

# Animal friendly and durable attachment for the future

Oskar Markusson

DIVISION OF INNOVATION | DEPARTMENT OF DESIGN SCIENCES  
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY  
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MASTER THESIS



# **Animal friendly and durable attachment for the future**

A product development project to improve the design of  
smart animal tags

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UNIVERSITY

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Department of Design Sciences  
Faculty of Engineering LTH, Lund University  
P.O. Box 118, SE-221 00 Lund, Sweden

Subject: Technical Design (MMKM10)

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Supervisor: Axel Nordin

Co-supervisor: Erik Svensson

Examiner: Joze Tavcar

# Abstract

This master thesis aims to improve the physical design of smart ear tags for animals. The focus was to minimize the risk of tags falling off or causing harm, while considering environmental and animal welfare aspects.

The project followed the methodology of Ulrich & Eppinger's product development process, which included stages such as planning, concept development, and testing. Data collection involved qualitative interviews with farmers, surveys, and observational studies, complemented by competitor analysis and market research. Key challenges identified include the durability of existing tags, risks of environmental impact from lost tags, and the balance between secure attachment and animal safety.

Multiple concepts were developed and tested using a custom-built obstacle course simulating farm condition. Testing of the evaluated parameters such as flexibility, ergonomic suitability, and resistance to environmental stress. Additionally, a factorial test was conducted to analyze the influence of specific design factors on the tags' performance. Results from this test highlighted the critical role of material flexibility and tag thickness in reducing the risk of tags snagging on obstacles.

The proposed solution contributes to better animal welfare, reduced environmental footprint, and enhanced farm efficiency. The findings provide a foundation for further development in the design of smart ear tags and support the adoption of sustainable and data-driven solutions in modern agriculture.

**Keywords:** Smart ear tags, Animal welfare, Sustainable and Data-driven farming.

# Sammanfattning

Detta examensarbete syftar till att förbättra den fysiska utformningen av smarta öronbrickor för djur. Fokus var att minimera risken för att taggarna lossnar eller orsakar skada, samtidigt som hänsyn tas till miljö- och djurskyddsaspekter.

Projektet följde metodiken i Ulrich & Eppingers produktutvecklingsprocess, som inkluderade steg som planering, konceptutveckling och testning. Datainsamlingen omfattade kvalitativa intervjuer med bönder, enkäter och observationsstudier. Dessa kompletterades med konkurrentanalyser och marknadsundersökningar. De viktiga utmaningar som identifierades var bland annat hållbarheten hos befintliga taggar, risken för miljöpåverkan på grund av förlorade taggar samt balansen mellan säker fastsättning och djursäkerhet.

Flera koncept togs fram och testades i en specialbyggd hinderbana som simulerar förhållandena på bondgårdar. Testerna utvärderade parametrar som flexibilitet, ergonomisk lämplighet och motståndskraft mot miljöpåfrestningar. Dessutom genomfördes ett faktoriellt test för att analysera hur specifika designfaktorer påverkade taggarnas prestanda.

Resultaten från detta test visade att flexibilitet och tjockleken spelar en avgörande roll för att minska risken för att taggarna fastnar. Den föreslagna lösningen bidrar till bättre djurvälstånd, minskat miljöavtryck och ökad effektivitet på gårdarna. Resultaten utgör även en grund för vidare utveckling av designen av smarta öronmärken och stöder utvecklingen av hållbara och datadrivna lösningar i det moderna jordbruket.

**Nyckelord:** Smarta öronmärken, Djurhälsa, Hållbart- och datadrivet jordbruk.

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# 1 Introduction

*This section presents an introduction to the project, its background, goal and delimitations.*

## 1.1 Background

The dairy farming industry has undergone significant advancements in recent decades due to the rise of precision farming technologies. One key area of innovation is the development of smart tags - devices attached to cows to monitor their behavior, health, and productivity in real-time. These technologies allow farmers to move beyond traditional herd management and adopt a data-driven approach that improves both milk production and animal welfare. This chapter explores the historical context, current challenges, and potential future developments in the use of smart tags for monitoring cow behavior.

### 1.1.1 Evolution of Dairy Farming Technologies

Dairy farming has long relied on basic mechanical systems to improve efficiency. The use of equipment in the ears of cows was used as a more animal friendly system for identification than its predecessor, hot-iron branding. This system was mainly used by the farmers and genetics companies to keep track of well performing cows.

The introduction of automatic milking systems (AMS) in the late 20th century marked a major leap toward automation. AMS allowed cows to be milked without direct human intervention, optimizing milking schedules and reducing labor costs. Alongside this, the integration of identification sensors in the shape of RFID-tags helped transform herd management from a reactive process into a predictive, data-driven model.

The early iterations of smart collars focused on simpler metrics, like cow identification and activity levels. However, as technology progressed, these devices were placed

d in the ears to be able to collect more nuanced data, such as rumination rates, heat detection, and feeding patterns, delivered in a smaller package. This information has been proven to improve milk yield, monitor cow health and enhance overall farm management efficiency.

### **1.1.2 Current Challenges in Smart Tag Design**

While the benefits of smart tags are clear, several challenges remain, particularly in the physical design of these devices. One of the primary issues is the size and bulk of current smart tags. This could prove even more challenging as more sensors and functionality are integrated. Larger devices are prone to getting caught on fences, vegetation, or equipment. This can lead to the tag falling off or causing injuries to the cow's ear. This is a critical concern, especially for ear tags, where constant movement and outdoor exposure can cause wear and tear.

Additionally, comfort and durability are major concerns. Tags must be lightweight and ergonomically designed to avoid causing irritation or chafing, especially since they will be worn for most of the cow's lifetime. The choice of materials is equally important, as tags must be resistant to UV radiation, water, chemicals, and microbial growth. These environmental factors are common in farm settings and can significantly shorten the lifespan of devices that are not specifically engineered to withstand them.

### **1.1.3 Importance of Data-Driven Dairy Farms**

The concept of the data-driven dairy farm has risen in popularity due to the ability to collect and analyze detailed information for individual cows. This approach improves not only milk production but also the well-being of the herd. By monitoring health indicators such as temperature, activity, and feeding patterns, farmers can detect health issues or changes in behavior early. This allows for taking preventive measures rather than reactive treatments. This can reduce veterinary costs, minimize the use of antibiotics, and ensure that cows remain productive for longer periods.

Furthermore, precision milking - where each cow is milked at the optimal time based on its individual data - can maximize milk output and minimize stress on the animal. This level of customization is key to improve both efficiency and animal welfare, as over-milking or under-milking can lead to health problems like mastitis or reduced milk yields.

In addition to improving productivity, sustainability is another critical benefit of a data-driven approach. By optimizing feed usage, monitoring cow health in real-

time, and reducing waste, farms can decrease their environmental footprint. This aligns with the growing consumer demand for ethical and eco-friendly dairy products, giving farms that adopt smart technologies a competitive edge in the market.

#### **1.1.4 Future Trends and Market Development**

As the market for smart farming technology expands, component size reduction and improved durability are key focus areas. Research is ongoing into the development of smaller, more lightweight sensors that can provide detailed data without compromising on comfort or performance. Innovations in battery technology, wireless communication, and energy efficiency will also play a major role in making these devices even more practical for large-scale use.

The global trend toward sustainable farming further emphasizes the need for these enhancements. Farms, that leverage smart technology to monitor individual cows more effectively, can make better use of resources, improve herd health, and reduce their environmental impact. The ability to customize care for each cow, based on its specific needs, could become a standard practice, leading to more efficient farms with higher profitability and improved animal welfare.

## **1.2 Goal**

The goal of this project is to provide a physical concept for a refined smart ear tag. Focusing on the physical design aspects to reduce the risk of tags falling off. This would have important effects across the board in fields such as economics, sustainability, animal welfare, and milk performance.

The project aims not only to make the tag as small as possible, but also to provide knowledge on what are the most important design aspects in relation to the tag's durability, functionality, and usability for the intended application. It seems obvious that the tag should be as short, thin and light as possible. But there could be more important factors and the relationship between these are unclear. This could help later development when compromises need to be done, to know which aspect should be prioritized.

Another goal of this project is to develop a method for testing the physical performance of the ear tags to ensure that the design meets the necessary requirements under realistic conditions and to be repeatable. Additionally, the project aims to investigate the environmental aspects of the design, considering sustainability and its potential long-term impact.

## 1.3 Delimitations

To delimit the work, the focus has been on the physical design of the tag. The functionality of the tag and specific components have not been considered. Instead, it is assumed the tag will include a sufficiently sized circuit board and a battery. Injection-molded plastic is assumed as the material due to its cost-effectiveness in mass production, lightweight properties, and durability. It also provides excellent water resistance, crucial for protecting internal electronics in outdoor conditions.

Alternative materials were considered but are thought to be less suitable. Metals, such as aluminum, are durable but heavier and more expensive. Bioplastics could lack the durability needed for long-term use outdoors, while elastomers are less wear-resistant and not ideal for housing electronics. Composites, though strong and lightweight, are costly and less practical for large-scale production. Given these factors, injection-molded plastic is the most logical choice.

Aspects such as costs, technical drawings and manufacturing methods was to be considered depending on time.

## 1.4 Report Structure

The report is structured into nine chapters, providing a clear progression from understanding the problem, to presenting and evaluating the final design:

### 1. Introduction

The report begins with an introduction, that outlines the background, goal and scope of the whole project. It highlights the challenges of smart ear tag design and its significance for animal welfare, sustainability, and farm efficiency.

### 2. Theory

To provide the report with fundamental context, the theory chapter explores the history and current systems of animal ear tags and relevant regulations. This chapter also introduces key methodologies and frameworks that guided the project.

### 3. Methods

Describes the approach taken throughout the project, including planning, concept development, detailed design, and testing. It also outlines the data collection methods, such as interviews, surveys, and market analysis, which were crucial for understanding user needs and defining design requirements.

#### **4. Data Collection**

Summarizes insights from interviews, surveys, and observational studies, as well as findings from the market analysis. These data points created the base for the design process and shaped the development of the concepts.

#### **5. Environmental Impact**

Explores sustainability considerations, including recyclability, battery life, and waste management. It also discusses potential solutions, such as rechargeability and energy harvesting, to minimize environmental impact.

#### **6. Concept Development**

This chapter contains the creation of specific design ideas, beginning with an analysis of the farm environment and its challenges. It also covers the ideation process, prototyping, and testing methods, including the obstacle course used to evaluate physical performance.

#### **7. Concept Evaluation**

Assesses the design options against important criteria such as flexibility, manufacturability, and battery life. The evaluation matrix and results are used to determine the strongest concept.

#### **8. Final Result**

Presents the selected design, with an explanation of why it was chosen. The chapter also describes the design's key features and performance in testing.

#### **9. Discussion**

Reflects on the project's results, discussing the effectiveness of the methods used and suggesting improvements for future design and testing processes.

This structure provides a logical flow throughout the project, from identifying challenges to presenting a tested and refined solution. Each chapter builds on the previous one, leading to a comprehensive understanding of the design process and its outcomes.

## 2 Theory

*This section outlines the evolution of ear tags, from traditional branding to modern smart tags. It highlights key advancements in design, functionality, and regulation, reflecting changes in agricultural practices and animal welfare considerations.*

### 2.1 Animal ear tags

The practice of marking cattle for identification and management has been around for a long time and therefore also has been improved significantly over time, adapting to technological enhancements, and changing of agricultural practices.

#### 2.1.1 History

Historically, methods for marking cattle date back thousands of years. Branding, one of the oldest methods, involved burning a unique mark onto an animal's skin to show ownership. Evidence of this practice can be traced to ancient Egypt, where livestock branding was used to prevent theft and establish property rights (Wikipedia, 2024).

