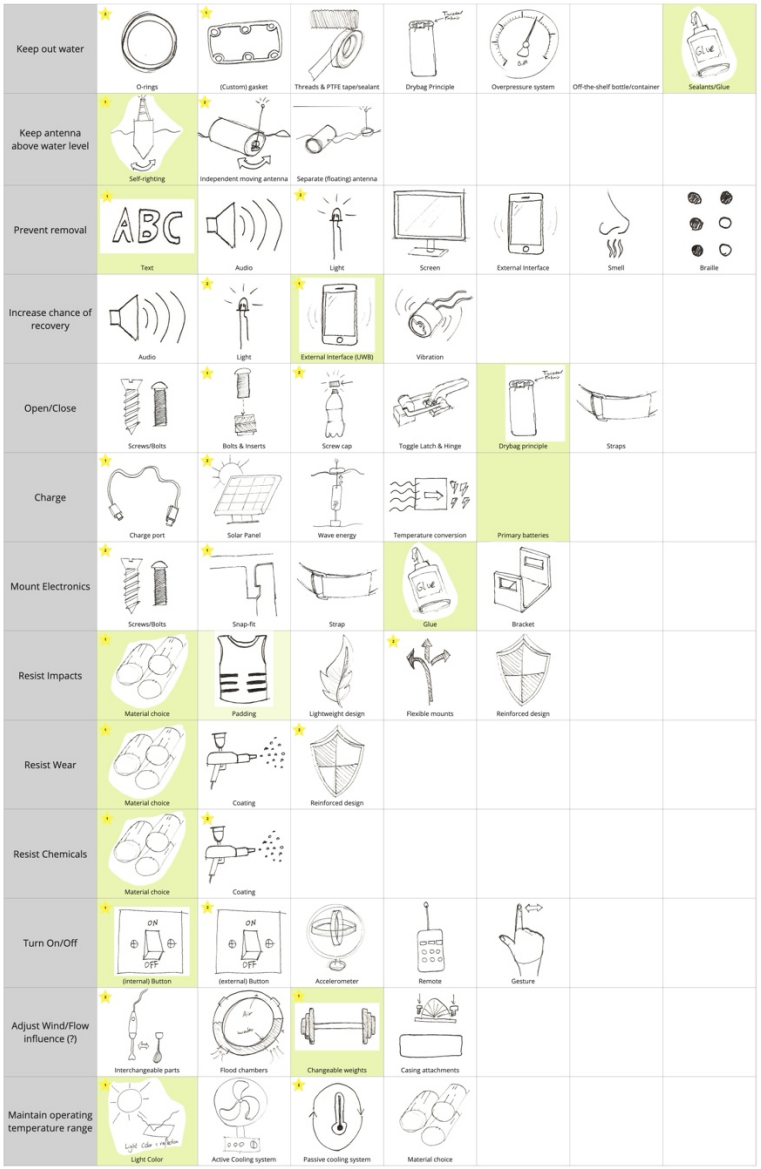



*Figure 30: example of a filled-in Morphological chart.*

## 8.3 Concept Generation

The concepts were developed according to different themes (e.g., "Premium" or "Outlandish"), with the goal of producing a diverse range of design ideas that exhibit varying characteristics. This approach was employed to gather insights from these varied concepts, ultimately enabling the combination of advantageous features from multiple designs into a final concept.

To further explore these ideas, sketches were created, and two of the simpler concepts were prototyped using household items, as physical prototypes often provide more insights than sketches alone (*see Figures 30 through 41*).

Below, each initial concept is concisely discussed with a description and learning points:

### Intuition Concept

**Description**: Combined the best solutions intuitively, offering maximum design freedom.

**Learning Points**: While effective, relying solely on intuition can lead to tunnel vision.

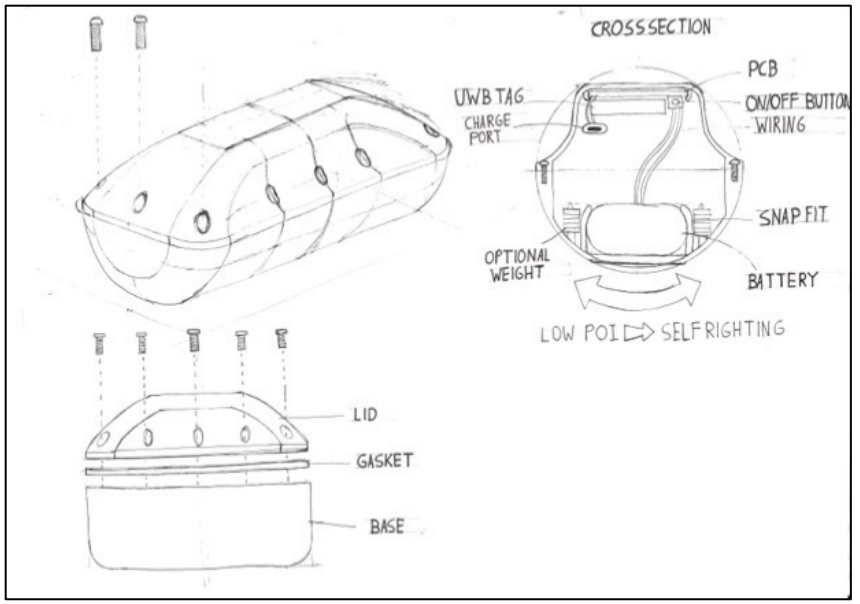



*Figure 31: "Intuition" Concept Sketch*

### Unstoppable Concept

**Description**: Featured a vertical design for reduced chances of getting stuck, along with solar power for extended lifespan.

**Learning Points**: Limited design freedom above the water level affects visibility and user interaction.

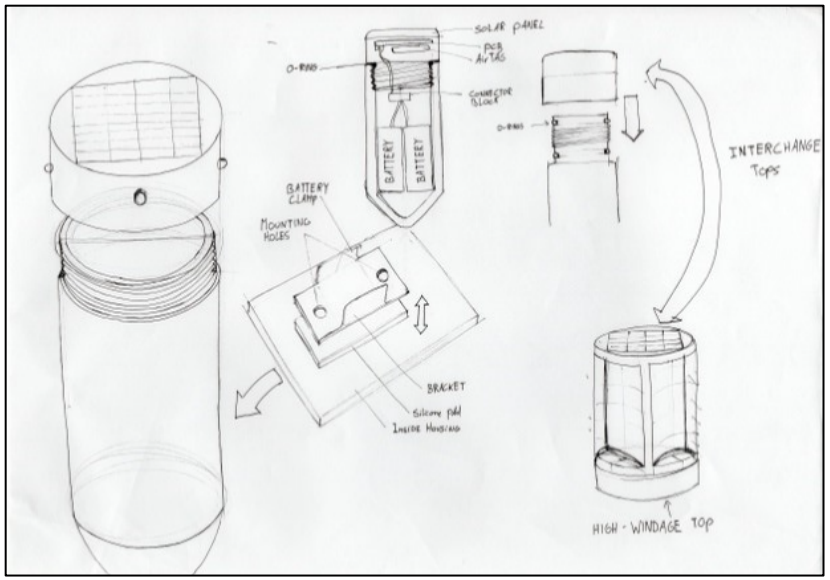



*Figure 32: "Unstoppable" concept sketch*

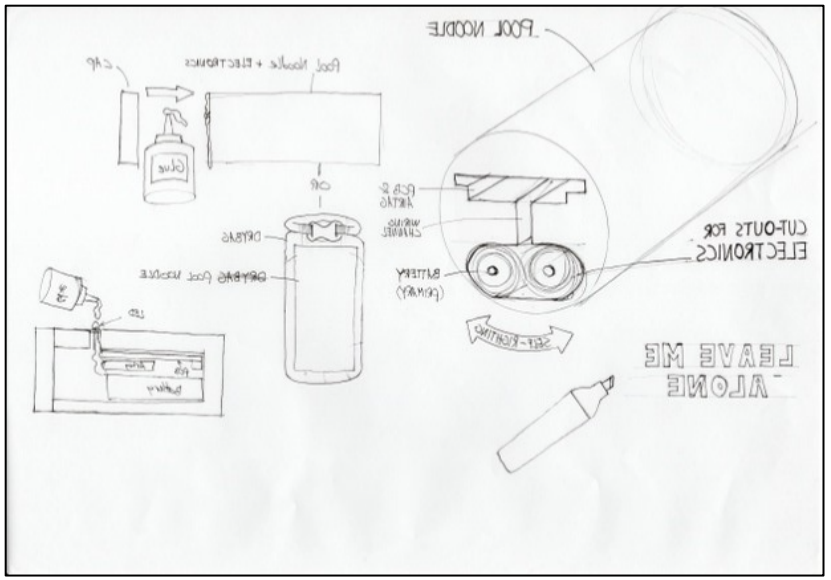



*Figure 33: "Low-Cost 1.0" concept sketch*

## Low-Cost 1.0 Concept

**Description**: Utilized a pool noodle and glue for a simple, affordable housing.

**Learning Points**: Highlighted the potential for cost-efficient solutions.

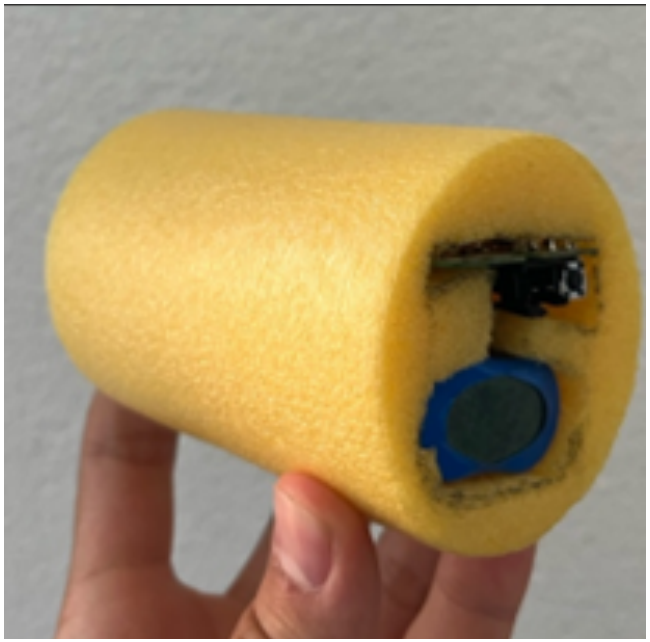


*Figure 34: "Low-Cost 1.0" Lo-Fi Prototype*

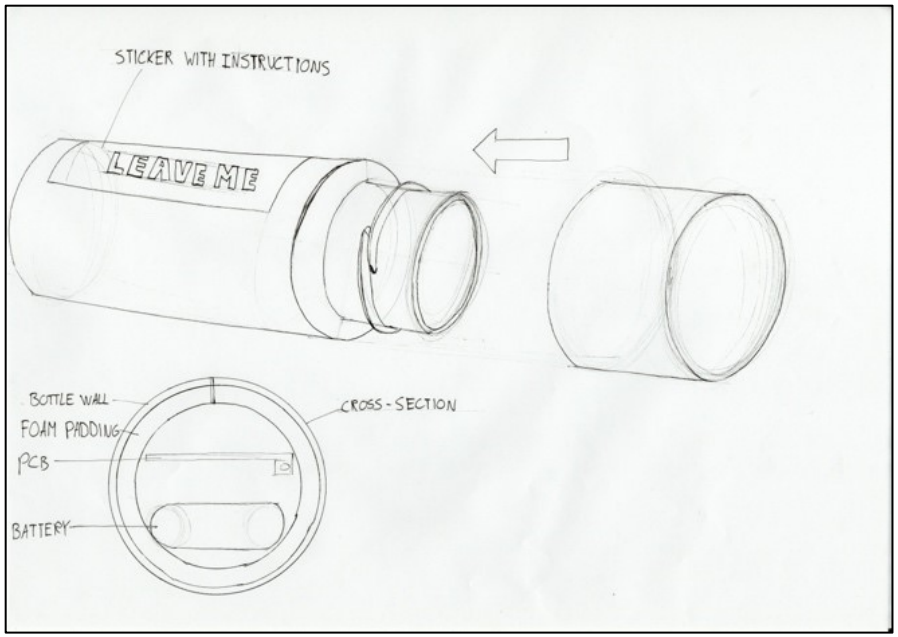



*Figure 35: "Low-Cost 2.0" concept sketch*

## Low-Cost 2.0 Concept

**Description**: Used a drinks bottle with foam padding to secure electronics.

**Learning Points**: Demonstrated the effectiveness of quick lo-fi prototyping over sketches.



*Figure 36: "Low-Cost 2.0" Lo-Fi Prototype*



*Figure 37: "Low-Cost 2.0" Lo-Fi Prototype internal*

## Outlandish Concept

**Description**: Explored unconventional ideas by disregarding typical constraints.

**Learning Points**: Stimulated out-of-the-box thinking.

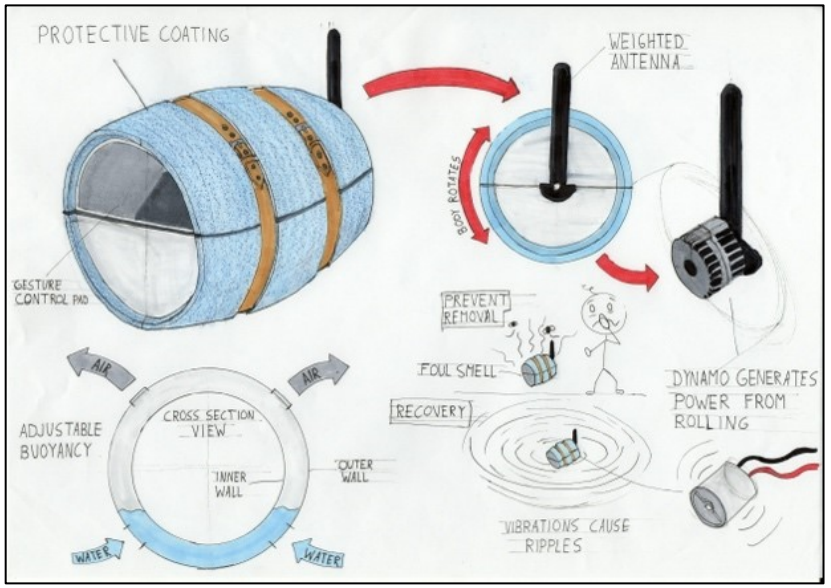



*Figure 38: "Outlandish" concept sketch*

## Stealth Concept

**Description**: Mimicked a log for camouflage, reducing recovery ease but preventing removal by bystanders.

**Learning Points**: Sacrifices in design are sometimes necessary. Machining (required for this concept) would not be cost-effective.

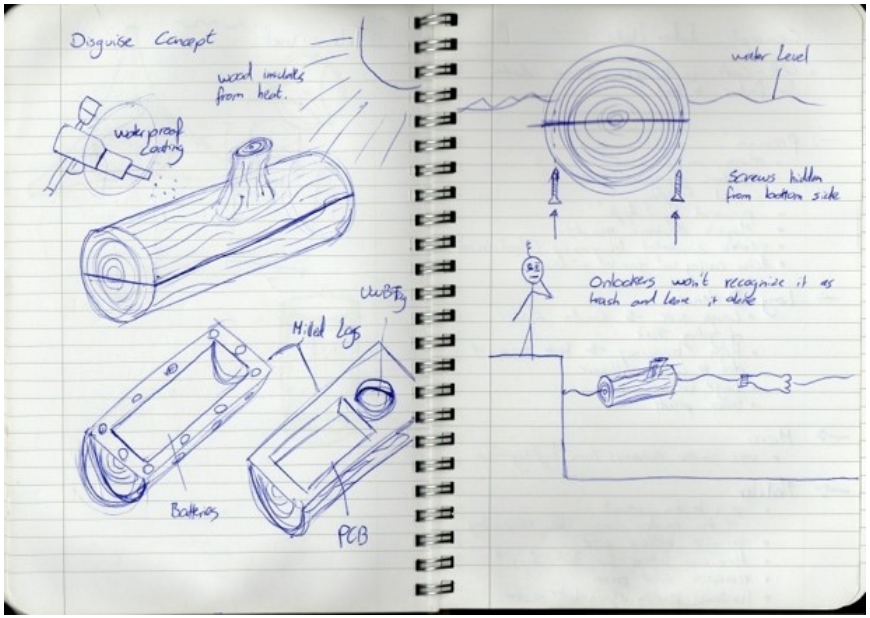



*Figure 39: "Stealth" concept sketch*

## Premium Concept

**Description**: Combined expensive materials and advanced features like remote-controlled buoyancy.

**Learning Points**: Expensive designs do not always add sufficient value.

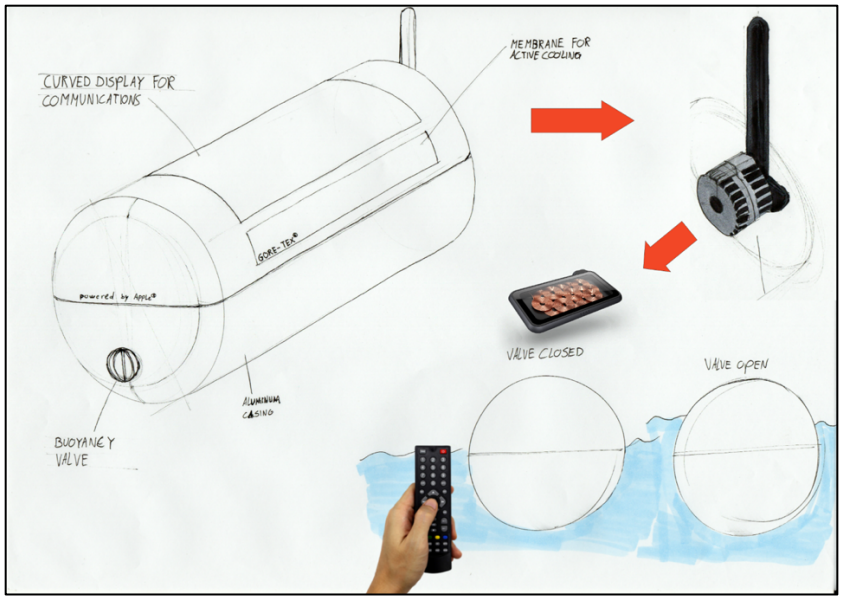



*Figure 40: "Premium" concept sketch*

## Long Distance Concept

**Description**: Large, buoyant tracker designed for long-distance movement, powered by solar panels.

**Learning Points**: Long-distance tracking does not align with project goals and complicates design.

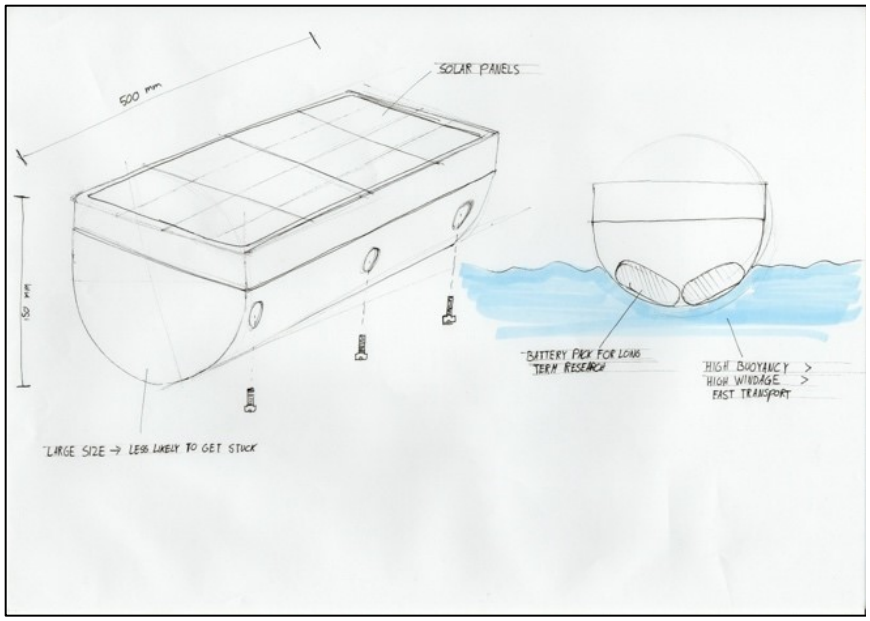



*Figure 41: "Long Distance" concept sketch*

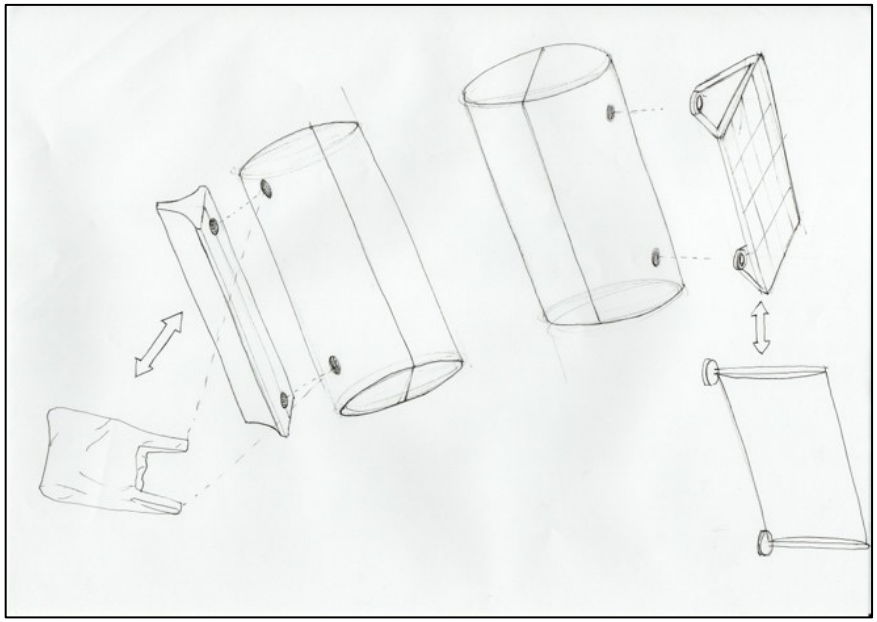


*Figure 42: "Modular" concept sketch*

## Modular Concept

**Description**: Allowed customization with attachable parts to modify the tracker's behavior.

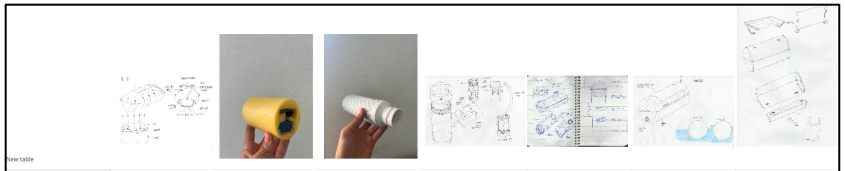
**Learning Points**: Simple, cost-effective, and aligned with Noria's interests.

## 8.4 Concept Evaluation

### Datum Method

The Datum Method was applied to evaluate the concepts against established design criteria (Van Boeijen et al., 2020). These criteria were derived from the most critical design requirements (*Chapter 7*). The method was repeated three times before a conclusion could be drawn. The last iteration of the Datum Method is shown in Figure 43.

The results indicated that the "Intuition" concept emerged as the top choice in two iterations, while the "Modular" concept was selected in one. After the initial round of evaluation, the "Outlandish" and "Long Distance" concepts were omitted due to their low scores.



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Production Cost | + | + | + | * | S | - | S |
| Plastic Representativity | + | + | + | * | - | + | + |
| Durability | + | - | - | * | + | - | S |
| Waterproofing | S | + | S | * | - | - | S |
| Ease of Deployment & Recovery | S | - | - | D | - | + | S |
| Prevents Removal/ Tampering | + | - | - | A | + | + | + |
| Aesthetics/Looks | + | - | - | T | - | + | + |
| Sustainability (Materials, production) | - | - | + | U | + | - | - |
| Reusability & Maintenance | + | - | - | M | - | - | + |
| + | 6 | 3 | 3 | * | 3 | 4 | 4 |
| - | 1 | 6 | 5 | * | 5 | 5 | 1 |
| = | 5 | -3 | -2 | * | -2 | -1 | 3 |

*Figure 43: Datum Method filled out (repetition 3)*

## Noria Design Team Validation

During the feedback session with Noria, members of the design team provided their input on the various concepts. The results of the Datum Method were not disclosed during the session in order to avoid influencing their opinions.

The feedback from this session can be summarized into the following key takeaways:

- **Cost Justification:** More expensive concepts need to deliver significant added value to justify the increased cost.
    - Aim to combine “fancy” aesthetics with more affordable production methods.
- **Tracker Status Visibility**: Being able to verify that the tracker is active from the outside is highly valuable, as it streamlines deployment and saves time.
- **Concept Combination**: A hybrid of the "Intuition" and "Modular" concepts was identified as the most promising direction to pursue.
- **Two-Tiered Design Strategy**: Consider developing one advanced design aimed at larger quantity production, which can showcase and refine my design skills. Simultaneously, create a simpler, more affordable bare-bones design, increasing the likelihood of short-term adoption.

# 9. Aesthetic Design and Removal Prevention

The design of the TrashTracer is meant to be aesthetically pleasing but also prevent removals. The design and the process toward it are discussed in this chapter.

## 9.1 Overall Aesthetic

The TrashTracer is meant to **hint to** the aesthetic of **a lifebuoy** which serves as a **metaphor** for the tracker contributing to **saving the environment**. This aesthetic also makes the tracker look like it is meant to be in the water, rather than something that is out of place and needs to be removed. Additionally, text and symbols to **prevent removals** are included in the design, as well as Noria's logo. The TrashTracer is shown in Figure 44.




*Figure 44: Aesthetics of the TrashTracer*

## Design Features

The design incorporates the following features, often tied to functions:

- The **recessed top** (*see Figure 44*) surface contributes to making the design look like a lifebuoy, but also functions as a place to put logos, symbols or instructions. Since it is recessed, it is less likely to wear off. It also allows more secure mounting of attachments. This is further discussed in *chapter 13*.
- **Feet** on the bottom makes it look more sophisticated and prevents scratches caused by placing it on the ground (*see Figure 45*).
- **Two-tone** color helps create contrast, which can help to spot the tracker when it needs to be recovered (*see Figure 46*). Due to the flat sides, the parting line can be moved upwards to ensure the seal is above the water level, reducing the chance of water entering inside.



*Figure 45: Feet on the bottom (placeholder)*




*Figure 46: Two-tone color.*

## Aesthetic Background

The Aesthetic design consists of its **form**, a **color scheme**, and **graphics**. Aside from being functional and providing the redesigned tracker with a more professional aesthetic, it was also important that it fitted with Noria as a company. These three aspects are discussed in this chapter, as well as how validation was done to reduce unplanned removals by bystanders and canal cleaning crews.

There are three established pillars for the identity of Noria Sustainable Innovators:

- **Sustainability**
- **Innovativeness**
- **Collaboration**

To fit in with Noria's identity and the company's portfolio, the design of the tracker should communicate these values.

It was chosen to achieve this using mainly color, to **prevent** a design that prioritizes **form over function**. Furthermore, while the meanings of (or associations with) colours are generally agreed on, form can be more divisive and is interpreted differently across individuals.

# 9.2 Color Scheme

Aside from representing Noria's core values, the chosen colors should also be functional. For example, to make the trackers easier to spot during recovery or to prevent disturbing wildlife.

For these reasons, the following color scheme was chosen:

- **(Dark) Blue:** This color is associated with intelligence, communication, trust, efficiency, duty, and logic (Fraser and Banks 2004; Mahnke 1996; Wright 1988, as cited in Labrecque & Milne, 2011). These qualities represent both **innovativeness** and **collaboration**. Additionally dark colors might be less disturbing to wildlife such as fish, as it more closely resembles floating organic debris such as pieces of wood.
- **Orange:** Considered to be lively, energetic, extroverted and sociable (Mahnke, 1996, as cited in Labrecque & Milne, 2011). Through those values it represents **collaboration**. Orange is also a high-visibility color which helps to spot trackers during recovery.
- **White:** Is, along other qualities, associated with purity and cleanliness (Fraser and Banks, 2004; Mahnke 1996; Wright 1988, as cited in Labrecque & Milne, 2011). Through purifying and cleaning waterways, Noria works on **sustainability.** It's also a neutral color that works well with the previously mentioned colors. Furthermore, I find the use of green to represent sustainability rather overused.

If we compare this with, grey, which is the color of the PVC tube that functions as the housing for the original tracker, this is associated with negative feelings and is considered to be a weak and passive color (Adams & Osgood, 1973).

*Figure 47* shows the chosen color palette.

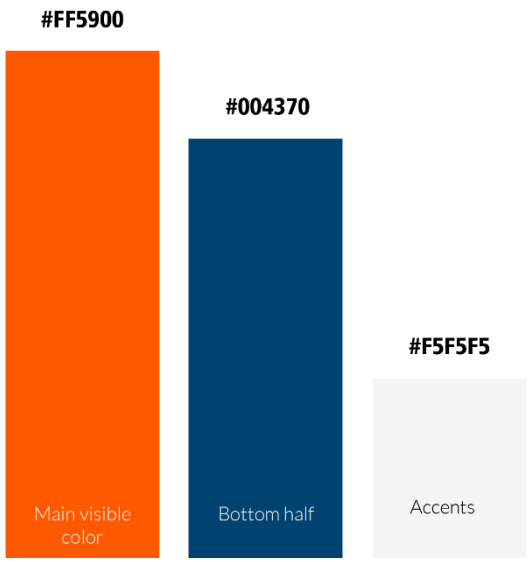



*Figure 47: Color pallet for the tracker housing*

## 9.3 Form

The form of the tracker housing highly influences the function of the product as it influences its **transport behaviour** (due to buoyancy, wind & flow influence), the **likelihood of removal** (something that looks like trash can trigger people to remove it), **waterproofing** (complex shapes are harder to keep water out of), and more.

For these reasons, functional requirements were the main drivers in the design of the form of the tracker, while also ensuring that its design would help improve Noria's professional image. The tracker form (including color but without graphics) is shown in Figure 48.



*Figure 48: Form of the TrashTracer (without graphics).*

### Form Design Process

The process towards designing the form of the tracker housing consisted of the following steps:

- **Mood boards:** Using OpenAI's Dall-E 3 (OpenAI, n.d.), a large number of mood boards were created to inspire the sketching phase of this process (see Appendix D). An example is shown in *Figure 49*.
- **Sketching:** Different shapes were brainstormed through sketching (see Appendix E). An example is shown in *Figure 50*.
- **Foam modelling:** The most promising sketches were turned into 3D models made of foam to be able to better

assess the designs and gather feedback (*see Figures 51 through 56*).

- **Validation & selection:** Feedback on the different shapes was gathered from Noria employees, as well as employees of canal cleaning crews. One of the designs was selected to use as a basis for executing the aesthetic design.
- **Design execution:** The chosen design was improved based on feedback and functional considerations and created in CAD software.

The “validation & selection”, and “design execution” steps are discussed hereafter.




*Figure 49: Mood board generated using Dall-E 3*

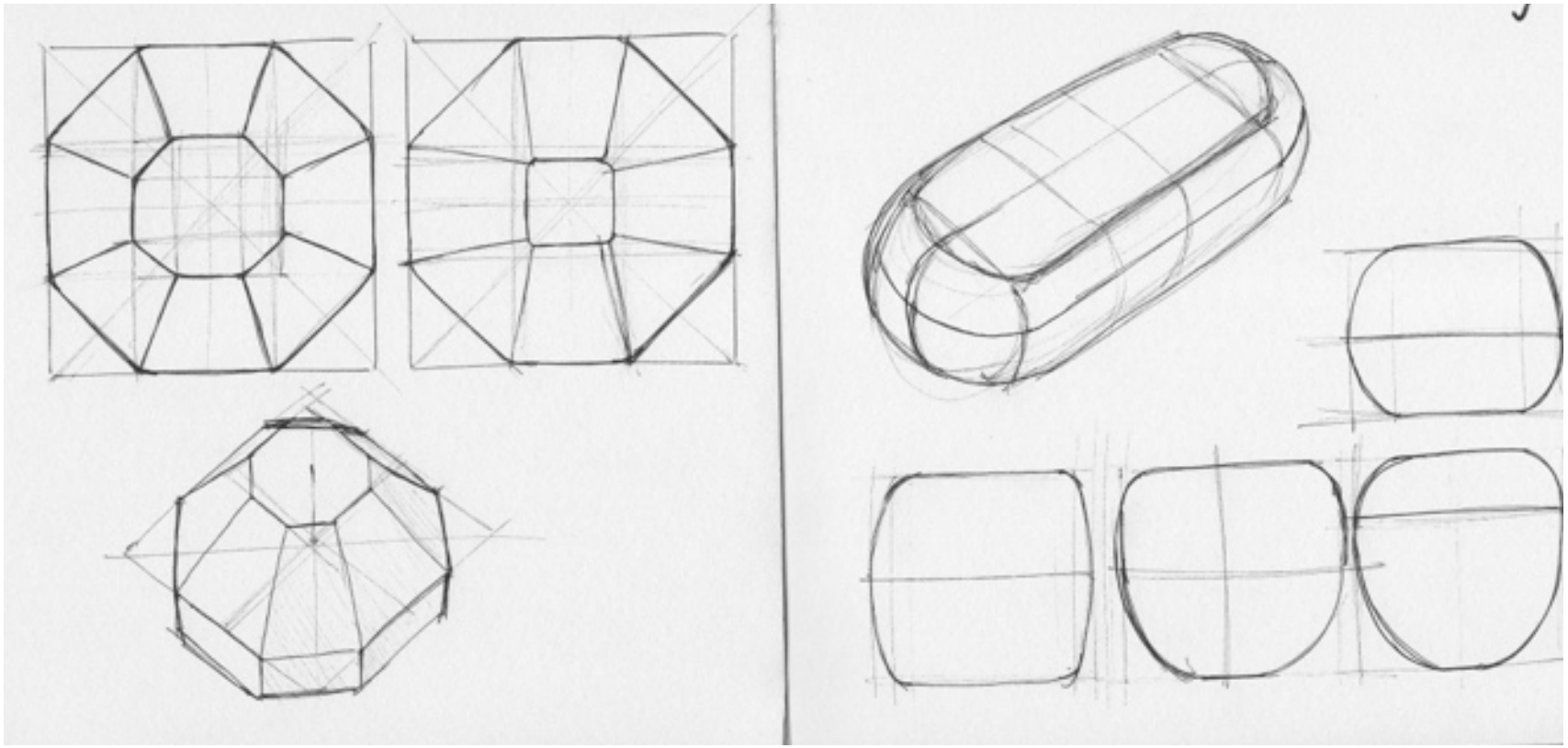


*Figure 50: Form exploration sketches.*



*Figure 51: "Angular" foam model*



*Figure 52: "Angular Concave" foam model*



*Figure 53: "Curvy Concave" foam model*



*Figure 54: "Capsule" foam model*



*Figure 55: "Flattened capsule" foam model*



*Figure 56: "Chamfered square" foam model*

## Validation & Selection:

To select a viable shape for the housing, feedback was gathered from stakeholders expected to interact with the trackers:

- **Noria employees (5 participants):** For Noria employees, it is crucial that the design accurately represents floating plastic, enhances the professional image, and aligns with company values.
- **Random civilians (6 participants):** Most importantly they should not remove it from the water, for example if they think it is trash or if they are curious.
- **Employees of Canal Hopper (canal cleaning crew) (2 participants):** It is mostly important that the trackers are recognizable to them as these parties can be informed when research is conducted in their respective region (Canal Hopper in Delft for example knows Noria and returns their trackers to the water).