In the 20th century, less invasive techniques such as metal ear tags, were introduced. Metal tags, often stamped with serial numbers, became common in the mid-1900s, offering a reusable and relatively humane alternative to branding. The change into these methods reflected a growing awareness of animal welfare and the need for standardized identification systems as livestock industries expanded (Swain, Bishop-Hurley, & Handcock, 2021).

#### 2.1.2 Current systems

Today, plastic ear tags are the most widely used form of cattle identification. These tags display information, such as unique animal identification numbers and farm registration codes and national identification numbers for traceability.

In Sweden, regulations require that cattle are marked in both ears with yellow tags displaying the country code (SE), the farm's registration number, the animal's unique ID, and a verification check digit. This ensures compliance with traceability and food safety standards (Swedish Board of Agriculture, 2024).

Electronic identification (EID) tags have modernized livestock management by embedding RFID-chips in ear tags. These allow for electronic identification, a requirement for automatic milking.

A further innovation includes "smart tags," which incorporate sensors to monitor animal health parameters such as body temperature, movement, and stress levels. These tags not only facilitate traceability but also support proactive health management and productivity optimization (EFSA, 2019) (Jones, Smith, & Taylor, 2023)

## 2.2 Regulations and Standards

### 2.2.1 European regulations

In the European Union (EU), cattle identification and traceability are governed by specific regulations to ensure animal welfare, food safety, and effective disease control. These regulations outline requirements for ear tags, including their design, durability, and the information they must display.

The primary EU regulation concerning cattle identification is Regulation (EC) No 1760/2000 (EUR-Lex, 2000), which establishes a system for the identification and registration of bovine animals. This regulation mandates that each animal is identified with an ear tag in each ear, bearing the same unique identification code. The ear tags must be approved by the responsible authority in each Member State and should comply with the standards set by the EU.

#### *2.2.1.1 Design and Durability Standards*

While the EU provides overarching guidelines, specific technical standards for ear tags, such as the force at which they should release to prevent ear injury, are not detailed in the EU regulations. Instead, these technical specifications are often determined at the national level by each Member State's responsible authority. Manufacturers typically design ear tags to balance durability with safety, ensuring they remain attached under normal conditions but can release under excessive force to prevent injury.

### 2.2.1.2 Weight and Material Specifications

The EU regulations do not specify exact weight limits for ear tags. However, tags are generally designed to be lightweight to minimize discomfort and reduce the risk of ear damage. Materials used are typically durable plastics that withstand environmental conditions while being safe for the animal.

### 2.2.1.3 Information Requirements

According to EU regulations, ear tags must display: The country code (e.g., 'SE' for Sweden). A unique identification number for the animal. Additional information as required by national authorities. In Sweden, the Swedish Board of Agriculture specifies that cattle must be marked with yellow ear tags in both ears, displaying the country code (SE), the farm's registration number, the animal's unique ID, and a check digit for verification.

## 2.3 Ulrich & Eppinger's methodology

The Ulrich and Eppinger framework (Ulrich & Eppinger, 2015) is a widely used methodology for structuring the product development process. It provides a systematic approach for developing products efficiently and effectively while balancing technical, market, and design considerations.

The framework consists of these six phases:

1. **Planning:** This phase establishes the foundation for the project. It defines the scope, objectives, and target market while identifying key constraints and setting major milestones. By clarifying these elements early, the planning phase ensures that all the work is aligned with the project's goals.
2. **Concept Development:** In this phase, ideas are generated, evaluated, and refined into a product concept. Activities include brainstorming potential solutions, analyzing feasibility, and weighing trade-offs to select the most promising direction. The outcome of this phase is a clear vision of the product's function and value proposition.
3. **System-Level Design:** Once a concept is selected, the focus shifts to defining the product's overall architecture. The product is broken into major subsystems, with their interactions and interfaces clearly specified. This phase makes sure all components will work together.
4. **Detail Design:** Here, the specifics of each component and subsystem are finalized. Decisions about materials, dimensions, tolerances, and production methods are made, ensuring the design is manufacturable and meets performance requirements.
5. **Testing and Refinement:** Prototypes are developed to evaluate the product's functionality, reliability, and usability. Feedback from testing

often leads to iterative refinements, ensuring the design meets specifications and addresses user needs effectively.

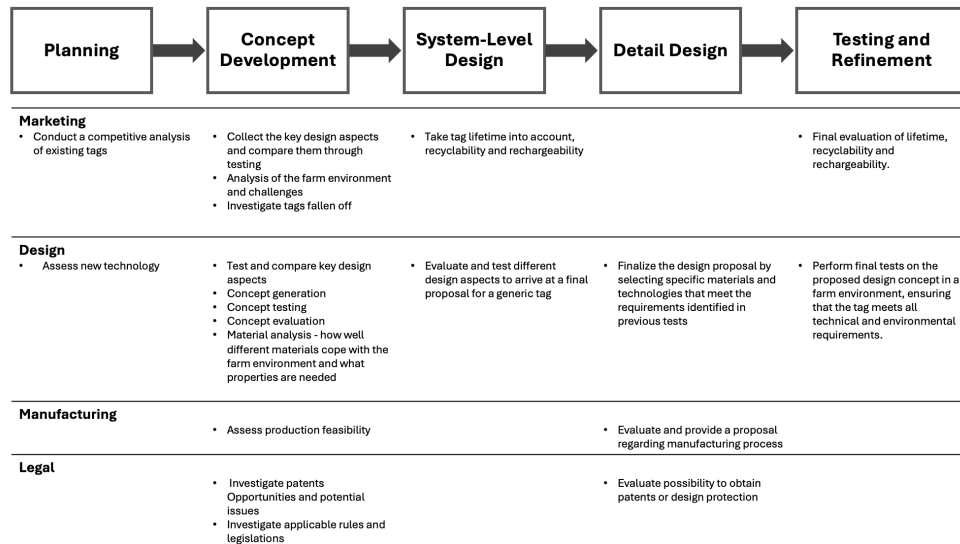
6. **Production Ramp-Up:** In this final phase, the product transitions from design to manufacturing. Early production units are tested, and the production process is fine-tuned to resolve any remaining issues before full-scale manufacturing begins.

The Ulrich and Eppinger framework is flexible and therefore allows for changes throughout the process. Feedback from later stages, like testing, can lead to updates in earlier phases, such as revising designs or materials. This adaptability makes it a strong tool for handling challenges in product development. Its clear structure simplifies complex processes, balancing technical, business, and user needs. Whether used fully or partially, it provides a reliable model for successful outcomes.

# 3 Methods

*A brief introduction to the methodology that is used in this project, including collection of input material.*

## 3.1 Applied parts of Ulrich & Eppinger



**Figure 1** An overview of the applied parts of Ulrich & Eppinger’s process and how they relate to this project (Author’s own, 2024)

### 3.1.1 Planning

The planning phase is essential for defining the market segment, identifying opportunities, and understanding the challenges associated with the farm environment. This phase includes an analysis of the farm environment, and the specific challenges related to fallen-off tags, which helps to identify user needs and product requirements. Additionally, mapping competitors' products and evaluating their performance is crucial to recognizing gaps in the market and uncovering opportunities for innovation. The insights gained during this phase form a solid

foundation for the subsequent Concept Development phase, where the focus shifts to generating and refining design solutions.

### **3.1.2 Concept Development**

The concept development phase focuses on investigating various solutions and developing product ideas. This begins with an analysis of fallen-off tags at farms to understand the challenges better. A competitive analysis of existing tags currently in use is conducted, focusing on parameters such as weight, torque, and tensile strength. Key design aspects are identified and compared using factorial experiment testing to evaluate performance differences.

During this phase, new concepts are generated, tested, and evaluated to identify the most promising solutions. Material analysis is also an essential part of this stage, assessing how well different materials cope with the farm environment and determining their suitability based on required properties. This includes evaluating materials for their ability to withstand environmental factors, recyclability, and overall sustainability. These steps align closely with Ulrich & Eppinger's framework, ensuring that the development process is systematic and well-informed by both user needs and competitive insights.

### **3.1.3 System-level design**

The system-level design phase focuses on creating a product architecture and defining the main components and their interfaces. This involves conducting a system-level analysis of the overall tag design, with a particular focus on durability, lifetime, and other key characteristics. During this phase, considerations regarding the environmental impact of the tag concept, such as recyclability and rechargeability, are evaluated. Additionally, the integration of different materials and recyclable options is explored to ensure sustainability is built into the product design. These activities align with Ulrich & Eppinger's framework, which emphasizes the importance of a structured approach to product architecture and sustainability planning.

### **3.1.4 Detailed design**

The detailed design phase focuses on finalizing the design proposal by selecting specific materials and technologies that meet the requirements identified in earlier tests. During this phase, the details of the product are defined, including material selection, dimensions, and tolerances. With the evaluation and testing of the main design aspects completed, these can now be refined into a finalized design. This phase also includes the preparation of detailed technical documentation, which

serves as the blueprint for the final product design. Following Ulrich & Eppinger's framework, this phase ensures that all aspects of the design are carefully specified to meet performance and sustainability goals.

### **3.1.5 Testing and Refinement**

The testing and refinement phase focuses on performing final tests on the proposed design concept in a real farm environment. These tests ensure that the tag meets all technical and environmental requirements, including durability, recyclability, and rechargeability. During this phase, the lifetime of the tag is thoroughly evaluated, along with its ability to perform reliably under actual usage conditions.

Field testing, as described by Ulrich & Eppinger, is essential to verify the product's performance, durability, and functionality. Based on the results, any necessary adjustments or improvements can be made to ensure that the final product fully meets the defined requirements.

## **3.2 Data Collection Methodology**

### **3.2.1 Overview**

To get as good and credible result as possible, data- and methodical triangulation was used when collecting information. According to Salkind, N. J. (Salkind, 2010) triangulation include several aspects when collecting information, using quantitative, qualitative and exploratory methods. To achieve this, qualitative interviews with farmers have been conducted, a quantitative survey as well as observational studies of farm equipment and its challenges.

### **3.2.2 Interview Methodology**

Interviews are an important part of qualitative data collection and can be conducted in different ways depending on the purpose of the study. In this study, semi-structured interviews were used to balance flexibility with guided inquiry. This method, as described by Bryman (2016), allows for the use of a predefined interview guide while leaving room for the conversation to flow freely, with questions asked in a flexible order. The aim of this approach was to encourage open and reflective responses and minimize the risk of steering the interviewee's thoughts towards specific expectations (Bryman, 2016), (Kvale & Brinkmann, 2009), (Patton, 2015).

Initially, questions were formulated in a broad and open-ended way to capture a wide range of responses and perspectives. Open-ended questions are central to qualitative research as they allow respondents to provide detailed and nuanced answers, providing insights that may not emerge through more structured questions (Patton, 2015). By encouraging spontaneous and in-depth responses, this method allows for a deeper understanding of respondents' perspectives.

As the interview process continued, questions were iteratively refined based on the insights gained from previous interviews. This approach, highlighted by Kvale and Brinkmann (2009), allows the interviewer to go deeper into topics or patterns that emerge and refine the focus in later interviews to better explore these areas. The iterative process of refining questions increases the depth and relevance of the data collected and increases the understanding of the context and the ongoing data collection process.

A combination of audio recordings and notes were used to document the interviews. Audio recording was the preferred method.

### **3.2.3 Survey Methodology**

For the quantitative part of the data collection, a survey was used to collect information from a larger group of participants. Surveys allow data to be collected from multiple people in a structured way, making it possible to compare results (Creswell & Creswell, 2018). In this study, the survey contained questions similar to those in the interview guide and used the lessons learned from its development. The questions were asked in the form of multiple-choice questions, sometimes with the possibility to elaborate on the answer. The multiple-choice format was chosen because it is easier for participants to respond quickly and makes it easier to analyze the results (Fowler, 2014), (Wright, 2017). To reach a large number of participants, the survey was shared online via social media. It was distributed in Facebook groups, which made it possible to target specific groups. The survey was designed with structured, closed questions to ensure that responses could be easily compared and analyzed. This approach helps to identify patterns and trends important to the study's objectives (Bryman, 2016).