Due to these differences, the questions varied for each stakeholder group. Noria employees were asked for their overall impressions, preferred designs, and aesthetic appeal, while civilians were asked which designs resembled trash and whether they would remove them from the water. Employees of Canal Hopper were asked how accidental removals caused by their cleanup activities could be prevented.

### Main Takeaways

Key feedback points are summarized below:

*Noria Employees*

- Noria employees preferred the "concave" shapes (*Figure 52 & 53*) and the "flattened capsule" shape (*Figure 55*).
    - Two employees preferred the "concave" shapes, two the "flattened capsule", one indicated that in general they preferred more "futuristic" looking designs.
    - There was no real preference between the "angular concave" and "curvy concave" models
    - The concave shapes look like handles.

*Civilians*

- All except two civilians indicated that they don't usually remove trash from the water
    - It is too much effort when it is in the water, some pick up trash on the ground when they are for example out for a walk.
    - One civilian had a small boat. When they use that they sometimes remove some trash.
    - Another sometimes removes floating trash close to their house (they lived by the water) as it ruins the street image.
- All civilians indicated that if they knew that the tracker was used for research, they would leave it alone.
    - This confirms that the **tracker's purpose should be clear** and that it should not look like waste too much
    - It is however unlikely that they would admit to stealing, if those were their true intentions. This potentially makes the feedback less reliable.

- Generally, the simpler shapes were found to look more like trash.
    - This included the “capsule” and “chamfered square” models for all civilians and the “flattened capsule” and “angular” model for two civilians.
    - Material, colour, symbols, text and more details can also communicate that it is not trash. Especially colour was said to be important.
- The concave shapes look like handles.

*Canal Hopper*

- Preventing accidental removals should be done by informing canal cleaning crews.
- A recognizable design will also reduce removals.

### Considerations

Based on this feedback, one of the concave shapes would be the best model for developing the aesthetic design further. There are however several things to consider before making this decision:

- Opinions on aesthetics (i.e. whether models looked like trash or not, which ones looked professional or not, etc.) varied largely between individuals. With different interviewees, the results might be completely different.
- Interviewees were asked to compare designs on how much they looked like trash to gain an understanding which shapes are more likely to be removed than others. However, it is possible that all shapes are very unlikely to be removed, which reduces the significance of differences between the shapes.
- The concave part in two of the foam models looks like a handle which might trigger people to grab it. When Noria recovers trackers, they use a fishing net, meaning that there is no need for a handle-like feature in the design.
    - The concave shape also reduces the stiffness of the design, making it more vulnerable.
- The two concave and the “angular” foam models have less volume in the top half of the design, resulting in less wind influence which will likely reduce the transport speed and distance. Objects more affected by wind are more likely to be moved faster and further (Schwarz et al., 2019). A **more symmetric design is likely more representative** of most floating plastic waste objects of a similar size.
- Round or square shapes are more stable due to their width which will make it harder to capsize them. This also means that if they do capsize (for example by bumping against a moving boat or after releasing it into the water), it might stay in that position. An oblong shape will rotate much easier (as it is less wide) and by giving it self-righting capabilities it will remain in its intended orientation.
    - Limited information exists on how various floating (plastic) shapes behave in waterways. It is mainly known that buoyancy influences transport behaviour. Since many floating plastics with a higher buoyancy are oblong shaped (beer cans, plastic bottles), it is a safer bet to use a

shape that is somewhat similar to ensure it is representative of floating plastic.

- For these reasons, most shapes that were modelled for this exploration were oblong shaped rather than square or circular.

### Shape selection

Based on these considerations, the preference of Noria and the fact that its more symmetrical shape will likely make it representative of a range of floating plastic waste, the "**flattened capsule" shape was chosen** as a basis for developing the aesthetic design of the tracker.

## 9.3 Graphics and Removal Prevention

The TrashTracer's casing contains text and symbols meant to communicate its purpose to bystanders (and canal cleaning crews) and to prevent unplanned removals (adheres to. The text is in Dutch rather than English as the tracker will be used in the Netherlands and Dutch is expected to be easier to understand for most bystanders who might encounter the tracker. Additionally, white strokes further hint to the aesthetic of a lifebuoy, an Noria's logo is included (see Figures 57 and 58).




*Figure 57: Graphic design on the tracker casing (1).*




*Figure 58: Graphic design on the tracker casing (2).*

### Validation

To test the effectiveness for preventing removals, the graphic design was tested with bystanders (Figure 59 shows the testing prototype). This subgroup of bystanders were members of WSVW De Lier, a recreational harbour club near Delft that is plagued by floating plastic, caused by their position relative to the wind direction.



*Figure 59: Graphic design on a prototype used for validation.*

### Procedure and Results

In total, 6 members were present who were willing to participate. Participants were asked one question upfront, after which the conversation was left to flow:

**"If you saw this thing floating in the water, what would you do with it?".**

Answers to this question are summarized below:

- 4 indicated they would pick it up from the water and return it after reading the text.
- 1 indicated they would not pick it up because the text could be read from several meters away.
- 1 indicated they would pick it up and try to see what is inside.
    - They indicated this was **caused by the screw holes** present in the top half of this earlier prototype (see Figure 59).

Afterward a picture of the prototype was sent in the group chat of WSVW De Lier to gather more responses. 10 responses that were gained this way are summarized below:

- 9 indicated they would pick it up from the water and return it after reading the text.
- 1 indicated they would not pick it up because they would not notice it.

## Conclusions

- The fact that most indicated that they would return it to the water after reading the graphics shows that this communicates the tracker's purpose (adheres to *Requirement #12*).
- People said they would take it out of the water and then return it. This indicates that *Requirement #4* is partially achieved, but this was also based off a photo sent to members of the club. In real life, the font size might be large enough that it can be read without the need to pick up the tracker.
- Screw holes were omitted from the visible part of the design by moving them to the bottom half of the casing, as it was indicated that this could trigger removals.
- Participants mentioned that they thought the orange color would increase the chance of the trackers being removed. Interestingly enough, almost all would not remove the trackers themselves. This makes it hard to determine whether this is a realistic judgement or whether participants had a rather negative view of others.
    - Since no clear conclusion could be drawn from this, and the orange color is beneficial to recovery, it was kept in the design.

# 10. Waterproofing

The tracker's casing must meet the core requirement of being waterproof (IP67) to protect the electronics, maintain buoyancy, and prevent damage or sinking. Three potential causes of water ingress were identified:

1. **Non-waterproof geometry of the casing.**
2. **Damage to the casing.**
3. **Separation between the mating surfaces.**

This chapter explains how these risks were addressed in the tracker design.

## 10.1 Non-waterproof geometry

The most obvious reason for water ingress could be an ineffective waterproof design. This can be divided in two categories:

- The **casing parts** are **not waterproof.**
- **Failure** of the waterproofing **seal**.

### Waterproofing the casing parts

The casing, produced via **Selective Laser Sintering (SLS)**, inherently has a porous structure. To mitigate water leakage:

- **Design Measure**: A minimum **wall thickness of 3mm** was implemented.
- **Post-Processing**: **Vapor-smoothing** was chosen which chemically melts and fuses the outer layer of the parts, improving waterproofing. While the procedure improves surface quality, it does not make parts perfectly smooth (see Figures 60 and 61). This could (but does not have to) create challenges with creating a waterproof seal, which was addressed with the selection of the waterproof seal, discussed in the next section.

→ Using **≥ 3mm wall thickness** and **vapor-smoothing ensures waterproof casing parts**, as was indicated by employees at Oceanz B.V.



*Figure 60: Surface quality of a SLS printed part, barrel finished.*



*Figure 61: Surface quality of a SLS printed prototype, vapor-smoothed.*

## Waterproofing Seal Design

A waterproof seal is critical to prevent water ingress occurring in between the mating surfaces, especially if the tracker gets submerged. To achieve this:

- **Solution**: An **O-ring** was selected for its availability, affordability, reliability, and proven success in similar applications, such as "Message in a Bottle" (Duncan et al., 2020).
- **Specifications**: An O-ring with a **2.62mm cross-section** and **Shore A 60** hardness was chosen for its **higher pliability** (compared to the standard Shore A 70). The softer material compensates for any uneven spots on the SLS surfaces (discussed above) and ensures better sealing. 2.62 mm was selected because of higher availability than similar sizes, and because it seemed appropriate to the scale of the tracker. Both EPDM and silicone (VMQ) are suitable, silicone was used during prototyping due to its availability.
- O-**ring lubricant** fills any gaps and increases waterproofing. It also reduces wear that could compromise the seal.

### Design Guidelines

To ensure a proper seal, **design guidelines** for creating **static "face seals"** specifically for **fluids** were adhered to for the geometric design of the seal:

- Gland **(**the groove that seats the O-ring) width: is **3.50mm** for a 2.62mm cross-section O-ring (ERIKS, n.d.; Parker Hannifin Corporation, 2021)
- Gland depth: **2mm**, allows 25% compression, should be 20-30% (ERIKS, n.d.; Parker Hannifin Corporation, 2021)
- O-ring stretch: **5% maximum**, to ensure proper performance (Parker Hannifin Corporation, 2021).
- Gland edges are **filleted** (**0.2mm**) to prevent O-ring damage (ERIKS, n.d.)
- **Screw holes** are **spaced ≤35mm apart** for even compression (Jon, 2024).

A cross-sectional view of the gland design is shown in Figure 62.

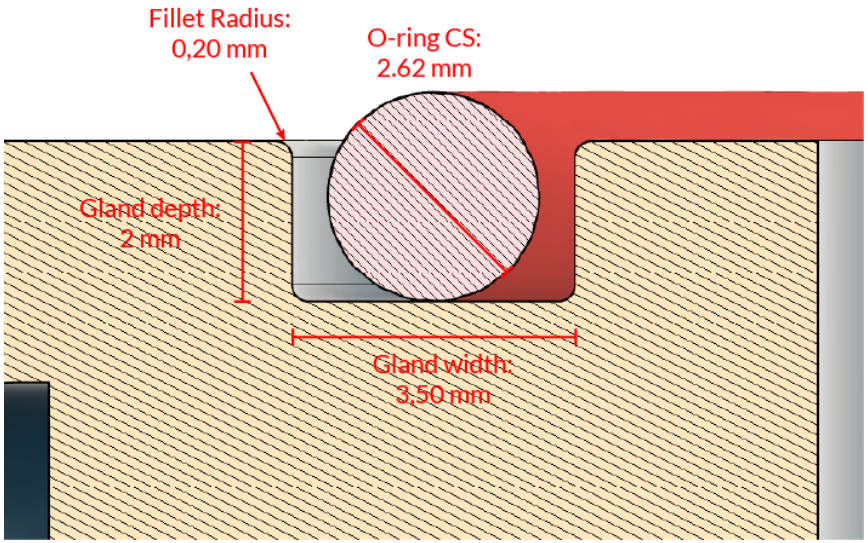



*Figure 62: cross-sectional view of the gland design with relevant dimensions.*

Since a face seal is used in combination with O-ring lubricant, there is virtually no abrasion that can compromise the seal. This adheres to *Requirement #16.*

→ **Proper seal design** combined with **waterproof casing parts** results in a **waterproof geometry** for the tracker.

## Waterproofing Testing

The TrashTracer was **successfully** tested to be **IP67 waterproof**, meaning there is no water ingress when submerged between 15 centimeters and **1 meter underwater for 30 minutes**. The test was done at the upper end of this range; **1 meter depth**. As there was no visible water ingress, it is likely the casing can withstand more extreme waterproofing challenges. IP67, especially when tested at a meter depth, is however already excessive for a floating tracker. Testing to a higher level than strictly necessary reduces the likelihood of seal failure over-time.

### Testing Procedure

To simulate the **IP67 conditions**, the TrashTracer was placed at the bottom of a tube filled with water to a height of **1 meter** (see Figure 63 for the test setup**)** and held underwater for **30 minutes**. A weight was placed on the casing to ensure it remained submerged at the bottom.



*Figure 63: Testing setup for IP67 waterproofing test.*

After 30 minutes, the TrashTracer was removed and inspected for water ingress. Upon opening the casing, it was confirmed that **no water had entered (**see Figure 64), validating the effectiveness of the seal design.



*Figure 64: Opened casing after IP67 testing (shiny surfaces inside the O-ring are caused by O-ring lubricant).*

### Intermediate Validation

Before ordering the final parts of the TrashTracer, the waterproofing seal design was tested with a small test model that was created using a PolyJet printer (see Figure 65). This design adhered to the same waterproofing seal design principles discussed above. This was done to evaluate the design's effectiveness at waterproofing before ordering the final (expensive) parts.



*Figure 65: PolyJet printed intermediate waterprooding validation part*

### Results and Conclusion

The successful test demonstrates that both the **casing parts and seal are watertight**.

This testing result highlights the effectiveness of the seal design and provides confidence in its application for the final tracker.

→ **Successful tests**, combined with following **guidelines for seal design and geometry** (3mm wall thickness) ensure a **reliably waterproof casing geometry**.

## 10.2 Damage to the casing

Water could also enter because of damage to the casing. This can be caused by **impacts** or by **loads** applied on the tracker casing. As shown in Table 4 (Failure Modes and Effects Analysis) in *chapter 7*, Noria does not expect this to be a mayor cause for losing trackers. For redundancy however, it has been addressed in the redesign. This section addresses the measures implemented to enhance the casing's resistance to these challenges.

### Impact resistance

For higher impact resistance, **PA11** was chosen as the casing material in consultation with Oceanz B.V.

Compared to its more common alternative PA12, PA11 is **tougher** and much **less likely to shatter**, but rather experiences **plastic deformation** in the case of material failure. While plastic deformation is of course not desirable, it does not necessarily

create openings for water to enter the housing, which is inherently the case with fractures.

Vapor-smoothing improves elastic modulus and yield strength, which should increase impact resistance further, it is however not clear by exactly how much.

## Failure due to loading

To prevent material failure caused by loads, the tracker has a sturdy design with the following features:

- **Rounded geometry** to distribute stresses.
- **3mm wall thickness** for structural integrity.
- **Ribs** and **crossbeams** for reinforcement (see Figure 66).

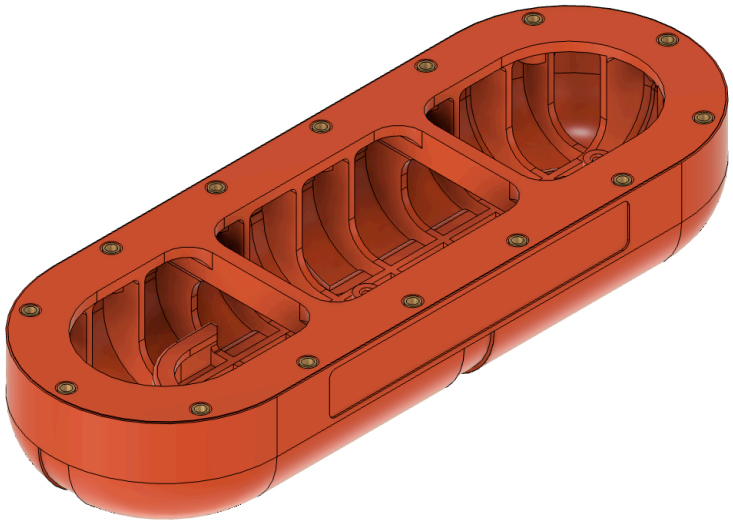


*Figure 66: Ribs and crossbeams improve the strength of the casing (this is the top half).*

The design was **evaluated by the Noria design team**, who concluded it would be **sufficiently strong** for the expected conditions of use, and potentially more robust than strictly necessary.

Additionally, **static stress simulations** in Autodesk Fusion **validated the design on its robustness**. These simulations were also used during the design process to identify areas of high stress or deformation, which was then addressed by adding ribs or fillets where necessary.

The goal of this testing was to validate the general robustness of the casing, not to perfectly represent a use case. As it remains largely unclear what scenarios the tracker can end up in, it is complicated to determine a realistic use case. A load of **1000 Newtons** was used as a benchmark and this was applied on both the **side surface** as well as the **top surface** of the casing in separate tests (see Figures 67 and 68). The tracker was constrained by an object simulating the embankment. Safety factors that resulted from both simulations are shown in Table 6 and the results are discussed further below. Safety factors below 1,00 signify material failure.

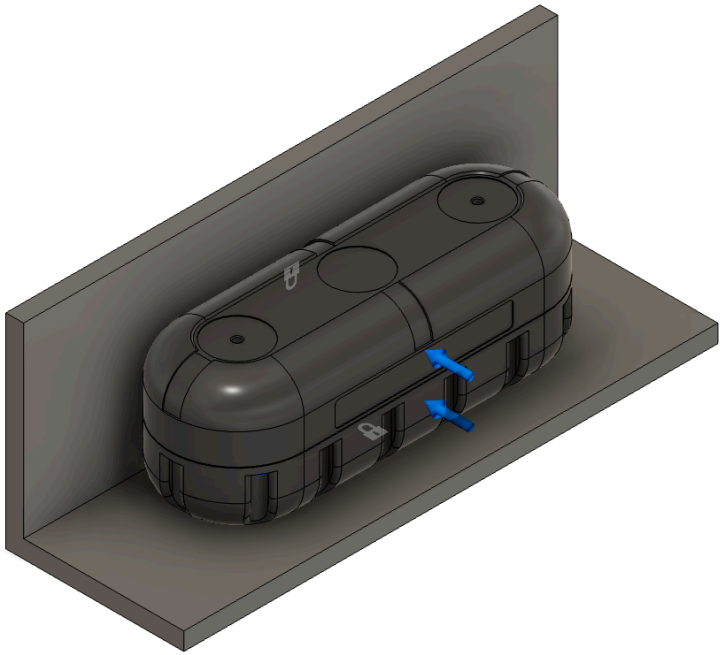


*Figure 67: Simulation setup with a load applied to the side surface, tracker constrained by a wall simulating an embankment.*

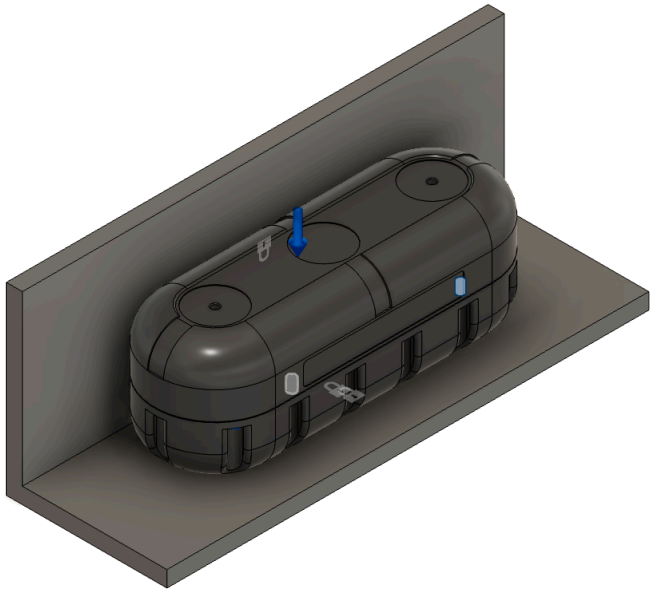


*Figure 68: Simulation setup with a load applied to the top surface, tracker constrained by a wall simulating an embankment.*

*Table 6: Safety Factors from simulations*

| **Load applied on:** | **Min. Safety Factor @1000N** |
|---|---|
| Side surfaces | 0.889 |
| Top/Bottom surfaces | 1.172 |

### Side surfaces

When the load is applied on the side surface, the casing experiences material failure in where the casing has an interface with one of the bolts, with a safety factor of **0.889** (see Figure 69). This failure is attributed to stress concentration from the

harder stainless-steel bolts against the softer PA11 casing material. Areas other than interfaces with the bolts, experienced no stress that came close to material failure.

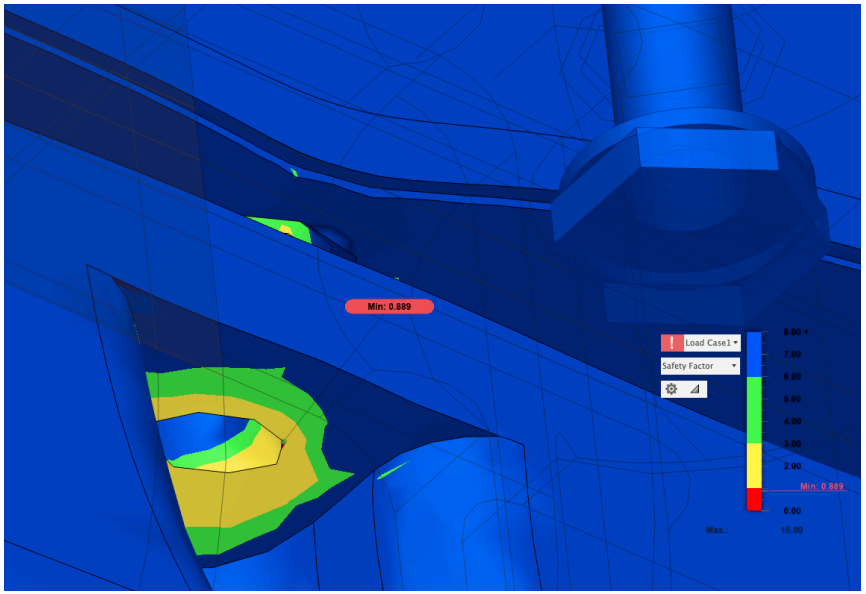



*Figure 69: Material failure at the interface between a bolt and its mounting hole, indicated by a small red spot.*

### Top and Bottom surfaces

When the load is applied on the top of the tracker, it achieves a safety factor of **1.172**, with the ribs showing the highest stress levels (see Figure 70). Rib failure (caused by higher loads) does not directly compromise the waterproof seal as it occurs on the inside of the casing.

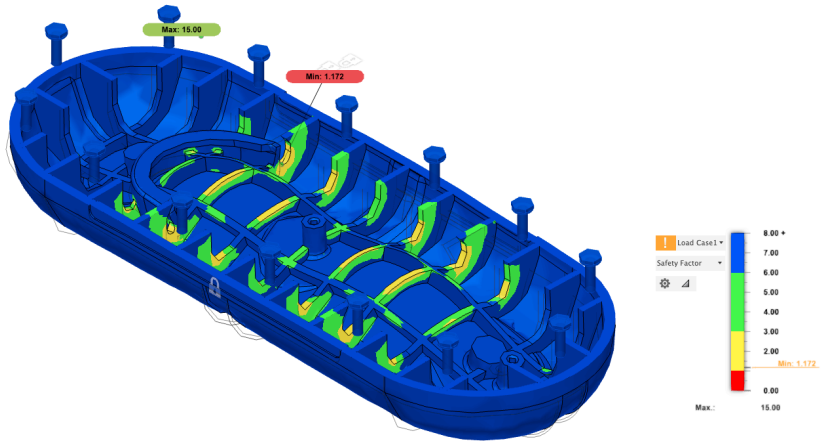



*Figure 70: Stress concentration in the ribs, section view.*

### Considerations

There are a number of things to consider when viewing these results:

- The simulations done for this testing include **static loads**, which do not fully represent a real-life scenario that would rather be dynamic. Static testing was chosen because it is efficient and provides a simplified baseline to evaluate the design's robustness.
    - Dynamic testing was not conducted because it would require more detailed and specific information about real-life conditions the tracker can encounter during its use. The goal of this testing was to validate the general robustness of the casing, not to perfectly represent a use case.

- The simulated conditions represent a **worst-case scenario**, where the tracker housing is compressed perfectly flat against a rigid surface, such as an embankment. In real life, it is more likely to encounter dynamic and uneven forces, such as being briefly squished between a boat and the embankment or compressed at an angle. These interactions allow the tracker to move away, redistribute forces, or (temporarily) submerge, reducing the likelihood of material failure.
- **Material failure** and **high stress** occurred very **locally**, and not in areas where it directly causes waterproofing issues, considering that material failure for PA11 often entails plastic deformation rather than fracture.
- The tensile properties used in simulations reflect **conservative estimates**. SLS produces parts with somewhat lower tensile strength in the direction perpendicular to the printing layers (Oceanz B.V., 2021a). This lower value was used in the simulations as to not overestimate the materials properties.
- **Vapor-smoothing** enhances the material's performance beyond the simulated results, as it **improves mechanical properties**. By how much remains unclear.

#### Conclusions

From these results, the following conclusions were made:

- Noria's design team evaluated the tracker casing and expect it to be **sufficiently strong**, potentially more robust than strictly necessary.
- From simulations in Autodesk Fusion, the **tracker casing can withstand** a (static) clamping load of **around 1000 Newtons** before any material failure.
- The tracker **may withstand higher loads** without being damaged to the point where water ingress occurs, but this is **complicated to quantify**.

## 10.3 Separation between the mating surfaces

**Separation** of the **mating surfaces** of the two casing halves can **compromise the seal**. The O-ring extends **0,62mm** above the gland. Since some contact between the O-ring and mating surfaces needs to be maintained to uphold the seal, a **separation** between the mating surfaces of **more than 0,5mm** can be expected to **compromise the seal**.

Anticipated causes for this potential separation are **loosening of the bolts** and **deformation of casing parts**. How both were addressed in the design of the tracker is discussed hereafter.

### Loosening of the bolts

Potential **causes** and their **solutions** for bolt loosening are discussed below:

#### Material Creep

**Spring washers** (see Figure 71) compensate for reduced clamping force due to plastic deformation under bolt load.



*Figure 71: Spring washer.*

### Thermal Expansion

The **temperature fluctuation** during one research period is likely **no more than 20 °C** (maximum duration of 6 weeks). For a 10mm long stainless-steel machine screw, this results in a **0,0032 mm lengthwise expansion**, which will not cause issues. A calculation is shown below, the generic thermal expansion coefficient for stainless steel of 16 $\mu$ m/(m·°C) was used (Engineering Toolbox, 2023).

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T$$
$$\Delta L = 0.01m \cdot 16\,\mu\,\mathrm{m/(m \cdot °C)} \cdot 20\,°C$$
$$\Delta L = 0.0032\ mm$$

### Impacts and Vibrations

**Thread-locking sealant** can be applied to prevent loosening as a result of impacts that the tracker experiences during use. The tracker is not expected to experience any significant vibrations.

### Permanent O-ring Compression

**Silicone O-rings** are used which have a **high compression set** (Essentra Components, 2019). Compression set is a measure of how well a seal can maintain a sealing force and therefore function (ERIKS, n.d.). O-rings should be checked for permanent deformation after each use (indicated by it being flattened, not round).

### Insufficient Preloading

Bolts are **tightened until the two mating surfaces meet**, approximately X Nm per bolt. Because of the reaction force of compressing the O-ring, this amount of tightening will create preloading.

## Deformation of the casing parts

During use, the casing of the tracker might be (temporarily) deformed which can separate the mating surfaces of the casing parts and allow for water to enter the enclosure. Possible causes for this are listed below:

- **External clamping forces.**
- **Reaction force of the O-ring.**
- **Thermal expansion.**
- **Water absorption.**

The following passages discuss how each of these are addressed.

*External clamping forces*

Failure of the material due to clamping forces (as discussed in Chapter 11.2) occurs before excessive separation of the mating surfaces (more than 0,5mm). Therefore, this is **not a concern for waterproofing**.

The simulations showed such little separation that the **exact value was hard to determine** and can be considered **negligible**. The value shown in Figure 72 (0,122 mm) represents total displacement of one of the mating surfaces, not the separation between the two. The results were similar for both load cases.

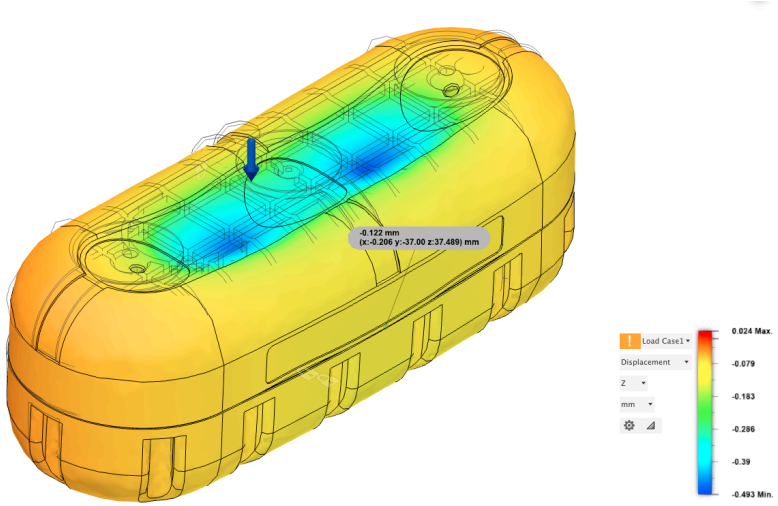



*Figure 72: Exaggerated displacement under load, separation of the mating surfaces is negligible.*

*Reaction force of the O-ring*

Compression of the O-ring when the tracker is assembled generates a reaction force on both mating surfaces which can cause deformation that can compromise the seal. This is prevented by:

- **Ribs** positioned **below the mating surfaces** that provide added stiffness (see Figure 73).
- **Evenly spaced bolts** ensure evenly distributed pressure.
- **Softer** (than standard) **O-ring** which limits the reaction force.

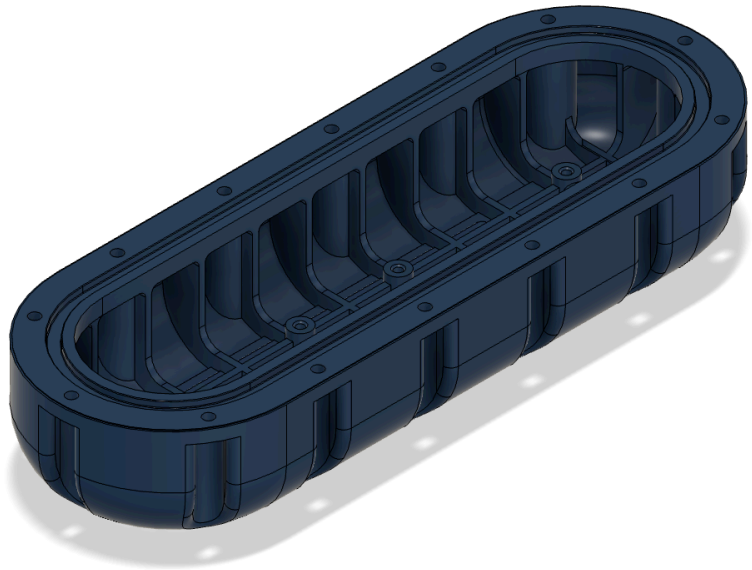


*Figure 73: Ribs supporting the mating surfaces and evenly spaced bolt holes mitigate deformation due to the reaction force of compressing the O-ring.*

### Thermal expansion

The expansion, or rather shrinkage (in the direction perpendicular to the seal faces), caused by a 20 °C temperature difference is **0.15 mm.**

It can be calculated as follows, where $\boldsymbol{\alpha}$ **= 100** $\mu$ **m/(m·°C)** (different sources state different values, this was chosen as an average) And $\boldsymbol{L_0}$ **= 0.075m** (the total height of the tracker):

$$\Delta L = L_0 \cdot \alpha \cdot \Delta T$$
$$\Delta L = 0.075m \cdot 100\,\mu\,\mathrm{m/(m \cdot °C)} \cdot 20\,°C$$
$$\Delta L = 0.15\,mm$$

This amount of expansion/shrinkage should not cause any issues, as it is well below the limit of 0.5 mm as discussed before.

### Water absorption

PA11 has a low water absorption rate of **1.6%** (Xometry, 2024). While water absorption could cause issues, this low rate signifies that water absorption of the casing material should be of no concern.

## 10.4 Conclusions

To conclude this chapter, the main takeaways are listed below:

- The tracker housing meets IP67 waterproofing standards, ensuring no water ingress under 1 meter of water for 30 minutes.
- The design was evaluated by Noria design team members who expect it to be more robust than strictly necessary.
- Simulations show the tracker housing can withstand a load of **around** 1000N before any failure.
    - Real-life conditions are expected to be more favorable, reducing the likelihood of failure.
- Separation of the mating surfaces is minimized and not expected to cause problems.

Having addressed the anticipated causes for water ingress, the tracker housing can be expected to remain watertight during its

# 11. Signal Reliability

Signal reliability of the TrashTracer was improved to be more than twice as high compared to the original tracker.

This was achieved by ensuring the **antenna's position** is at least 22.5 mm **above the water level** (with four batteries this reaches the parting line), and by giving the TrashTracer **self-righting properties** through a low center of gravity, achieved by placing batteries at the bottom of the casing.

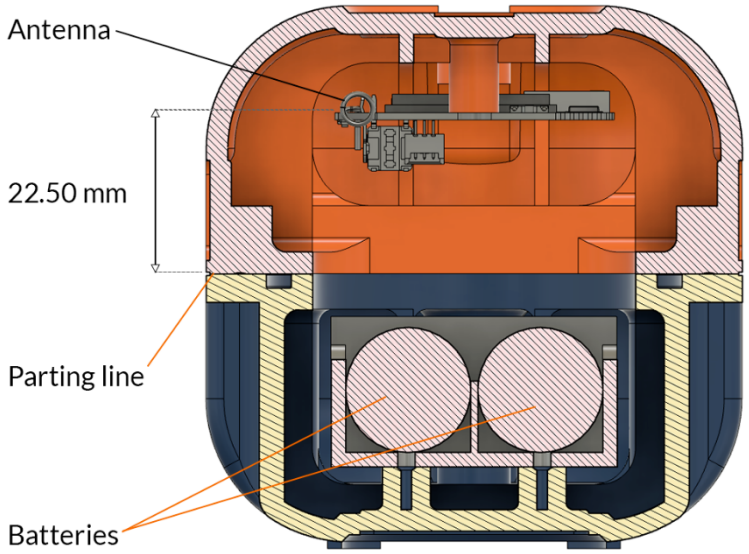



*Figure 74: Cross section of tracker casing, water level reaches the parting line when 4 batteries are used, giving around 22.5 mm clearance.*

Signal reliability was one of the first failure modes addressed in this project, as it was identified by Noria as the **most critical issue** with the original tracker (see Table 4 in *chapter 6*). Signal reliability issues lead to **less valuable research** results and **can lead to losing the trackers**. The approach taken to address this issue is detailed below. This chapter describes how a solution was integrated into the design and the final validation done through testing.

## 11.1 Integration into design

As stated in chapter 7.1, the root cause behind the signal reliability issues is that the antenna is positioned below the water level. Earlier signal reliability testing showed that addressing this root cause by placing the antenna higher in the casing and placing batteries (weight) in the bottom for self-righting properties, resulted in higher signal reliability of around 80% (Appendix B).

The **TrashTracer improves** on this earlier testing prototype by achieving a **greater clearance to the water** (at least 22.5 v.s. ≤ 5), caused by higher buoyancy and better placement of the PCB (to which the antenna is attached). Placement of the PCB and batteries can be seen in Figure 74.