### **3.2.4 Observational Studies**

In this study, observational methods were used to understand natural behaviors and interactions in a specific environment. Observation is a qualitative research technique as it allows to collect data without directly influencing what is occurring (Cohen, Manion, & Morrison, 2018). This method is particularly useful when it is not possible to ask direct questions.

To reduce the impact of the observer on the situation, a version of the 'fly on the wall' method was used. This technique involves remaining as unobtrusive as possible while observing the environment (Martin & Hanington, 2012). The aim is to see genuine behaviors without influencing the actions of the observed. However, even with this method, it can be difficult to completely avoid being noticed, which can still influence behavior in some way.

During the observations, notes were taken, and photographs were used to document key moments. The notes captured immediate thoughts and details, while the photographs provided a visual image of key interactions and environments, and also provide the possibility to go back and discover new details, even long after the visit.

### **3.2.5 Data for Competitor Analysis**

For the competitor analysis, it was not possible to obtain a small sample of smart tags from suppliers, as these tags are part of larger and more expensive systems only sold on request. The data used in this analysis was therefore taken from publicly available product information provided by manufacturers on their websites. This information includes details on product specifications and features. In addition to this, data was collected during farm visits and by attending Elmia Lantbruk 2024, the largest agricultural fair in Sweden, where several suppliers of animal tags had stands where they displayed their products. This allowed direct observation of the products and interaction with the suppliers, providing further insights into the competitive landscape.

Using publicly available product data and attending industry events such as trade fairs is a common approach to competitor analysis, as it allows for the collection of relevant and timely information without the need to purchase sample products (Kotler & Keller, 2016).

## **3.3 Test Methodology**

A significant part of this project involved the development of both the testing methodology and the test equipment. The goal was to create a testing environment that accurately simulates real-world conditions. This approach follows Ulrich and Eppinger's (Ulrich & Eppinger, 2015) recommendation to design test environments that mirror actual usage scenarios, ensuring that design strengths and weaknesses are clearly identified under realistic conditions. By testing in environments that reflect real use, the methodology ensures more valid and usable results.

The testing process was designed to be repeatable, measurable, and easy to understand. This approach aligns with Pahl and Beitz's (Pahl & Beitz, 2013) emphasis on the importance of structured and systematic testing. Their work highlights that a well-defined testing process, with clear and measurable criteria, is essential for obtaining reliable and consistent results. In this project, the tests were structured to evaluate the product based on defined metrics, ensuring that each iteration could be consistently assessed.

In developing the test equipment, it was crucial that the equipment replicated the real-world conditions in which the product would be used. This approach is consistent with Pahl and Beitz's (Pahl & Beitz, 2013) principles of engineering design, which stress the importance of aligning the design and testing processes with practical applications. Additionally, the equipment was designed to be user-friendly, ensuring that the tests were easy to carry out and interpret, as recommended by Ulrich and Eppinger (Ulrich & Eppinger, 2015).

# 4 Data collection

*The goal of the data collection chapter is to build a strong foundation for the design, development, and testing process.*

## 4.1 Interview learnings

### 4.1.1 Overview of the interview methodology

The interviews were held with farmers during farm visits both in Italy and in Sweden. An interview guide was developed (see Appendix B), based on the knowledge available at the time of preparation. The guide served as a framework for the interviews and helped to make sure that all relevant topics were covered. The early interviews were held in a semi structured way, as the goal was to get open and reflective answers and thoughts that were not limiting the answers to what was wanted to be heard. As the interviews progressed, the questions evolved by earlier answers and learnings from previous interviews. This to understand whether they agreed with each other or had different perspectives. The questions were not asked in a strict order but were adapted to the course of the conversation and the answers given by the interviewees. If a topic had already been discussed in a previous answer, the corresponding question was skipped. In this way, the guide served as a supportive tool rather than a rigid structure.

### 4.1.2 Themes emerging from interviews

From the interviews done the farmers seems to experience that the issue of tags fallen off comes in bursts and that some batches of the smart tags are worse. Could also be that something specific happens at the farm at this specific time. One thought was that some batches of the tags had bad teeth.

One other concern is regarding the environmental impact regarding where the fallen off tags end up. Also, the aspect that if a tag falls off a new hole needs to be done in the cow's ear. For smart tags the cost of replacing a new tag is not negligible, together with that collected data will be lost and a heat could be missed.

Most farmers interviewed preferred ear tags compared to collars as less dirt and bacteria's get stuck in the ear tag when cows lay down. Also, the collars tend to chafe on the skin through general activity.

In Sweden it is thought to be the worst when a tag tears the ear and causes the cow to suffer, but in Italy they had another mindset of fallen off tags being the biggest problem. Had the ear gotten torn, that would have showed that the lock of the tag was strong enough.

#### **4.1.3 Challenges during interviews**

The biggest challenge performing the interviews was the sound level at the farm. Audio recording was the preferred method, but it was rarely used as it was often noisy or in some cases the interviewee did not want to be recorded. Instead, it was only used when the interviewees agreed to it and supporting notes were written down.

## **4.2 Survey results**

This section presents the insights gathered from the survey, which aimed to understand the challenges and issues related to ear tags for cattle. While the survey received responses from only eight participants, the findings provide a useful perspective on the key problem areas.

#### **4.2.1 Survey development and distribution**

The survey was designed to gather feedback from farmers on their experiences with ear tags, focusing on areas such as injuries to animals, replacement costs, data loss, environmental impact, and animal welfare. Questions covered both qualitative and quantitative aspects to identify trends and recurring themes. Despite the limited sample size, the responses provide a valuable foundation for exploring the broader challenges associated with ear tags. All survey answers can be found in Appendix CAppendix B

#### **4.2.2 Quantitative insights and trends**

Although the survey's small sample size limits the scope for statistical generalizations, several trends emerged:

#### *4.2.2.1 Injuries to animals*

A recurring concern was the risk of physical harm caused by ear tags. Many respondents emphasized that this issue is "very serious and must be avoided at all costs", highlighting the need for safer designs to protect animal welfare.

#### *4.2.2.2 Replacement Costs*

Participants frequently cited the financial and operational burden of replacing lost tags. This was coupled with frustration over the time required to locate and replace tags, which impacts farm productivity.

#### *4.2.2.3 Data Loss*

Lost ear tags were identified as a key source of data loss, affecting valuable information such as heat detection and animal tracking. Respondents expressed concern over how these losses hinder effective herd management.

#### *4.2.2.4 Environmental Impact*

Several respondents voiced concerns about the environmental impact of lost or discarded tags, particularly their contribution to plastic waste. This emphasizes the importance of exploring sustainable solutions.

#### *4.2.2.5 Lost Tags and Feed Tables*

An interesting trend emerged regarding the locations of lost tags. Feed tables were frequently associated with higher rates of tag loss, particularly on farms reporting frequent issues. This suggests that equipment or activities near feed tables might contribute to the problem, or rather be the factor that makes a farm a "problem farm". At the same time, the data indicated a baseline level of tag loss.

### **4.2.3 Comparison to interview insights**

The results of the interviews and the survey are consistent in several important areas, such as animal welfare, replacement costs and data loss due to lost ear tags. Both approaches highlight the need for safer designs to prevent injuries and reduce the financial and operational costs associated with replacements. However, while the interviews provided a deeper understanding and highlighted regional differences, like Swedish farmers addressing the prevention of torn ears and Italian farmers addressing the prevention of lost tags, the survey added detail to the findings. The survey added another perspective and revealed specific patterns, such as feed tables being an important site for tag loss. In addition, the environmental issues regarding plastic waste were prominent in both the survey and interview responses, but with a slightly different weight.

## 4.3 Observational studies

### 4.3.1 Observation setup and goals

The goal is to be in the places where farmers perceive that tags are dropped and try to monitor what kind of environment that could cause the ear tags to fall off. To be in the correct environment, watching the cow's behavior.

### 4.3.2 Techniques documentation

Observation during the site visits were photographed and recorded along with notes from the interviews.

### 4.3.3 Observed behaviors and patterns

When observing the cow's behavior, it was noticed that the movements are rough and uncoordinated when buffing against each other and against fences. When getting stuck somewhere, they push harder and harder to become free and are at the same time getting more stressed out.

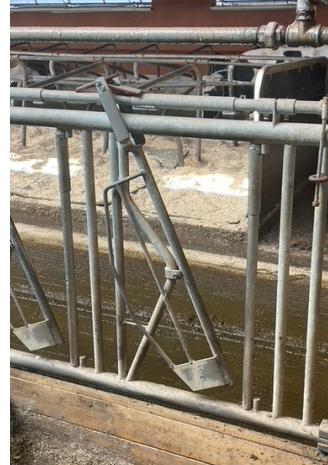
At the same time the farm environment was studied. How the headlocks were constructed, their dimensions and where there was a risk of an ear tag getting stuck. Also, aspects such as how much space the cow had in different situations, like feeding and resting was observed.

#### *4.3.3.1 Headlock pictures from farm visit*

In Figure 1 to Figure 4 examples of farm environments are shown, showing where the ear tags can get stuck. It can be seen that different headlocks are more prone for the ear tags to get stuck.



**Figure 2** First example of a headlock with a lot of moving parts and small gaps (Authors own photo, 2024)



**Figure 3** Second example of a headlock, also with smaller gaps and moving parts (Authors own photo, 2024)



**Figure 4** Third example of a headlock, large gaps and few moving parts (Authors own photo, 2024)

#### 4.3.3.2 Headlock pictures from the agricultural fair at Elmia Lantbruk 2024

In Figure 5 through Figure 7 some examples of different headlocks are shown, found at the agricultural fair, Elmia Lantbruk 2024. Here it can be seen that different materials are used, as well as different dimensions and types of pipes.



**Figure 5** A smaller stainless headlock for young stock (Authors own photo, 2024)



**Figure 6** A galvanized headlock with an intricate design and small gaps (Authors own photo, 2024)



**Figure 7** Another headlock with intricate design and small gaps (Authors own photo, 2024)

#### **4.3.4 Limitations of observational methods**

When observing cows, they tend to change their behavior and are not forgetting that an observer is there. They continue to stare at you. This means you need to observe from a distance to not affect the outcome of the observation.

## **4.4 Market Analysis**

### **4.4.1 Sources of market data**

#### *4.4.1.1 Manufacturers' and retailers' websites*

Data was collected from publicly available sources such as manufacturers' and retailers' websites. This included technical specifications, product descriptions, and marketing materials, which provided an overview of the available solutions and their features.

#### *4.4.1.2 Elmia Agricultural Fair*

Visit to Sweden's largest agricultural fair, Elmia Lantbruk 2024, allowed for observation and direct interaction with suppliers of smart ear tags. The fair offered an opportunity to gather information about products, communicate with representatives, and gain practical insights into the current market offerings and trends.

### **4.4.2 What is measured?**

The market for dairy cow monitoring technologies revolves around several key measurements that provide insight into their health, behavior, and productivity. These measurements allow farmers to make informed decisions and optimize their farm management. The parameters that are measured and provided are presented below.

#### *4.4.2.1 Heat Monitoring*

Detecting when a cow is in heat is an important part for breeding management. Sensors like accelerometers and temperature sensors are used to identify changes in activity, body temperature and other factors to detect when a cow is ready to be inseminated.

#### *4.4.2.2 Eating Behavior*

Monitoring a cow's eating habits and feed intake is an important indicator of health and productivity. Reduced or irregular eating patterns can signal issues like illness or nutritional deficiencies.

#### *4.4.2.3 Rumination*

Rumination is an important indicator of a cow's overall health and digestion. A decrease in rumination time can signal stress, illness, or a change in diet. Sensors in the ear tag or collar can track rumination activity.

#### *4.4.2.4 Positioning*

Real-time tracking of a cow's location is useful for herd management, safety, and health monitoring. GPS or other location-based sensors track the cow's movements, allowing farmers to identify cows that may be isolated or in distress.

#### *4.4.2.5 Health Monitoring*

Various health indicators, such as body temperature, respiratory rate, and heart rate, can be tracked to identify early signs of illness. This can help prevent the spread of disease and improve overall herd health.

#### *4.4.2.6 Measurement insights*

These metrics provide critical insights into the cow's well-being and enable proactive management strategies. Smart tags and sensors are key tools in improving dairy herd performance, optimizing breeding schedules, and detecting health issues before they become critical.

### **4.4.3 Product categories**

The market offers a range of solutions for dairy cow monitoring, and the products can generally be divided into the following categories.

#### *4.4.3.1 Ear tags*

Smart ear tags are a wearable device for dairy cows attached to their ears and contain sensors to monitor heat, rumination, eating behavior, and more. Ear tags are easy to apply, reasonably protected by the ear and is well placed for detecting head movements.

#### 4.4.3.2 Collars

Smart collars are worn around the cow's neck and offer similar monitoring capabilities as ear tags, with the added benefit of potentially being easier to remove or replace. Collars are bulkier, gather more dirt and risk to chafing the cow's neck, but they can offer more space for additional sensors or battery capacity.

#### 4.4.3.3 Camera-based solutions

These solutions involve using cameras combined with image processing and machine learning algorithms to monitor cows in real-time. Cameras can track eating behavior, health indicators (like body posture or signs of distress), and even environmental factors. However, camera-based solutions are typically more complex, requiring significant infrastructure in the form of cameras as well as an identification system that will work together. They can provide very detailed insights but lack the mobility and real-time capabilities of wearable devices.

#### 4.4.3.4 Category summary

Each method has its strengths and weaknesses, depending on the farm's specific needs and the desired level of monitoring. While this project focuses on ear tags, other solutions like collars and camera systems are also considered to provide a broader context and understanding of the available options.

### 4.4.4 Manufacturers of smart ear tags

The five main companies on the smart ear tag market, are SCR (A part of Allflex), Nedap, DeLaval, Cow Manager, and SmartBow. The first three also offer sensors of the collar variety. The data transmission technology used by the tags where also considered, as this is an area where the tags differ a lot from each other.

#### 4.4.4.1 SCR SenseHub (a part of Allflex):



Figure 8 SCR SenseHub (SenseHub Örontransponder, 2024)

SCR is one of the major companies specialized in dairy cow monitoring. Their products include both ear tags and collars. Their tag, seen in Figure 8 Figure 8 SCR SenseHub , provides insight into the following parameters: Heat detection, Rumination, Eating and Health. They have two versions of their tag, the original one with a claimed battery life of 3 years and a new one, for which they have a 4-year warranty. That suggests that their expected battery life is at least 4 years, but probably even longer due to having safety margins.

They are communicating with the tags on the 2.4GHz frequency band, more specifically 802.15.4, which is a standard typically used for IoT-sensors and the technology have a reading range around 100 meters. (SenseHubTM, 2020)

#### **4.4.4.2 Nedap CowControl SmartTag Ear**



**Figure 9 Nedap CowControl SmartTag Ear**

This is a new smart ear tag that will be introduced in 2025. Today Nedap (Nedap CowControl, 2024) is already a large actor on the market with their smart collars. And the ear tag will enter into their current ecosystem providing further flexibility for the farmers. The tag will have all the features that the collar has today except for positioning, that means heat detection, rumination, eating and health performance. They have a promised 7+ year battery life. The tag will transmit its data on the 433 MHz frequency band and have a reading range of around 75m inside and up to 250m outside. See Figure 9.

#### **4.4.4.3 DeLaval Behavior Analysis 200/300 BiosensorEar tags**



**Figure 10 DeLaval Behavior Analysis 200/300 BiosensorEar tags (DeLaval Plus Behavior Analysis, 2024)**

The DeLaval ear tag system shown above in Figure 10 DeLaval Behavior Analysis 200/300 BiosensorEar tags , is the only ear tag on the market that in addition to heat detection, rumination, eating and health performance also provides positioning for their tags. They have a battery lifetime of about 5 years and are using UWB Technology for transferring data from the tag as well as positioning the tag. A limitation of UWB is while it makes for accurate positioning the reading range is shorter at about 30-40m. This tag is presented in Figure 10.

#### **4.4.4.4 CowManager Ear tag**



**Figure 11 CowManager Ear tag**

The CowManager ear tag, depicted above in Figure 11, (LIFETIME MONITORING, 2024) is developed especially for the Benelux market, as the cows are not allowed to have more than one hole per ear due to governmental regulations. Their attachment system is different in that it can be attached to some models of the ISO-transponder. The ISO-transponder is part of the required equipment that dairy cows need to have. The Cowmanager tag is not only sold in this region, but in other markets where the one-hole rule does not apply, it is usually attached with a “dummy tag”. They use the 2.4GHz Zigbee protocol to transfer data and have a

reading range of around 100m. They have an expected battery lifetime of about 5 years and they also provide a 5 year warranty for their tags.

#### 4.4.4.5 Smartbow (Zoetis)



**Figure 12 Smartbow (SMARTBOW INTEGRATION: DAIRYCOMP, 2024)**

The exact specifications for the Smartbow ear tags are not available on their website, only on request, and as they are also not sold in Sweden and not present at the Swedish agricultural fair, the exact specifications are still unknown. They are still included due to having every function as well as a different shape than the rest of the tags on the market. Figure 12 shows the design.

#### 4.4.5 Comparison matrix

Table 4.4-1 compares the different features of the respective vendors.

**Table 4.4-1 Comparison matrix**

	<b>SCR (Allflex)</b> SenseHub Ear tag	<b>Nedap</b> CowControl SmartTag Ear	<b>DeLaval</b> Biosensor Ear tag	<b>CowManager</b> Ear tag	<b>Smartbow</b> Ear tag
<b>Functions:</b>					
Heat detection	✓	✓	✓	✓	✓
Rumination	✓	✓	✓	✓	✓
Eating	✓	✓	✓	✓	✓
Health	✓	✓	✓	✓	✓
Positioning			✓		✓
<b>Other info:</b>					
Technique for data transfer	2,4GHz 802.15.4	433MHz	UWB	2,4 GHz Zigbee	N/A
Battery life	3-4 years	7+ years	~5 years	~5 years	N/A
Warranty	4 years on new tags	N/A	4 years	5 years	N/A
Unique selling point	The original smart ear tag with the longest experiance	Market leaders in smart collars	Very accurate positioning	Can fit onto ISO-transponders, not requireing a second hole in the era	Positioning

# 5 Environmental Impact

*The environmental impact of smart ear tags for dairy cows is an important consideration as their use grows. While offering significant benefits for livestock management, these devices also pose challenges related to sustainability and waste. This chapter examines the recyclability of ear tags, the risks of lost or discarded tags, and potential solutions to reduce their ecological footprint. Minimizing tag loss, along with design improvements such as modularity and better recycling options, can play a key role in reducing waste and supporting more sustainable farming practices.*

## 5.1 Recyclability

The recyclability of smart ear tags is closely tied to the way they are designed and manufactured. Most tags are produced as molded units, often combining a plastic front and back or using potting materials to encase the electronics. This approach, while challenging for recycling, has probably been chosen primarily due to the harsh conditions in which these devices must function. Smart ear tags are exposed to moisture, manure, temperature fluctuations, and rough handling in the barn environment. The need for robustness and durability in these tough conditions means that the materials used, and the construction methods, often prioritize long-lasting performance over recyclability.

A modular design, while potentially beneficial for recycling, may not be able to meet the demanding environmental conditions that smart tags face in daily use. Components that are easily separable or removable could be more vulnerable to damage, moisture ingress, or malfunction, reducing the overall effectiveness and reliability of the tag. Therefore, the current design choices may be a direct response to the need for longevity and resilience in the field, where tags must withstand not only the physical environment but also the wear and tear of livestock interactions.

However, this presents a challenge in terms of waste management. When these tags reach the end of their lifecycle, their inability to be easily disassembled for recycling means that they can contribute to electronic waste. Given that these devices are used worldwide, the global inconsistency in e-waste management only adds to the problem. Some regions may have advanced recycling systems, while others do not,

creating the risk that improperly disposed of tags could end up polluting the environment.

To address this, manufacturers could consider design improvements that balance the need for durability with better recyclability. For example, making the battery removable could extend the tag's lifespan and allow the battery to be recycled separately, reducing environmental harm. While a fully modular design might not be feasible, incremental improvements in tag design that enhance recyclability without compromising performance could help mitigate the environmental impact.

## 5.2 What happens to fallen-off tags?

During interviews with farmers, it became clear that many smart ear tags that fall off are never recovered. While some tags are found on the feed tables or in the cubicles, the vast majority go missing. The most common assumption is that these lost tags are scraped away by the manure scraper, which is typically used to clear waste from the barn floor. Once the tags are lost, they are collected by the scraper, and ultimately spread out across the fields when the manure is used as fertilizer.

This scenario presents a significant environmental concern. The electronic components and batteries inside these tags pose a threat to both the soil and the surrounding ecosystem. Batteries can leek harmful chemicals such as heavy metals into the environment. Over time, these toxins can potentially contaminate crops, water supplies, and the broader agricultural ecosystem. Additionally, as the tags are made from various materials, they can take a very long time to break down, further compounding the environmental impact.

Although the loss of tags is not a widespread issue, it is usually a couple of percent of tags. It remains a serious environmental concern that should not be overlooked. Even a small number of lost tags can contribute to electronic waste, as well as pose environmental risks due to the presence of batteries and electronic components. When tags are lost and not recovered, they can end up in fields, where they may release harmful substances into the soil or water. This is particularly troubling for the sustainability of farming practices, which are already under increasing pressure to reduce waste and limit environmental impact. To address this issue, it is essential to focus on improving tag retention and minimizing the likelihood of loss. Potential solutions include designing more secure attachment mechanisms for the tags, using environmentally friendly or recyclable materials, and exploring recovery methods that help farmers locate and retrieve lost tags before they are discarded. By addressing these challenges, we can reduce the environmental footprint of ear tags while supporting more sustainable farming practices.

## 5.3 Tag battery and lifetime

According to a study published by (De Vries & Marcondes, 2020) and data gathered from interviews and surveys, the typical productive lifespan of a dairy cow ranges from 2.5 to 4 years. While cows can often live longer on smaller farms, their lifespan tends to be shorter on larger farms due to higher turnover rates. Therefore, the minimum battery life of the smart ear tag should be at least 4 years without the need for intervention. This would be especially beneficial for larger farms, where avoiding battery replacements and other maintenance tasks would significantly reduce labor costs and save valuable work hours.

To achieve such long battery life, the ear tags may need to integrate energy-efficient technologies, such as energy harvesting (e.g., solar panels) or low-power consumption components. By reducing the frequency of manual battery replacements, farmers could focus more on animal welfare and less on maintenance.

In addition to time savings, the extended battery life also contributes to sustainability by reducing the number of batteries that need to be replaced and disposed of. This, in turn, helps lower the environmental impact of the farm's operations.

## 5.4 Rechargeability

The potential for rechargeability could be a key factor in extending the lifespan of smart ear tags. Several approaches can be considered to minimize battery waste and reduce the need for frequent replacements of the tags. In this project, energy harvesting, wireless charging, and charging while removed from the animals are explored. Each of these options has potential, but the choice of method will depend on factors such as energy needs, and environmental conditions.