**Separate 18650 batteries** were used in combination with **battery holders** (reasoning behind this decision is discussed in chapter "*14.4 Electronics*"). Battery holders and the PCB are **screwed into** dedicated **bosses** in the casing using (thread-forming) screws rather than threaded inserts (reasoning explained in "*14.3 Fasteners*") For the PCB, washers (nylon) are recommended to distribute forces caused by impacts.

## 11.2 Final Validation

The signal reliability of the TrashTracer was tested against Noria's original tracker. The following passages describe the method of testing, the results that were achieved, and conclusions that were made.

### Testing Method

Alongside the signal reliability, **power consumption** was evaluated at the same time. This was especially interesting as the change to separate batteries meant the omission of the thermistor that is normally present in the Lightbug's batteries to regulate battery temperatures for higher efficiency. This is discussed in more detail in *chapter 14.4*.

#### Signal Reliability

Trackers were placed in a **waterway in Delft** (along the Troelstralaan) and left to float around for **50 hours** (similar to earlier testing (Appendix B)). Trackers were attached to a rope that was attached to a balcony without public access (see Figure 75). This was done to prevent any risk of the TrashTracer being lost or stolen (considering there was only one prototype). This setup allowed the trackers to experience close to real-life conditions (only transportation was limited), without taking too much risk.

After 50 hours, the data was evaluated in the Lightbug portal to assess how reliable the trackers had been in transmitting data. This was done by calculating the **proportion of successful transmissions** relative to the total number of transmission attempts. The number of attempts was 50, as the trackers were configured to send a signal once per hour.



*Figure 75: Testing location for final signal reliability test.*

If the Lightbug Pro PCB fails to transmit a signal, it tries again in the next few minutes, these additional transmissions were ignored as they skew the results. The interval was set at once per hour, so only the hourly transmissions were considered.

When the Lightbug Pro fails to transmit, it presents these as "Approximate" locations in the portal (see Figure 76). These are generally only accurate to a few hundred meters, making them completely useless.

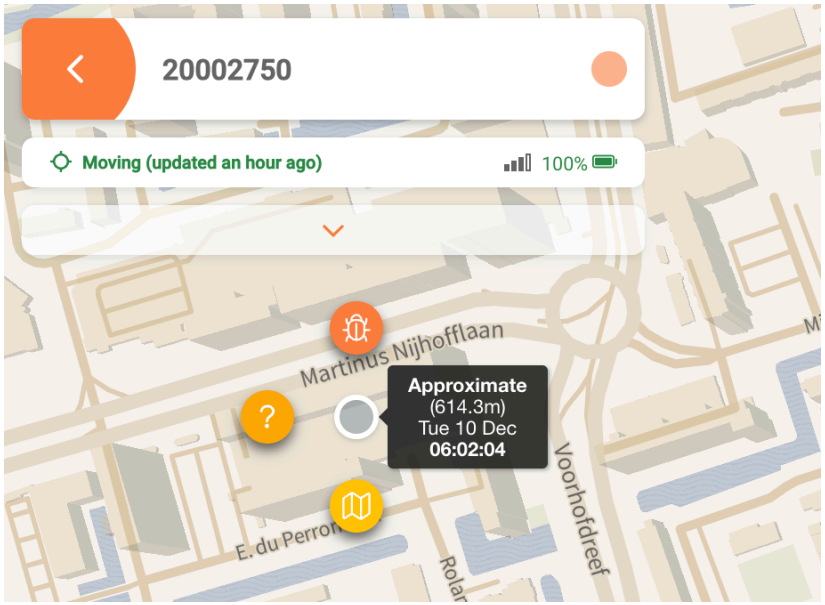



*Figure 76: "Approximate" location, which equals a failed transmission.*

### Power Consumption

Power consumption was monitored in the Lightbug portal to evaluate whether the added batteries could indeed be expected to allow 6-week research durations. The Battery percentage at the start of testing was **57%.** Batteries that were used during testing were slightly lower capacity than the Lightbug's battery at 3000 mAh (12000 mAh total), meaning that a **full charge should last around 38 days** (5 weeks and 3 days), considering that the normal duration with a 6600 mAh is three weeks, as reported by Noria.

## Results

### Signal reliability

The results from the test are shown in Table 7

*Table 7: Signal Reliability testing results*

| | Successful Transmissions | Reliability (in %) |
|---|---|---|
| Original tracker | 12/50 | 24% |
| TrashTracer | 31/50 | 62% |

### Power Consumption

After 50 hours of testing (roughly two days), the battery percentage was at 53%, meaning a **4% drop in battery level**, averaging roughly **2% per day**. If we extrapolate this, a **full charge results in 50 days**.

## Considerations

The following should be considered when viewing these results:

- The reliability test results appear rather low, especially when compared to earlier testing as described in Appendix B. This is likely caused by the **trackers floating underneath the balcony**, which is made out of concrete and can hinder the trackers from transmitting signals (see Figure 75). During a period of repeated transmission failures, for both trackers, it was observed that the trackers had indeed floated underneath the balcony. As this can happen to trackers during deployment, this occurrence does not invalidate the test results.
- The test was conducted using the TrashTracer with 4 batteries in it. **It is** however also **possible to use two batteries** (if the research period spans three weeks or less). This lowers the weight and therefore increases

buoyancy which **could** in theory **further increase signal reliability** as there will be more clearance between the antenna and the water level (discussed further in *Recommendations*).

- Trackers were attached to a rope but could still move around with the wind and the current, creating a **mostly realistic testing scenario**.
- This test also represented a **temperature fluctuation challenge** for the TrashTracer (although this was not the purpose of the test). The test was done during winter with temperatures dropping to 4 °C during the night. This means there was a roughly **16 °C difference** to when it was assembled (which was done inside). The fact that the tracker remained operational and there was no water ingress, further shows the robustness of the seal design as discussed in the previous chapter.
- The **low temperatures can be straining on batteries**. If the TrashTracer is used during warmer periods, even longer research durations might be achieved.
- The 12000 mAh battery capacity was only expected to last for 38 days. The fact that the result was considerably higher (extrapolated to 50) could be caused by inaccurate measurements, or because the **TrashTracer's signal reliability is better**, meaning that it does not retry to transmit as often, **lowering power-consumption**.
    - 50 days equals (more than) a 7-week period. With higher capacity batteries this could be increased further.

## Conclusions

- TrashTracer has **significantly better signal reliability** compared to the original tracker, during this test at 62% compared to 24% for the original tracker, which is **more than 2.5 times better**. In more open areas (without concrete structures) this can be expected to be considerable higher. With this test, *Requirement #2* was not met.
- The **6-week period should be easily achievable** (adhering to *Requirement #6*), likely considerably longer, especially if higher capacity batteries are used.

# 12. Recovery

As discussed in the analysis section, recovery of trackers can be quite challenging and time-consuming. Trackers can also be lost if recovery presents too many issues.

To make recovery of the trackers smoother, faster and more successful, an **Apple AirTag** was integrated into the design. The **key technology** behind this device is **Ultra-Wideband (UWB)**, a wireless transmission technology with the ability to determine the **distance** to - and **direction** of, in this case, the tracker. With the use of an **iPhone** (11 or newer) and its built-in **interface** (see Figure 77), the **location of the AirTag**, located inside the tracker casing, can be determined to **0,1 meters**.

To arrive at this solution, various technologies were considered. This chapter describes how technologies to solve this issue were explored, selected, tested, and how the AirTag was integrated into the design of the tracker.



*Figure 77: AirTag interface*

## 12.1 Benchmarking

First, a benchmark was done regarding what technologies are available that might aid the recovery of the trackers. Potential technologies that were identified in this step are as follows:

- RFID, Near-Field Communication (NFC)
    - Passive
    - Active
- Radio Frequency (RF) beacons
- Acoustic Beacons
- Ultra-Wideband (UWB)
- Audible Beepers (speakers)
- Flashing lights
- Vibration Motors

To assess these technologies on relevant aspects in a structured way, a Harris Profile was used (Van Boeijen et al., 2020). Filled-in Harris profiles for these technologies can be found on the next two pages in Figures 78 and 79. These profiles clearly show that Ultra-Wideband scored the highest.

*Figure 78: Filled in Harris profiles for Recovery benchmark (1).*

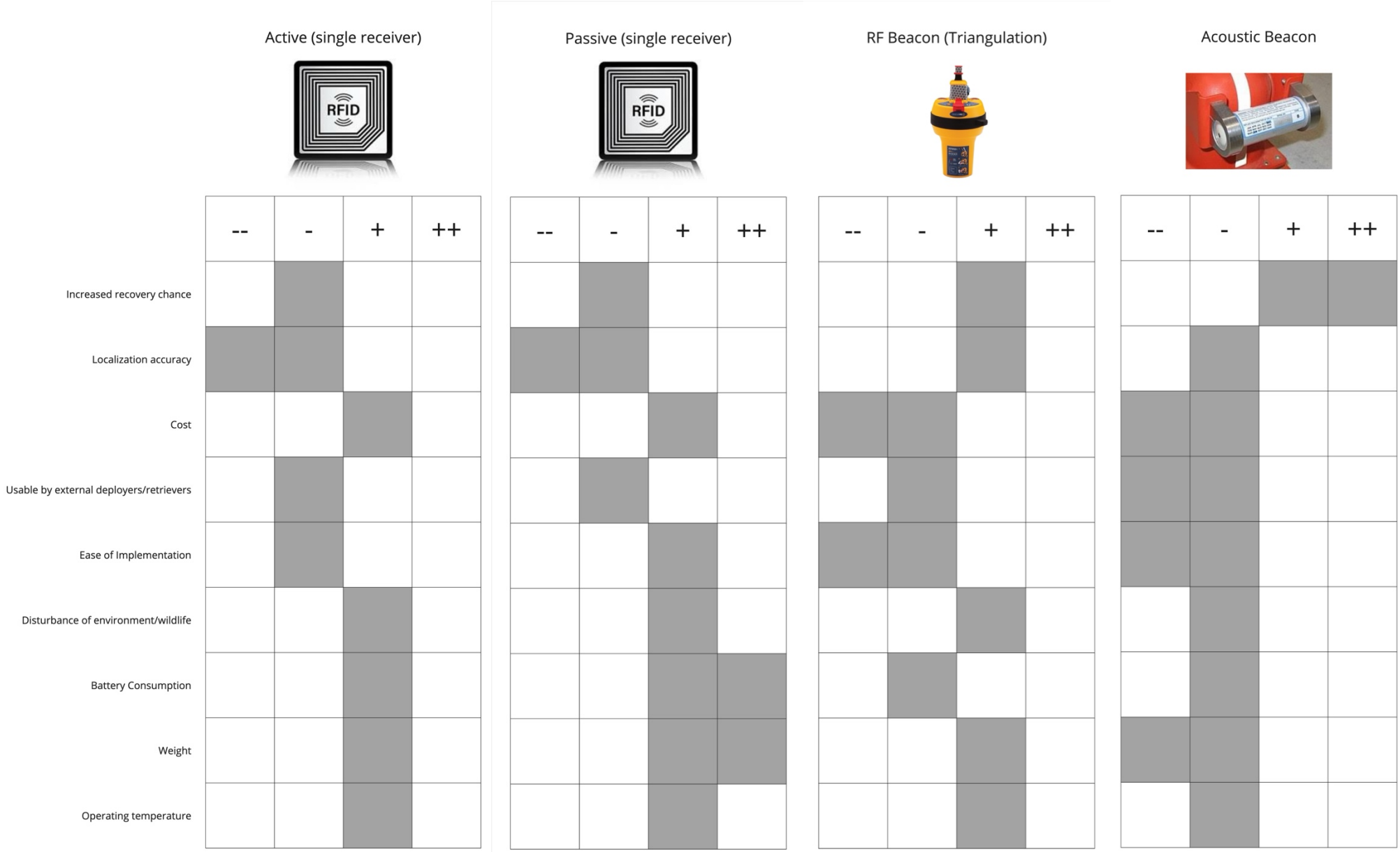
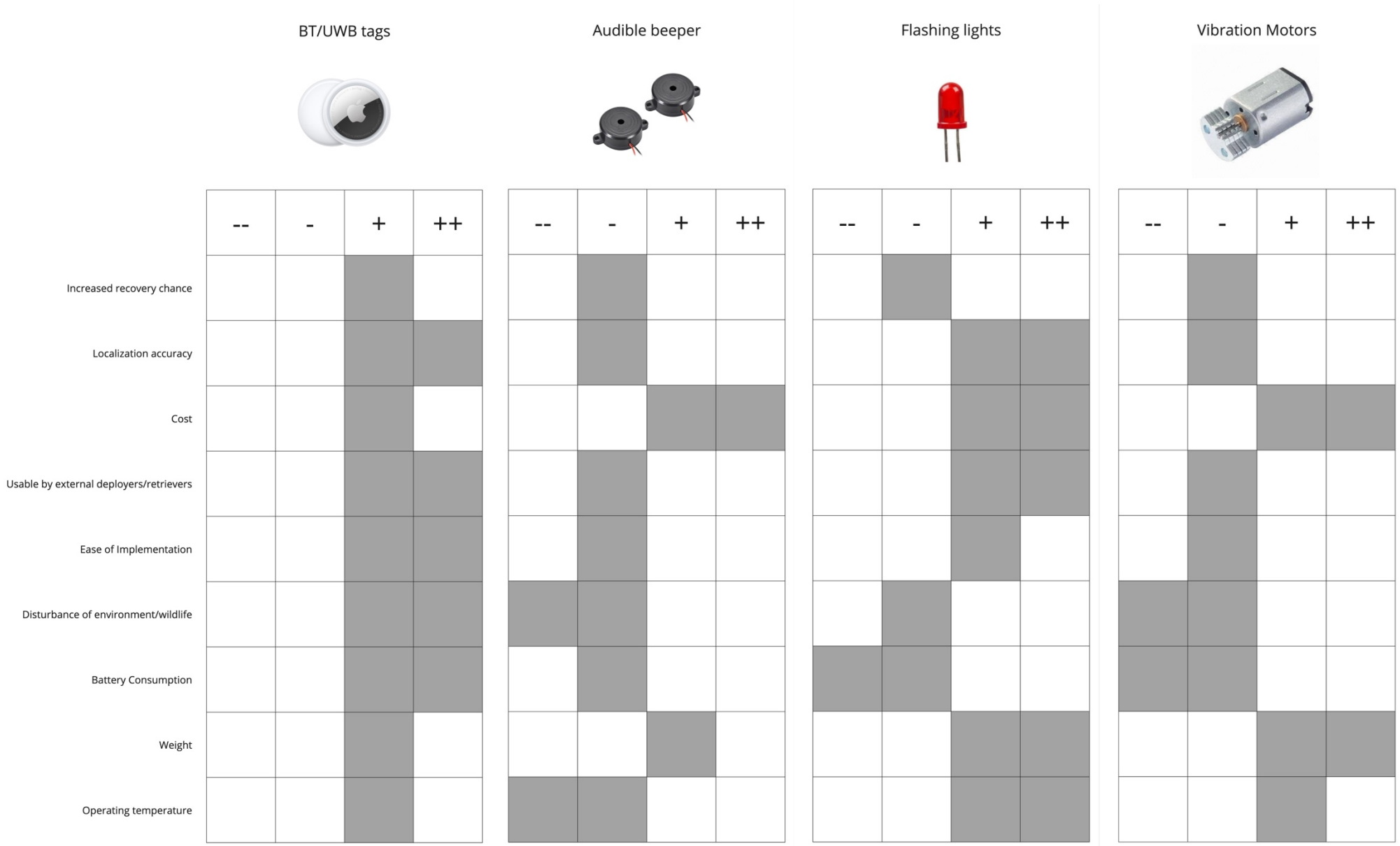


*Figure 79: Filled in Harris profiles for Recovery benchmark (1).*



## 12.2 Technology Selection

From this benchmark, **Ultra-Wideband (UWB)** was the most interesting to explore. This technology is for example used in the Apple AirTag and Samsung Galaxy Smarttag 2. These devices can connect to certain mobile phones which have a built-in interface to help locate them.

Out of all technologies that were included in the benchmark, this has the most potential to be of use for recovering the trackers for the following reasons (specific information provided about the AirTag):

- UWB can determine **distance** and **direction** of the transmitter (AirTag) to the receiver (iPhone) **very accurately**.
- UWB is **proven technology** (increasing reliability).
- **Own, functional interface** (iPhone 11 or newer).
- **Small** and **lightweight** (at 11 grams), making it **easy to implement.**
- **Affordable** (around €25, - p.p. when bought in bulk).
- **Low-power signal,** results in **low power consumption** and is **unlikely to disturb wildlife** (adhering to *Requirement #24)*.
- **No privacy breaches** due to end-to-end encryption (adhering to *Requirement #24)* (Apple, 2024).

UWB tags are very suited to be used **in combination with the GPS** of the Lightbug Pro, as the latter provides the tracker's approximate location within about **5 meters**. The phone's **interface** starts displaying the exact location of the tag at **5-10 meters** distance from the phone. When the person trying to recover the tracker travels to this location, his/her phone can connect to the tag through UWB, which allows the tracker to be located much more precisely, helping to find it, **especially when** it is **obscured from sight**.

One downside of these devices is that either brand only works with (mobile) devices of their own brand, limiting the amount of people that can use them. There are other brands like Tile who offer non-brand-specific keytags, but these lack the Ultra-Wideband technology which is the most valuable aspect of these devices. The only two keytags currently offering UWB technology are the Apple AirTag and the Samsung Galaxy Smarttag 2.

From these two, the **Apple AirTag was selected** because it is **smaller** and **lighter**, making it easier to integrate, and because Apple sells more phones in the **Netherlands** in the age group of **18-35** than Samsung (*Telecompaper*, 2022, as cited in iCulture, 2022). This (mostly) covers the age group of Noria employees and covers the age group of **external tracker deployers** (expected to be students), meaning more people will be able to make use of this technology using their own phone to help locate trackers. Apple also allows you to **share access to AirTags** to other iPhone users (Apple, n.d.-b). This makes the TrashTracer more **suitable for use by external deployers/retrievers** (adhering to (*Requirement #23*)).

### Technology Testing

To evaluate whether the UWB tags were useful for locating the trackers, tests were conducted.

In the past, **Noria** has **tried** incorporating **Samsung Galaxy Smarttags** (the first version that lacked UWB) in their tracker casings, but these were **not helpful** to them. These tags were however tested alongside the Apple AirTag so see the difference that UWB technology made. During early signal reliability testing (Appendix B), both tags were put inside original casings so that the usability for recovery could be tested simultaneously. This is also discussed hereafter.

## Galaxy Smarttag

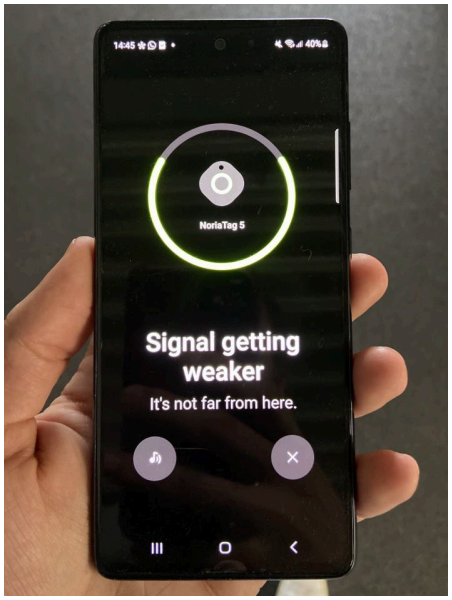



*Figure 80: Samsung Galaxy Smarttag Interface*

When using the Galaxy Smarttag's interface to locate a tag, it shows a circular meter that fills up as you get closer to the Smarttag (*see Figure 80*). This, however, does **not** seem very **accurate** as in testing it was **inconsistent** in how full the meter was with regards to the **distance** of the phone to the Smarttag. It is also **delayed**, only showing a change in how full the circle is a few seconds after moving toward or away from the Smarttag. It **does not indicate** the **distance or direction** of the Smarttag compared to the user's phone. The Galaxy Smarttag has a ring function where it plays a ringtone so that you can locate it. Although it is reasonably loud, it gets muffled when inside the PVC Tube and in an environment with traffic or wind it could be harder to hear. When testing the use for improving recoverability, it proved to not be helpful, often providing false information about the tracker's whereabouts.




*Figure 81: Incorrect information of Samsung Galaxy Smarttag*

## Apple AirTag




*Figure 82: Apple AirTag interface*

Compared to the Galaxy Smarttag, the **Apple AirTag performs much better**. Instead of a global proximity, it **displays distance** (0,1 meter accuracy) **and direction** on the interface (*see Figure 82*). It also feels **undelayed** compared to the Smarttags, updating the distance and direction immediately as you move around. The AirTags have a ring function as well that also gets muffled when inside the PVC tube, but due to its accurate distance and direction indication, it is still very easy to locate the AirTags.

When the Apple AirTag was in a real-world setting (during tests described in Appendix B), it proved to function as desired (see Figure 83).

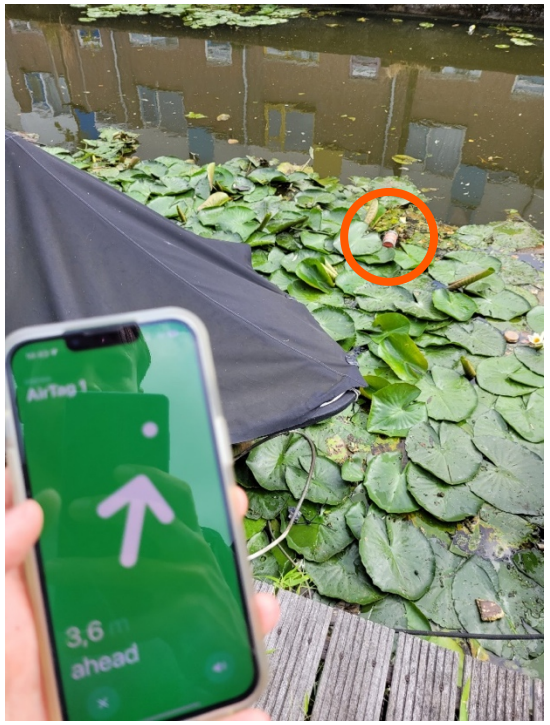



*Figure 83: AirTag accurately providing distance and direction for the location of the tracker (visible in vegetation).*

## Conclusion

Based on these testing results, the Apple AirTag should be well suited to aid recovery of the trackers and therefore was integrated into the TrashTracer. It is also clear that not any electronic key tag is usable. **Ultra-Wideband**, used in the AirTag **is key.**

## 12.3 Integration into Design

The Apple AirTag is mounted in the **top of the casing** (wireless signals struggle underwater) using a **friction-fit** (*see Figure 84*). This allows it to be mounted and replaced with ease and prevents the need for fasteners. The positioning inside the tracker and exact dimensions for a functioning friction fit were found through iterative prototyping (*see Figures 85 & 86*).




*Figure 84: AirTag integrated in the TrashTracer*



*Figure 85: Apple AirTag mounted in a prototype using a friction fit.*



*Figure 86: Prototype for finding the correct dimensions for a friction fit.*

## 12.4 User Validation

Testing indicated that the process of recovering the TrashTracer will likely be faster and easier for Noria compared to the original tracker. This subchapter discussed how this was validated with Noria employees.

The test simulated the **root cause** for the **failure mode** of **excessive recovery time:** that the **tracker is obscured from sight,** in a controlled environment. The test was not conducted in a real-life situation since there was only one TrashTracer prototype, and risks of losing it were prevented.

### Testing Procedure

The TrashTracer was compared to the original tracker to evaluate the improvements achieved through its redesign. The trackers were **concealed within a pile of litter** retrieved from the water by Noria (see Figure 87).

Three participants, all employees of Noria, conducted the test and were tasked with locating the trackers. **First**, they searched for the **original tracker** using its GPS location and visual observation. **Next**, they searched for **the TrashTracer**, utilizing the Apple AirTag and its iPhone interface alongside GPS and visual observation. After each search, participants were asked to **rate the ease of locating** the trackers on a scale from 1 to 5. This included a specific evaluation of how easy it was to use the provided location information (GPS and/or UWB) and how easy it was to visually spot the tracker, with 5 indicating excellent ease of use. The **time** required to locate each tracker **was** also **recorded**.

To ensure consistency and reduce potential biases, the **hiding location** for the trackers **was kept identical** for all participants.

Participants were shown the AirTag interface briefly before the test to help understand how it works.



*Figure 87: Participant looking for the tracker in piles of (dried) litter.*

## Test Results

Results from this test are summarized in Table 8 below. Stars are used to indicate the ratings, with empty starts signifying a half point (e.g. ★★☆ = 2.5/5). Average ratings are rounded to half-stars for clarity.

*Table 8: Results form Recoverability validation*

| Participant | Recovery time original tracker | Recovery time TrashTracer | Rating original tracker (1-5) | Motivation | Rating TrashTracer (1-5) | Motivation |
|---|---|---|---|---|---|---|
| Average | **64.87 seconds** | **41.66 seconds** | Overall: ★★☆ | - | Overall: ★★★★☆ | - |
| | | | GPS: ★★★ | - | GPS/UWB: ★★★★☆ | - |
| | | | Visual: ★★☆ | - | Visual: ★★★☆ | - |
| Participant #1 | 53.15 seconds | 42.08 seconds | Overall: ★★★ | "Tracker was hidden and not very noticeable. Blends in with plastic litter." | Overall: ★★★★ | "With more practice it would be probably 5/5. It said "below" which was a bit confusing." |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | GPS: ★★ | "Not very precise but it provides the general direction." | GPS/UWB: ★★★★ | " " |
| | | | Visual: ★★ | You have to know what to look for. Between plants I think it would be 4/5" | Visual: ★★★★ | "It looks less like waste. Blue instead of grey ". |
| Participant #2 | 57.35 seconds | 34.63 seconds | Overall: ★★ | "Color is similar to waste, orange and red are common in litter". | Overall: ★★★★★ | "very easy using the phone, shadow made it harder to see so could be quicker" |
| | | | GPS: ★★★ | "Not accurate but not terrible, usefulness depends on environment". | GPS/UWB: ★★★★★ | "very precise location". |
| | | | Visual: ★★★ | "Quite hard here, in plants for example it would stand out more". | Visual: ★★★ | "depends on lighting which one is more visible. The longer it is in the water the harder it gets." |
| Participant #3 | 84. 12 seconds | 48.27 seconds | Overall: ★★ | "It is hidden in litter which made it hard to find". | Overall: ★★★★☆ | "very easy, especially for the last few meters" |
| | | | GPS: ★★★★☆ | "5-10 meters of accuracy is good for the price of the Lightbug" | GPS/UWB: ★★★★☆ | "phone can be used like a compass towards the tracker". |
| | | | Visual: ★★ | "The colors don't stand out, but they would in vegetation". | Visual: ★★★★ | The orange stands out more, larger surface and used more compared to original". |

## Considerations

There are a few things to consider when interpreting these results:

- There were limited participants (three). More could give more accurate averages and more feedback, but this test does clearly show that there is an improvement for the TrashTracer compared to the original tracker.
- Although this test was conducted without the presence of water, the **functionality** of the AirTag's UWB technology is **expected to remain unaffected**, as the device is positioned above the water level during use. Intermediate tests during the prototyping phase demonstrated that the AirTag consistently provided the tracker's accurate position when installed in the casing and left to float on water.
- The trackers were obscured by trash, which could occur if trackers end in a floating litter hotspot. According to Noria employees, trackers more often get stuck in vegetation (green/brown colored), which would contrast more with the tracker colors. This was however complicated to test as water vegetation is mainly

present during the summer, and these tests were conducted in December. Future testing could be done during summer to evaluate visibility between water vegetation (discussed in Recommendations).

- Recovery times for the TrashTracer could be faster once users know their way around the AirTag interface better.
- The overall rating provided by participants is not the same as the average of the ratings they gave for provided location and visibility. This hints that overall ratings were not purely fact-based. Location provided by the tracker and its visibility are the two means used to find trackers.

## Conclusions

- **Recovery times** showed a **clear improvement** for all three participants, averaging 41.66 seconds compared to 64.87 of the original.
- The **TrashTracer was rated higher** overall by all participants, at ★★★★☆ (4.5/5) compared to ★★☆ (2.5/5) for the original tracker.
- The **largest difference** was in the **provided location information**, rather than visually. The AirTag interface displays the location up to 0,1 meters and allows the user to use a phone as a detector.
- The **original tracker** visually **blended in more with litter** than the TrashTracer. This is mostly caused by the grey color of the PVC tubing.
    - This should make it easier to spot for Noria employees (better recovery rates) and easier to recognize for canal cleaning crews (lower chance of removal) if trackers end in a floating litter hotspot.
    - But by being more visible it could be spotted more by bystanders which might increase the chance of removals.

# 13. Litter Representativeness

**Four threaded inserts** have been included in the design (see Figures 88 and 89). These serve as **mounting points** for **attachments** (see Figures 90 and 91) that can alter the influence of wind and waterflow, allowing it to **represent different kinds of floating litter**.




*Figure 88: Threaded inserts on the top half of the casing.*




*Figure 89: Threaded inserts on the bottom half of the casing.*




*Figure 90: Rake-like attachment to simulate certain litter types.*




*Figure 91: Attachment for added wind influence.*

Threaded inserts were chosen for the following reasons:

- **Cost**: inserts are inexpensive to integrate, especially because installation will be done in-house.
- **Easy of implementation:** with threaded inserts already included in the design, adding four more requires minimal effort.
- **Strength:** when melted into a plastic part, threaded inserts create a strong connection which never caused any complications throughout this project.
- **Modularity:** it allows many items to be used, ranging from 3D-printed attachments to plastic bags (see Figures 90 and 91)

- **Lightweight:** M3 threaded inserts weigh 0.35 grams, adding a total of only **1.4** grams to the tracker.

## 13.1 Risks and Solutions

Adding inserts to the design comes with the risk of the threads getting **clogged with debris or biofouling** if the trackers are deployed without any attachments, but this can **easily** be **prevented** by using **placeholder screws.**

If the threads still get filled up (for example because placeholder screws are omitted), the threads can still be cleaned with the use of compressed air, water, cleaning products, and small brushes.

## 13.2 Considered Alternative

Another method for mounting attachments that was *seriously* considered (Velcro and straps were also considered but quickly dismissed for aesthetic and feasibility reasons) was the use of **magnets**, but these were rejected for the following reasons:

- Attachments could more easily **fall off** during use.
- Trackers can **stick to metal objects** or structures they encounter in the water, especially if attachments fall off.
- Strong magnets are generally **heavier** than threaded inserts, having a larger effect on buoyancy.

## 13.3 Value of this Feature

Noria has indicated that the ability to alter the behaviour of the tracker and therefore represent different types of floating litter, **adds significant value** to the project.

By integrating simple threaded inserts, the design achieves this functionality at **low cost** and **limited implications**.

## 13.4 Buoyancy

The total weight of the tracker, when four batteries are installed is **537 grams**. The total volume, measured through a water displacement test, is roughly **920 cm$^3$**. This results in a density of **0,584g/cm$^3$**, adhering to *Requirement #14*.

# 14. Implementation

This chapter is focused on providing the client of this project, Noria Sustainable Innovators, with information on how to realize the TrashTracer. It is important to remember only **20-25 pieces** will be produced initially.

First, a Bill of Materials (BoM) is presented. This is followed up by argumentation for the choices that were made in the selection of parts, materials and production methods. The chapter closes with the steps required for assembling the tracker.

## 14.1 Bill of Materials

Below a Bill of Materials is presented encapsulating all parts that go into the TrashTracer. For each part, a possible supplier is mentioned. This can however be deviated from to reduce costs.

*Table 9: Bill of Materials*

| Subsystem | Component | Type | Material | Pcs. | Supplier |
|---|---|---|---|---|---|
| Outer casing | Bottom half | SLS (vapor smoothed) | PA11 (Oceanz) | 1 | Oceanz |
| | Top half | SLS (vapor smoothed) | PA11 (Oceanz) | 1 | Oceanz |
| | Graphics (text, logo, symbols) | Weather resistant stickers | Plastic (often PVC), adhesive | 6 | Various online services |
| Waterproofing | O-ring | CS: 2.62mm, ID: ≈138-144mm | VMQ (Silicone) (or EPDM), Shore A 60 | 1 | O-ring stocks EU |
| | lubricant | O-ring lubricant | Silicone-based | - | O-ring stocks EU |
| Fasteners | Threaded inserts | M3, opposing diagonal ridges | Brass | 18 | Amazon/ Mouser |
| | Machine Screws | M3x10mm (Torx) | Stainless steel A2 (Optionally A4) | 14 | Fabory |
| | Washers for closing | M3*6mm*0,5mm | Stainless steel A2 (Optionally A4) | 14 | Fabory |
| | Washers for PCB mounting | M3*6mm*0,5mm | Nylon | 2 | Fabory |
| | Screws | Thread-forming, 3*6mm | Steel (any) | 10 | Fabory |
| Electronics | GPS hardware | Lightbug Pro PCB | Multiple | 1 | Lightbug |

| | | | | | |
|---|---|---|---|---|---|
| | Ultra-Wideband (UWB) tag | Apple AirTag | Multiple | 1 | Coolblue |
| | Batteries | 18650, >3300 mAh | Li-ion | 4 | RS or similar |
| | Battery holder | 18650, 2 batteries | Plastic | 2 | RS or similar |
| | Internal Wiring | Hook-up wire | Copper, Plastic | - | RS or similar |
| | Wire loom | Braided or heat shrink | Plastic | 1 | RS or similar |

## 14.2 Production Method of the Casing

To save cost, reduce unnecessary complexity, and allow better repairability, **most components** of the tracker **can be purchased**. The casing of the tracker, however, requires a custom design as using off-the-shelf parts is likely to result in an aesthetic that makes it look like a waste item, which could trigger people to remove it from the water, disrupting research.

### Selected Method

Due to this custom design, a suitable production method had to be selected which is **Selective Laser Sintering (SLS)**. Although the per-unit price of SLS printing is somewhat high, it is **one of the more cost-effective methods** considering that the (initial) production run of the trackers will only be around 25 units. Positive attributes of SLS printing are listed below:

- Exceptional **design freedom.**
- Good **range of material options.**
- Requires **no support structures** (which is often the case for other Additive Manufacturing technologies).
- Only the exact amount of required material is used, and **high complexity** can be used to safe material, making it more **efficient** and **sustainable** (Lefteri, 2019).
- Suitable for **small production runs**, multiple parts can be printed in one powder bed (Lefteri, 2019).
- Extremely **high tolerances** (Lefteri, 2019).
- **Close to Isotropic** material properties ((Oceanz B.V., 2021a, 2021b).
- Can produce **reliably watertight** parts with sufficient wall thickness and vapor-smoothing (discussed in Chapter 10.1).

Aside from waterproofing purposes, vapor-smoothing also makes the parts **less susceptible to biofouling** (adhering to *Requirement #31*). The micro-organisms responsible for this phenomenon can attach themselves more easily to rough surfaces (Lakshmi et al., 2011).

The geometric design of the tracker adheres to the design guidelines provided by Oceanz (2022).