### 5.4.1 Energy Harvesting

This method captures ambient energy, such as solar power or movement, to charge the tag. While it can reduce reliance on traditional charging, the amount of energy harvested may be limited, especially in less optimal conditions.

#### *5.4.1.1 Small scale solar panels*

Solar panels are a widely used method for powering smart sensors, and incorporating one into the smart ear tag design could be a viable solution. However, the farm environment presents unique challenges, especially when it comes to ensuring the tag remains durable and functional. To assess the feasibility of using

solar power, the readily available SM340K10L solar panel (SM340K10L, 2024), which measures 34,0 x 16,0 x 2,0 mm (5,44 cm<sup>2</sup>), was considered. This size is slightly smaller than the circuit board dimensions typically used for this project, meaning it should not significantly impact the overall design or dimensions of the tag.

This solar panel delivers 73,5 mW under optimal sunlight conditions. According to the market analysis, the maximum energy consumption for a smart ear tag is 1 Wh per year. Given this, the panel would be able to fully charge the tag in approximately 13.7 hours of direct sunlight.

(calculated as  $1000 \text{ mWh} / 73,5 \text{ mW} \approx 13,7 \text{ hours}$ )

This energy generation time seems promising and suggests that the concept of using solar panels for the tag is feasible in terms of energy requirements. However, the main challenge is the availability of sunlight. In many regions, cows are kept indoors and may not have access to natural sunlight, especially during winter months when daylight is limited. While artificial light may provide some energy, it is likely insufficient to fully charge the tag under typical indoor lighting conditions. Therefore, the battery would need to be sufficiently large to account for periods of limited sunlight, ensuring the tag can still operate effectively during times when solar charging is not feasible.

Additionally, it is important to consider that the solar panel itself could potentially interfere with the ear tag's wireless signal. The presence of a solar panel near the tag's wireless communication system (e.g., UWB or RFID) could result in signal interference. Depending on the panel's material, size, and positioning, it may act as a shield or cause reflection, which could reduce the effective range or reliability of the communication. Attention will need to be paid to the integration of the solar panel in the design to ensure that the ear tag's functionality is not compromised by these potential issues.

#### *5.4.1.2 Wireless Charging*

Wireless charging is another potential method for powering smart ear tags. Unlike solar panels, wireless charging does not depend on environmental conditions like sunlight. The concept of inductive charging uses electromagnetic fields to transfer energy between a charging coil and a compatible receiver. For small devices like ear tags, wireless charging can offer a practical solution for recharging without the need for manual intervention.

However, while the technology is proven, several challenges arise when considering its use in a real-world farming environment. One of the most significant issues is the alignment and proximity required for effective wireless charging. For inductive charging to work efficiently, the charging coil on the ear tag must be placed very close to the charging surface, and the tag needs to remain relatively still during charging.

Given that cows are often moving, or even when they are stationary, their ears are subject to movement and vibration, making it difficult to ensure that the ear tag stays in the correct position relative to the charging pad. In practice, this could lead to inefficient charging or even complete failure to charge the tag if it shifts out of alignment.

Another challenge lies in the size of the ear tag. To enable wireless charging, a coil must be integrated into the tag. This introduces a design constraint since the coil must be small enough to fit into the tag while still being large enough to transfer sufficient energy for recharging. The presence of this coil may increase the size of the tag, potentially making it bulky and less comfortable for the animal. Furthermore, the coil's presence can also affect the signal strength of the tag's wireless communication system (e.g., UWB or RFID). The coil may introduce electromagnetic interference, leading to a reduction in signal range or reliability, which is crucial for real-time monitoring and tracking.

Thus, while wireless charging offers a promising and convenient method for powering ear tags, careful design considerations are required to ensure the charging efficiency and functional integrity of the tag. This includes overcoming the alignment and positioning challenges as well as minimizing any negative impact on the tag's performance in terms of signal strength and comfort for the animal.

#### **5.4.2 Charging While Removed**

An alternative solution for extending the lifespan of smart ear tags is to design them to be charged when removed from the animal. This approach could help to prolong the overall lifetime of the tag by allowing it to be periodically recharged without the need for continuous energy harvesting or wireless charging while attached to the cow.

However, for this solution to be viable, the tag's battery life would need to support the 4-year lifespan of the tag without requiring frequent recharging. Currently, many ear tags on the market use non-rechargeable batteries that are designed to last up to four years. It is unlikely that rechargeable batteries would match the same level of performance, as they typically have a shorter lifespan per charge cycle.

While charging the tag when removed from the animal could help extend its use, this solution requires careful consideration of the charging infrastructure and the tag's overall durability. The tag would need to remain functional for a sufficient period before requiring a recharge, ensuring that it continues to meet the needs of the farming operation over the long term.

## 5.5 Conclusion of environmental considerations

The most straightforward and effective way to reduce the environmental impact of the smart ear tag in this project is by focusing on minimizing the risk of tags falling off. Ensuring that the tag stays securely in place throughout its lifespan would significantly reduce the potential for electronic waste and environmental harm, as lost tags are difficult to recover and can end up in the fields.

In addition to prevent tag loss, extend the tag's lifespan should be a key priority, even though it is not a part of this project. This could be achieved by integrating rechargeable batteries or developing energy-harvesting solutions that reduce the need for frequent replacements. A longer-lasting tag would help to reduce waste and the need for new resources, thus promoting sustainability.

Lastly, the recyclability of the tag is essential for minimizing its long-term environmental footprint. The tag's design should prioritize the use of recyclable or biodegradable materials, and manufacturers should take responsibility for ensuring proper disposal or recycling methods. This would not only reduce electronic waste but also create a more circular lifecycle for the product, aligning with broader sustainability goals in the agricultural industry. By addressing these key areas, to secure attachment, extended lifespan, and improved recyclability the benefits of smart ear tags are maximized.

# 6 Concept development

*The chapter covers the methods used to generate and evaluate multiple design concepts, including requirements gathering, ideation, prototyping, and testing.*

## 6.1 Farm Environment Analysis

### 6.1.1 Overview

As shown by the data collected, there are several challenges faced by farmers and their cows. These challenges can be linked to the environment in which the cows are kept, the material from which the ear tags are made and the stress to which the animals themselves are exposed. These are the aspects that have been identified through farm visits, interviews and literature reviews.

### 6.1.2 Risk of the tag getting stuck

In free range barns, where cows can move freely, they come into contact with other cows or equipment (e.g. headlocks at feed tables, automatic milking systems or feeders), which may increase the risk of the ear tag getting stuck resulting in a lost tag or injury to the animal.

Interaction with furnishing and outside environment, ear tags can get caught in fences, bushes or other equipment that animals move nearby. This is especially true for cows kept in outdoor environments with lots of vegetation or confined spaces. The risk is that the ear tags could be torn off or damage the animal's ear if they get stuck.

### 6.1.3 Chemicals and cleaning agents

The farm environment is harsh in regard to chemicals. In the stables, manure and urine is highly present meaning that the cows and in turn their ear tags will come into contact with manure and urine. They are highly corrosive and can affect the tag

negatively. Therefore, the ear tag materials must be sufficiently resistant to not degrade or deteriorate in this environment.

Contact with chemicals is also likely in this environment. Ear tags may be exposed to chemicals when cleaning the stables or in treatment areas where disinfectants and other cleaning products are used. This can also affect the durability of the plastic in the ear tags, causing them to become brittle or fade over time.

#### **6.1.4 UV light and weather effects**

For cows that have access to go outdoor, the ear tags are exposed to continuous solar radiation. UV radiation can degrade most plastic materials over time, making them brittle and can cause ear tags to break. The weather itself also has an effect on the tag. Just in different parts of Sweden, cows are exposed to large temperature variations. Ear tags can be exposed to both high heat during summers and cold winters, these temperatures affect their durability. Cold temperatures can make the material more brittle, while heat can make it softer and less durable. As well as repeated heat cycles causing larger effects.

Another aspect is if the tag is made from multiple types of plastics, the temperature changes could result in lost adhesion and delamination between the plastics.

#### **6.1.5 Physical stresses**

Cows often rub their heads against different surfaces, such as poles or each other, which through rubbing and chafing can cause wear on ear tags. Also, the natural movement and interactions with other cows can also affect the longevity of ear tags. In larger herds or intense interactions between cows, such as when they are in heat, ear tags can be put under extra stress.

## **6.2 Requirements**

### **6.2.1 Overview**

There is an extensive list of different requirements in several areas to consider when developing a new ear tag. To delimit the work in this project, all requirements have been grouped into three subgroups: Project specific requirements, Concept evaluation specific requirements and General requirements.

#### *6.2.1.1 Project specific requirements (PSR)*

These are requirements that are set for this project that serves as the guideline for the concept generation.

#### *6.2.1.2 Concept evaluation specific requirements (CESR)*

These are the requirements that are dependent of the physical design of the tag. Therefore the concepts are evaluated on how well they fulfill/facilitate these requirements.

#### *6.2.1.3 General requirements (GR)*

These are requirements that directly affect the performance of the tags, but they are general to the extent that the design of the tag does not affect them. But they cannot be ignored.

### **6.2.2 List of the different requirement areas, including sub requirements**

This list of ear tag requirements has been collected when doing market analysis, field visits, farmer surveys and interviews.

#### *6.2.2.1 Ear tag component requirements (PSR)*

- Contain battery
- Contain lock
- Contain circuit board
- Housing made of plastic

#### *6.2.2.2 Material requirements*

- Facilitate Injection molding (CESR)
- UV-resistant to prevent degradation and fading. (GR)
- Chemical-resistant to withstand contact with cleaning agents, manure, and disinfectants. (GR)
- Water-resistant and corrosion-proof to handle moisture and harsh weather. (GR)

#### *6.2.2.3 Mechanical Property requirements*

- Impact-resistant to handle the physical stress from rubbing or collisions with surfaces and other animals. (GR)
- Flexible enough to avoid causing injury, yet strong enough to resist breaking. (CESR)

- Temperature-resistant, able to endure both cold and heat without becoming brittle or soft. (GR)

#### *6.2.2.4 Ergonomic requirements (CESR)*

- Lightweight to avoid discomfort or strain on the cow's ear.
- Soft and minimized contact after attachment to prevent irritation or infection.
- Compact and snag-free shape to minimize the risk of getting caught and falling off.

#### *6.2.2.5 Durability and longevity*

- Battery life, (CESR)
- Long-lasting readability, ensuring information like company logo, serial numbers and production code stays legible despite sun, weather, and dirt exposure. (GR)
- Resistant to microbial growth to avoid health issues. (GR)

#### *6.2.2.6 Safety Requirement*

- Smooth edges to prevent injuries to the animal. (CESR)
- Safe release if the tag gets caught to not damage ears. (GR)
- Secure attachment mechanism to prevent loss during daily activity. (GR)

#### *6.2.2.7 Compliance with Regulations*

- Must meet national or local agricultural standards. (CESR)
- Use of eco-friendly and recyclable materials to minimize environmental impact. (GR)

#### *6.2.2.8 Summary table of included requirements*

**Table 6.2-1 Requirement summary**

List of requirements	Project specific requirements	General Requirements	Concept evaluation requirements
<b>Ear tag components</b>			
Battery			
Lock			
Circuit board			
Housing made of plastic			
<b>Material</b>			
Facilitate injection molding			
UV-resistancy			
Chemical-resistancy			
Water-resistancy			
<b>Mechanical properties</b>			
Impact-resistancy			
Flexibility			
Temperature resistancy			
<b>Ergonomics</b>			
Lightweight			
Soft - minimize skin contact			
Compact & snag-free			
<b>Durability/Longevity</b>			
Battery life			
Readability (markings)			
Microbial - resistancy			
<b>Safety</b>			
Smooth edges			
Safe release			
Secure attachment			
<b>Compliance</b>			
Agricultural standards			
Eco-friendly materials			

### 6.3 Concept Generation

The concept generation phase begins by defining the essential components required for a functional smart ear tag. Once these components are identified, the ideation phase follows, where different ways to combine and arrange these parts are explored. The primary focus during this phase is to ensure that the tag’s design prevents it from getting caught in the cow’s environment, which could lead to the tag falling off or causing injury. While the locking mechanism must be secure enough to keep the tag in place, this is not the central focus of the project. Instead, the emphasis is on designing the rest of the tag to minimize the risk of it getting

caught or causing harm to the cow, ensuring it stays securely attached to the cow's ear for as long as possible. To test and evaluate this, a method for testing the different concepts is developed in parallel.

### 6.3.1 Required parts

#### 6.3.1.1 Battery

For the battery, both rechargeable and non-rechargeable batteries are considered. For cost effectiveness, widely readily available batteries are prioritized. To enable a wider range of concept, some more custom/niched batteries have also been included. In Table 6.3-1 Table 4.4-1 Comparison matrix a summary of all included batteries can be found. Figure 13 and Figure 14 presents a rendering of all possible batteries included in this thesis.

**Table 6.3-1 Battery comparison**

<i>Batteries</i>	<i>Voltage (V)</i>	<i>Milliamperere hours (mAh)</i>	<i>Watt hours (Wh)</i>	<i>Size WxLxH or DxH (mm)</i>	<i>Volume (cm<sup>2</sup>)</i>	<i>Weight (g)</i>	<i>Wh / cm<sup>2</sup></i>	<i>Wh / g</i>	<i>Charge cycles</i>
Rechargeable									
Li-Po 403040	3,7	500	1,85	40x30x4	4,8	10	0,39	0,185	N/A
Li-ion 14500	3,7	1000	3,7	14,5x50	7,6	21	0,49	0,176	>500
Li-ion 14250	3,7	400	1,48	14,5x24	4,1	10	0,36	0,148	>500
LIR2450	3,0	100	0,3	24,5x5	2,4	5,3	0,13	0,057	>1000
LIR2477	3,0	180	0,54	24,5x7,7	3,6	7	0,15	0,077	>1000
Custom rechargeable									
Ring-Shaped Lipo Grepow GRP3238030	3,9	200	0,77		2,5	N/A	0,46		>1000
Round Lipo Grepow GRP7535035	4,0	845	3,38	35x7,5	6,6	N/A	0,51		>1000
Non-rechargeable									
ER14250	3,6	1200	4,32	14,5x25	4,1	9,2	1,05	0,47	0
ER14335	3,6	1650	5,94	14,5x33,5	5,5	14	1,08	0,42	0
CR123A	3,0	1500	4,5	17x34,5	7,7	21	0,58	0,21	0
CR2	3,0	920	2,76	15,6x27	5,1	11	0,54	0,25	0
CR2450	3,0	620	1,86	24,5x5	2,4	6	0,77	0,31	0
CR2477	3,0	1000	3	24,5x7,7	3,6	7	0,82	0,42	0

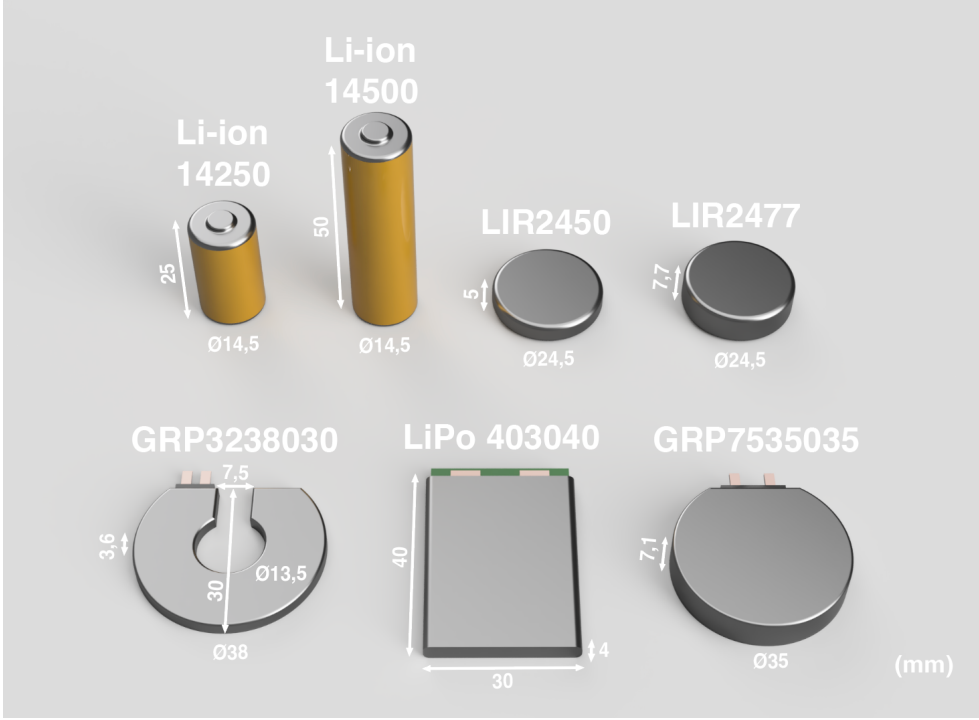


Figure 13 Rendering of rechargeable battery alternatives



**Figure 14 Rendering of non-rechargeable battery alternatives**

### 6.3.1.2 Circuit board

The dimensions of the circuit boards used in the concepts were derived from publicly available information. By analyzing pictures, renders, and photographs of existing tags on the market, particularly data published by SCR, the approximate area of their internal circuit boards was estimated. To ensure consistency, the shared locking mechanism dimensions between the tags were used as a reference point to scale and compare the other dimensions of the tags.

The normal thickness of a circuit board base sheet was assumed to be 1.6 mm, with components estimated to add an additional 2 mm in height. Importantly, due to antenna limitations, the circuit board must be positioned above the battery to ensure the battery does not interfere with the tag's signal strength. This spatial constraint is a critical factor in the concept generation.

The inclusion of the circuit board area in the project is one of the key constraints established for the concept development phase. Only the area of the circuit board itself is considered in this project, see Figure 15 to Figure 17. To not go into the

specific components that would be placed on the board or the footprint they would require. This simplification was made to focus on the high-level design considerations of the tags.

It is worth noting that concepts utilizing non-rectangular circuit boards may face greater challenges in fitting components due to reduced usable space. However, this challenge is left outside of this project and is not a part of the concept evaluation. The simplified approach is a good foundation for developing concepts, but additional development work and adaptations will be needed in future stages.

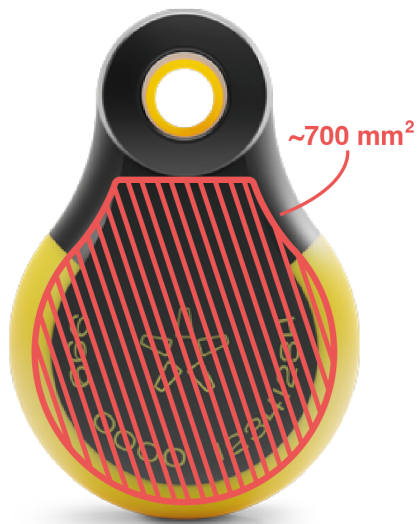


Figure 15 Circuit board area 1



Figure 16 Circuit board area 2

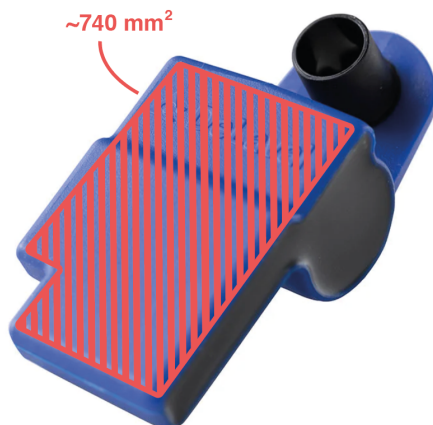


Figure 17 Circuit board area 3

### 6.3.1.3 Lock and Backplate

To attach ear tags to cows' ears, most manufacturers use a system with a backplate, shown in Figure 18, that goes through the ear and a lock, see Figure 19, on the other side to secure the tag. This is the standard method used in the industry today. In this project, a standard off-the-shelf backplate and lock will be used for all concepts to keep the attachment system consistent. The lock design will not change between concepts because this project focuses on improving the tag design, not the locking mechanism.

The lock does play a role in keeping the tag secure, but it has its limits. A lock that is too strong could hurt the cow by tearing the ear if too much force is applied. For this reason, the project focuses on designing tags that are less likely to get stuck or caught in the first place. By solving this main problem, the project can improve how reliable the tags are while also ensuring the animals' welfare.



Figure 18 Backplate



Figure 19 Lock

### 6.3.2 Ideation stage

For the ideation stage, a small workshop was prepared with 3D-printed models of all the relevant batteries, a lock, real backplates and corrugated fiberboard from a pizza box to simulate the circuit board. Figure 20 and Figure 21 show the simulated parts. The goal was to find the most compact and valid combinations.

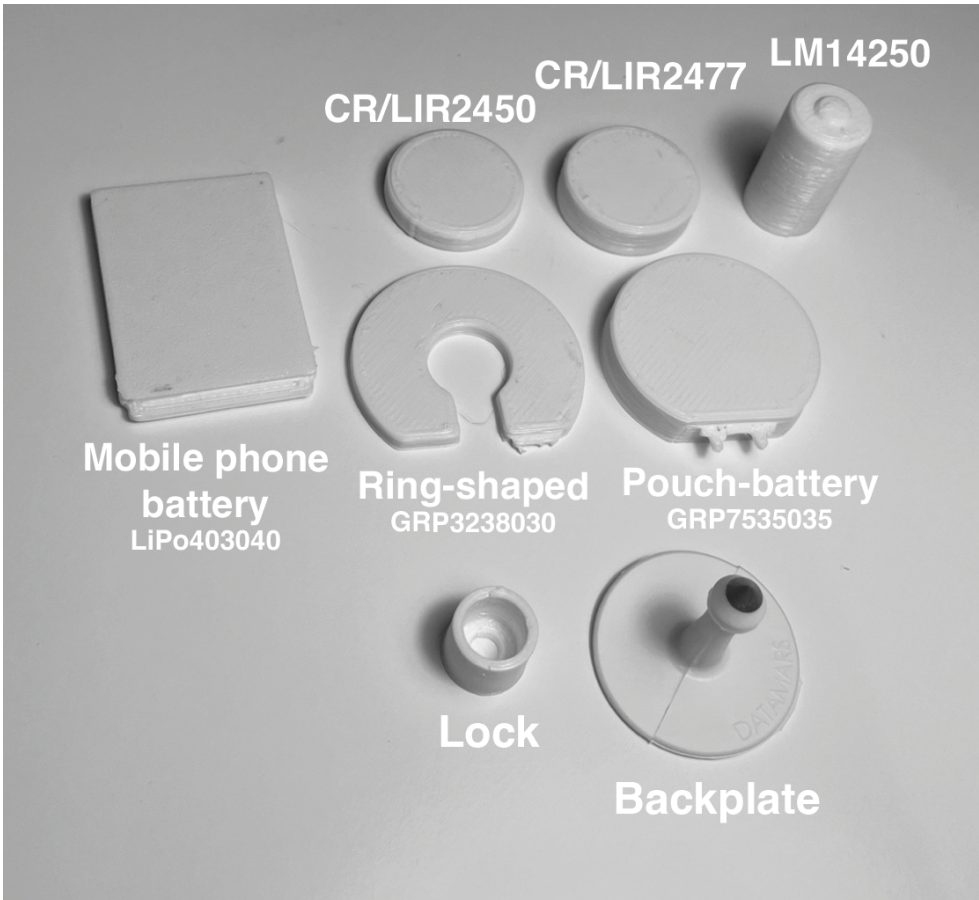


Figure 20 3D-Printed parts + backplate:

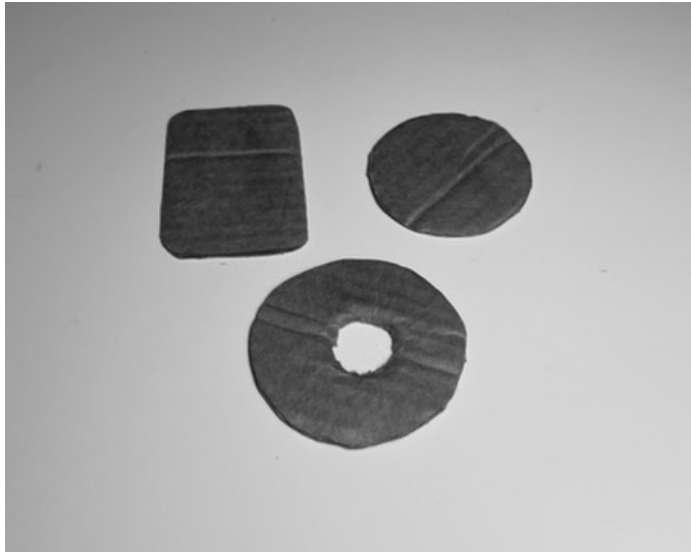


Figure 21 "Circuit boards" cut out from corrugated fiberboard

### 6.3.3 Concepts

#### 6.3.3.1 Concept 1 "The large ISO-transponder"

Through utilizing the rechargeable ring-shaped battery from GrePow (GRP3238030), the lock can be placed inside of the ring. The tag gets a well-balanced center of mass, large enough front area for the circuit board and a thin overall package. In Figure 22 to Figure 25, concept 1 is depicted from idea to a full CAD-model.

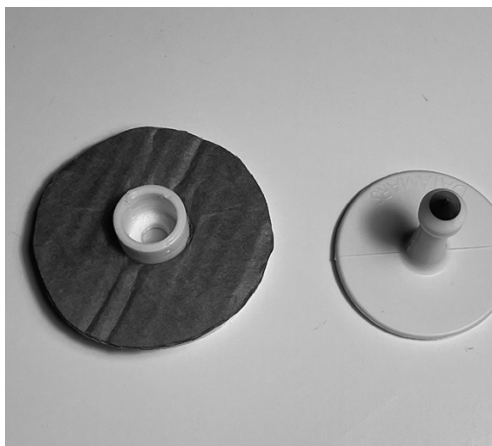


Figure 22 Prototype Concept 1

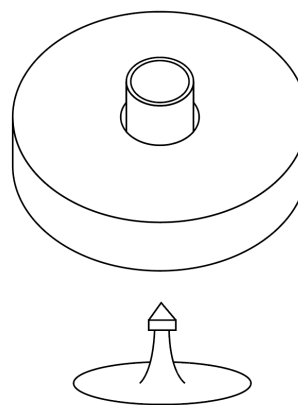


Figure 23 Schematic view Concept 1



**Figure 24 CAD-models: Complete view for Concept 1**



**Figure 25 CAD-models: Split view for Concept 1**

### 6.3.3.2 Concept 2 “¿Back lock and frontplate?”

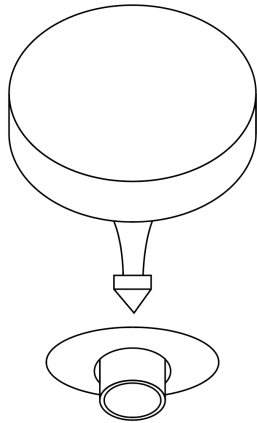
Concept 2 is about changing what is normally done with ear tags, which is putting the backplate, the intelligent part of the tag, on the back of the ear. The pin of the backplate is now instead combined with the tag itself and the lock is placed on the back of the ear. This makes it possible for a tag to have a compact design with a centered center of mass without a hole through it. Which in turn makes the use of any button shaped battery cell possible. This concept is presented in Figure 26 through Figure 28.



**Figure 26 Prototype Concept 2.1**



**Figure 27 Prototype Concept 2.2**



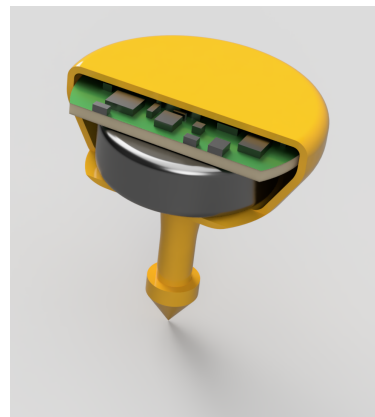
**Figure 28 Schematic view  
Concept 2**

**Concept 2.1:**

This concept uses the CR2477/LIR2477 battery, which has a smaller surface area than  $7 \text{ cm}^2$  and therefore gets an awkward shape. But this smaller footprint on the ear could be an advantage when it comes to chafing and breathability for the skin. The CAD models are shown in Figure 29 and Figure 30.



**Figure 29 CAD-models: Complete view for  
Concept 2.1**



**Figure 30 CAD-models: Split view for  
Concept 2.1**

**Concept 2.2:**

Instead the GrePow GRP7535035 battery is used, which is a closer match for the surface area of the needed circuit board ( $7 \text{ cm}^2$ ) and therefore gets more of a puck shape. This has a larger footprint on the ear, but a shape that should be less likely to get stuck. Figure 31 and Figure 21 are showing the CAD-models for Concept 2.2.



**Figure 31 CAD-models: Complete view for Concept 2.2**



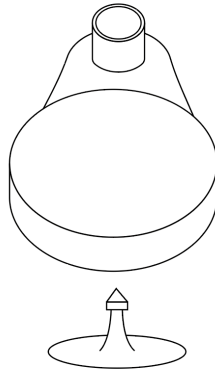
**Figure 32 CAD-models: Split view for Concept 2.2**

*6.3.3.3 Concept 3 “The large keychain blip”*

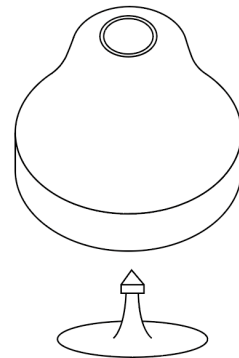
The inspiration for this concept is the RFID-tags that are used for keypads and are usually carried on keychains. This uses a button shaped battery (CR2477) and the battery placed on the same side as the lock. Two variants were made. One that is as compact as possible, and the other one is slightly longer to allow for some flexing. Prototype and schematic pictures are presented in Figure 33 to Figure 35 below.



**Figure 33 Prototype Concept 3**



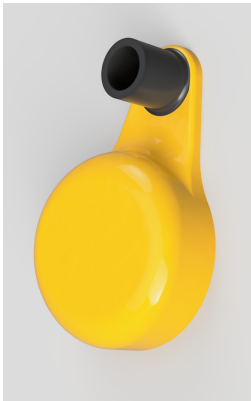
**Figure 34 Schematic view Concept 3.1**



**Figure 35 Schematic view Concept 3.2**

**Concept 3.1:**

To allow for some flex, a 6 mm distance between the housing of the battery/circuit board was inserted between the housing and the lock, see the CAD-model in Figure 36.



**Figure 36 CAD-models: Complete view for Concept 3.1**

**Concept 3.2:**

This concept is instead made without a flex and a minimal distance between the housing of the battery/circuit board and the lock to make the tag the smallest possible. The CAD-model is shown in Figure 37.

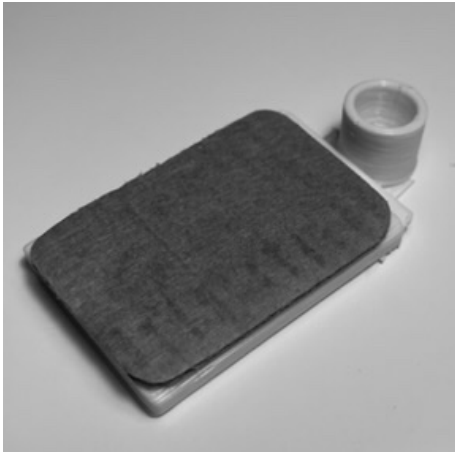


**Figure 37 CAD-models: Complete view for Concept 3.2**

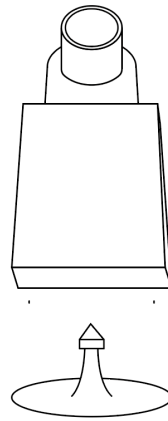
*6.3.3.4 Concept 4 “The handbag”*

To make the thinnest possible tag, the “mobile phone” battery was used. At only 4mm thick the LiPo403040 with 12 cm<sup>2</sup> area on its front, it makes room for a larger

circuit board than the rest of the concepts. This is depicted in Figure 38 through Figure 41.



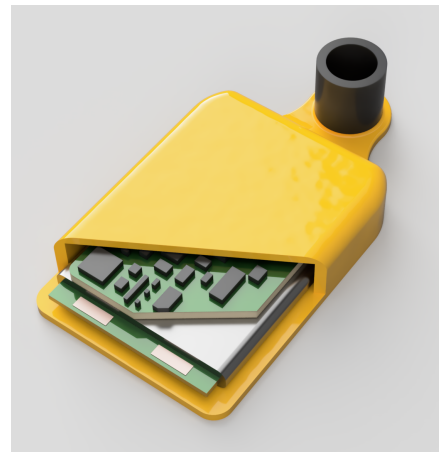
**Figure 38 Prototype Concept 4**



**Figure 39 Schematic view Concept 4**



**Figure 40 CAD-models: Complete view for Concept 4**



**Figure 41 CAD-models: Split view for Concept 4**

## 6.4 Concept testing

The main part of the concept testing has been made with the test setup called the “obstacle course”. The development process for the obstacle course is described in Appendix D. This chapter focuses on the final test setup and its application in the project.

### 6.4.1 Test Setup “The Obstacle course”

During farm visits and observations, the design of headlocks was found to be one of the main causes of ear tags getting stuck or falling off. These headlocks often have narrow openings that get caught in the ear tags when the animals use them. To address this problem, a controlled test set-up, called the obstacle course, was developed.

The aim is to test and compare how different ear tags handle the stresses and obstacles they are exposed to in real farm conditions. By using a mechanical testing method, it is possible to repeat the tests under consistent conditions without risking animal health. This ensures that the evaluation of durability and functionality is accurate and reproducible.