## Considered Methods

Other methods that were considered are listed below, as well as reasons why they were not chosen:

- **Stereolithography (SLA)**: Produces higher quality and smoother surfaces than SLS (Lefteri, 2019). The problem is however that SLA parts weaken with over-exposure of sunlight (does not satisfy *Requirement #33*), and the parts are generally more brittle compared to other techniques which hinders it from producing functional parts. Additionally, SLA prints generally require supports which adds a step in the production process to remove and complicates printing multiple parts in one print job, something that is much easier with SLS printing.
- **Digital Light Synthesis (DLS)**: As it is another UV-curing printing technique, parts also deteriorate with extended exposure to sunlight. Additionally, the availability of companies offering this technology is limited (Lefteri, 2019).
- **Multi Jet Fusion (MJF)**: While it offers a better surface finish and more isotropic parts compared to SLS, there are a few downsides to MJF printing. Firstly, the technology is owned by Hewlett Packard (HP), meaning that you are dependent on one company in terms of pricing, availability, materials, etc. Secondly, it is also a less mature technology, meaning there is a smaller knowledge base and production partners to choose from. Thirdly, for smaller production runs, up to around 100 units, it is generally less cost-effective compared to SLS printing (Fictiv, 2019). Lastly, while it offers a less course surface finish compared to SLS, the parts will still require a (vapor) smoothing treatment to ensure waterproofness and reduce biofouling.
- **Moulding (various types):** Produces fully isotropic products with a smooth surface finish and a low per-unit-cost but requires high upfront costs for mould production which only makes it viable above a few hundred units. Moulding also has limited design freedom (e.g. no undercuts) as the mould needs to be opened to extract the part.
- **Sand Casting:** Results in a very rough surface finish that requires grinding and polishing (Lefteri, 2019). For small production runs it also requires a worker to cast the products manually which entails high labour costs. Sand casting is also best suited to simple shapes and usually requires a 3-5mm wall thickness (Lefteri, 2019). This limits design freedom and makes the casing too heavy (material would be aluminum rather than plastic).
- **Investment Casting:** Is a time-consuming process as many steps need to be taken (making a wax pattern, ceramic coating, melting the wax, pouring metal, post-processing) which also makes it more expensive (Lefteri, 2019). While it can produce more complex parts compared to sand-casting, it is generally more expensive for small production runs.

## 14.3 Materials and type

### Casing

The material of choice for the casing of the tracker is **PA11 (or Nylon/Polyamide 11)**. Below are key reasons for its selection:

- **Production Compatibility**:
  - SLS (Selective Laser Sintering) was chosen as the production method for the casing.
  - PA11 is a material available for SLS production.
- **Material Properties**:
  - **Higher elongation at break and impact resistance** compared to the standard PA12 (in consultation with an Oceanz B.V. engineer this was found to be more suitable to the application).
- **Biocompatibility**:
  - Certified according to EN ISO 10993-1 (Oceanz B.V., 2021a).
  - Ensures no water poisoning during use, unlike some other polymers (*adheres to Requirement #17*)
- **Dimensional Stability**:
  - Minimal deformation from thermal changes or water absorption (discussed in chapter 10.3).
- **Environmental Resistance** (Sayani, 2023):
  - Exceptional resistance to moisture, UV radiation, and weathering, meeting Requirements #26 & #33.
- **High Chemical Resistance** (Sayani, 2023)
  - Adheres to *Requirement #37*.

### Waterproofing components

#### O-ring

**Silicone rubber (VMQ)** was chosen as the O-ring material for the following reasons:

- **Temperature range**: -54°C to 204°C (Parker Hannifin Corporation, 2021).
- Good **chemical stability**, adhering to *Requirement #37* (Hebei Jinwo Machinery Technology Co., Ltd., 2024).
- **Resistance to weathering and UV** (Applerubber, 2021).
- **Biocompatibility**: no chemicals will leach in the water (Applerubber, 2021).
- **Good compression set** (permanent deformation after compression), adhering to *Requirement #16* (Essentra Components, 2019).

#### O-ring lubricant

**O-ring lubricant** (silicone-based) is recommended as it **helps waterproofing** and because it **reduces deterioration**. Although lubricants are mostly beneficial in dynamic seals, it also helps in static seals to **seat the O-ring** properly during assembly, **reduce** damage from **abrasion, pinching or cutting**, create a better seal by **filling in inclusions in the gland**, and **protecting the O-ring from atmospheric elements** such as ozone (Parker Hannifin Corporation, 2021). O-ring lubricant is **mostly beneficial** to use during the **first installation** (Parker Hannifin Corporation, 2021). It might however be advisable to maintain this after every couple of uses.

## Fasteners

### Threaded inserts

**M3-sized brass threaded inserts** with opposing diagonal ridges are the recommended type (*see Figure 92*). Different types of threaded inserts exist (knurled, vertical ridges). CNC Kitchen (2019) found that the type opted for in this design are the strongest, meaning more pressure can be exerted on the waterproofing seal and increased durability of the product. Brass is chosen as this is the most commonly used material and it is corrosion resistant and the M3 size was selected as this balances compactness with availability (for example M2 is much less common and offers less strength). Threaded inserts allow the casing to be opened with minimal wear, adhering to *Requirement #16.*

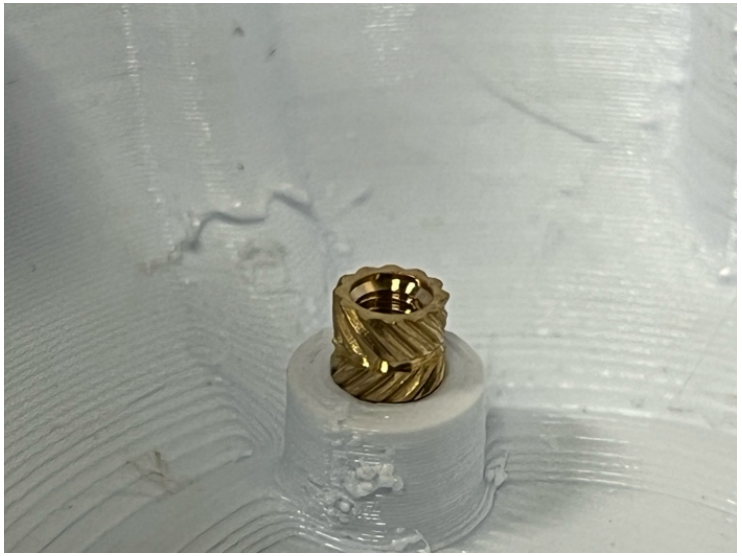


*Figure 92: Threaded insert with opposing diagonal ridges (the insert is heat-pressed into the boss during assembly).*

### Machine Screws and Washers

The recommended material for the machine screws used to bolt the two halves of the case together is **stainless steel** (A4) to prevent corrosion. A4 Stainless steel is more corrosion resistant compared to stainless steel A2 which is why “they are the standard choice for many applications in the construction, automotive, marine and engineering sectors” (Bolts.co.uk, n.d.). Since the trackers will be used in an aquatic environment, it is recommended to use this grade.

The type of bolts used should have a **Torx** (hexalobular) head to **prevent stripping**. Again, **M3** is chosen for the same reasons and so that they match the inserts.

Washers are used to **distribute the force** applied by the machine screws on the plastic housing and to **reduce abrasion** that occurs when tightening the screws. For the same reasons as for the screws, the recommended material is A4 **stainless steel**.

Washers are also used to mount the PCB to the casing, it is recommended to use plastic ones (nylon) here.

### Thread-forming screws

**Thread-forming screws** are used inside of the casing to **mount the PCB and the battery holders**. Since these components are not expected to be deinstalled often (or at all), they can be fastened with screws rather than a combination of machine screws and threaded inserts which reduces costs by lowering the number of components and reducing assembly time. Thread-forming screws also keep the plastic relatively intact which allows for reinstallation of the components if required. **3.0 mm** is chosen as this fits with the mounting points on both

the battery holders and the PCB. Since these do not meet water, it is not necessary to use stainless steel.

## Text, Symbols and Logos

To communicate to users, the tracker's casing includes text, symbols and Noria's logo. The selected method for including this in the design is **waterproof, UV resistant stickers**, **embedded in the surface of the casing** (see Figure 93). By embedding them into the surface and using high-quality stickers they are less likely to peel off, reducing required maintenance and adhering to *Requirement #16.*



*Figure 93: Stickers applied on embedded surface of the casing.*

## 14.4 Electronics

### GPS Hardware

The **Lightbug Pro PCB** was selected as the GPS hardware.

The motivation behind this has been discussed previously in *chapter 1.6*.

### Ultra-Wideband Tag

The **Apple AirTag** was selected to help increase the ease of recovery and reduce the time spent on this. Argumentation for this choice can be found in *chapter 12*.

### Power Supply

The default battery pack used in the Lightbug tracker has been replaced with **four** individual **18650 batteries** installed in **two battery holders** (see Figure 94). This change was made for three key reasons:

1. **Ease and Reliability of Mounting**: The holders can be securely screwed into the casing, ensuring a stable and reliable connection.
2. **Ease of Replacement**: Individual batteries can be replaced without applying force to the wires, reducing the likelihood of damaging the tracker (adhering to *Requirement #34*).
3. **Increased deployment time**: Doubling the number of batteries extends the deployment time from a maximum of three weeks to over six weeks.



*Figure 94: Prototype casing with battery holders and four 18650 batteries installed.*

### Original Battery Configuration and Capacity

The original Lightbug Pro battery pack contains **two 18650 batteries**, connected in **parallel** and enclosed in shrink wrap, with the following key specifications:

- **Total Capacity**: **6600 mAh,** resulting in a maximum deployment time of three weeks
- **Nominal Voltage**: **3.7V**, matching that of a single 18650 battery. The operating range of this battery type is **2.75V to 4.2V** (Tycorun, 2022).

Figure 95 shows the battery pack with its specifications noted on the shrink wrap.




*Figure 95: Lightbug Pro original battery pack.*

In the redesigned system, **four 18650 batteries** are similarly connected in **parallel**, resulting in the following specifications:

- **Total Capacity**: **13,200 mAh**, effectively doubling the deployment time.
- **Nominal Voltage**: Maintained at **3.7V**.

This configuration ensures compatibility with the existing electronics while increasing performance. see Figure 96 for how this was connected.

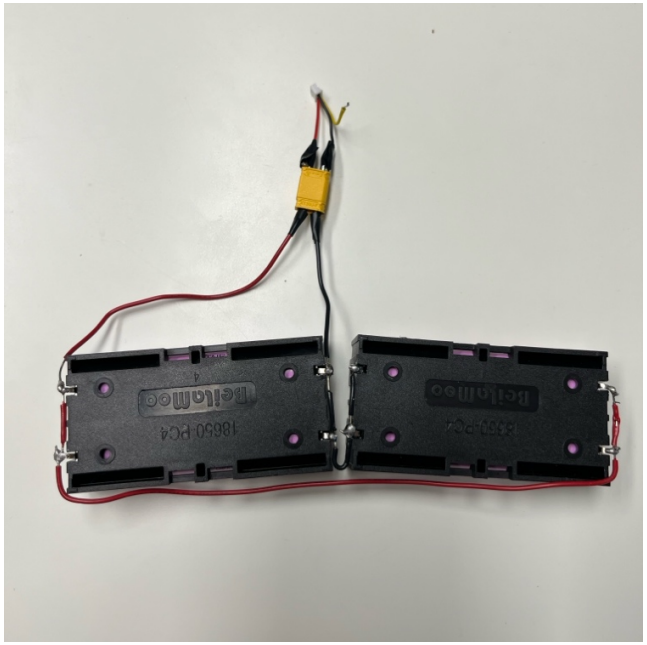


*Figure 96: Prototyped circuit connecting batteries to the PCB*

A maximum of four batteries was determined for the following reasons:

- **Weight Constraints**: Adding more batteries would increase the weight significantly, requiring a larger casing to maintain buoyancy.
- **Casing Size**: The current casing size is comparable to a (relatively large) bottle or drinks can, ensuring the tracker remains similar in size to common floating plastic.

### Thermal Considerations

Upon inspecting Lightbug's battery pack, there is a **yellow wire** exiting the battery pack (*see igure X*). After some research, this proved to be connected to a **thermistor** used to monitor the battery temperatures. Consultation with Lightbug proved that the battery pack could be replaced by separate 18650 batteries inserted in a battery holder **without** using this **thermistor**. Generally, the highest temperatures in batteries occur during charging, which is done in a separate charging station outside of the tracker for the redesigned version. Additionally, since the housing of the redesign is more spacious and has more air surrounding the electronics, overheating should be less of an issue.

### Compatibility testing

While it was validated with Lightbug that separate batteries in battery holders could be used, it was further confirmed by connecting the circuit to the PCB to test if it worked and if the two were compatible. To prevent damage to the PCB, a multimeter was used to measure the voltage of the battery circuit before connecting it which showed the output voltage was **4,15 Volts** (see Figure 97), which is within the voltage range for this battery type. After connecting the PCB to the circuit, the PCB performed the same start-up procedure as normal (as indicated by LED's on the PCB, see Figure 98), indicating it was operational.

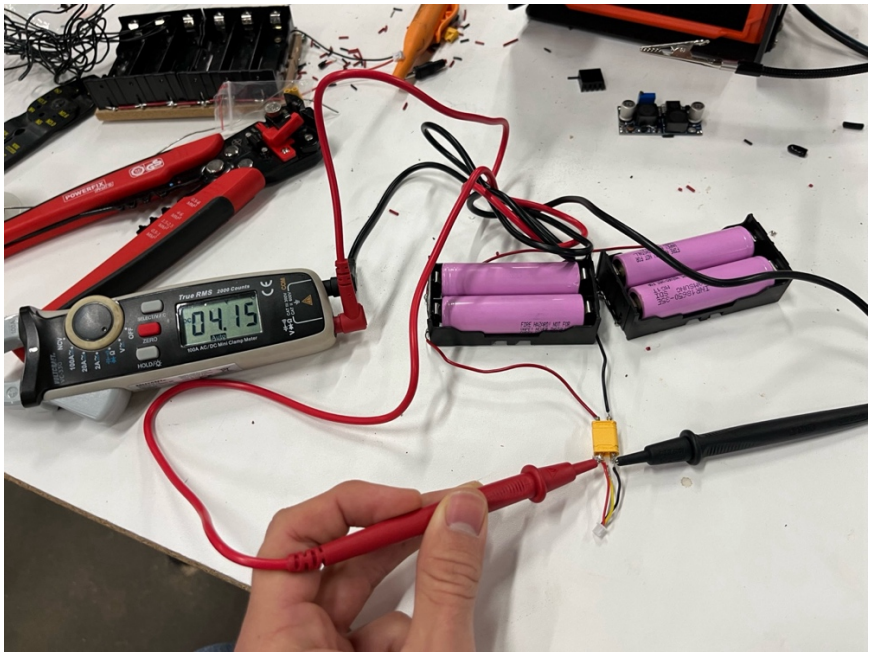



*Figure 97: Output voltage of the battery circuit.*

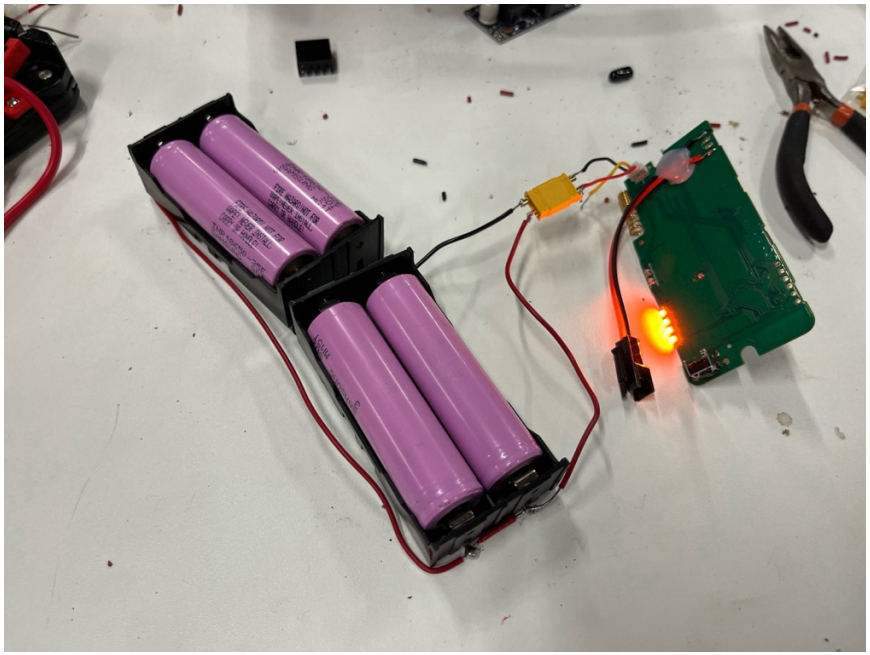


*Figure 98: Successful start-up procedure indicated by a light pattern.*

### Internal Wiring

Single-core hook-up wire was selected for its increased durability compared to multi-core (in the case of low-voltage wiring) which reduces the chance of damage to the wires. When opening the casing, which is done to replace the batteries, the wires are moved around, which is why they require some durability to prevent repairs.

### Wire loom

To protect the wires and keep them contained together, a wire loom is recommended. This can either be a heat-shrink sleeve or a braided wire loom.

## 14.5 Assembly

Assembly of the TrashTracer will be done by a student employee working at Noria. The assembly process has been discussed and is not expected to cause any complications. For the process to go smoothly, a heat set insert soldering tip and heat set insert press should be purchased (totaling around €50, -).

One TrashTracer was assembled (the prototype) which took a total of around 40 minutes. This was however done with improper tools (incorrect soldering iron tip, no heat-insert press), and included soldering the battery holders together. If proper tools and prefabricated battery holders are used, assembly should be possible well within 10 minutes, without prefabricated battery holders likely within 20 minutes. Both would adhere to *Requirement #28*.

### Assembly Steps

Assembling the trackers requires a number of steps which are shown below:

1. Heat-press the threaded inserts into the bottom half of the casing using a soldering iron and heat set insert press.
2. Solder the wires to the battery holders, or use prefabricated (connected in parallel) holders.
3. Solder a power connector to the cables, this power connector will be attached to the PCB.

4. Create a wire loom (either by heat-shrinking a sleeve or inserting the cables in a braided sleeve) from the wires exiting the battery holders.
5. Mount the battery holders in the bottom half of the casing using thread-forming screws.
    a. The battery holders should be oriented so that the cables are pointed toward the middle of the casing.
6. Lubricate the O-ring and the gland (top half of the casing) using a silicone-based lubricant
7. Seat the O-ring in the gland, lubricant makes this process easier.
8. Mount the PCB using thread-forming screws and nylon washers, the PCB should be oriented such that the power coupler is in the center of the casing.
9. Install the AirTag by sliding it into the friction-fit clamp.
10. Connect the PCB to the battery holders
11. Place the top half of the casing on the bottom half, making sure the wire loom is tucked inside.
12. Put a spring washer, followed by a regular washer on a machine screw..
13. Insert machine screws, and tighten them in a crosswise pattern (similar to how you tighten a wheel on a car).
14. Check that all spring washers are compressed (this adheres to *Requirement #13*).
15. Check to see that there is no gap around the parting line (this adheres to *Requirement #13*).

# 15. Viability

Aside from being a better research tool, the TrashTracer can also be expected to bring **financial gain** for Noria, despite the higher upfront costs. **One tracker, over its lifetime** is expected to increase profits **up to €500, -** compared to the original tracker Noria has used so far. This is achieved by:

- Expectedly **losing fewer** trackers
  - Higher signal reliability (chapter 11)
  - Easier recovery (chapter 12)
  - Better waterproofing (chapter 10)
- **Shorter recovery** times (chapter 12)
- Possibly **fewer unplanned removals** (chapter 9).

Figures 99 to 101 provide some insight into the financial aspects of the tracker. It is expected (based off test results) that **a realistic scenario is in-between the Medium-case – and Best-case scenario** displayed in the figures. These scenarios are discussed in chapter 15.4. Since the TrashTracer can be used at least up to 6 weeks (likely longer, as discussed in in chapter 11), this was also included.

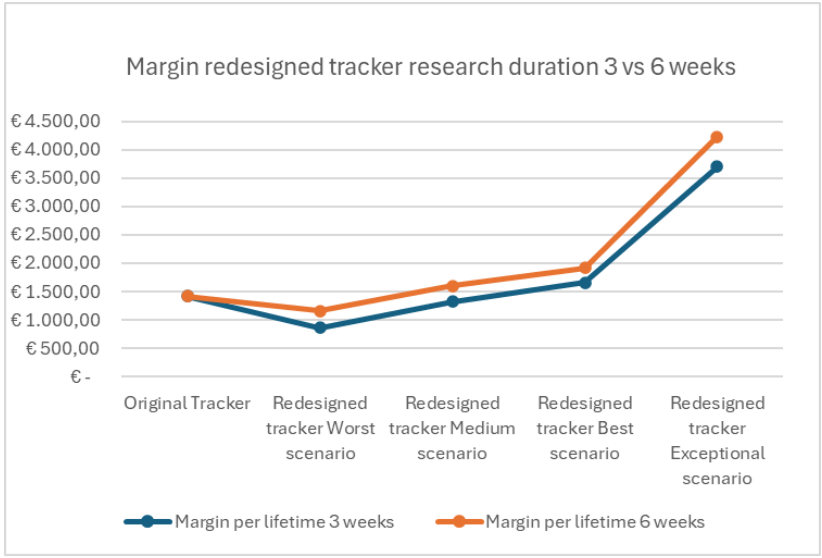



*Figure 99: Expected margin for different scenarios, for 3/6 week periods.*

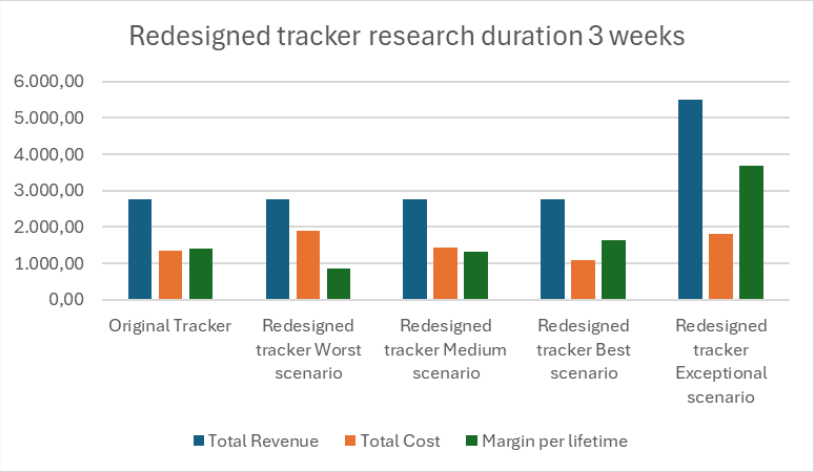



*Figure 100: Revenue, Cost, and Margin for different scenarios (3 weeks).*

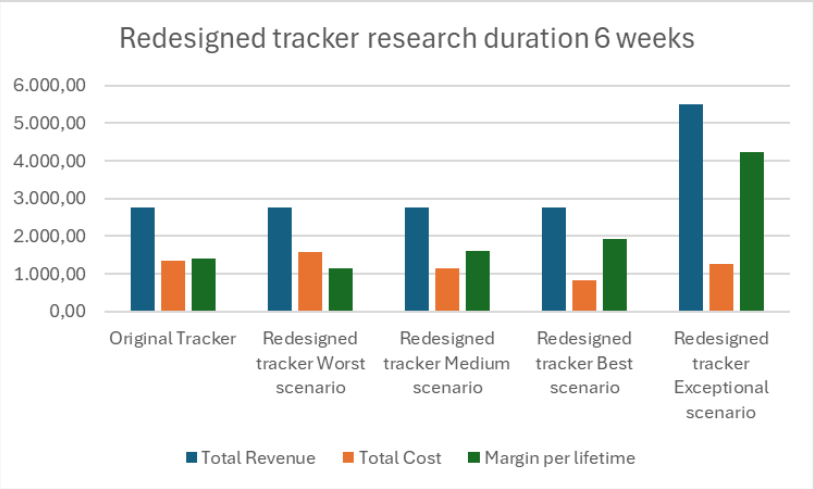



*Figure 101: Revenue, Cost, and Margin for different scenarios (3 weeks).*

To determine the viability aspect of the TrashTracer, an Excel file was created to compare the cost-structure and potential revenue of the redesigned tracker with the original version. This was done for the **total costs, revenue and margin over the lifetime of one tracker.** These excel sheets can be found in Appendix H.

## 15.1 Key information

To inform this estimation, data from a Work Package (information about a previous tracker research assignment Noria conducted) provided by Noria and information gained through conversations that I held with Noria Employees was used. Key information includes:

- The orginal tracker costs **€200, -**
  - The Lightbug Pro GPS sensor costs €150, -
  - Construction of the PVC tube that houses the tracker costs €50, -
- The total production **cost of the TrashTracer is €390, -**
  - Cost structure can be found in Table 10.
- Out of 50 tests, 6 have been lost, resulting in a **12% chance of loss** per deployment
- Out of 50 tests, 3 were removed from the water and required picking up, resulting in a **6% chance of requiring pick up** per deployment.
- Noria assumes trackers are used **16** times in their lifetime (depreciation time).
- A base value for the number of trackers per research is **10** (this is used to calculate deployment/retrieval costs per tracker).

- The mileage allowance is set at **€0,23 per kilometer**.
- The hourly rate for a Noria employee is set at **€40, -**
- Deployment time (of 10 trackers) is **1 hour** with the original tracker.
- Retrieval time (of 10 trackers) is **2 hours** with the original tracker

*Table 10: TrashTracer production cost structure.*

| **Cost Price Redesigned Tracker** | **Cost** |
|---|---|
| Lightbug Pro Tracker | € 150,00 |
| Casing | € 170,00 |
| AirTag | € 25,00 |
| Waterproofing seal | € 5,00 |
| Batteries | € 15,00 |
| Additional Components | € 15,00 |
| Assembly | € 10,00 |
| **Total** | **€ 390,00** |

## 15.2 Assumptions

Several informed assumptions had to be made to be able to create this cost estimation:

### Time Assumptions

- Deployment time is not significantly increased by the TrashTracer. This is 1 hour in all cases.
- Retrieval time can be reduced by a maximum of 1 hour as you still need to move around to different locations where trackers have ended up (For the original tracker this is around 2 hours).
- Deployment time is fixed at one hour, as confirmed in consultation with Noria. This is not expected to change with the redesign.

### Cost Assumptions

- *Income* from research scales *linearly* with the research duration, meaning that a 6-week research period generates double the revenue compared to a 3-week research period.

### Performance Assumptions

- The amount of uses in the life of a tracker depends on the duration of research, as *wear* is expected to scale *linearly* with the research duration.
- The chance of *losing* a tracker or an *unplanned removal* scale *linearly* with the research period.
- The signal reliability of the redesigned tracker is better than the original tracker, as shown from testing (chapter 11.2. In my cost estimation I assume that a higher fee can be charged, which is partially motivated by this.
- The redesigned tracker looks more professional compared to the original tracker which helps to charge a higher fee for conducting research.

## 15.3 Deployment and Retrieval Costs

Aside from these assumptions, it is also important to note that **external workers** (such as students) that could deploy and retrieve trackers for Noria, **were not considered in the cost calculation**. Even though it would benefit the argument for why the TrashTracer is better than the original tracker, truthfully,

there is no **absolute** reason why Noria's original tracker cannot be deployed or retrieved by external people. For this reason, this factor was left out of the viability estimation for implementing the redesigned tracker and **wages of Noria employees were used** to determine deployment and retrieval costs. **If this were included, the financial gains from implementing the redesign would be larger**.

Employing external tracker deployers/retrievers would be beneficial to Noria as it can save them significant costs (due to lower wages of external workers) and allows them to deploy their staff more freely.

The redesigned tracker is more suitable to be used by external workers for the following reasons:

- The tracker is held together by (machine) screws, meaning it requires tools and more effort to open compared to the original trackers. This reduces the chance of external workers opening it and potentially compromising the waterproof seal.
- Retrieval of trackers can be challenging, which might demotivate external workers from continuing to search as they have little personal gain aside from a (limited) monetary compensation. The redesigned tracker mitigates this by making it easier to locate for the following reasons:
    - More use of bright orange and more contrasting colors which makes it easier to spot.
    - Higher signal reliability, meaning that the last-known location has a bigger chance of being close to the tracker's actual location
    - Integration of an Apple AirTag which helps locating the tracker by providing an approximate direction and distance up to 0,1 meters through an iPhone. This is especially helpful when the tracker is obscured from sight.

## 15.4 Scenarios

Since it is hard to argue exactly how much better the redesign will perform compared to the original, a total of four scenarios were created to give insight on the financial gains that the redesigned tracker might bring for Noria:

1. **Worst Case Scenario:** tracker performs similarly to the original tracker.
    a. 12% chance of losing the tracker
    b. 6% chance that it is removed and requires picking up
    c. Retrieving trackers takes 2 hours (adds up to 4 including transport)
2. **Medium Case Scenario:** tracker performs somewhat better than the original.
    a. 6% chance of losing the tracker
    b. 4% chance that it is removed and requires picking up
    c. Retrieving trackers takes 1,5 hours (adds up to 3,5 including transport)
3. **Best Case Scenario:** Tracker performs significantly better than the original.
    a. 2% chance of losing the tracker

   b. 2% chance that it is removed and requires picking up
   c. Retrieving trackers takes 1 hour (adds up to 3 including transport)
4. **Exceptional Case Scenario:** Tracker performs much better and is more robust.
   a. 2% chance of losing the tracker
   b. 2% chance that it is removed and requires picking up
   c. Retrieving trackers takes 1 hour (adds up to 3,5 including transport)
   d. Tracker is more robust than the original and can be used **twice as many times** in its lifetime.

## 15.5 Results

The Excel sheets were created in such a way that certain values can be changed (under "Variables") to see the effects on costs, revenue and consequently margins. For these reasons it cannot be stated **with certainty** which scenarios bring about what financial gains for Noria. However, it is likely a reasonable estimation that the "Medium Case Scenario" already brings about financial gains compared to the original tracker. Table 11 and 12 provide an overview of the total revenue, total costs, and margin over the lifetime of the trackers for both 3 -, and 6-week research durations (the latter only for the TrashTracer). More specific numbers can be found in the Excel sheets (Appendix H). Explanations are given in purple text in the Excel.

*Table 11: Revenue, Cost, Margin (3 weeks)*

| Scenario | Revenue per use | Uses | Total Revenue | Total Cost | Margin over lifetime |
|---|---|---|---|---|---|
| Original Tracker | €172, - | 16 | €2752, - | €1338,56 | **€1413,44** |
| TrashTracer Worst Scenario | €172, - | 16 | €2752, - | €1893,36 | **€858,64** |
| TrashTracer Medium Scenario | €172, - | 16 | €2752, - | €1433,84 | **€1318,16** |
| TrashTracer Best Scenario | €172, - | 16 | €2752, - | €1099,12 | **€1652,88** |
| TrashTracer Exceptional Scenario | €172, - | 32 | €5504, - | €1808,24 | **€3695,76** |

*Table 12: Revenue, Cost, Margin (6 weeks)*

| Scenario | Revenue per use | Uses | Total Revenue | Total Cost | Margin over lifetime |
|---|---|---|---|---|---|
| TrashTracer Worst Scenario | €344, - | 8 | €2752, - | €1595,76 | **€1156,24** |
| TrashTracer Medium Scenario | €344, - | 8 | €2752, - | €1152,24 | **€1599,76** |
| TrashTracer Best Scenario | €344, - | 8 | €2752, - | €833,53 | **€1918,48** |
| TrashTracer Exceptional Scenario | €344, - | 16 | €5504, - | €1277,04 | **€4226,96** |

As can be seen from Tables 11 & 12, as well as from Figures 99 to 101, the break-even point is around the Medium-case scenario. The exceptional scenario is when the difference is really starting to show, caused by the higher amount of uses resulting in more revenue.

## 15.6 Considerations and Conclusion

### Considerations

- It might be possible to start charging a higher fee because the TrashTracer has a more professional aesthetic and because it collects more valuable data (as discussed in chapter 11.2). This was not included in the numbers and visuals presented in this chapter as it appeared speculative, but there is a variable in the "balance" sheet of the Excel file that lets you change this number. Doing so brings about much larger financial gains than if the fee is kept the same.
- Numbers presented in this chapter are based of (informed) assumptions and will not perfectly reflect reality.

### Conclusions

- The tracker is expected to bring about financial gain for Noria.
- If the TrashTracer proves to be usable for a longer duration than the original tracker, the financial gains really start to make a difference. This however remains to be seen.

# 16. Evaluation

The TrashTracer's design was evaluated at different stages during the project. This chapter summarizes the validation that was done, assesses what *Requirements* were met and provides a short reflection on the validation process.

## 16.1 Summary of Validation

Different categories that were tested are listed below:

- Waterproofing
- Signal Reliability
- Battery Life (incorporated in Signal Reliability testing).
- Ease of recovery
- Aesthetics & Removal Prevention
- Viability Assessment

## 16.2 Requirement Evaluation

The final design of the TrashTracer was evaluated on how much it adheres to the design requirements as shown in *chapter 7*. This is shown in Table 13 below.

*Table 13: Requirement Evaluation*

| Req. # | Requirement | Achieved? | Validated? | Chapter # |
|---|---|---|---|---|
| **1** | Design of the tracker is found to look more professional compared to the original by >80% of people. | Yes | No | |
| **9** | Tracker has a recognizable design. | Yes | No | |
| **12** | Tracker communicates its purpose to bystanders who encounter it. | Yes | Yes | 9.3 |
| **4** | Tracker discourages people from removing it from the water and encourages them to return it. | Yes | Yes | 9.3 |
| **2** | Signal reliability is at least 80%. | No* | Yes | 11.2 |
| **3** | Finding a tracker (during recovery) after arriving at the last-known GPS location should not take more than 10 minutes on average. | Yes | Yes | 12.4 |
| **5** | Trackers are lost <5% of the times they are used. | Unknown | No | |
| **14** | Tracker has a maximum density of 0.7g/cm$^3$. | Yes | Yes | 13.4 |
| **15** | The antenna must maintain its position above the water level during use. | Yes | Yes | 11. |
| **18** | The tracker can be expected to last at least 16 uses (three-week periods). | Yes | No | 14.3 |
| **35** | Tracker location can be determined to 1 meter or less. | Yes | Yes | 12.4 |
| **6** | Tracker has a 6-week battery life. | Yes | Yes | 11.2 |
| **7** | Tracker housing is waterproof (IP67). | Yes | Yes | 10.1 |
| **8** | Tracker can survive being thrown in the water from 3 meters height. | Unknown | No | |
| **11** | Tracker is impact resistant. | Yes | No | 14.3 |
| **16** | Tracker housing is designed to be wear-resistant and require minimal maintenance. | Yes | No | 10.1, 14.3 |
| **26** | All tracker components can operate between -20°C and 60°C. | Yes | No | |
| **31** | Housing is not prone to biofouling. | Yes | No | 14.2 |
| **33** | Tracker housing can withstand exposure to Sunlight (UV). | Yes | No | 14.3 |
| **36** | Casing and waterproofing strips withstand light abrasion. | Yes | No | |

| | | | | |
|---|---|---|---|---|
| **37** | Casing and waterproofing strips are chemically resistant to mild cleaning agents. | Yes | No | 14.3 |
| **32** | Tracker is compliant with rules and regulations in the environment of use (e.g. water boards). | Yes | No | |
| **13** | The method of assembling/closing the tracker ensures a waterproof seal and includes an indication. | Yes | Yes | 14.5 |
| **17** | Tracker does not contain unnecessarily polluting or toxic materials and processes. | Yes | No | 14.3 |
| **21** | Manufacturing and assembly are outsourced. | Yes | Yes | 14.5 |
| **22** | (Standard) components are readily available. | Yes | Yes | 14.3 |
| **25** | The design of the tracker housing accommodates the integration of Lightbug Pro hardware. | Yes | Yes | 11.1 |
| **28** | Assembly of the trackers takes a maximum of 20 minutes to reduce costs. | Yes | No | 14.5 |
| **39** | All internal tracker components are replaceable. | Yes | No | |
| **24** | Tracker does not unnecessarily disturb wildlife. | Yes | No | 12.2 |
| **29** | Technology used in the tracker cannot lead to privacy breaches of individuals who interact with it. | Yes | No | 4.6, 12.2 |
| **30** | Tracker is unlikely to startle or scare bystanders who encounter it. | Yes | No | |
| **38** | Tracker resists being opened or tampered with. | Yes | No | 8.4 |
| **10** | Tracker is representative of floating plastic litter. | Yes | No | 13. |
| **23** | The process of deploying and recovering trackers is straightforward and can be executed by externals. | Yes | No | 12.2 |
| **27** | Tracker stands out visually in vegetation. | Yes | No | |
| **34** | Batteries can be recharged or replaced with ease. | Yes | Yes | 14.4 |
| **19** | The tracker should generate a profit margin of > €1400, - over its lifetime to add value for Noria. | Yes | Yes | 15. |
| **20** | Production cost does not exceed €400, -. | Yes | Yes | 15.1 |

*: *Requirement #2* was not successfully tested, but this was most likely caused by a concrete balcony obstructing the signal, as signal reliability was also considerably lower for the original tracker compared to earlier tests (further discussed in chapter 11.2).

## 16.3 Reflection

Generally speaking, the more **technical aspects were achieved and tested the most**. The design can be expected to perform well in its intended environment with regard to things like durability, recoverability and signal reliability. **More testing related** to stakeholders, especially **bystanders** who might remove the trackers could have been done and would have validated the design in its ability to prevent unplanned removals. This is discussed further in the recommendations (*chapter 18.3*).

# 17. Discussion

## 17.1 Key Findings and Implications

The TrashTracer resolves several key challenges identified with Noria's original tracker. **Improvements in waterproofing, signal reliability, battery life, and localization technology** have addressed issues of water ingress, power limitations, recovery challenges and incomplete data collection experienced with the original tracker. These changes not only enhance the tracker's functionality but also contribute to reducing operational costs and improving its dependability during deployments.

The modularity allowed by optional attachments enables flexibility in adapting the tracker for various research objectives and environments, making the TrashTracer a more versatile tool to help understand the plastic pollution problem in Dutch waterways.

## 17.2 Limitations

Although the redesigned TrashTracer demonstrates significant improvements, there are some limitations to consider.

While the tracker was tested in a close to real-life environment (Signal reliability testing), the **research duration** of 50 hours was **significantly shorter** than the 6-week period it will be used for, and therefore did not represent **long-term exposure to harsh environments** such as prolonged temperature fluctuations, water exposure and biofouling.

Testing **whether** the **aesthetics** of the tracker (specifically the graphics) **prevented removal** was **not** fully **conclusive** as a limited group was interviewed and opinions varied between individuals. It was indicated during a feedback session with bystanders (WSVW De Lier) that the **orange color could trigger more removals**, but participants projected this behaviour onto others, rather than stating they would enact it themselves. Since the **orange colour helps** Noria **find trackers** and it **helps to recognize trackers for canal cleaning crews**, it was kept in the design.

## 17.3 Practical Outcomes

The project outcomes deliver meaningful value to Noria's research activities. The TrashTracer is expected to improve on performance compared to the original tracker and thereby **reduce operational costs** associated to loss of trackers and long recovery times. Doubling the battery life extends operational periods, reducing the frequency of redeployment and associated labor costs, further adding to financial gains. Overall, these improvements contribute to a more efficient, cost-effective, and reliable solution for monitoring floating debris in waterways.

# 18. Conclusions and Recommendations

To conclude this report, the contributions of this project to the field, recommendations for the continuation of this work and a personal reflection are provided in this chapter. For clarity, the main objective for this project is repeated.

## 18.1 Main Objective

The goal of this project was to redesign the TrashTracer to address issues experienced with its functionality, and thereby improve cost-efficiency. Furthermore, a more professional aesthetic was desired. The project aimed to create a tracker that supports Noria in researching floating plastic waste and contributes to their mission of improving waterway environments in the Netherlands.

## 18.2 Contributions

To address an issue (waterway plastic pollution), it is essential to first understand the problem thoroughly. With this project, a research tool for understanding this problem has been analysed and improved through a redesign, resulting in the TrashTracer. This improved tracker can help Noria, one of the few organizations in the Netherlands addressing this issue, by providing better insights into floating waste behavior.

The key contributions of this project are:

**Improved Research Tool**: The redesign enhances the tracker's performance, ensuring more reliable data collection for studying floating plastic waste.

**Operational Efficiency**: The improvements result in lower operational costs through reduced tracker losses, extended battery life, and faster recovery times.

**Environmental Impact Support**: By aiding in the research of floating plastic waste, the tracker indirectly supports efforts to improve the quality of aquatic environments.

**Adaptable Design**: The inclusion of modular features ensures flexibility, making the tracker suitable for different research requirements.

**Strengthened Perception**: The more professional looking redesign reflects positively on Noria, potentially enhancing stakeholder confidence which might allow Noria to do more research into this pressing issue.

## 18.3 Recommendations

There are still things left to be tested, added, or improved on the design. These are noted concisely below:

- **Weight Savings**: Reduce the weight of the tracker where possible to improve buoyancy and lower production costs. The current design is likely overly robust which was caused by a late change in wall thickness (relating to waterproofing).

- **Visibility Testing**: Conduct tests to determine the tracker's visibility in dense water vegetation during the summer, ensuring it can still be retrieved easily.
- **Design for Attachments**: Evaluate attachments (discussed in *Chapter 13*) mounted to the bottom of the tracker to ensure they do not reduce the effectiveness of the self-righting mechanism. Depending on the density it can turn into a floatation element.
- **Manufacturer Guidelines**: The design was based of Oceanz B.V. guidelines (Oceanz B.V., 2022). If Noria switches to a different manufacturer, their design guidelines should be checked. Adjustments to geometry may be necessary to align with the new production process.
- **Antifouling**: Consider the use of antifouling on trackers. It is not recommended (directly) from a sustainability standpoint, but it can reduce required maintenance and enhance the lifetime of the trackers.

## 18.4 Personal Reflection

First and foremost, I am proud of the final result of this project. One of my main goals was to contribute to something meaningful and positive—in this case, helping to improve the environment. I didn't want to write a thesis that would end up on a shelf, never to be looked at again. With this project, I created something that will actually be put into production and used in the fight against plastic pollution. It's a product that is feasible, desirable, and viable, and I'm happy to see it goes beyond just being a concept. Along the way, I also learned a lot—about the design process, about writing, and about myself.

One of the biggest lessons I learned was the importance of working with a clear plan from the very beginning. For example, throughout most of the analysis phase, I let myself be guided by what caught my attention instead of having a structured approach. I would look at the tracker and just see where things took me. In hindsight, it would have been much better to decide upfront which aspects I wanted to analyze, what I needed for that analysis (e.g., tests, people to consult), and then execute that plan step by step. This would have made the analysis phase both faster and more complete.

The same applies to my writing. When I look back at what I submitted for the midterm, there was no clear structure. I was writing without a plan, and it showed. The story meandered without a clear ending in mind, either in my head or on paper. What really helped me later was applying the Pyramid Principle. Not only did this make my writing clearer for others, but it also gave me a better overview of my own work. In fact, I would go so far as to say that it changed the way I think. It's something I now apply not only to writing but also to how I communicate things to people in everyday life.

Another important thing I learned was to trust in my own abilities. In the first half of the project, I often hesitated to make decisions because I felt there was always more research I could do, or I doubted whether it was "okay" to make decisions as the sole person working on the project. This uncertainty slowed me down a lot. Over time, I realized that I needed to trust my judgment and move forward, even if I didn't have perfect information. Once I started doing that, my process became much smoother.

A smaller but surprisingly impactful change was learning to make use of lists. After my supervisors recommended a book by Adam Savage, I started using lists to organize my tasks. It sounds simple, but it helped me keep track of what I needed to do—not just for this project, but in my day-to-day life as well. It gave me clarity and helped me stay on top of both the thesis and my other activities.

In the end, this project wasn't just about creating a product. It was also about learning how to work more effectively, communicate more clearly, and trust myself. These lessons will stick with me long after this project, and I'm excited to apply them in future challenges.

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# 20. Appendix

## Appendix A: Project Brief

# IDE Master Graduation Project

## Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

### STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

| | | | | | |
|---|---|---|---|---|---|
| Family name | | IDE master(s) | IPD | Dfl | SPD |
| Initials | | 2nd non-IDE master | | | |
| Given name | | Individual programme *(date of approval)* | | | |
| Student number | | Medisign | | | |
| | | HPM | | | |

### SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

| | | | |
|---|---|---|---|
| Chair | | dept./section | |
| mentor | | dept./section | |
| 2nd mentor | | | |
| client: | | | |
| city: | | country: | |
| optional comments | | | |

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

### APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name _____ Date _____ Signature _____

**CHECK ON STUDY PROGRESS**

To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ____ EC

Of which, taking conditional requirements into account, can be part of the exam programme ____ EC

| | | |
|---|---|---|
| ★ | **YES** | all 1st year master courses passed |
| | **NO** | missing 1st year courses |

Comments:

Sign for approval (SSC E&SA)

Rik Ledoux — Digitally signed by Rik Ledoux Date: 2024.05.13 09:42:51 +02'00'

Name Rik Ledoux Date 13-05-2024 Signature

**APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM** -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

| | | |
|---|---|---|
| **YES** | ★ | Supervisory Team approved |
| **NO** | | Supervisory Team not approved |

Comments:

Based on study progress, students is ...

| | |
|---|---|
| ★ | **ALLOWED** to start the graduation project |
| | **NOT** allowed to start the graduation project |

Comments:

Sign for approval (BoEx)

Monique von Morgen — Digitally signed by Monique von Morgen Date: 2024.05.14 10:47:45 +02'00'

Name Monique von Morgen Date 14/5/2024 Signature

DESIGN FOR our future

TU Delft

# Personal Project Brief – IDE Master Graduation Project

**Name student** Stijn Wiltingh **Student number** 5170486

## PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

**Project title** Redesigning a Tracking Device for Researching Waterway Plastic Pollution

*Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.*

### Introduction

*Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)*

This project takes place in the domain of plastic pollution monitoring. Noria Sustainable Innovators research the movement of plastic through waterways like rivers and canals to understand how long it takes plastic to reach the ocean and identify hotspots where plastic waste accumulates. To conduct this research, Noria uses GPS trackers packed in PVC tubes that are placed in the water. These trackers send out coordinates periodically, allowing Noria to track the journey of plastic before it reaches the sea or gets stuck along the way.

Key stakeholders include:
- Noria: wants a reliable product with a professional appearance and a high recovery rate
- Noria's clients: accurate results and want to work with a professional company
- Flora & Fauna (birds, fish, plants, etc.): Trackers must not be harmfull or disruptive (also limitation)
- People deploying the trackers: easy-to-understand, foolproof deployment process
- Waterway cleaners & others who encountrer trackers: Prevent them from seeing tracker as pollution/removing it

Opportunities & Limitations:
+ Variants with different materials, shapes, buoyancy, etc. to simulate different pollution types
+ Features to increase recovery rate (lights, colors, RFID, waterproof, etc.)
+ Design to self-right, ensuring the GPS module is always above the waterline (more reliable signal)
+ Design to be deployed by external people (instructions, intuitiveness, foolproof)
+ Dashboard with information can be taken into consideration/designed
- Budget & regulations
- Almost impossible to simulate all types of floating plastic waste
- Getting trackers unstuck (if desired) is complicated to do remotely

➔ *space available for images / figures on next page*

*introduction (continued): space for images*

click to add picture

image / figure 1 Current GPS tracking module (PVC pipe that houses the trackers with a label to inform who finds it)

image / figure 2 CirCleaner machine used to scoop floating plastic out of the water

DESIGN FOR our future

TU Delft

# Personal Project Brief – IDE Master Graduation Project

**Problem Definition**

*What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.*
*(max 200 words)*

The current tracking device, a PVC tube with a label, lacks professionalism and is often mistaken for plastic waste. Its design can submerge the tracker below the waterline, preventing consistent data transmission and compromising data accuracy. When recovering trackers after they get stuck or after the research period has passed, they are sometimes not found, for example because they are concealed by vegetation or stuck underneath a jetty. This then further pollutes the environment rather than help clean it. Additionally, the PVC tube housing may leak, causing loss or damage to the tracker.

As an Industrial Designer, my graduation project aims to solve these issues and identify other potential problems. I will explore potential solutions to the existing issues and propose a redesign of the tracker that looks professional and suits the research environment it will be deployed in. Furthermore, I will seek ways to add value to the product and its service for the main stakeholders of the project by also looking outside of the scope of the physical GPS tracker. This could involve the design and content of the dashboard, ensuring that deployment by external people works succesfully, and questioning/rethinking the current system of which the tracker is a part.

**Assignment**

*This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:*

*Redesign a GPS tracker for Noria Sustainable innovators that is used for researching plastic pollution in waterways such as rivers and canals to improve functionality and professional image, and to increase the value it has for its stakeholders.*

*Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)*

*For this project I plan to use the Double Diamond design process to go through the different stages of the project.*

*For the approach I plan to implement an User-Centred Design & Agile approach. The first to ensure that the needs of the users and stakeholders are taken into account in design, and the second in the sense that I aim to quickly iterate, and test prototypes & assumptions. I will design solutions for every identified failure mode to effectively address existing issues.*
*Business aspects will not be one of the mayor focus points in this project.*

*There is a multitude of design methods that could be implemented in this project. These methods will mainly revolve around understanding the problem (interviews, product & context analysis, lists of requirements, etc.), exploring solutions (brainstorming, conceptualizing, low-high fidelity prototyping, etc.), and testing assumptions and proposed solutions (simulations, real-world testing, prototype reflection cards, etc.). In this project I want to focus on building prototypes and testing a lot in order to end up with a design proposal and prototypes meeting the requirements to be a useful research tool creating added value for Noria and the stakeholders of the product.*

**Project planning and key moments**

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

*Make sure to attach the full plan to this project brief.*
*The four key moment dates must be filled in below*

| | |
|---|---|
| **Kick off meeting** | 30/04/2024 |
| **Mid-term evaluation** | 25 Jun 2024 |
| **Green light meeting** | 20 Aug 2024 |
| **Graduation ceremony** | 17 Sep 2024 |

*In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project*

| | |
|---|---|
| Part of project scheduled part-time | |
| For how many project weeks | |
| Number of project days per week | |

Comments:

**Motivation and personal ambitions**

*Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).*

*Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.*
*(200 words max)*

For my graduation I want a project with a focus on embodiment design that allows me to showcase current skills, and develop new ones in the process. I want the work that I do to have a positive impact and I believe that addressing sustainability is a good way to do so. The assignment allows me to implement a wide range of skills and has a focus on the embodiment phase of product design in which I want to develop myself the most during this project. I aim to do so through prototyping, testing, and developing the product as far as possible within the boundaries of the project.

During the project I want to work in a structured way through planning, managing the project, and utilizing proven design methodologies to guide design decisions. This is something that thus far has not been my strong suit and want to learn to do for this project.

Additionally, I want to learn about different production methods, materials and processes and when to implement each one. I also hope to improve my skills in creating renders of my designs through using Blender. In previous projects I have not worked a lot with electronics, however I want to implement this in my prototypes and design for this graduation project.

Lastly, I want to gain a deeper understanding of the plastic pollution problem, and how to solve it as I can envision myself addressing this issue through my work later in life.

## Appendix B: Signal Reliability, Temperature and Recovery Testing

# Test Plan

## Goal

There are three main things to be tested.
Firstly, reliability of the signal. Various prototypes have been made aimed at improving the reliability of the GPS signal transmitted by the tracker. The aim of this test is to evaluate which design performs the best and then define design principles that can be implemented in the final design to ensure it consistently sends out its coordinates. For this test, two 3D-printed inserts that fit in the currently used PVC tubes are chosen as they performed the best in preliminary testing and will thus most likely be successful in improving signal reliability. There is also a limited number of trackers available to test with, which is why only two could be chosen. Another goal is to test the hypothesis that signal reliability is improved when the antenna is kept above the water level.

Secondly, the aim is to find whether the trackers reach temperatures over the operating temperatures of the hardware as this may also cause reliability issues. If this is the case, or if it gets close to these values, it will be taken into account in the redesign of the floating tracker.

Lastly, use of the AirTags in the intended environment will be tested. The aim here is to test out this new feature and evaluate how helpful it is to find trackers and to discover potential issues.

## Method

In total, four trackers and three different variants were tested. Two variants are 3D printed prototype inserts that can be put inside the current PVC tube. The third (which is used twice) is the currently used GPS tracker. The prototypes were designed based on the assumption that ensuring the GPS antenna remains above the waterline will improve the signal reliability. One prototype (and the currently used floating tracker) uses the Lightbug Pro tracker as is, while the other prototype uses a disassembled version that uses two batteries (the original Lightbug Pro tracker has one battery). All trackers are designed to float horizontally, although the original tracker design tends to float diagonally due to its tendency to slide to one end of the PVC tube.
The prototype using the disassembled Lightbug Pro tracker has its weight concentrated at one side (batteries) and the PCB with the antenna on the other. This should give the tracker self-righting possibilities and keep the antenna above the water line. Another prototype suspends the Lightbug Pro tracker in the middle of the tube. The three different versions are shown in Figure 1.



*Figure 1: Three versions of Noria's tracker used in signal reliability testing; Original (top), Suspended (right), Self-Righting (left).*

*One floating tracker (the disassembled, self-righting version) has an AirTag (see Figure 2) inside while the other two used a Samsung Galaxy Smarttag. Although the main goal was to test the AirTag, the Smarttags were used so that the two could be compared, and because it might help locate the trackers if they are hard to find. Table 1 provides an overview of the different tracker versions. The names shown in the left column will be used in the remainder of this test report.*



*Figure 2: AirTag inside the floating tracker housing (PCB is wrapped in red protective film).*

*Table 1: Overview used trackers*

| | Description | Recovery Tag |
|---|---|---|
| Original | Tracker as currently used by Noria | Samsung Smarttag |
| Suspended | suspends the tracker in the middle of the tube | Samsung Smarttag |
| Self-righting | Separates battery (mass) and the antenna to ensure it stays above the water level | Apple AirTag |

The trackers will be released into Buitenwatersloot in Delft and left there to float around freely for 2 full days (48 hours) (see Figure 3). The Buitenwatersloot was chosen as there are no large ships using this waterway which could hinder retrieval of the tracker. It is also relatively narrow which makes it more likely that the trackers can be retrieved without needing to use a boat which would bring along extra challenges (transporting the boat, releasing it into the water somewhere, etc.) The trackers will not be fixed with for example a rope to simulate a real-life scenario as accurately as possible and so that finding the tracker using the AirTag can be tested. After the testing period, the GPS data will be compared to see which prototypes were most reliable at transmitting their data. In addition to this, temperatures will also be recorded to determine whether temperatures in the tube exceed the operating temperatures of the hardware (60°C). This testing is done during relatively warm days (@28°C). It will also be evaluated to what extent the AirTag was useful in helping to locate the trackers. This testing will be conducted twice to generate more data and to improve the reliability of the results.



*Figure 3: trackers being released in the Buitenwatersloot.*

The day before testing in the Buitenwatersloot, a separate test focused on temperatures was conducted where one tracker was placed on land and one was placed in the water, attached to a

rope. This test was done because of the more extreme conditions during that day (33°C, UV-index 7). Testing in the Buitenwatersloot was done the day after due to technical issues with the trackers.

After analysing the data, design principles will be identified that can be used in the final design for Noria's new GPS tracker.

## Risks and mitigation

- Loss of the tracker (due to sinking, loss of signal, or being obscured from sight)
    - All caps will be screwed on tightly
    - Plastic bags will be used inside the tubes to further protect the hardware from damage
    - The chosen canal is relatively narrow which narrows down the search area and will likely allow the trackers to be retrieved from the embankment. There is vegetation but no reed (which is likely to hide trackers from sight). If necessary, the height between the embankment and water seems to allow you to lower down a small boat.
    - The chosen canal flows quite slowly so that trackers are more likely to be found if they lose their signal.
    - The chosen designs performed the best in preliminary testing and should thus transmit a signal. This will also be tested beforehand in controlled conditions.
    - Trackers are charged beforehand to prevent them from running out of battery

- Removal of tracker from the water
    - Original PVC casings are used that contain information and instructions
    - The research lasts for only two days which reduces likelihood of removal

## Hypotheses

- The horizontally floating tracker where the batteries are separated from the PCB is expected to perform the best as it has self-righting properties and should ensure the antenna remains above the water level.
- The horizontally floating tracker that suspends the Lightbug Pro in the middle of the PVC tube is expected to perform worse than the disassembled, self-righting design but better than the original. The antenna is located in one corner of the box-shaped housing of the Lightbug Pro. This means that it might end up below the water level as the tube rotates in the water. The center of gravity of the Lightbug Pro tracker is located toward the bottom of the casing, meaning that the center of gravity of the suspended tracker design is also located slightly to one side. This gives this design some self-righting properties, but (as also showed in previous testing (REFER TO THIS IN REPORT) not nearly as strong as the prototype using the disassembled version of the Lightbug Pro. The antenna is also located much more to the center of the PVC tube.

- Temperatures could reach above 60°C inside the tube, considering how warm, for example, a car gets when parked in the sun. If this is true it might be the reason - or it might contribute to - signal reliability issues.
- The AirTag will be helpful in determining the location of the tracker as it uses UWB technology which provides distance and direction of the tracker.

# Test Results

## Signal Reliability

After two days of monitoring, the results in terms of reliability proved that the version which uses the disassembled Lightbug Pro tracker is significantly more reliable. This is likely caused by the fact that its design ensures that the antenna remains above the water level.

To determine reliability of the signal, the data was analysed to identify how many data points it had gathered in two days (maximum is 49 as it records at an 1-hour interval, first datapoint is recorded after 0 hours) and how many of these data points are approximate (this is the case when the tracker fails to find GPS and uses GSM instead). Approximate locations are much less accurate, usually ranging between 100 and 1000 meters in accuracy (as indicated by Lightbug's portal), making this data largely useless. In most cases, floating plastic debris will not be displaced these distances within an hour (the interval at which the trackers transmitted a signal). For this reason, we will consider approximate locations as missed data points. Table 2 provides information about the reliability performance for the different tracker versions

*Table 2: Signal Reliability for different trackers*

| | Data points | Successful Transmissions | Reliability (in %) |
|---|---|---|---|
| **Original tracker – Test 1** | 48 (1 missed) | 20/49 | 40,82% |
| **Suspended tracker – Test 1** | 49 (0 missed) | 23/49 | 46,94% |
| **Self-righting tracker – Test 1** | 49 (0 missed) | 42/49 | 85,71% |
| **Original tracker – Test 2** | 49 (0 missed) | 19/49 | 38,78% |
| **Suspended tracker – Test 2** | 49 (0 missed) | 29/49 | 59,18% |
| **Self-righting tracker – Test 2** | 49 (0 missed) | 37/49 | 75,51% |
| **Original tracker – Cumulative** | 97 (1 missed) | 39/98 | **39,80%** |
| **Suspended tracker – Cumulative** | 98 (0 missed) | 53/98 | **54,08%** |
| **Self-righting tracker – Cumulative** | 98 (0 missed) | 79/98 | **80,61%** |

As can be seen, the disassembled, self-righting tracker design has (more than) double the signal reliability compared to the original design (average over the two tests). The suspended tracker shows an improvement compared to the original tracker (mainly in the second test). Why the suspended tracker shows such an improvement in the second test compared to the first test is not clear. It is however worth noting that this tracker started moving a significant distance at around 11 p.m on the second day of its deployment (likely it was stuck in vegetation or behind a boat and became dislodged at this point) before getting stuck between a boat and the embankment 1800 meters downstream (see Figure 4). around 12 hours later, where it was finally retrieved at the end of the test. The other two trackers remained in approximately the same location.

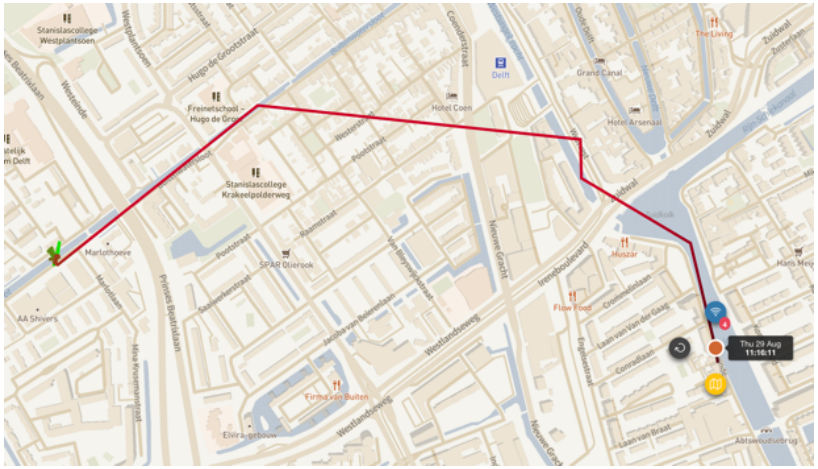



*Figure 4: Travel path of the suspended tracker (LightBug - IoT & Tracking Portal, n.d.).*

It can however not be said that this movement would have increased the reliability of this tracker as there were eight approximate (inaccurate and useless) locations transmitted within this 12-hour period.

Important to note is that the self-righting design used two batteries, making it heavier and thus submerged further compared to a one-battery design such as the original tracker and the suspended tracker. This should negatively influence the signal reliability of the tracker, making it even more notable that this version of the floating tracker shows such a high reliability compared to the other two.

Furthermore, this finding supports the theory that the low reliability of the original tracker design is caused by the antenna being positioned below the water level during its deployment.

Another interesting finding is that biofouling (bacterial/algal film growing on a plastic particle which affects density and buoyancy (Noria Sustainable Innovators, 2024; Deltares, 2019)) on the PVC tubes seemed to show how consistent the floating orientation of the trackers were. The disassembled, self-righting tracker, which is expected to be the most stable in his regard, showed a clear line above which biofouling had started to occur (see figures 7 & 8). The original tracker showed this to a lesser extent (see figures 5 & 6), whereas the suspended design showed no biofouling at all, likely because it had rotated during the 48 hours (about 2 days) it was in the water (see figures 9 & 10).



*Figure 5: biofouling on the original tracker design (Test 1).*



*Figure 6: biofouling on the original tracker design (Test 2).*




*Figure 7: biofouling pattern on self-righting tracker (Test 1).*




*Figure 8: biofouling pattern on self-righting tracker (Test 2).*



*Figure 9: no biofouling on the suspended tracker design (Test 1).*




*Figure 10: no biofouling on the suspended tracker design (Test 2).*

When looking at the biofouling pattern left on the PVC tube of the self-righting tracker after Test 2, it can be concluded that

this tracker must have floated at an angle (see figure 8)

Although this tracker should be (relatively) balanced, there is some room (approximately 10mm) inside the PVC tube for the 3D-printed insert to slide around. In addition to this, the side with the screwcap is heavier as well due to the added material. These two factors are likely the reason why this occurred. From Table 2 it can further be seen that the signal reliability in the second test was about 10% lower compared to the first test. It is likely that this was caused by the tracker floating at an angle which would have reduced the clearance between the antenna and the water level.

Although the screw caps had been screwed on tightly, the original tracker design leaked some water inside the tube (see Figure 11). This occurred in both tests which means there is likely something wrong with this PVC tube casing. This could be an imperfection of the rubber waterproofing strip or a leak in the glue connection that fixes the bottom cap to the rest of the tube.



*Figure 11: water leakage inside the PVC tube housing.*

# Temperature

## Separate temperature test

The highest measured temperature was 47.91 °C. This value was measured during the separate temperature test by the tracker that was placed outside in the sun on a concrete floor during a warm day (33°C, UV-index 7). This value is actually close to the temperatures that were measured when the trackers were activated in the Lightbug portal (likely due to higher power consumption as a result of activation and connecting to Lightbug servers), and do not raise concerns as they do not come close to the 60°C limit for the operating temperature as indicated by lightbug (Lightbug, n.d.). In comparison, the highest measured temperature for the tracker that was placed in the water was 43.17 °C. After this tracker was removed from the water and placed back inside, it still measured 41.74 °C, suggesting that the highest temperatures are largely dictated by the trackers' own processes such as connecting to GPS, rather than external factors like sunlight or temperature of the atmosphere.

**Average temperature tracker on land:** 43.41 °C
**Average temperature tracker in water:** 33.47 °C

Looking at the average temperatures for both trackers, it can be seen that the tracker in the water was significantly cooler on average (-9.94 °C). This can be caused by the cooling of the tracker by water, but it is also possible that it was caused by shadow. The tracker in the water was fixed to a piece of rope and placed in the sun but could still move around to an extent which might have moved it into the shadow of the embankment.

Both trackers did, however, stay clear of the upper limit of 60 °C.

## Buitenwatersloot test

During the tests in the Buitenwatersloot, no "extreme" temperatures were recorded. This is likely the case because the trackers had been activated for a while and were thus more stable. During this test period, atmospheric

temperatures were also slightly lower (@28°C) and the weather was cloudier. There was supposed to be a tracker placed on land during this period as well, but one of the trackers became unresponsive just before the test was planned. Below, average -, and highest temperatures for the trackers placed in the water during this test are shown in Table 3.

All three trackers reported similar temperatures during this test, aside from a slight outlier in the maximum temperature of the disassembled, self-righting tracker during Test 2. Temperatures stayed well clear of the 60°C upper limit.

*Table 3: Recorded temperatures Buitenwatersloot test*

| | Avg. Temp. Test 1 | Max. Temp. Test 1 | Avg. Temp. Test 2 | Max. Temp. Test 2 |
|---|---|---|---|---|
| **Original tracker (ID: 20002750)** | 25.36 °C | 28.74 °C | 22.28 °C | 25.14 |
| **Suspended tracker (ID: 20003387)** | 25.47 °C | 28.78 °C | 22.80 °C | 27.78 °C |
| **Disassembled, self-righting tracker (ID: 20004835)** | 24.75 °C | 29.07 °C | 22.80 °C | 31.56 °C |

## Recovery

The AirTag proved to be a helpful tool for locating trackers. Although the tracker that was fitted with the AirTag was not obscured from sight (in both test), the iPhone used in conjunction with the AirTag quickly found the signal and provided an accurate distance and direction for the location of the tracker (see Figure 12).

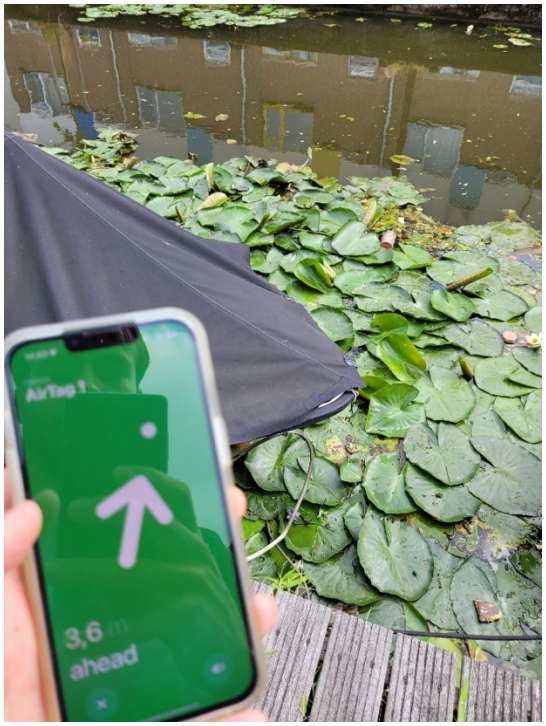



*Figure 12: AirTag providing distance and direction for the location of the tracker (visible in vegetation).*

The distance and direction that is indicated by the AirTag is only shown when the user is in close proximity to it. Typically, this information became available between 4- and 5-meters distance to the AirTag. The typical accuracy of the GPS location from the Lightbug Pro tracker is 0.5-5 meters (Lightbug, n.d.). Noria employees who work with these trackers have also confirmed this to be correct. This means that if the user travels to the GPS location provided by the Lightbug tracker, they should usually already be in range for the AirTag to point them to the tracker's exact location. If this is not the case, a short walk along the embankment should bring the AirTag in range.

Compared to the Samsung Galaxy Smarttag, the AirTag was much more helpful as it provides a distance and direction whereas the Smarttag only tells the user whether they are moving closer or further away from it. It was more confusing than helpful as it once stated that the tracker was moving away further even though I was walking toward it (see Figure 13).

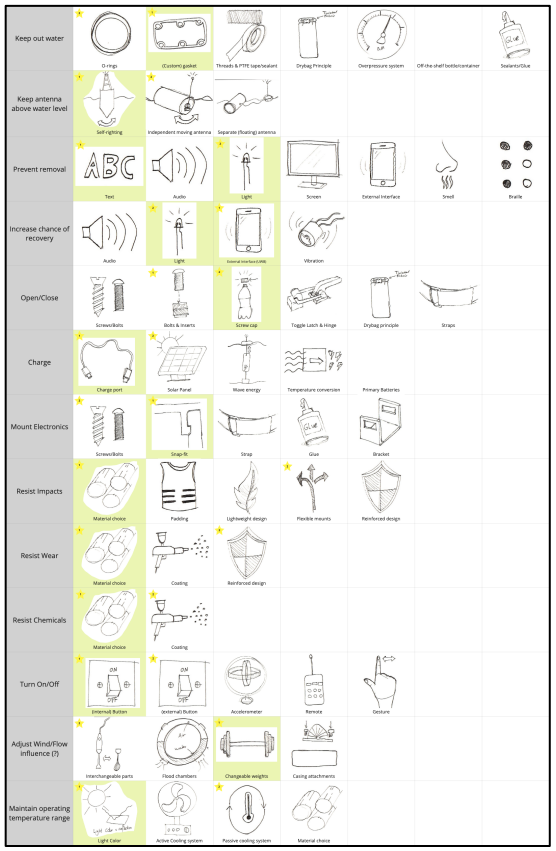


*Figure 13: Incorrect information of Samsung Galaxy Smarttag*

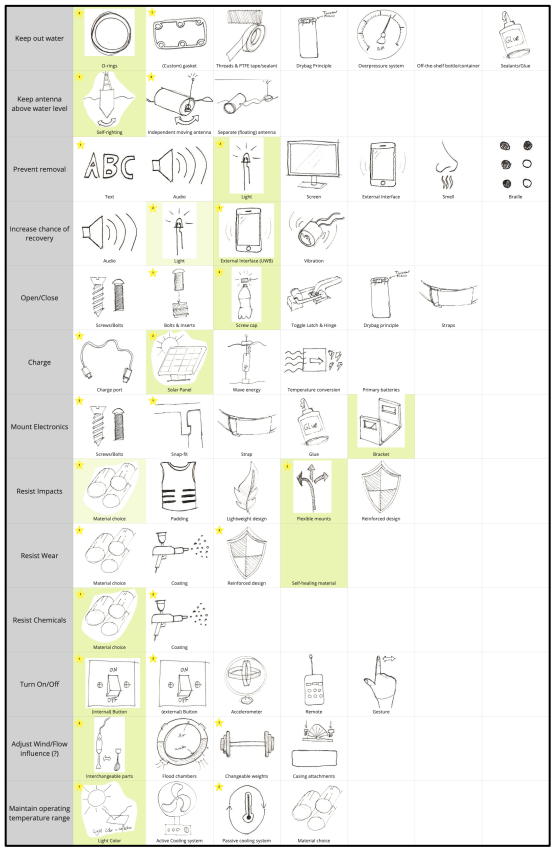
# Conclusions

- The self-righting tracker design used in this test which ensures the antenna remains above the water level results in a much higher signal reliability. This design principle will be applied for the design of the floating tracker. Its performance will be tested in the future to validate the reliability of the final design.
- Properly balancing the weight of the tracker is important to ensure a horizontal floating orientation, which is important for achieving a high signal reliability
- As expected, the “suspended” version performs better than the original but not as well as the “self-righting” version.
- Over-heating of the trackers proved to not be an issue during the tests. Since the first (temperature) test was conducted in quite harsh conditions, and all tests were conducted during summer, it is concluded that heat management does not require further attention for now. During testing of the final design, temperatures during deployment will however be analysed again.
- The AirTag proved to be a helpful tool for locating trackers in the water and will be integrated in the redesign of the floating tracker.

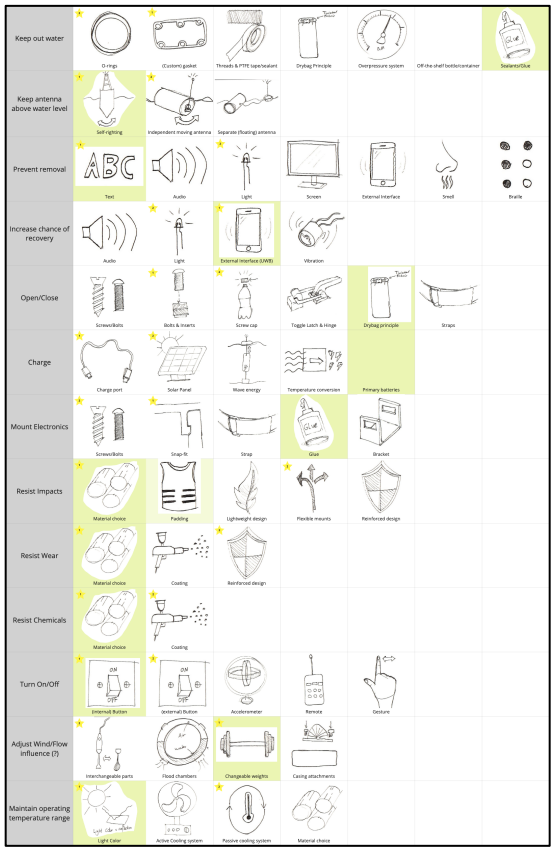
# Appendix C: Morphological Charts



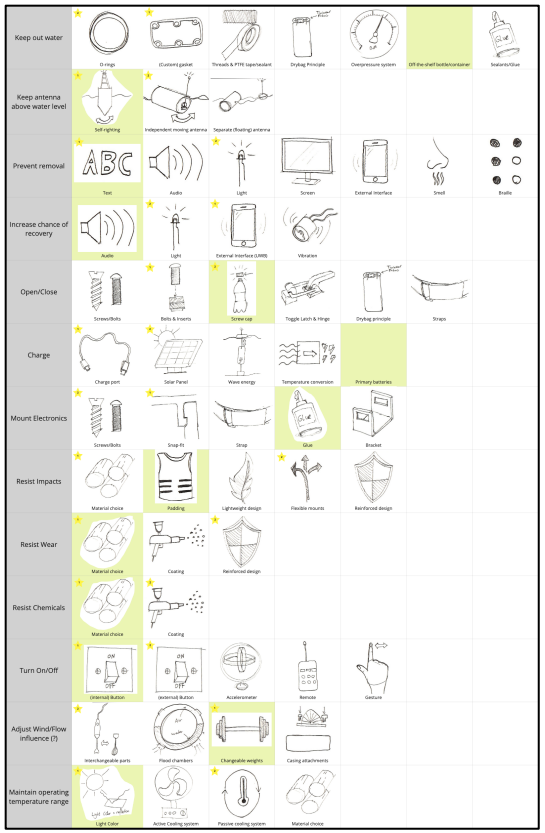

*Morphological Chart for "Intuition" concept*



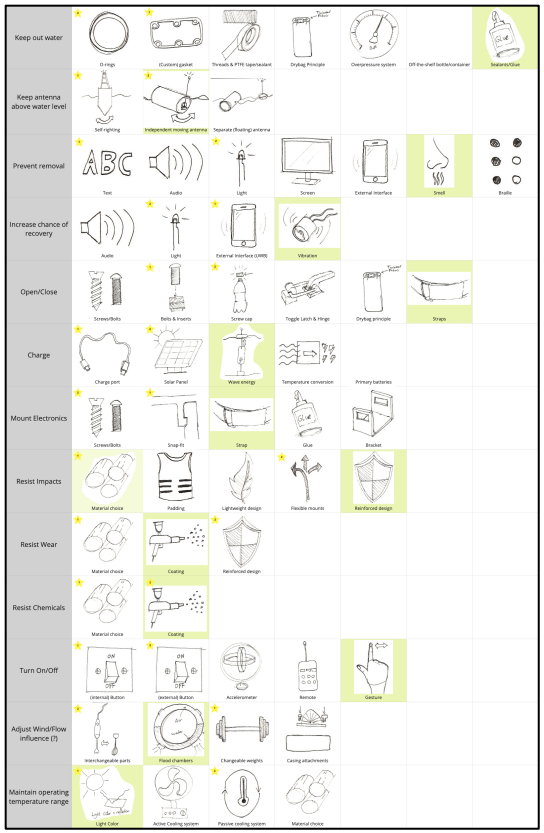

*Morphological Chart for "Unstoppable" concept*



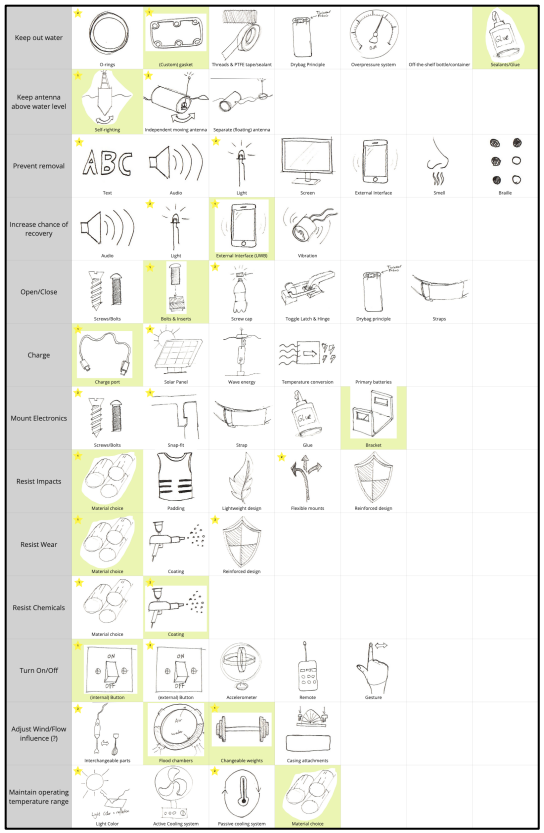

*Morphological Chart for "Low-Cost 1.0" concept*



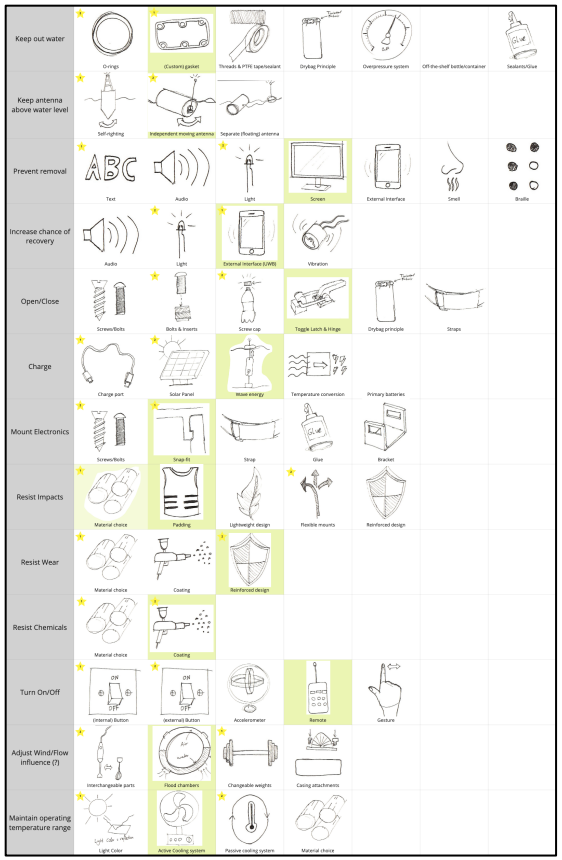

*Morphological Chart for "Low-Cost 2.0" concept*



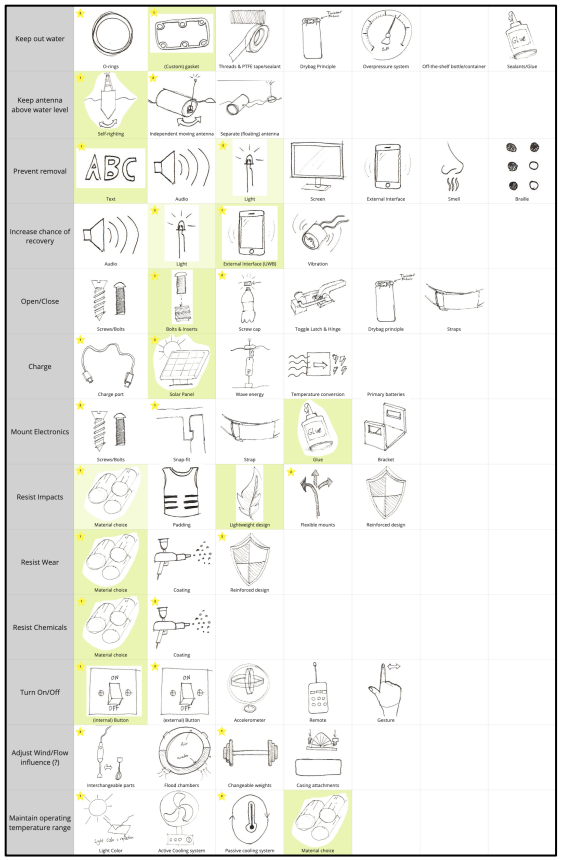

*Morphological Chart for "Outlandish" concept*



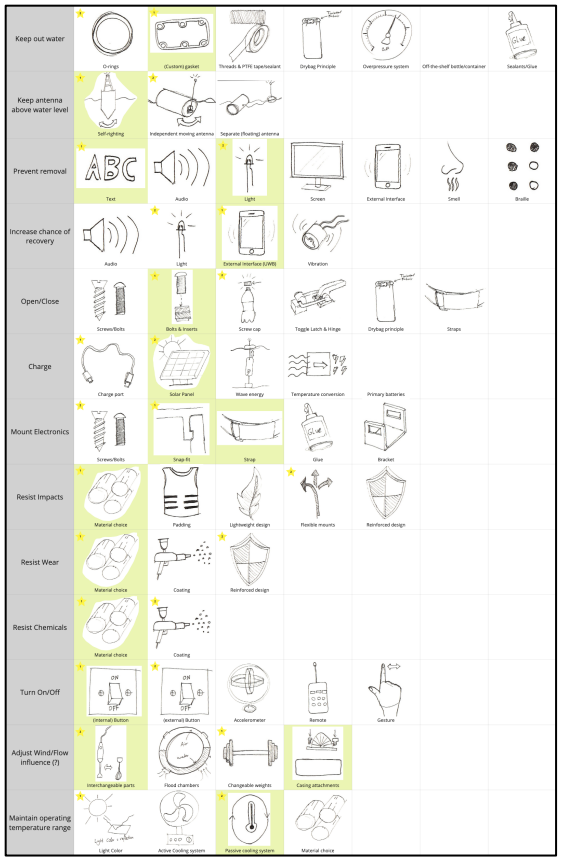

*Morphological Chart for "Stealth" concept*




*Morphological Chart for "Premium" concept*




*Morphological Chart for "Long Distance" concept*




*Morphological Chart for "Modular" concept.*

## Appendix D: Mood boards generated using Dall-E 3








PRACTICAL & COCTIVE MANTERIALS
ACCESSIBLE PRODUCTURING
AASSE OF MANUFACTURING
AND PRODUCTION METHODS


PRODUCTIONS








PRODUCT DESIGN
COLLABORATION
COLLABORATION
SOLLAINABUE
METERIALS
SULLAINATTION




PRODUCT DESIGN
PRODUCT DESIGN
PRODUCT DESIGN


RESEARCH DEVICE
EFFIENT PRODUCTIOIONS
POLYCARBON
EFFIENT PRODUCTION METHODS




GPS
Tracker
Floating
plastic
debsic
Floating
plastic
Recyclable
plastics
Recycled
plastics
GPS transport

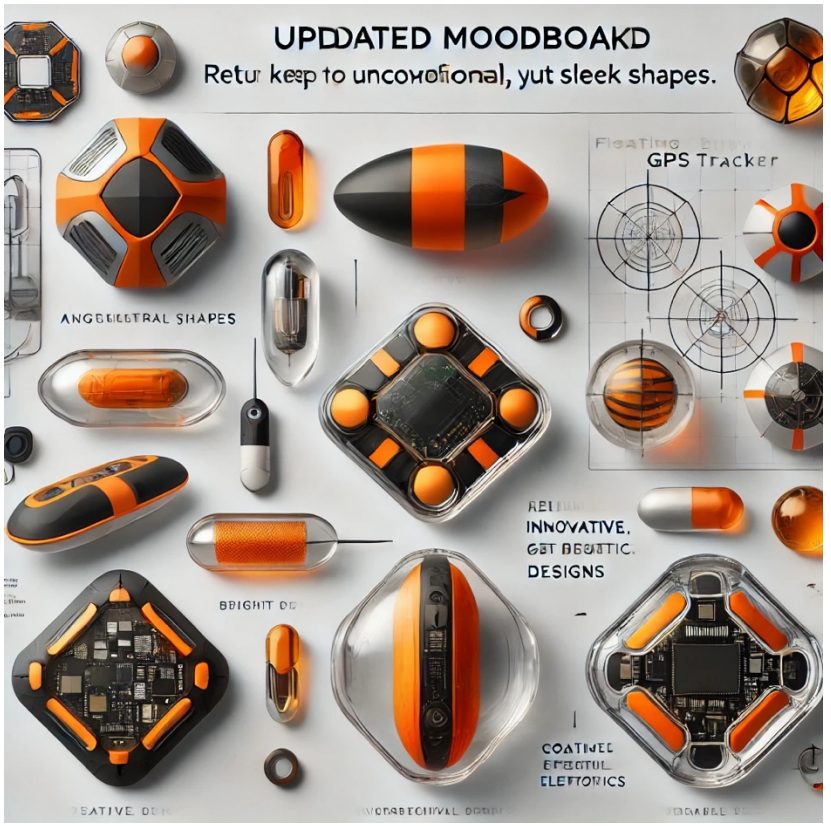

Simulating plastic debris transport
Transport in Riverine environments


Floating
Hydrodybic
GPS Tracker
Sleek
Hyatodpraoof
Constructions
Fermible
Plastics
Funtuible
Punstprable
Contructions
Momulable
Polycpatics
Functable
Polycanbatles
recycled plastics


PLASTICS
PLASTIC
INFLATEDE
PLASTICS
PLASTIC
PLASTICS


Simulating Plastic Debeise
Transport
Plastic Tracker
Simulatinl Plestic
Internal Plastics


Floating
GPS Tracker

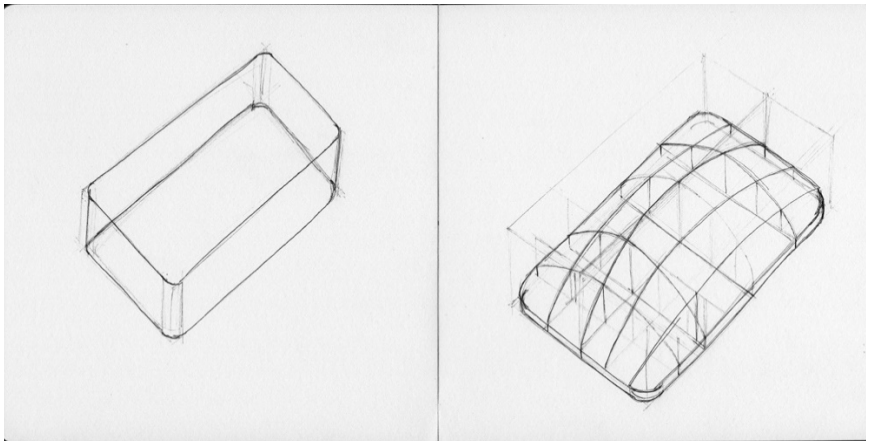

UPDATED MOODBOARD
GPS Tracker
INNOVATIVE,
DESIGNS

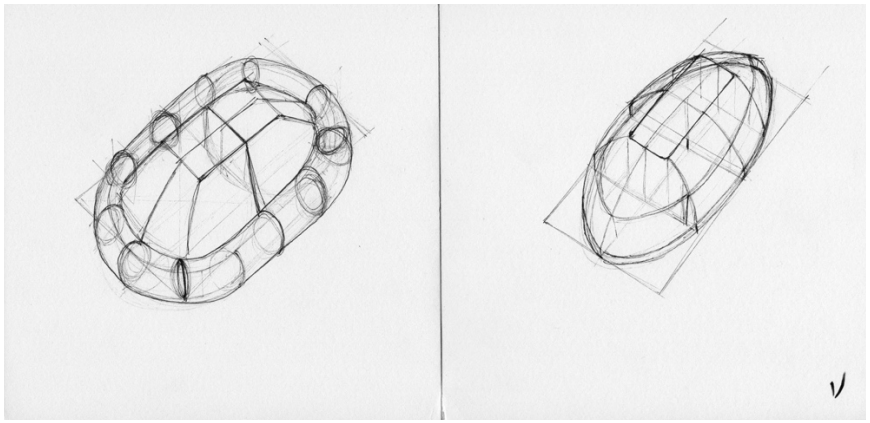

Innovative
GPS Tracker

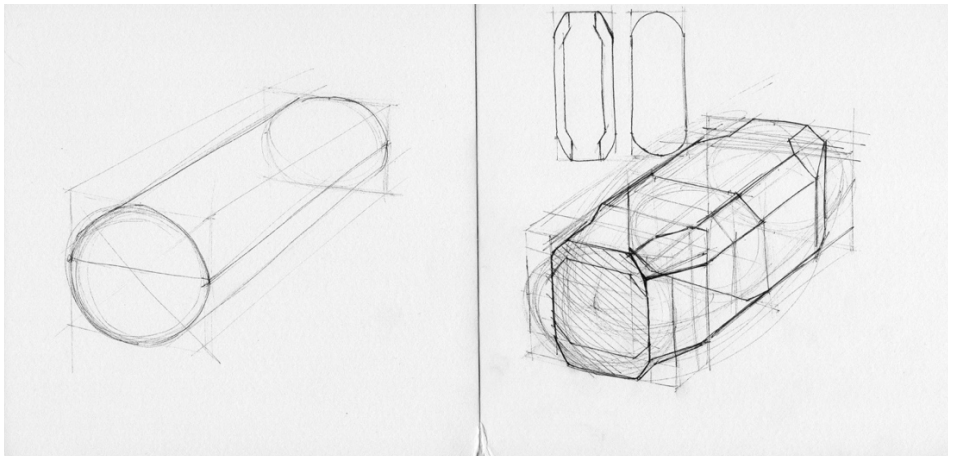

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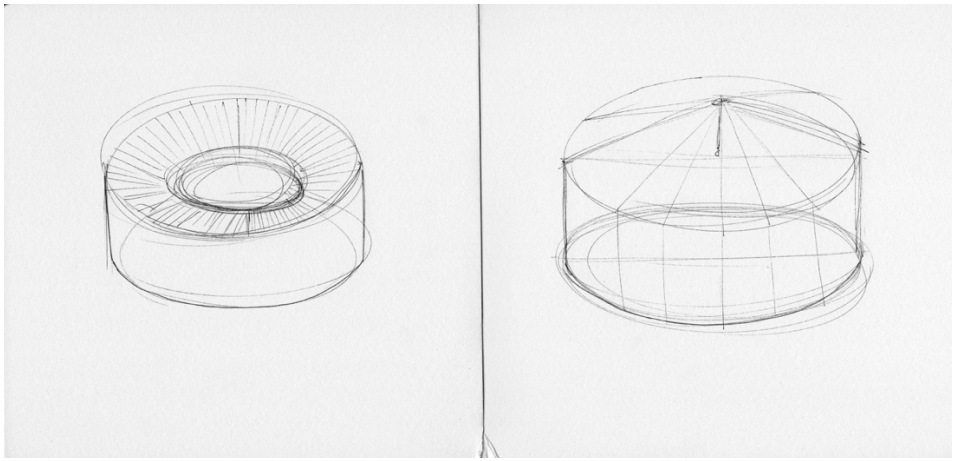

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VISIBLE INN SHAPES

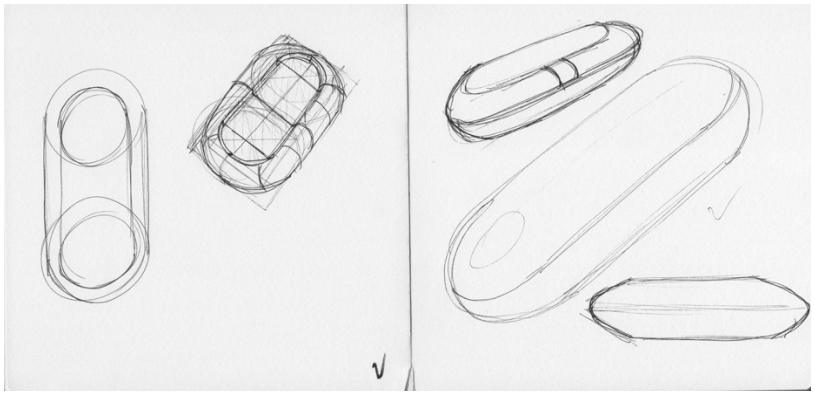
## Appendix E: Form Exploration Sketches

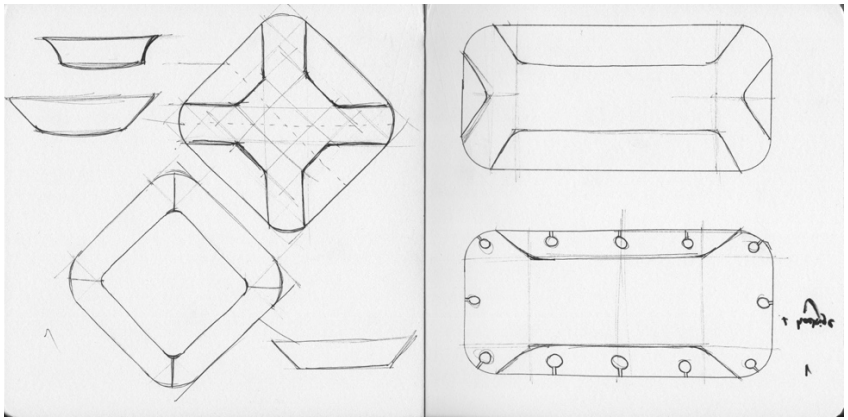


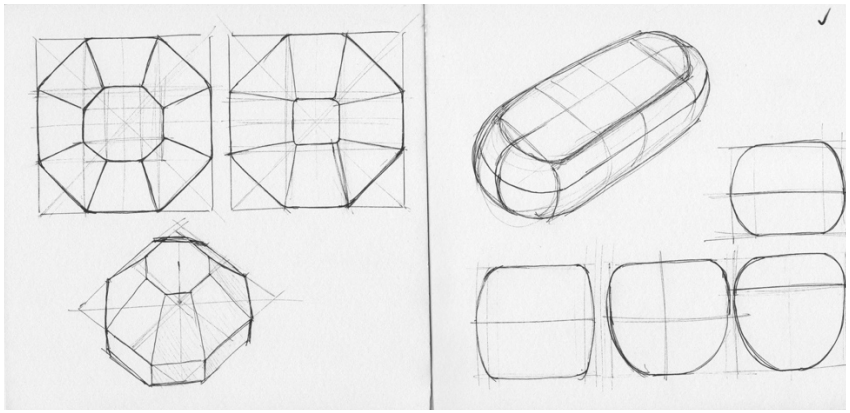


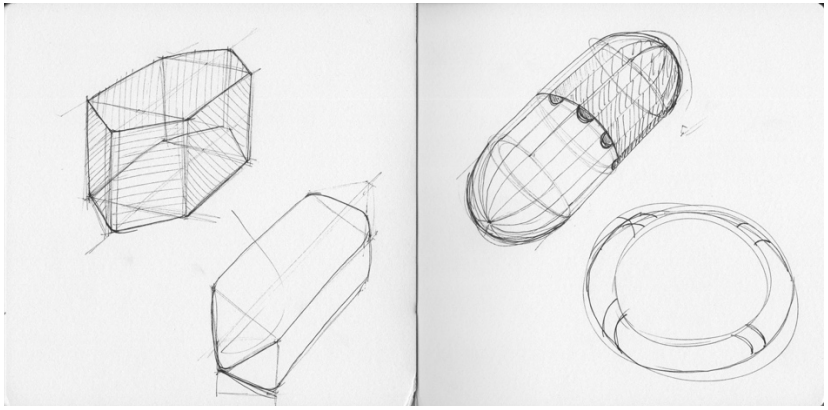


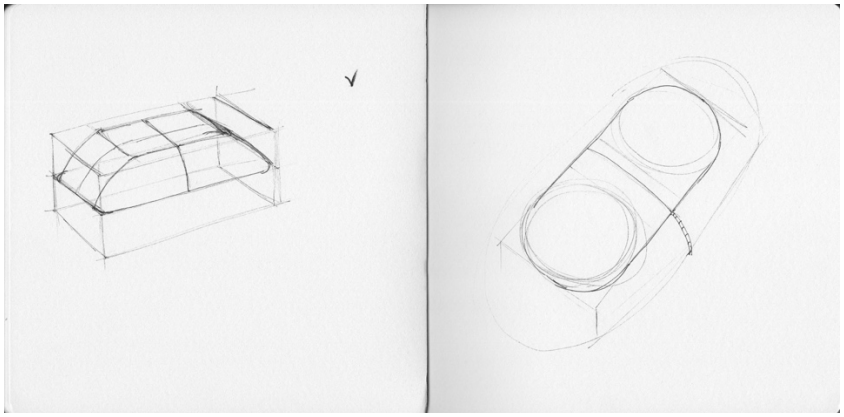




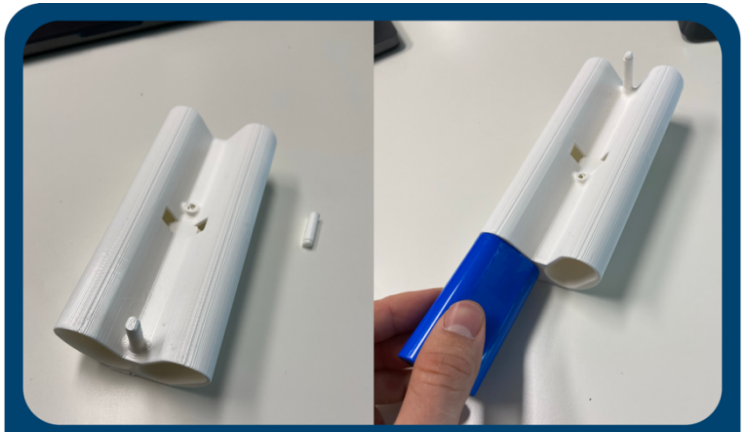








# Appendix F: Prototype Reflection Cards



**CONTEXT OF PROTOTYPE**

This prototype was created to tackle the issue of an unreliable signal that is likely caused by the submersion of the GPS module below the water line. The prototype is a 3D printed bracket that fits inside the currently used PVC tube to test this assumption. This design assumes a horizontally floating tube that should self-right due to the weight of the batteries on one side. The PCB is mounted higher to hopefully keep it above the water line.

**PURPOSE OF TEST**

To test whether the self-righting design works properly and if the PCB stays above the waterline (height in the design and bouyancy with 4 batteries).

To see whether the mounting method for the PCB and batteries works and if it can be assembled reasonably easily

**KNOWLEDGE GAINED**

Could not be properly tested as it requires refinement.

PCB mounts broke off due to the directions of the layers. Will print them sideways and as separate parts so that they can be replaced. Can do with a slightly looser fit.

Batteries do not fit due to layer directions which causes the cavity to not have smooth and accurate edges. Will adjust print direction.

**REFLECTION ON PROCESS**

The design, with relation to the production method (3D printing) could have been considered more. I have enough knowledge of the technique to have anticipated these issues.

On the other hand it is good to try things out, especially when it can be done with such low cost and effort as 3D prints.

**THREE TAKE-AWAYS**

layer direction is very important to make parts fit together

layer direction needs to be considered in relation to the direction of the load that is applied to a part

PCB mounting can be a bit more flexible and possibly replaceable

**REMAINING QUESTIONS**

How does this design behave in the water?

How easy is it to assemble?

Will this design allow the tracker to send out a more consistent signal?

06-05-24



**CONTEXT OF PROTOTYPE**

This prototype houses the AirTag, multiple prototypes with slightly different dimensions were made.

Prototypes are made of PLA using a FDM printer.

**PURPOSE OF TEST**

This prototype was mode to test the correct dimensions for a friction fit for the AirTag.

**KNOWLEDGE GAINED**

A friction fit is feasible and allows for easy mounting of the AirTag, without needingf additional materials.

The correct measurements. Might need to be altered slightly when using a different production method.

**REFLECTION ON PROCESS**

Quick and easy way to test the fit.

**THREE TAKE-AWAYS**

General dimensions are known after this test.

Might need to be altered when using for example a SLS printer.

A friction fit works well for this.

**REMAINING QUESTIONS**

How different will the dimension be for the chosen production method?

02-10-'24




## CONTEXT OF PROTOTYPE

This prototype was created as part of the conceptualization phase. Instead of sketching this idea could easily be realised through prototyping which does a better job at conveying ideas.

It uses a reusable water bottle for a housing. Electronics are placed inside with some foam for protection and maintaining the position of the electronics.

The concept was to keep it very cheap.

## PURPOSE OF TEST

To try out a concept focused on budget and have it as a physical thing.

Prototyping gives more insight than a sketch.

## KNOWLEDGE GAINED

It is technically possible to make a floating tracker very cheaply

Desirability as well as performance would likely suffer.

An off-the-shelf case that is reliable waterproof would be quick and easy, but other than that it will perform worse that is designed for a purpose.

## REFLECTION ON PROCESS

Good way to test out and show new design. Whenever possible, prototyping is usually better than sketching.

Doing this "exercise" forced me to think in a different way of how design can be simplified or made cheaper which is a valuable lesson.

## THREE TAKE-AWAYS

Will not work (well) as the actual design.

Thinking of ways to make the design simpler or cheaper is important.

Off-the-shelf casings might be cheap but will not result in a good product.

## REMAINING QUESTIONS

What can be simplified about the tracker design?

Where can we use off-the-shelf parts that will not lower the quality of the design?

28-08-'24



## CONTEXT OF PROTOTYPE

A first, somewhat crude prototype for the new aesthetic design aimed to hint to the looks of a lifebuoy. It lacks most functional aspacts but is focused on evaluating the aesthetic. The bottom is rounded to be more similar to for example a plastic bottle while the top looks like a buoy for aesthetic reasons

## PURPOSE OF TEST

This prototype was created to get a feeling for how this design looks like before detailing the design to be functional which costs considerable time.

## KNOWLEDGE GAINED

The buoy like design has potential and will be detailed further after additional validation.

The more rounded bottom (compared to the top half) has the issue that it takes up less volume whic reduces buoyancy. A future design will be more symmetric.

When spray painting a prototype, use primer and perferrably sand it.

## REFLECTION ON PROCESS

When spray painting a prototype, use primer and perferrably sand it.

This served as a quick and easy way to get a feeling for the new design

## THREE TAKE-AWAYS

Buoy-like design will likely be continued (depending on validation).

Bottom half should be more symmetrical compared to the top half for buoyancy (but it also looks better i.m.o.)

For a proper-looking aesthetic prototype, more time needs to be taken to result in a higher-quality-looking part.

## REMAINING QUESTIONS

What symbols, text, etc. should be used to prevent removals?

What will the aesthetic qualities be after using a proper production method?

02-10-'24



## CONTEXT OF PROTOTYPE

After choosing a concept direction these foam models were made to explore form and to be able to validate this with stakeholders. The models are made of hard foam and processed with power tools and hand tools.

## PURPOSE OF TEST

To explore form and validate this with stakeholders in order to determine what the aesthetic design of the tracker will be like.

I tried to separate the form from other aesthetic qualities like color and texture as there are otherwise endless combinations that can be made

## KNOWLEDGE GAINED

Simpler shapes are generally associated with plastic trash more than complex shapes.

Concave features were perceived as handles which is undesirable.

Separating form from other aesthetic qualities is complicated as they all contribute to how an object is perceived.

## REFLECTION ON PROCESS

There could have been a slightly wider exploration into form.

Contacting stakeholders earlier for validation could have streamlined the process.

A more "ready" prototype including color, etc. would have brought more insights but would have taken too much time to do for all shapes. In the end there are endless combo's anyways.

## THREE TAKE-AWAYS

"flattened capsule" shape will be used as a basis for developing the design.

How the tracker is perceived depends on a combination of aesthetic qualitie where color might be thge most important.

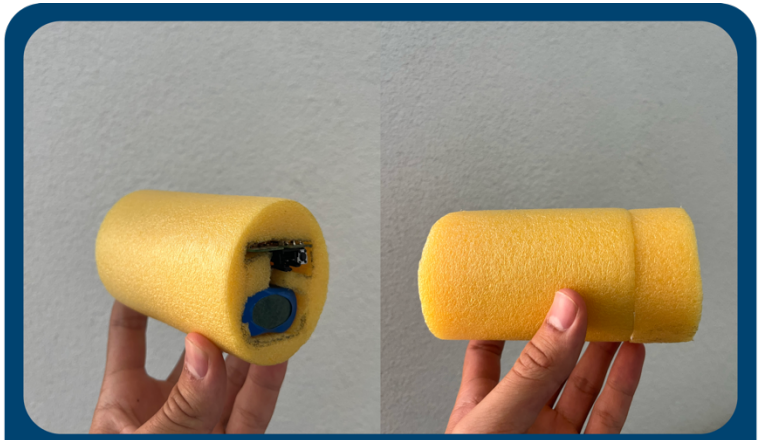
To really evaluate perception, a next, more complete prototype is required.

## REMAINING QUESTIONS

How can the tracker be designed to result in the desired behaviour of people who encounter it (leaving it alone)?

What instructions/symbols/etc. should be used?

20-09-'24



## CONTEXT OF PROTOTYPE

This prototype was created as part of the conceptualization phase. Instead of sketching this idea could easily be realised through prototyping which does a better job at conveying ideas.

It uses a pool noodle for a housing. The pool noodle has cutouts to house electronics and a cap is glued on for waterproofing.

The concept was to keep it very cheap.

## PURPOSE OF TEST

To try out a concept focused on budget and have it as a physical thing.

Prototyping gives more insight than a sketch.

## KNOWLEDGE GAINED

It is technically possible to make a floating tracker very cheaply

Desirability as well as performance would likely suffer.

Foams might be interesting as they are waterproofed (as long as they are closed-cell) and very lightweight

## REFLECTION ON PROCESS

Good way to test out and show new design. Whenever possible, prototyping is usually better than sketching.

Doing this "exercise" forced me to think in a different way of how design can be simplified or made cheaper which is a valuable lesson.

## THREE TAKE-AWAYS

Will not work (well) as the actual design.

Thinking of ways to make the design simpler or cheaper is important.

Foams might be interesting.

## REMAINING QUESTIONS

What can be simplified about the tracker design?

Are foams feasible for the design?

How could this material be processed to make a tracker housing in a viable way?

28-08-'24



## CONTEXT OF PROTOTYPE

A prototype for the new aesthetic design aimed to hint to the looks of a lifebuoy. It contains mounting for the PCB and AirTag, as well as a waterproofing (gasket) design. This prototype is a FDM PLA print of which the top half was spray painted orange

## PURPOSE OF TEST

This prototype was created to be able to show the design to stakeholders for an "early" round of validation and to test out fitting of the parts so that changes can be made before moving to a more complex, expensive and time-intensive production method such as SLA or SLS printing.

## KNOWLEDGE GAINED

Parts fit together well, although the current gasket type seal will likely be replaced by an O-ring which will change the design of the seal.

The basis of this aesthetic design will be used, although it requires further detail like symbols, text, color, etc.

The Airtag and PCB mount work well as is

## REFLECTION ON PROCESS

Lack of detailing such as text and symbols made it harder to validate the aesthetic design properly as it's not the full picture.

Battery mounting is not included, should optimally be there before moving to more advanced production methods.

FDM (especially PLA) works fine for these tests but is not suitable for functionality and proper surface quality

## THREE TAKE-AWAYS

Good basis for continuing the design, but further detailing is required.

Fitment seems to be in order but needs to be reevaluated after design changes and other production methods (i.e. AirTag friction fit).

Aesthetic design needs to be completed in the form of a prototype so that this can be validated

**02-10-'24**

## REMAINING QUESTIONS

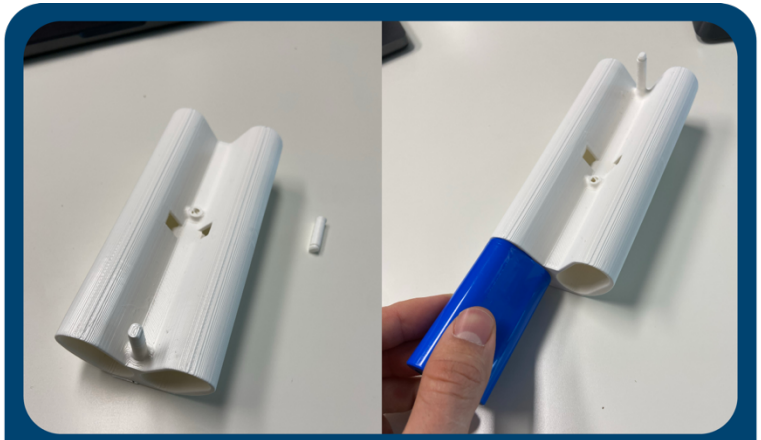
What symbols, text, etc. should be used to prevent removals?

What will the aesthetic qualities be after using a proper production method?

How will the fitment be after design changes to accomodate the use of an O-ring?

Is the design waterproof?

How will it handle impacts/forces and what changes are needed?



## CONTEXT OF PROTOTYPE

This prototype was created to tackle the issue of an unreliable signal that is likely caused by the submersion of the GPS module below the water line. The prototype is a 3D printed bracket that fits inside the currently used PVC tube to test this assumption. This design assumes a horizontally floating tube that should self-right due to the weight of the batteries on one side. The PCB is mounted higher to hopefully keep it above the water line.

## PURPOSE OF TEST

To test whether the self-righting design works properly and if the PCB stays above the waterline (height in the design and bouyancy with 4 batteries).

To see whether the mounting method for the PCB and batteries works and if it can be assembled reasonably easily

## KNOWLEDGE GAINED

Could not be properly tested as it requires refinement.

PCB mounts broke off due to the directions of the layers. Will print them sideways and as separate parts so that they can be replaced. Can do with a slightly looser fit.

Batteries do not fit due to layer directions which causes the cavity to not have smooth and accurate edges. Will adjust print direction.

## REFLECTION ON PROCESS

The design, with relation to the production method (3D printing) could have been considered more. I have enough knowledge of the technique to have anticipated these issues.

On the other hand it is good to try things out, especially when it can be done with such low cost and effort as 3D prints.

## THREE TAKE-AWAYS

layer direction is very important to make parts fit together

layer direction needs to be considered in relation to the direction of the load that is applied to a part

PCB mounting can be a bit more flexible and possibly replaceable

**06-05-24**

## REMAINING QUESTIONS

How does this design behave in the water?

How easy is it to assemble?

Will this design allow the tracker to send out a more consistent signal?





## CONTEXT OF PROTOTYPE

This prototype is a 2-battery version of the other horizontally floating design. It should be less submerged and thus send out a signal more reliably. In this design the PCB is also protected from the batteries that could crush it if the tube rotates quickly. The design still self-rights and should keep the PCB above the waterline. It has a different mounting method for the PCB.

## PURPOSE OF TEST

Test whether self-righting works well with less weight

Discover potential (new) issues

See how deep it floats and whether this could hinder reliability

See whether different mounting method works better

## KNOWLEDGE GAINED

Self-righting still works really well with the weight of two batteries (in this configuration)

PVC tube is about 2/3 submerged with 2 batteries

This PCB mounting method also does not work well (3D printing not accurate enough)

## REFLECTION ON PROCESS

The iterative process helped to improve the design step-wise which led to this seemingly well-functioning design

## THREE TAKE-AWAYS

There should be more clearance for the batteries. The print split in two as a result of too little clearance

Self-righting is quite easy to achieve with a slight imbalance

This design appears to be the most succesful

## REMAINING QUESTIONS

Will this design prove to be reliable in a real life setting?

What is a better way to mount the PCB?

27-05-2024





## CONTEXT OF PROTOTYPE

This prototype was created to tackle the issue of an unreliable signal. The prototype is a 3D printed bracket that fits inside the currently used PVC tube to test this assumption. This design assumes a horizontally floating tube where the lightbug is suspended in the middle of the tube.

## PURPOSE OF TEST

to see whether this simple intervention could already solve the reliability issues. Depends on how far it is submerged and what the orientation of the Lightbug will be.

To see how far it will be submerged

## KNOWLEDGE GAINED

In this design, the tracker is about halfway submerged

It actually self-rights (with limited force) indicating that one side of the lightbug is heaviest. After checking this proved to be the bottom side.

It can be said with almost certainty that batteries are in the bottom of the Lightbug

## REFLECTION ON PROCESS

Good to make simple changes and see what the impact is. This allowed me to focus on certain aspect and learn from that

## THREE TAKE-AWAYS

Could be an easy way to make a quick improvement on the current design

Gave more insight into the layout of the Lightbug (without needing to take it apart)

Self-righting already works with a slight weight imbalance

## REMAINING QUESTIONS

Will this position of the antenna be far away enough from trhe waterline to make it reliable?

27-05-24



## CONTEXT OF PROTOTYPE

This prototype was created to tackle the issue of an unreliable signal that is likely caused by the submersion of the GPS module below the water line. The prototype is a 3D printed bracket that fits inside the currently used PVC tube to test this assumption. This design assumes a vertically floating tube. Without adding weight the top will likely be submerged (and not be upright) but with added weight it might sink.

## PURPOSE OF TEST

To test whether these assumptions are correct and whether a vertically floating tracker is feasible (and desireable). Determine if it still floats after adding enough weight for it to float in an upright, vertical position. This will inform me if it is necessary to use separate components from the Lightbug Pro or whether it can be used as is.

## KNOWLEDGE GAINED

Without added weight it floats top-down (as expected). With added weight it is mostly submerged and won't send a signal

The PVC tubes have more buoyancy than estimated

Some water tends to come inside when screwing the top open, does not seem to leak in the water (for short periods)

## REFLECTION ON PROCESS

The test with the separate tube and the original setup (loose tracker inside) should have been done before making prototypes as this could have already provided insights that could have been implemented in these prototypes

Simply throwing it in the water brings many insights

## THREE TAKE-AWAYS

Different closing method could be better to prevent water from entering when handling the device

GPS module needs to be high-up in the design

Continue testing like this as it speeds up the process and knowledge gained

## REMAINING QUESTIONS

What is the max. weight before it sinks? Can I create a function for this with regards to length of the tube?

Where in the Lightbug Pro tracker is the PCB and the batteries?

Could a similar design with the tracker in the middle also work well?

**27-05-24**



## CONTEXT OF PROTOTYPE

This prototype was created to tackle the issue of an unreliable signal. The prototype is a 3D printed bracket that fits inside the currently used PVC tube to test this assumption. This design assumes a vertically floating tube with the PCB (and antenna) located at the top to ensure a reliable signal. This version uses 2 batteries compared to the 4 in the first vertical design.

## PURPOSE OF TEST

To see how it behaves in the water in terms of its stability (straight or at an angle) and buoyancy.

The 4 battery version was submerged too much, maybe this version will be beter and can give an indication where the balance between stability and not being submerged too much lies.

## KNOWLEDGE GAINED

the weight of 2 batteries makes it float at an angle, which can make it a bit less reliable as the position of the antenna in relation to the water changes

It does not really seem to self-right, which is logical since the weight is concentrated in the centre axis of the tube (axis from top to bottom)

## REFLECTION ON PROCESS

I started designing these vertical trackers before I fully realised that most plastic litter will float horizontally, which is more stable. As a result this seems like a bit unnecessary work.

Since I already made them, it's not much extra effort to test them and might still give me insight into buoyancy and how design influences the way things float which can be helpful in future stages of the project.

## THREE TAKE-AWAYS

Floating at an angle is likely undesireable as it could lead to lower reliability. Could also look less professional.

There are boundaries in weight (too light makes it float askew and too heavy makes it overly submerged).

Horizontal trackers could allow customizability in battery. Depending on research circumstances more/less can be used

## REMAINING QUESTIONS

Does the orientation in which the tracker floats (horizontal, vertical or diagonal) influence the perceived level of professionality?

To what extent would customizability in battery pack be desirable? This also influences the weight and thus its behaviour in the water.

**28-05-2024**





## CONTEXT OF PROTOTYPE

This prototype was created to tackle the issue of an unreliable signal. The prototype is a 3D printed bracket that fits inside the currently used PVC tube to test this assumption. This design assumes a vertically floating tube with the PCB (and antenna) located at the top to ensure a reliable signal. This version uses 3 batteries compared to the 4 in the first vertical design.

## PURPOSE OF TEST

To see how it behaves in the water in terms of its stability (straight or at an angle) and buoyancy.

The 4 battery version was submerged too much, maybe this version will be beter and can give an indication where the balance between stability and not being submerged too much lies.

## KNOWLEDGE GAINED

3 batteries keeps it floating in a vertical orientation while it is less submerged compared to the 4-battery version.

It is almost submerged up to the screw cap, approx. 4 cm is above the water.

## REFLECTION ON PROCESS

I started designing these vertical trackers before I fully realised that most plastic litter will float horizontally, which is more stable. As a result this seems like a bit unnecessary work.

Since I already made them, it's not much extra effort to test them and might still give me insight into buoyancy and how design influences the way things float which can be helpful in future stages of the project.

## THREE TAKE-AWAYS

There is little room for the antenna to go which would likely make it unreliable.

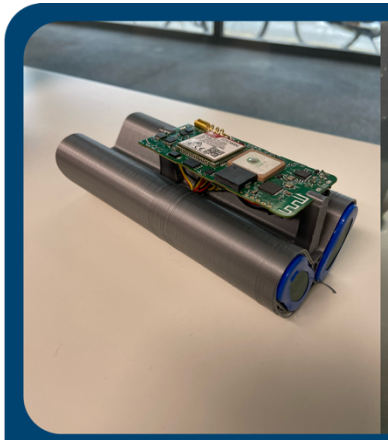
There are boundaries in weight (too light makes it float askew and too heavy makes it overly submerged).

Horizontal trackers could allow customizability in battery. Depending on research circumstances more/less can be used

## REMAINING QUESTIONS

How could a vertical tracker be designed so that it is stable, yet portrudes above the water level enough so that the antenna can reliably send out a signal?

28-05-2024





## CONTEXT OF PROTOTYPE

This prototype was created to tackle the issue of an unreliable signal. The prototype is a 3D printed bracket that fits inside the currently used PVC tube to test this assumption. This design assumes a horizontally floating tube that should self-right due to the weight of the batteries on one side. The PCB is mounted higher to hopefully keep it above the water line. This is V2 since V1 could not be tested properly (batteries did not fit inside)

## PURPOSE OF TEST

To test whether the self-righting design works properly and if the PCB stays above the waterline (height in the design and bouyancy with 4 batteries).

To see whether the mounting method for the PCB and batteries works and if it can be assembled reasonably easily

## KNOWLEDGE GAINED

Self-righting works well due to high weight of batteries which is concentrated at one end of the tube.

4 batteries was too heavy for this tube and made it almost sink. Larger tube could do the trick.

Mounting PCB did not work. Too much play as they are separate parts without proper mounting technique. Inaccuracies due to 3D printing made the click-fit fail (wrong layer direction)

## REFLECTION ON PROCESS

Quick Iterative process helped to gain insight and knowledge in/on different aspects

A bit more attention could have been spent on mounting of the PCB but wasn't the main priority of the testing

## THREE TAKE-AWAYS

For final design, buoyancy needs to be accurately calculated

Use proven mounting methods, not (just) 3D printing with its inaccuracies and lack of rigidity

This design has the risk that of the tube quickly rotates 180 degrees (i.e. an external hit/ colission), the PCB gets crushed by the batteries

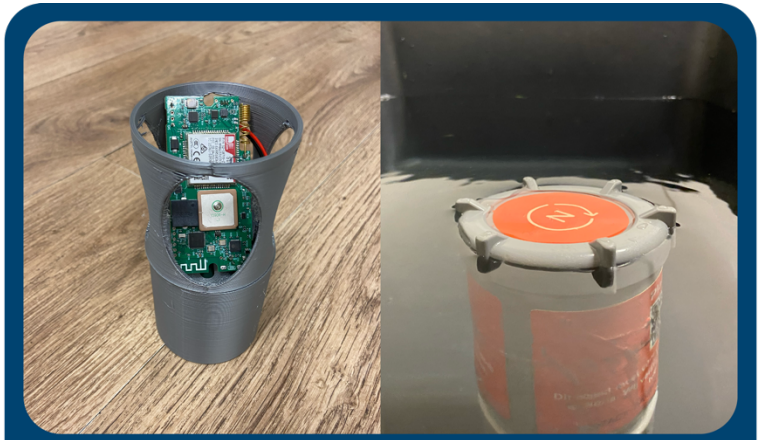
## REMAINING QUESTIONS

What could be a reliable mounting method for the PCB (as its mounting points are quite inconvenient)?

How can the PCB be best protected?

How far above the waterline should the antenna be?

27-05-24



### CONTEXT OF PROTOTYPE

This prototype was created to tackle the issue of an unreliable signal. The prototype is a 3D printed bracket that fits inside the currently used PVC tube to test this assumption. This design assumes a vertically floating tube with the PCB (and antenna) located at the top to ensure a reliable signal

### PURPOSE OF TEST

To see how it behaves in the water in terms of its stability (straight or at an angle) buoyancy

To see whether this mounting method for the batteries is viable

To see whether a vertically floating tracker is an option

### KNOWLEDGE GAINED

It floats straight but is almost submerged which will likely prevent the GPS from sending out a signal. It was also tested with less batteries which made it float at an angle but the battery bracket was not designed for this.

A vertically floating tracker is likely not very representative of actual plastic litter.

### REFLECTION ON PROCESS

Should have tested with actual plastic litter before designing this vertically floating prototype. It seems like most plastic litter floats horizontally so the tracker should too.

### THREE TAKE-AWAYS

4 batteries adds too much weight for this configuration as the trackers are almost entirely submerged (both horizontal and vertical, brackets are relatively light)

Tracker should probably float horizontally but more testing with litter should be done

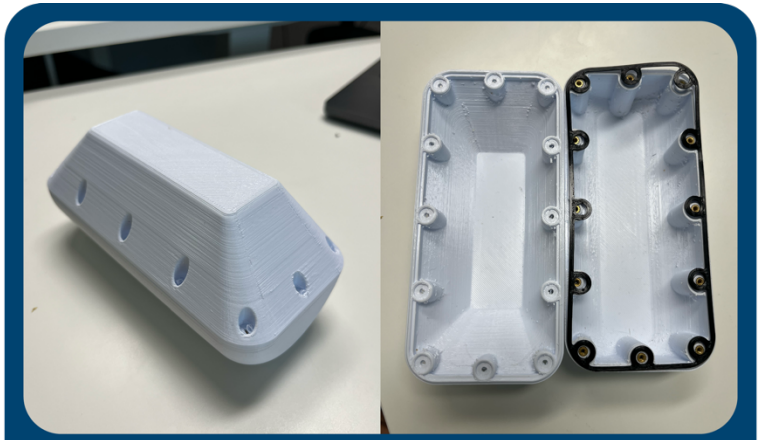
Mounting method (pressure fit) seems to work well

### REMAINING QUESTIONS

How does this design behave with less batteries?

What could be a better way to mount the PCB?

**27-05-2024**



### CONTEXT OF PROTOTYPE

This prototype is the first redesign for the shape of the tracker housing. It is a simple shape to try something different than the current design before delving into aesthetics. It is FDM printed PETG. It consists of two halves where the bottom contains a groove to house a waterproofing strip (black part, printed TPU) and threaded inserts, while the top has a ridge for pinching the waterproofing strip and holes to put bolts through.

### PURPOSE OF TEST

This prototype was created to test out something different in terms of aesthetics and to learn more about the specifics of making two halves fit together, clearances, waterproofing techniques, etc.

What is learned from this exploration will be used for future designing and prototyping

### KNOWLEDGE GAINED

TPU waterproofing strip did not fit due to insufficient clearance and expansion due to FDM printing. In hindsight a printed waterproofing seal will likely not work.

PETG is a much better material in terms of toughness than PLA, although FDM is still not suitable.

Custom gasket might complicate things but could be necessary

### REFLECTION ON PROCESS

Good way to test out and show new design.

Incorporating more things in the design (i.e. mounting) allows you to test more things which is more time-efficient.

Fitting of all components could have been incorporated in the dimensioning better.

### THREE TAKE-AWAYS

FDM printing is eventually not feasible for the casing as well as waterproofing.

If a simpler and more affordable way to waterproof the design is possible, this is prefferable.

Design needs some finetuning for proper fitting but general direction seems promising

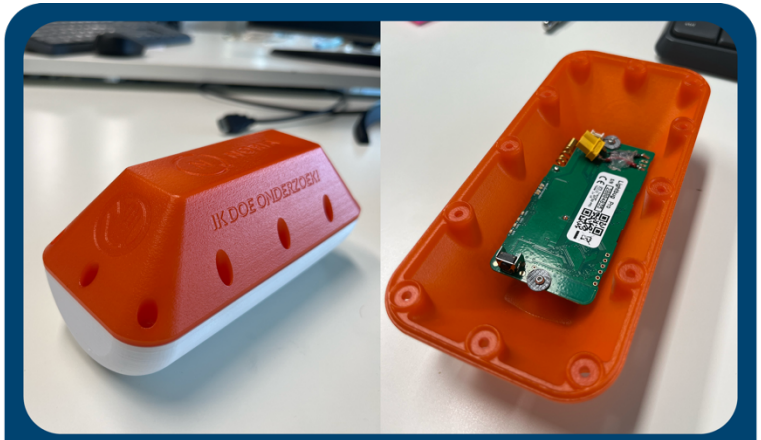
### REMAINING QUESTIONS

What should the aesthetic design be like?

What material and production method will be suitable?

How can this be made reliably waterproof?

**01-07-'24**




## CONTEXT OF PROTOTYPE

This prototype is an SLS 3D printed top half of a preliminary design for the enclosure of the floating tracker. It purposely includes delicate features such as embossed text and symbols at different depths .
SLS printed parts are waterproof when designed correctly and somewhat isotropic (Formlabs, n.d.). The part was also vaporsmoothed for a better surface finish which also aids waterproofing.

## PURPOSE OF TEST

This prototype was created to try out the characteristics of a SLS 3D-printed part in order to evaluate how suited this technique is in the context of this project.
The aim of this test is to learn more about the possibilities and limitations of SLS printing

## KNOWLEDGE GAINED

SLS offers high precision and a rough surface finish (this one was vapor smoothed). Although less smooth than SLA, the part looks professional. Details are less accurate, possibly due to vapor smoothing.

SLS prints have "somewhat" isotropic material properties and are waterproof.

SLS printing is more suitable as it is more durable than SLA (impacts, UV, etc.).

## REFLECTION ON PROCESS

Process of testing out this part was good. Inclusion of the PCB mount was nice as this allowed me to test the fitting.

Ordering SLS parts should be chosen wisely as it is relatively expensive.

## THREE TAKE-AWAYS

SLS printing will likely be the most suitable production method at the quantity of 25 trackers.

Details are not perfect and due to reflection the embossed text is hard to read. Different way for displaying this is necessary.

SLS needs no support which increases design freedom and leaves no marks. This is a huge deal.

## REMAINING QUESTIONS

How isotropic is SLS really and can it be modelled as such?

What is the best way for displaying information?

What shape will the design take and how does this influence pricing, properties, etc.

Can vapor smoothing be done by Noria to save cost?

**13-09-'24**

# Appendix G: Data from signal Reliability Testing

Data 20002750

| lat | lng | timestamp | speed | altitude | course | sats | hdop | accuracy | locationType | batteryVoltage | created | address | sendReason | alertType | gsmSignal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **51.9976571** | 4.3716864 | 2024-12-09 15:35:43 | null | null | null | null | -1 | 634 | gsm | 4.211 | Mon Dec 09 2024 14:35:43 GMT+0000 (Coordinated Universal Time) | Delft University of Technology, Leeghwaterstraat, 2628 CA Delft, Netherlands | 2 | 2 | 26 |
| **51.9976571** | 4.3716864 | 2024-12-09 16:14:29 | null | null | null | null | -1 | 634 | gsm | 4.217 | Mon Dec 09 2024 15:14:29 GMT+0000 (Coordinated Universal Time) | Delft University of Technology, Leeghwaterstraat, 2628 CA Delft, Netherlands | 2 | 10 | 21 |
| **51.9976571** | 4.3716864 | 2024-12-09 16:14:35 | null | null | null | null | -1 | 634 | gsm | 4.217 | Mon Dec 09 2024 15:14:35 GMT+0000 (Coordinated Universal Time) | Delft University of Technology, Leeghwaterstraat, 2628 CA Delft, Netherlands | 1 | null | 21 |
| **51.9941626** | 4.3714681 | 2024-12-09 16:16:52 | null | null | null | null | -1 | 712.7 | gsm | 4.228 | Mon Dec 09 2024 15:16:52 GMT+0000 (Coordinated Universal Time) | Rotterdamseweg 328, 2628 AT Delft, Netherlands | 1 | 2 | 99 |
| **51.9976571** | 4.3716864 | 2024-12-09 17:16:53 | null | null | null | null | -1 | 634 | gsm | 4.216 | Mon Dec 09 2024 16:16:53 GMT+0000 (Coordinated Universal Time) | Delft University of Technology, Leeghwaterstraat, 2628 CA Delft, Netherlands | 2 | 2 | 25 |
| **51.9941626** | 4.3714681 | 2024-12-09 17:31:18 | null | null | null | null | -1 | 712.7 | gsm | 4.239 | Mon Dec 09 2024 16:31:18 GMT+0000 (Coordinated Universal Time) | Rotterdamseweg 328, 2628 AT Delft, Netherlands | 1 | null | 24 |
| **51.9976571** | 4.3716864 | 2024-12-09 17:33:35 | null | null | null | null | -1 | 634 | gsm | 4.23 | Mon Dec 09 2024 16:33:35 GMT+0000 (Coordinated Universal Time) | Delft University of Technology, Leeghwaterstraat, 2628 CA Delft, Netherlands | 1 | null | 99 |
| **51.9964296** | 4.352734 | 2024-12-09 18:33:21 | null | null | null | null | -1 | 614.3 | gsm | 4.216 | Mon Dec 09 2024 17:33:21 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | 2 | 26 |
| **51.9964296** | 4.352734 | 2024-12-09 18:35:27 | null | null | null | null | -1 | 614.3 | gsm | 4.219 | Mon Dec 09 2024 17:35:27 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | 2 | 19 |
| **51.9964296** | 4.352734 | 2024-12-09 19:35:36 | null | null | null | null | -1 | 614.3 | gsm | 4.186 | Mon Dec 09 2024 18:35:36 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | 2 | 19 |
| **51.9964296** | 4.352734 | 2024-12-09 20:35:38 | null | null | null | null | -1 | 614.3 | gsm | 4.217 | Mon Dec 09 2024 19:35:38 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 22 |
| **51.9964296** | 4.352734 | 2024-12-09 21:10:47 | null | null | null | null | -1 | 614.3 | gsm | 4.186 | Mon Dec 09 2024 20:10:47 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 24 |
| **51.997926** | 4.35204 | 2024-12-09 21:11:37 | 0 | 40 | 0 | 12 | null | 11 | gps | 4.184 | Mon Dec 09 2024 20:11:53 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats, 2624 NM Delft, Netherlands | 1 | null | 24 |
| **51.9980989999999996** | 4.351668 | 2024-12-09 22:11:41 | 0 | -32 | 0 | 12 | null | 13 | gps | 4.176 | Mon Dec 09 2024 21:11:52 GMT+0000 (Coordinated Universal Time) | Persepolishof, 2624 NM Delft, Netherlands | 2 | null | 19 |
| **51.9964296** | 4.352734 | 2024-12-09 22:30:32 | null | null | null | null | -1 | 614.3 | gsm | 4.177 | Mon Dec 09 2024 21:30:32 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 19 |
| **51.9978319999999995** | 4.352136 | 2024-12-09 22:31:10 | 0 | 69 | 306 | 12 | null | 9 | gps | 4.206 | Mon Dec 09 2024 21:31:12 GMT+0000 (Coordinated Universal Time) | HEMA, Troelstralaan 71A, 2624 ET Delft, Netherlands | 16 | null | 19 |
| **51.997765** | 4.351659 | 2024-12-09 23:32:05 | 0 | 38 | 166 | 13 | null | 9 | gps | 4.174 | Mon Dec 09 2024 22:32:17 GMT+0000 (Coordinated Universal Time) | Troelstralaan 63B, 2624 ET Delft, Netherlands | 2 | null | 25 |
| **51.9964296** | 4.352734 | 2024-12-09 23:33:33 | null | null | null | null | -1 | 614.3 | gsm | 4.173 | Mon Dec 09 2024 22:33:33 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 23 |
| **51.998149** | 4.351691 | 2024-12-09 23:33:59 | 0 | 2 | 0 | 12 | null | 10 | gps | 4.198 | Mon Dec 09 2024 22:34:04 GMT+0000 (Coordinated Universal Time) | Persepolishof, 2624 NM Delft, Netherlands | 16 | null | 25 |
| **51.998041** | 4.3517009999999999 | 2024-12-10 00:34:19 | 0 | -10 | 206 | 10 | null | 8 | gps | 4.19 | Mon Dec 09 2024 23:34:30 GMT+0000 (Coordinated Universal Time) | Persepolishof, 2624 NM Delft, Netherlands | 64 | null | 17 |
| **51.9964296** | 4.352734 | 2024-12-10 01:33:47 | null | null | null | null | -1 | 614.3 | gsm | 4.176 | Tue Dec 10 2024 00:33:47 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 18 |
| **51.9964296** | 4.352734 | 2024-12-10 02:22:48 | null | null | null | null | -1 | 614.3 | gsm | 4.175 | Tue Dec 10 2024 01:22:48 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 17 |
| **51.9975529999999996** | 4.35176 | 2024-12-10 02:24:07 | 0 | 59 | 176 | 12 | null | 20 | gps | 4.166 | Tue Dec 10 2024 01:24:23 GMT+0000 (Coordinated Universal Time) | De Hoven Passage, Taj Mahalplaats, 2624 NH Delft, Netherlands | 16 | null | 23 |
| **51.997574** | 4.351618 | 2024-12-10 03:23:59 | 0 | 43 | 0 | 13 | null | 8 | gps | 4.168 | Tue Dec 10 2024 02:24:16 GMT+0000 (Coordinated Universal Time) | De Hoven Passage, Taj Mahalplaats, 2624 NH Delft, Netherlands | 2 | null | 18 |
| **51.9964296** | 4.352734 | 2024-12-10 04:01:56 | null | null | null | null | -1 | 614.3 | gsm | 4.176 | Tue Dec 10 2024 03:01:56 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 21 |
| **51.997946** | 4.351986 | 2024-12-10 04:02:09 | 0 | 13 | 0 | 11 | null | 10 | gps | 4.163 | Tue Dec 10 2024 03:02:14 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats, 2624 NM Delft, Netherlands | 1 | null | 21 |
| **51.997845** | 4.3519689999999995 | 2024-12-10 05:02:41 | 0 | -15 | 0 | 12 | null | 24 | gps | 4.177 | Tue Dec 10 2024 04:02:57 GMT+0000 (Coordinated Universal Time) | HEMA, Troelstralaan 71A, 2624 ET Delft, Netherlands | 2 | null | 21 |
| **51.9964296** | 4.352734 | 2024-12-10 06:02:04 | null | null | null | null | -1 | 614.3 | gsm | 4.169 | Tue Dec 10 2024 05:02:04 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| **51.9964296** | 4.352734 | 2024-12-10 06:29:19 | null | null | null | null | -1 | 614.3 | gsm | 4.166 | Tue Dec 10 2024 05:29:19 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 20 |
| **51.9979669999999996** | 4.35169 | 2024-12-10 06:30:22 | 0 | -10 | 332 | 13 | null | 10 | gps | 4.195 | Tue Dec 10 2024 05:30:33 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 11, 2624 NM Delft, Netherlands | 16 | null | 25 |
| **51.998007** | 4.3516509999999995 | 2024-12-10 07:29:41 | 0 | -9 | 0 | 11 | null | 20 | gps | 4.175 | Tue Dec 10 2024 06:29:58 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 9, 2624 NM Delft, Netherlands | 64 | null | 20 |
| **51.9964296** | 4.352734 | 2024-12-10 07:32:59 | null | null | null | null | -1 | 614.3 | gsm | 4.166 | Tue Dec 10 2024 06:32:59 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 22 |
| **51.997932** | 4.351789 | 2024-12-10 07:33:10 | 2 | 16 | 150 | 11 | null | 22 | gps | 4.166 | Tue Dec 10 2024 06:33:12 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 16 | null | 22 |
| **51.997951** | 4.351817 | 2024-12-10 08:33:42 | 0 | -4 | 124 | 12 | null | 13 | gps | 4.168 | Tue Dec 10 2024 07:33:59 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 15, 2624 NM Delft, Netherlands | 64 | null | 25 |
| **51.9964296** | 4.352734 | 2024-12-10 09:05:21 | null | null | null | null | -1 | 614.3 | gsm | 4.166 | Tue Dec 10 2024 08:05:21 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 23 |
| **51.9975389999999996** | 4.351985 | 2024-12-10 09:05:44 | 0 | 1 | 0 | 11 | null | 27 | gps | 4.179 | Tue Dec 10 2024 08:05:46 GMT+0000 (Coordinated Universal Time) | HEMA, Troelstralaan 71A, 2624 ET Delft, Netherlands | 16 | null | 23 |
| **51.9964296** | 4.352734 | 2024-12-10 10:24:02 | null | null | null | null | -1 | 614.3 | gsm | 4.166 | Tue Dec 10 2024 09:24:02 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 22 |
| **51.9977559999999995** | 4.351869 | 2024-12-10 10:24:44 | 0 | 47 | 0 | 12 | null | 8 | gps | 4.19 | Tue Dec 10 2024 09:24:49 GMT+0000 (Coordinated Universal Time) | Troelstralaan, 2624 ET Delft, Netherlands | 1 | null | 25 |
| **51.9980429999999996** | 4.3516509999999995 | 2024-12-10 11:24:37 | 0 | 1 | 0 | 12 | null | 18 | gps | 4.168 | Tue Dec 10 2024 10:24:48 GMT+0000 (Coordinated Universal Time) | Persepolishof, 2624 NM Delft, Netherlands | 2 | null | 23 |
| **51.9964296** | 4.352734 | 2024-12-10 11:27:04 | null | null | null | null | -1 | 614.3 | gsm | 4.162 | Tue Dec 10 2024 10:27:04 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 24 |
| **51.99796** | 4.351792 | 2024-12-10 11:27:16 | 0 | 0 | 0 | 12 | null | 20 | gps | 4.154 | Tue Dec 10 2024 10:27:21 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 16 | null | 21 |
| **51.998003** | 4.351745 | 2024-12-10 12:27:52 | 0 | -14 | 0 | 13 | null | 11 | gps | 4.164 | Tue Dec 10 2024 11:28:08 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 64 | null | 21 |
| **51.9964296** | 4.352734 | 2024-12-10 12:49:35 | null | null | null | null | -1 | 614.3 | gsm | 4.197 | Tue Dec 10 2024 11:49:35 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 18 |
| **51.9978969999999995** | 4.352094 | 2024-12-10 12:50:13 | 0 | 33 | 328 | 12 | null | 9 | gps | 4.188 | Tue Dec 10 2024 11:50:15 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats, 2624 ET Delft, Netherlands | 1 | null | 18 |
| **51.9979699999999995** | 4.3517719999999995 | 2024-12-10 13:50:16 | 0 | -7 | 184 | 13 | null | 5 | gps | 4.171 | Tue Dec 10 2024 12:50:28 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 2 | null | 24 |
| **51.9964296** | 4.352734 | 2024-12-10 14:49:49 | null | null | null | null | -1 | 614.3 | gsm | 4.17 | Tue Dec 10 2024 13:49:49 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| **51.9964296** | 4.352734 | 2024-12-10 15:24:19 | null | null | null | null | -1 | 614.3 | gsm | 4.161 | Tue Dec 10 2024 14:24:19 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 21 |
| **51.997623** | 4.3517 | 2024-12-10 15:25:46 | 0 | 49 | 0 | 12 | null | 8 | gps | 4.168 | Tue Dec 10 2024 14:26:16 GMT+0000 (Coordinated Universal Time) | De Hoven Passage, Taj Mahalplaats, 2624 NH Delft, Netherlands | 16 | null | 25 |
| **51.9979919999999996** | 4.351779 | 2024-12-10 16:25:05 | 0 | -2 | 106 | 11 | null | 9 | gps | 4.156 | Tue Dec 10 2024 15:25:16 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 2 | null | 18 |
| **51.9964296** | 4.352734 | 2024-12-10 16:51:40 | null | null | null | null | -1 | 614.3 | gsm | 4.159 | Tue Dec 10 2024 15:51:40 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 23 |
| **51.997948** | 4.351674 | 2024-12-10 16:51:53 | 0 | 2 | 0 | 11 | null | 13 | gps | 4.153 | Tue Dec 10 2024 15:51:55 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 9, 2624 NM Delft, Netherlands | 16 | null | 25 |
| **51.9979329999999996** | 4.351807 | 2024-12-10 17:52:30 | 0 | -8 | 152 | 12 | null | 8 | gps | 4.167 | Tue Dec 10 2024 16:52:41 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 2 | null | 20 |
| **51.9964296** | 4.352734 | 2024-12-10 18:51:53 | null | null | null | null | -1 | 614.3 | gsm | 4.155 | Tue Dec 10 2024 17:51:53 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 20 |
| **51.9964296** | 4.352734 | 2024-12-10 19:24:34 | null | null | null | null | -1 | 614.3 | gsm | 4.156 | Tue Dec 10 2024 18:24:34 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 19 |
| **51.997916** | 4.3517589999999995 | 2024-12-10 19:25:11 | 0 | -16 | 300 | 12 | null | 9 | gps | 4.182 | Tue Dec 10 2024 18:25:16 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 16 | null | 17 |
| **51.997999** | 4.351821 | 2024-12-10 20:25:29 | 0 | 0 | 150 | 11 | null | 35 | gps | 4.158 | Tue Dec 10 2024 19:25:46 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 15, 2624 NM Delft, Netherlands | 2 | null | 21 |
| **51.9964296** | 4.352734 | 2024-12-10 21:24:47 | null | null | null | null | -1 | 614.3 | gsm | 4.156 | Tue Dec 10 2024 20:24:47 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 16 |
| **51.9964296** | 4.352734 | 2024-12-10 22:24:44 | null | null | null | null | -1 | 614.3 | gsm | 4.169 | Tue Dec 10 2024 21:24:44 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 21 |
| **51.9964296** | 4.352734 | 2024-12-10 23:11:27 | null | null | null | null | -1 | 614.3 | gsm | 4.153 | Tue Dec 10 2024 22:11:27 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 27 |
| **51.9979979999999995** | 4.35182 | 2024-12-10 23:12:32 | 0 | -9 | 62 | 13 | null | 10 | gps | 4.168 | Tue Dec 10 2024 22:12:55 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 15, 2624 NM Delft, Netherlands | 16 | null | 99 |
| **51.9964296** | 4.352734 | 2024-12-11 00:13:37 | null | null | null | null | -1 | 614.3 | gsm | 4.161 | Tue Dec 10 2024 23:13:37 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 20 |
| **51.9977499999999996** | 4.352707 | 2024-12-11 01:12:04 | 0 | 145 | 0 | 12 | null | 8 | gps | 4.16 | Wed Dec 11 2024 00:12:21 GMT+0000 (Coordinated Universal Time) | De Hoven Passage, Taj Mahalplaats, 2624 NH Delft, Netherlands | 2 | null | 16 |
| **51.9964296** | 4.352734 | 2024-12-11 02:11:48 | null | null | null | null | -1 | 614.3 | gsm | 4.151 | Wed Dec 11 2024 01:11:48 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 21 |
| **51.9964296** | 4.352734 | 2024-12-11 03:11:51 | null | null | null | null | -1 | 614.3 | gsm | 4.157 | Wed Dec 11 2024 02:11:51 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 18 |
| **51.9964296** | 4.352734 | 2024-12-11 04:11:53 | null | null | null | null | -1 | 614.3 | gsm | 4.151 | Wed Dec 11 2024 03:11:53 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 20 |
| **51.9964296** | 4.352734 | 2024-12-11 05:11:57 | null | null | null | null | -1 | 614.3 | gsm | 4.152 | Wed Dec 11 2024 04:11:57 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 16 |
| **51.9964296** | 4.352734 | 2024-12-11 06:12:00 | null | null | null | null | -1 | 614.3 | gsm | 4.154 | Wed Dec 11 2024 05:12:00 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 17 |
| **51.9964296** | 4.352734 | 2024-12-11 07:12:03 | null | null | null | null | -1 | 614.3 | gsm | 4.153 | Wed Dec 11 2024 06:12:03 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 18 |
| **51.9964296** | 4.352734 | 2024-12-11 08:12:06 | null | null | null | null | -1 | 614.3 | gsm | 4.147 | Wed Dec 11 2024 07:12:06 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 17 |
| **51.9964296** | 4.352734 | 2024-12-11 09:12:08 | null | null | null | null | -1 | 614.3 | gsm | 4.148 | Wed Dec 11 2024 08:12:08 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 17 |
| **51.9964296** | 4.352734 | 2024-12-11 10:12:11 | null | null | null | null | -1 | 614.3 | gsm | 4.154 | Wed Dec 11 2024 09:12:11 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 22 |
| **51.9964296** | 4.352734 | 2024-12-11 11:12:09 | null | null | null | null | -1 | 614.3 | gsm | 4.149 | Wed Dec 11 2024 10:12:09 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 19 |
| **51.9964296** | 4.352734 | 2024-12-11 12:12:16 | null | null | null | null | -1 | 614.3 | gsm | 4.149 | Wed Dec 11 2024 11:12:16 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 24 |
| **51.9964296** | 4.352734 | 2024-12-11 13:12:19 | null | null | null | null | -1 | 614.3 | gsm | 4.149 | Wed Dec 11 2024 12:12:19 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| **51.9964296** | 4.352734 | 2024-12-11 14:12:16 | null | null | null | null | -1 | 614.3 | gsm | 4.15 | Wed Dec 11 2024 13:12:16 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| **51.9964296** | 4.352734 | 2024-12-11 15:12:24 | null | null | null | null | -1 | 614.3 | gsm | 4.149 | Wed Dec 11 2024 14:12:24 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| **51.9964296** | 4.352734 | 2024-12-11 16:12:27 | null | null | null | null | -1 | 614.3 | gsm | 4.153 | Wed Dec 11 2024 15:12:27 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 22 |
| **51.9964296** | 4.352734 | 2024-12-11 17:12:24 | null | null | null | null | -1 | 614.3 | gsm | 4.145 | Wed Dec 11 2024 16:12:24 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 18 |
| **51.9964296** | 4.352734 | 2024-12-11 18:12:32 | null | null | null | null | -1 | 614.3 | gsm | 4.144 | Wed Dec 11 2024 17:12:32 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 20 |
| **51.9964296** | 4.352734 | 2024-12-11 19:12:29 | null | null | null | null | -1 | 614.3 | gsm | 4.143 | Wed Dec 11 2024 18:12:29 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 21 |
| **51.9964296** | 4.352734 | 2024-12-11 20:12:37 | null | null | null | null | -1 | 614.3 | gsm | 4.14 | Wed Dec 11 2024 19:12:37 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 20 |
| **51.9964296** | 4.352734 | 2024-12-11 20:48:01 | null | null | null | null | -1 | 614.3 | gsm | 4.158 | Wed Dec 11 2024 19:48:01 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | 2 | 31 |
| **51.998132** | 4.3515169999999999 | 2024-12-11 20:48:54 | 0 | -13 | 0 | 12 | null | 22 | gps | 4.148 | Wed Dec 11 2024 19:49:20 GMT+0000 (Coordinated Universal Time) | Persepolishof, 2624 NM Delft, Netherlands | 16 | 2 | 22 |

Data 20004834

| lat | lng | timestamp | speed | altitude | course | sats | hdop | accuracy | locationType | batteryVoltage | created | address | sendReason | alertType | gsmSignal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51.9964296 | 4.352734 | 2024-12-09 18:33:21 | null | null | null | null | -1 | 614.3 | gsm | 4.216 | Mon Dec 09 2024 17:33:21 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | 2 | 26 |
| 51.9964296 | 4.352734 | 2024-12-09 18:35:27 | null | null | null | null | -1 | 614.3 | gsm | 4.219 | Mon Dec 09 2024 17:35:27 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | 2 | 19 |
| 51.9964296 | 4.352734 | 2024-12-09 19:35:36 | null | null | null | null | -1 | 614.3 | gsm | 4.186 | Mon Dec 09 2024 18:35:36 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | 2 | 19 |
| 51.9964296 | 4.352734 | 2024-12-09 20:35:38 | null | null | null | null | -1 | 614.3 | gsm | 4.217 | Mon Dec 09 2024 19:35:38 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 22 |
| 51.9964296 | 4.352734 | 2024-12-09 21:10:47 | null | null | null | null | -1 | 614.3 | gsm | 4.186 | Mon Dec 09 2024 20:10:47 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 24 |
| 51.997926 | 4.35204 | 2024-12-09 21:11:37 | 0 | 40 | 0 | 12 | null | 11 | gps | 4.184 | Mon Dec 09 2024 20:11:53 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats, 2624 NM Delft, Netherlands | 1 | null | 24 |
| 51.9980989999999996 | 4.351668 | 2024-12-09 22:11:41 | 0 | -32 | 0 | 12 | null | 13 | gps | 4.176 | Mon Dec 09 2024 21:11:52 GMT+0000 (Coordinated Universal Time) | Persepolishof, 2624 NM Delft, Netherlands | 2 | null | 19 |
| 51.9964296 | 4.352734 | 2024-12-09 22:30:32 | null | null | null | null | -1 | 614.3 | gsm | 4.177 | Mon Dec 09 2024 21:30:32 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 19 |
| 51.9978319999999995 | 4.352136 | 2024-12-09 22:31:10 | 0 | 69 | 306 | 12 | null | 9 | gps | 4.206 | Mon Dec 09 2024 21:31:12 GMT+0000 (Coordinated Universal Time) | HEMA, Troelstralaan 71A, 2624 ET Delft, Netherlands | 16 | null | 19 |
| 51.997765 | 4.351659 | 2024-12-09 23:32:05 | 0 | 38 | 166 | 13 | null | 9 | gps | 4.174 | Mon Dec 09 2024 22:32:17 GMT+0000 (Coordinated Universal Time) | Troelstralaan 63B, 2624 ET Delft, Netherlands | 2 | null | 25 |
| 51.9964296 | 4.352734 | 2024-12-09 23:33:33 | null | null | null | null | -1 | 614.3 | gsm | 4.173 | Mon Dec 09 2024 22:33:33 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 23 |
| 51.998149 | 4.351691 | 2024-12-09 23:33:59 | 0 | 2 | 0 | 12 | null | 10 | gps | 4.198 | Mon Dec 09 2024 22:34:04 GMT+0000 (Coordinated Universal Time) | Persepolishof, 2624 NM Delft, Netherlands | 16 | null | 25 |
| 51.998041 | 4.351700999999999 | 2024-12-10 00:34:19 | 0 | -10 | 206 | 10 | null | 8 | gps | 4.19 | Mon Dec 09 2024 23:34:30 GMT+0000 (Coordinated Universal Time) | Persepolishof, 2624 NM Delft, Netherlands | 64 | null | 17 |
| 51.9964296 | 4.352734 | 2024-12-10 01:33:47 | null | null | null | null | -1 | 614.3 | gsm | 4.176 | Tue Dec 10 2024 00:33:47 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 18 |
| 51.9964296 | 4.352734 | 2024-12-10 02:22:48 | null | null | null | null | -1 | 614.3 | gsm | 4.175 | Tue Dec 10 2024 01:22:48 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 17 |
| 51.9975529999999996 | 4.35176 | 2024-12-10 02:24:07 | 0 | 59 | 176 | 12 | null | 20 | gps | 4.166 | Tue Dec 10 2024 01:24:23 GMT+0000 (Coordinated Universal Time) | De Hoven Passage, Taj Mahalplaats, 2624 NH Delft, Netherlands | 16 | null | 23 |
| 51.997574 | 4.351618 | 2024-12-10 03:23:59 | 0 | 43 | 0 | 13 | null | 8 | gps | 4.168 | Tue Dec 10 2024 02:24:16 GMT+0000 (Coordinated Universal Time) | De Hoven Passage, Taj Mahalplaats, 2624 NH Delft, Netherlands | 2 | null | 18 |
| 51.9964296 | 4.352734 | 2024-12-10 04:01:56 | null | null | null | null | -1 | 614.3 | gsm | 4.176 | Tue Dec 10 2024 03:01:56 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 21 |
| 51.997946 | 4.351986 | 2024-12-10 04:02:09 | 0 | 13 | 0 | 11 | null | 10 | gps | 4.163 | Tue Dec 10 2024 03:02:14 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats, 2624 NM Delft, Netherlands | 1 | null | 21 |
| 51.997845 | 4.3519689999999995 | 2024-12-10 05:02:41 | 0 | -15 | 0 | 12 | null | 24 | gps | 4.177 | Tue Dec 10 2024 04:02:57 GMT+0000 (Coordinated Universal Time) | HEMA, Troelstralaan 71A, 2624 ET Delft, Netherlands | 2 | null | 21 |
| 51.9964296 | 4.352734 | 2024-12-10 06:02:04 | null | null | null | null | -1 | 614.3 | gsm | 4.169 | Tue Dec 10 2024 05:02:04 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| 51.9964296 | 4.352734 | 2024-12-10 06:29:19 | null | null | null | null | -1 | 614.3 | gsm | 4.166 | Tue Dec 10 2024 05:29:19 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 20 |
| 51.9979669999999996 | 4.35169 | 2024-12-10 06:30:22 | 0 | -10 | 332 | 13 | null | 10 | gps | 4.195 | Tue Dec 10 2024 05:30:33 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 11, 2624 NM Delft, Netherlands | 16 | null | 25 |
| 51.998007 | 4.3516509999999995 | 2024-12-10 07:29:41 | 0 | -9 | 0 | 11 | null | 20 | gps | 4.175 | Tue Dec 10 2024 06:29:58 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 9, 2624 NM Delft, Netherlands | 64 | null | 20 |
| 51.9964296 | 4.352734 | 2024-12-10 07:32:59 | null | null | null | null | -1 | 614.3 | gsm | 4.166 | Tue Dec 10 2024 06:32:59 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 22 |
| 51.997932 | 4.351789 | 2024-12-10 07:33:10 | 2 | 16 | 150 | 11 | null | 22 | gps | 4.166 | Tue Dec 10 2024 06:33:12 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 16 | null | 22 |
| 51.997951 | 4.351817 | 2024-12-10 08:33:42 | 0 | -4 | 124 | 12 | null | 13 | gps | 4.168 | Tue Dec 10 2024 07:33:59 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 15, 2624 NM Delft, Netherlands | 64 | null | 25 |
| 51.9964296 | 4.352734 | 2024-12-10 09:05:21 | null | null | null | null | -1 | 614.3 | gsm | 4.166 | Tue Dec 10 2024 08:05:21 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 23 |
| 51.9975389999999996 | 4.351985 | 2024-12-10 09:05:44 | 0 | 1 | 0 | 11 | null | 27 | gps | 4.179 | Tue Dec 10 2024 08:05:46 GMT+0000 (Coordinated Universal Time) | HEMA, Troelstralaan 71A, 2624 ET Delft, Netherlands | 16 | null | 23 |
| 51.9964296 | 4.352734 | 2024-12-10 10:24:02 | null | null | null | null | -1 | 614.3 | gsm | 4.166 | Tue Dec 10 2024 09:24:02 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 22 |
| 51.9977559999999995 | 4.351869 | 2024-12-10 10:24:44 | 0 | 47 | 0 | 12 | null | 8 | gps | 4.19 | Tue Dec 10 2024 09:24:49 GMT+0000 (Coordinated Universal Time) | Troelstralaan, 2624 ET Delft, Netherlands | 1 | null | 25 |
| 51.9980429999999996 | 4.3516509999999995 | 2024-12-10 11:24:37 | 0 | 1 | 0 | 12 | null | 18 | gps | 4.168 | Tue Dec 10 2024 10:24:48 GMT+0000 (Coordinated Universal Time) | Persepolishof, 2624 NM Delft, Netherlands | 2 | null | 23 |
| 51.9964296 | 4.352734 | 2024-12-10 11:27:04 | null | null | null | null | -1 | 614.3 | gsm | 4.162 | Tue Dec 10 2024 10:27:04 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 24 |
| 51.99796 | 4.351792 | 2024-12-10 11:27:16 | 0 | 0 | 0 | 12 | null | 20 | gps | 4.154 | Tue Dec 10 2024 10:27:21 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 16 | null | 21 |
| 51.998003 | 4.351745 | 2024-12-10 12:27:52 | 0 | -14 | 0 | 13 | null | 11 | gps | 4.164 | Tue Dec 10 2024 11:28:08 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 64 | null | 21 |
| 51.9964296 | 4.352734 | 2024-12-10 12:49:35 | null | null | null | null | -1 | 614.3 | gsm | 4.197 | Tue Dec 10 2024 11:49:35 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 18 |
| 51.9978969999999995 | 4.352094 | 2024-12-10 12:50:13 | 0 | 33 | 328 | 12 | null | 9 | gps | 4.188 | Tue Dec 10 2024 11:50:15 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats, 2624 ET Delft, Netherlands | 1 | null | 18 |
| 51.9979699999999995 | 4.3517719999999995 | 2024-12-10 13:50:16 | 0 | -7 | 184 | 13 | null | 5 | gps | 4.171 | Tue Dec 10 2024 12:50:28 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 2 | null | 24 |
| 51.9964296 | 4.352734 | 2024-12-10 14:49:49 | null | null | null | null | -1 | 614.3 | gsm | 4.17 | Tue Dec 10 2024 13:49:49 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| 51.9964296 | 4.352734 | 2024-12-10 15:24:19 | null | null | null | null | -1 | 614.3 | gsm | 4.161 | Tue Dec 10 2024 14:24:19 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 21 |
| 51.997623 | 4.3517 | 2024-12-10 15:25:46 | 0 | 49 | 0 | 12 | null | 8 | gps | 4.168 | Tue Dec 10 2024 14:26:16 GMT+0000 (Coordinated Universal Time) | De Hoven Passage, Taj Mahalplaats, 2624 NH Delft, Netherlands | 16 | null | 25 |
| 51.9979919999999996 | 4.351779 | 2024-12-10 16:25:05 | 0 | -2 | 106 | 11 | null | 9 | gps | 4.156 | Tue Dec 10 2024 15:25:16 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 2 | null | 18 |
| 51.9964296 | 4.352734 | 2024-12-10 16:51:40 | null | null | null | null | -1 | 614.3 | gsm | 4.159 | Tue Dec 10 2024 15:51:40 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 23 |
| 51.997948 | 4.351674 | 2024-12-10 16:51:53 | 0 | 2 | 0 | 11 | null | 13 | gps | 4.153 | Tue Dec 10 2024 15:51:55 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 9, 2624 NM Delft, Netherlands | 16 | null | 25 |
| 51.9979329999999996 | 4.351807 | 2024-12-10 17:52:30 | 0 | -8 | 152 | 12 | null | 8 | gps | 4.167 | Tue Dec 10 2024 16:52:41 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 2 | null | 20 |
| 51.9964296 | 4.352734 | 2024-12-10 18:51:53 | null | null | null | null | -1 | 614.3 | gsm | 4.155 | Tue Dec 10 2024 17:51:53 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 20 |
| 51.9964296 | 4.352734 | 2024-12-10 19:24:34 | null | null | null | null | -1 | 614.3 | gsm | 4.156 | Tue Dec 10 2024 18:24:34 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 19 |
| 51.997916 | 4.3517589999999995 | 2024-12-10 19:25:11 | 0 | -16 | 300 | 12 | null | 9 | gps | 4.182 | Tue Dec 10 2024 18:25:16 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 13, 2624 NM Delft, Netherlands | 16 | null | 17 |
| 51.997999 | 4.351821 | 2024-12-10 20:25:29 | 0 | 0 | 150 | 11 | null | 35 | gps | 4.158 | Tue Dec 10 2024 19:25:46 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 15, 2624 NM Delft, Netherlands | 2 | null | 21 |
| 51.9964296 | 4.352734 | 2024-12-10 21:24:47 | null | null | null | null | -1 | 614.3 | gsm | 4.156 | Tue Dec 10 2024 20:24:47 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 16 |
| 51.9964296 | 4.352734 | 2024-12-10 22:24:44 | null | null | null | null | -1 | 614.3 | gsm | 4.169 | Tue Dec 10 2024 21:24:44 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 21 |
| 51.9964296 | 4.352734 | 2024-12-10 23:11:27 | null | null | null | null | -1 | 614.3 | gsm | 4.153 | Tue Dec 10 2024 22:11:27 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 1 | null | 27 |
| 51.9979979999999995 | 4.35182 | 2024-12-10 23:12:32 | 0 | -9 | 62 | 13 | null | 10 | gps | 4.168 | Tue Dec 10 2024 22:12:55 GMT+0000 (Coordinated Universal Time) | Taj Mahalplaats 15, 2624 NM Delft, Netherlands | 16 | null | 99 |
| 51.9964296 | 4.352734 | 2024-12-11 00:13:37 | null | null | null | null | -1 | 614.3 | gsm | 4.161 | Tue Dec 10 2024 23:13:37 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 20 |
| 51.9977499999999996 | 4.352707 | 2024-12-11 01:12:04 | 0 | 145 | 0 | 12 | null | 8 | gps | 4.16 | Wed Dec 11 2024 00:12:21 GMT+0000 (Coordinated Universal Time) | De Hoven Passage, Taj Mahalplaats, 2624 NH Delft, Netherlands | 2 | null | 16 |
| 51.9964296 | 4.352734 | 2024-12-11 02:11:48 | null | null | null | null | -1 | 614.3 | gsm | 4.151 | Wed Dec 11 2024 01:11:48 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 21 |
| 51.9964296 | 4.352734 | 2024-12-11 03:11:51 | null | null | null | null | -1 | 614.3 | gsm | 4.157 | Wed Dec 11 2024 02:11:51 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 18 |
| 51.9964296 | 4.352734 | 2024-12-11 04:11:53 | null | null | null | null | -1 | 614.3 | gsm | 4.151 | Wed Dec 11 2024 03:11:53 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 20 |
| 51.9964296 | 4.352734 | 2024-12-11 05:11:57 | null | null | null | null | -1 | 614.3 | gsm | 4.152 | Wed Dec 11 2024 04:11:57 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 16 |
| 51.9964296 | 4.352734 | 2024-12-11 06:12:00 | null | null | null | null | -1 | 614.3 | gsm | 4.154 | Wed Dec 11 2024 05:12:00 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 17 |
| 51.9964296 | 4.352734 | 2024-12-11 07:12:03 | null | null | null | null | -1 | 614.3 | gsm | 4.153 | Wed Dec 11 2024 06:12:03 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 18 |
| 51.9964296 | 4.352734 | 2024-12-11 08:12:06 | null | null | null | null | -1 | 614.3 | gsm | 4.147 | Wed Dec 11 2024 07:12:06 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 17 |
| 51.9964296 | 4.352734 | 2024-12-11 09:12:08 | null | null | null | null | -1 | 614.3 | gsm | 4.148 | Wed Dec 11 2024 08:12:08 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 17 |
| 51.9964296 | 4.352734 | 2024-12-11 10:12:11 | null | null | null | null | -1 | 614.3 | gsm | 4.154 | Wed Dec 11 2024 09:12:11 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 22 |
| 51.9964296 | 4.352734 | 2024-12-11 11:12:09 | null | null | null | null | -1 | 614.3 | gsm | 4.149 | Wed Dec 11 2024 10:12:09 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 19 |
| 51.9964296 | 4.352734 | 2024-12-11 12:12:16 | null | null | null | null | -1 | 614.3 | gsm | 4.149 | Wed Dec 11 2024 11:12:16 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 24 |
| 51.9964296 | 4.352734 | 2024-12-11 13:12:19 | null | null | null | null | -1 | 614.3 | gsm | 4.149 | Wed Dec 11 2024 12:12:19 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| 51.9964296 | 4.352734 | 2024-12-11 14:12:16 | null | null | null | null | -1 | 614.3 | gsm | 4.15 | Wed Dec 11 2024 13:12:16 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| 51.9964296 | 4.352734 | 2024-12-11 15:12:24 | null | null | null | null | -1 | 614.3 | gsm | 4.149 | Wed Dec 11 2024 14:12:24 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 23 |
| 51.9964296 | 4.352734 | 2024-12-11 16:12:27 | null | null | null | null | -1 | 614.3 | gsm | 4.153 | Wed Dec 11 2024 15:12:27 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 22 |
| 51.9964296 | 4.352734 | 2024-12-11 17:12:24 | null | null | null | null | -1 | 614.3 | gsm | 4.145 | Wed Dec 11 2024 16:12:24 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 18 |
| 51.9964296 | 4.352734 | 2024-12-11 18:12:32 | null | null | null | null | -1 | 614.3 | gsm | 4.144 | Wed Dec 11 2024 17:12:32 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 20 |
| 51.9964296 | 4.352734 | 2024-12-11 19:12:29 | null | null | null | null | -1 | 614.3 | gsm | 4.143 | Wed Dec 11 2024 18:12:29 GMT+0000 (Coordinated Universal Time) | In de Hoven, Martinus Nijhofflaan 17K, 2624 ER Delft, Netherlands | 2 | null | 21 |

# Appendix H: Viability sheets

| **Cost Trackers per lifetime** | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | |
| **Production Costs Original Tracker** | **Cost** | | | | | | | | | | | | | | | | | | |
| Lightbug Pro Tracker | € | 150,00 | | | | | | | | | | | | | | | | | |
| Tube materials + construction | € | 50,00 | | | | | | | | | | | | | | | | | |
| **Total** | **€** | **200,00** | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |
| **Original Tracker** | **Mileage allowance** | | **Distance (back and forth) in km** | **Hours worked by Noria employee** | **Hourly rate** | **chance of loss/removal per use** | **# of deployments in product life** | **# of trackers deployed/research** | Total Costs (per lifetime) | | | | | | | | | | |
| Production Cost Original Tracker | | | | | | | | | € 200,00 | | | | | | | | | | |
| Travel Cost deployment | € | 0,23 | 200,00 | 3 | € 40,00 | | 16 | 10 | € 265,60 | Cost of deployment per tracker. 10 trackers are deployed at a time, so cost is divided over this number to find the cost per tracker. | | | | | | | | | |
| Travel Cost retrieval | € | 0,23 | 200,00 | 4 | € 40,00 | | 16 | 10 | € 329,60 | Cost of retrieval per tracker. 10 trackers are retrieved at a time, so cost is divided over this number to find the cost per tracker. | | | | | | | | | |
| Cost of unplanned removal | € | 0,23 | 200,00 | 3 | € 40,00 | 6% | 16 | | € 159,36 | Trackers have been removed by people which then required an employee to pick up the trackers which costs wages and transportation costs. | | | | | | | | | |
| Losing Tracker | € | 0,23 | 200,00 | 3 | € 40,00 | 12% | 16 | | € 384,00 | ################## | | | | | | | | | |
| Total Cost | | | | | | | | | € 1.338,56 | | | | | | | | | | |
| Total Cost True Pricing | | | | | | | | | € 1.338,56 | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|
| **Cost Trackers per lifetime** | | | | | | | | | | |
| | | | | | | | | | | |
| **Cost Price Redesigned Tracker** | **Cost** | Upfront costs for implementing the redesigned tracker (per tracker) | | | | | | | | |
| Lightbug Pro Tracker | € 150,00 | | | | | | | | | |
| Casing | € 170,00 | Price based on portal quote of Makerverse, might be somewhat different | | | | | | | | |
| AirTag | € 25,00 | | | | | | | | | |
| Waterproofing seal | € 5,00 | | | | | | | | | |
| Batteries | € 15,00 | | | | | | | | | |
| Additional Components | € 15,00 | | | | | | | | | |
| Assembly | € 10,00 | Assumes a duration of 15 minutes per tracker and an hourly rate of €40,-. | | | | | | | | |
| **Total** | **€ 390,00** | | | | | | | | | |
| | | | | | | | | | | |
| **Variables** | These values can be changed to see the effects on cost, revenue and margin. | | | | | | | | | |
| Research Duration (weeks) | 6 | Due to double the battery capacity, the research duration can be increased to a maximum of 6 weeks. | | | | | | | | |
| Deployments based on duration | 8 | It is assumed that the amount of uses changes based on the research durations, as the tracker wears down more if it is in the water for longer. This number changes automatically if the research duration is adjusted. | | | | | | | | |
| Number of trackers per research | 10 | The costs for deployment and retrieval are divided over this number, as this document considers the costs, revenue and margins per tracker over its lifetime. 10 is used as a base value as this was found in a Work Package provided by Noria. | | | | | | | | |
| Total use duration in lifetime | 48 | | | | | | | | | |
| | | | | | | | | | | |
| **Worst Case Scenario** | Mileage allowance | Distance (back and forth) | Hours worked by Noria employee | Hourly rate | Duration Research (weeks) | chance of loss/removal | # of deployments in product life | # of trackers deployed/research | Total Costs (per lifetime) | This scenario entails that the redesigned tracker performs to the same level as the original tracker (except for signal reliability as this was already proven to be better): 12% chance of losing a tracker and 6% chance that it is removed and requires picking up. Retrieving the trackers takes 2 hours (which adds up to 4 including transport). Deploying trackers is assumed to remain the same in all scenario's. |
| Cost Price Redesigned Tracker | | | | | | | | | € 390,00 | |
| Travel Cost deployment | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | | 8 | 10 | € 132,80 | |
| Travel Cost retrieval | € 0,23 | € 200,00 | 4 | € 40,00 | 6 | | 8 | 10 | € 164,80 | |
| Cost of unplanned removal | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | 12% | 8 | | € 159,36 | |
| Losing Tracker | | | | | 6 | 24% | 8 | | € 748,80 | |
| Total Cost | | | | | | | | | **€ 1.595,76** | |
| | | | | | | | | | | |
| **Medium Case Scenario** | Mileage allowance | Distance (back and forth) | Hours worked by Noria employee | Hourly rate | Duration Research (weeks) | chance of loss/removal | # of deployments in product life | # of trackers deployed/research | Total Costs (per lifetime) | This scenario entails that chance of losing trackers is 6% and chance of requiring picking up is 4%. Retrieving trackers takes 1,5 hours (3,5 including transport). |
| Cost Price Redesigned Tracker | | | | | | | | | € 390,00 | |
| Travel Cost deployment | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | | 8 | 10 | € 132,80 | |
| Travel Cost retrieval | € 0,23 | € 200,00 | 3,5 | € 40,00 | 6 | | 8 | 10 | € 148,80 | |
| Cost of unplanned removal | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | 8% | 8 | | € 106,24 | |
| Losing Tracker | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | 12% | 8 | | € 374,40 | |
| Total Cost | | | | | | | | | **€ 1.152,24** | |
| | | | | | | | | | | |
| **Best Case Scenario** | Mileage allowance | Distance (back and forth) | Hours worked by Noria employee | Hourly rate | Duration Research (weeks) | chance of loss/removal | # of deployments in product life | # of trackers deployed/research | Total Costs (per lifetime) | This scenario entails that chance of losing trackers is 2% and chance of requiring picking up is 2%. Retrieving trackers takes 1 hour (3 including transport). |
| Cost Price Redesigned Tracker | | | | | | | | | € 390,00 | |
| Travel Cost deployment | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | | 8 | 10 | € 132,80 | |
| Travel Cost retrieval | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | | 8 | 10 | € 132,80 | |
| Cost of unplanned removal | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | 4% | 8 | | € 53,12 | |
| Losing Tracker | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | 4% | 8 | | € 124,80 | |
| Total Cost | | | | | | | | | **€ 833,52** | |
| | | | | | | | | | | |
| **Exceptional Case Scenario** | Mileage allowance | Distance (back and forth) | Hours worked by Noria employee | Hourly rate | Duration Research (weeks) | chance of loss/removal | # of deployments in product life | # of trackers deployed/research | Total Costs (per lifetime) | This scenario is the same as the "Best Case Scenario" except that the number of deployments during its life is double because the redesigned tracker is assumed to be more durable here. This scenario can be created by changing the variables but is presented here separately to show potential financial gains of this redesign |
| Cost Price Redesigned Tracker | | | | | | | | | € 390,00 | |
| Travel Cost deployment | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | | 16 | 10 | € 265,60 | |
| Travel Cost retrieval | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | | 16 | 10 | € 265,60 | |
| Cost of unplanned removal | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | 4% | 16 | | € 106,24 | |
| Losing Tracker | € 0,23 | € 200,00 | 3 | € 40,00 | 6 | 4% | 16 | | € 249,60 | |
| Total Cost | | | | | | | | | **€ 1.277,04** | |

| **Costs Per lifetime** | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | |
| **Variables** | | | | | | | | | | | | | | | | | | | | | | |
| Price rate (%) | 100% | Due to a more professional image and more reliable data, I assume a higher price can be asked. This can be changed to play with the margin. It is assumed that the price for research is dependant on the research duration and scales linearly (i.e. 6 weeks is double the price of 3 weeks). | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | |
| Scenario | Duration (weeks) | Price rate (%) | Revenue per use | Uses | Total Revenue | Total Cost | Margin per lifetime | | | | | | | | | | | | | | | |
| Original Tracker | 3 | 100% | € 172,00 | 16 | € 2.752,00 | € 1.338,56 | **€ 1.413,44** | | | | | | | | | | | | | | | |
| Redesigned tracker Worst scenario | 6 | 100% | € 344,00 | 8 | € 2.752,00 | € 1.595,76 | **€ 1.156,24** | | | | | | | | | | | | | | | |
| Redesigned tracker Medium scenario | 6 | 100% | € 344,00 | 8 | € 2.752,00 | € 1.152,24 | **€ 1.599,76** | | | | | | | | | | | | | | | |
| Redesigned tracker Best scenario | 6 | 100% | € 344,00 | 8 | € 2.752,00 | € 833,52 | **€ 1.918,48** | | | | | | | | | | | | | | | |
| Redesigned tracker Exceptional scenario | 6 | 100% | € 344,00 | 16 | € 5.504,00 | € 1.277,04 | **€ 4.226,96** | Margin on the "Exceptional Case Scenario" is much higher because it assumes that the redesigned tracker will be more robust and can be used twice as often it its life. | | | | | | | | | | | | | | |