#### *6.4.1.1 Relevance of the “obstacle course” test method*

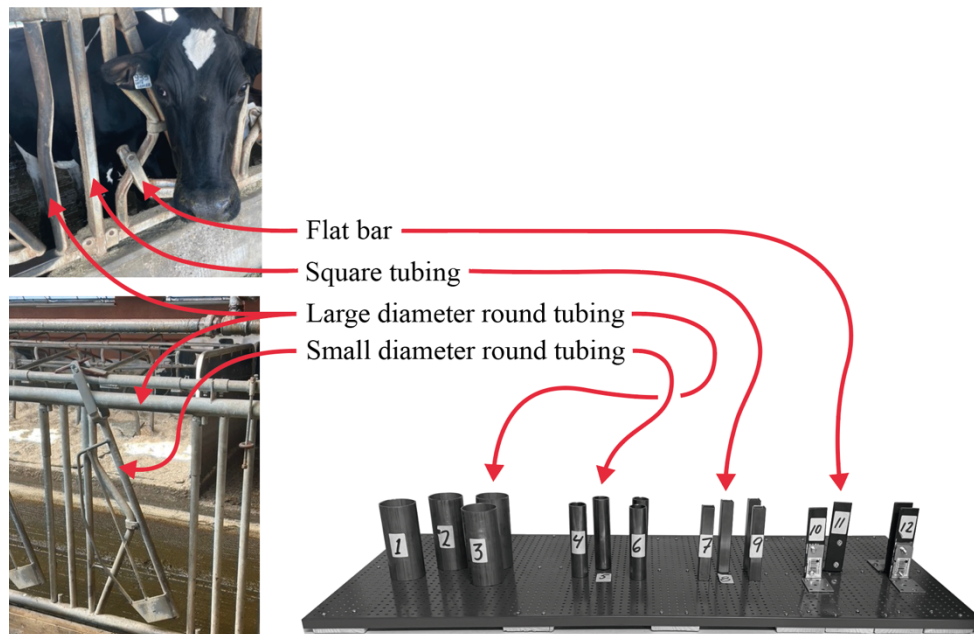
The obstacle course is designed to mimic the challenges that the earmarks face on the farms, visualized in Figure 42. The design is based on measurements and dimensions of pipes and other obstacles observed during farm visits, ensuring that the installation accurately simulates the environment that the ear tags will face in real-life conditions.

To achieve consistent testing, the mechanical pulling system runs at a repeatable speed and force during each test. This minimizes the variation between individual tests and allows for reliable and comparable results between different ear tag designs. The standardized path of 900 mm also provides a consistent environment for evaluating the tags, allowing for fair and objective comparisons. There is some flex in the obstacles, but since every tag is tested with the same setup, that is not seen as an issue.

The controlled test environment strengthens the validity of the method. By avoiding unpredictable factors such as animal behavior or other environmental influences, tag performance can be evaluated in isolation. This makes sure that the results reflect the tags' own characteristics rather than external variables.

Finally, the accuracy of the force measurements is a critical aspect of the method. A calibrated force gauge is used to measure the resistance force that occurs as the

tags navigate through the obstacles. The speed of the trajectory has been optimized to match the sampling rate of the force meter, providing accurate and reliable measurements. This focus on accuracy and consistency reinforces the obstacle course's usefulness as a robust and effective test method.



**Figure 42** Connection between headlock observations (Figure 2 and 3) and the “obstacle course”

## 6.4.2 Prototypes that were tested

All the prototypes tested were 3D-printed from PETG with the exception for a second run of tests for Concept 3.1 which was 3D-printed using TPU filament instead.

To really test the performance of the different concepts, several parts of the designs were standardized. These included the dimensions of the lock, the backplate attachment and the thickness of materials.

## 6.4.3 Results

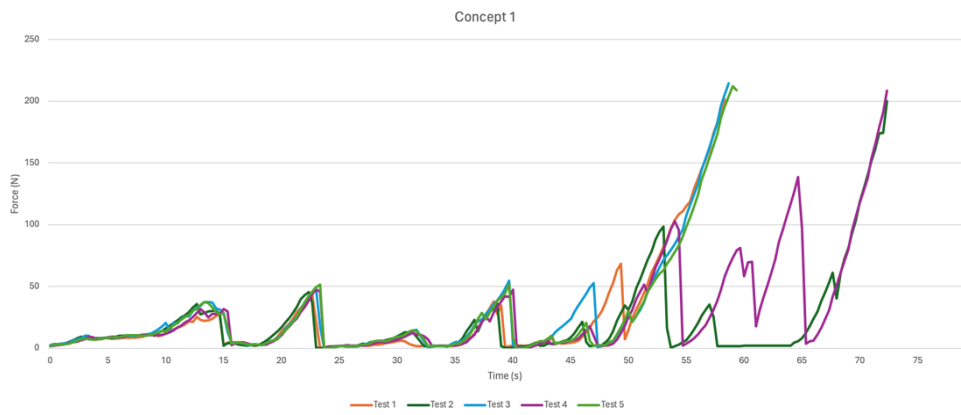
### 6.4.3.1 Concept 1

The 3D-printed prototype of Concept 1, shown in Figure 43, is attached to a modified backplate using a 3x8 mm wooden screw. This standardized screw and backplate combination is consistently used for all tested concepts to ensure comparability in performance.



**Figure 43 3D-printed prototype of Concept 1**

The graph in Figure 44 presents the force measurements logged over time for all five test runs through the obstacle course. The Y-axis represents the force in Newtons (N), while the X-axis shows the time in seconds (s). When a graph ends, it indicates that the tag became caught on an obstacle and could not continue.



**Figure 44 Force measurements Concept 1**

A visual representation of the obstacle course is provided in Figure 45, with markings indicating where each tag became caught. Specifically, runs 1, 3, and 5 were stopped at obstacle 9, while runs 2 and 4 were halted at the final obstacle, number 12.



**Figure 45** Test run 1,3 and 5 got stuck on obstacle 9 while test run 2 and 4 got stuck on the final obstacle (12).

#### 6.4.3.2 *Concept 2.1*

The 3D-printed prototype of Concept 2.1, shown in Figure 46, is attached to the same backplate as the one used for the other concepts. However, this design includes an additional lock on the backside, as the concept reverses the locking mechanism.



**Figure 46** 3D-printed prototype of Concept 2.1

The results of the five test runs are illustrated in Figure 47 and Figure 48. The graph in Figure 47 presents the force measurements logged during each test run, while Figure 48 provides a visual representation of the obstacle course, marking where the tag became stuck. Together, these figures show how runs 2 and 3 stuck at

obstacle 3, while runs 1 and 5 stopped at obstacle 6. Run 4 advanced further, getting stuck at obstacle 9.

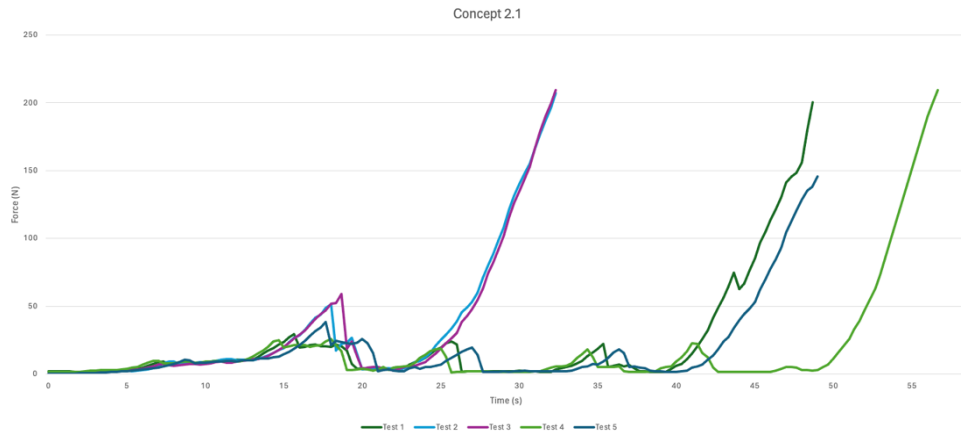


Figure 47 Force measurements Concept 2.1

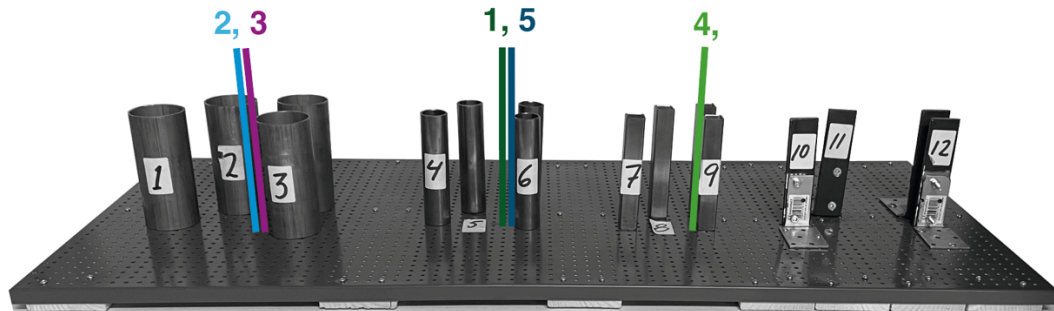


Figure 48 Test run 2 and 3 got stuck on obstacle 3. Test run 1 and 5 got stuck on obstacle 6 while test run 4 made it to obstacle 9.

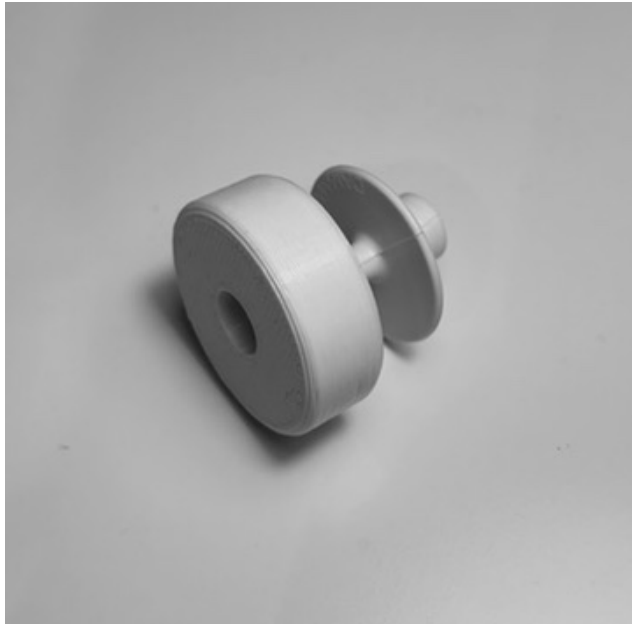
Lastly, Figure 49 provides a close-up image of Concept 2.1 from test run 2 as it became stuck on obstacle 3, illustrating the point of failure.



**Figure 49 Concept 2.1(Test run 2) stuck on obstacle 3**

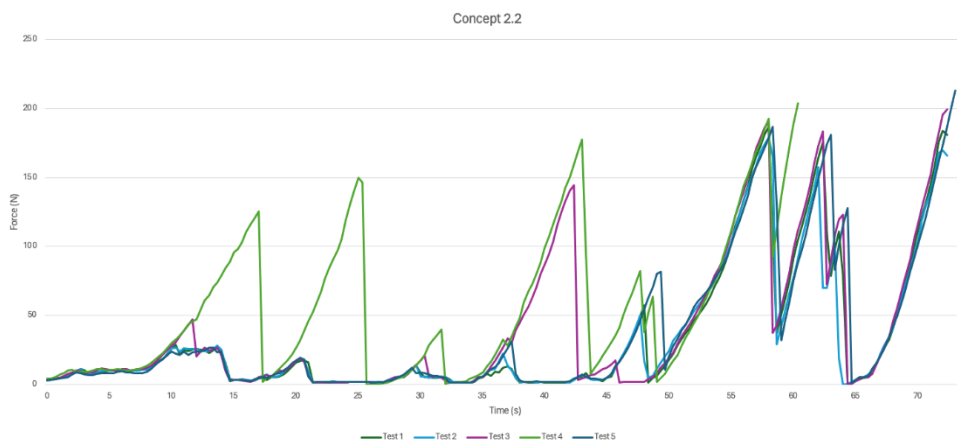
#### *6.4.3.3 Concept 2.2*

The 3D-printed prototype of Concept 2.2, shown in Figure 50, is attached to the same backplate as the other concepts. Like Concept 2.1, this concept includes an additional lock on the backside, as the locking mechanism is reversed.



**Figure 50 3D-printed prototype of Concept 2.2**

The results of the five test runs are presented in Figure 51 and Figure 52. These figures show that test run 4 got stuck at obstacle 10, while the other runs successfully reached the final obstacle.



**Figure 51 Force measurements Concept 2.2**



**Figure 52** Test run 4 got stuck on obstacle 10, while the rest all made it to the final obstacle.

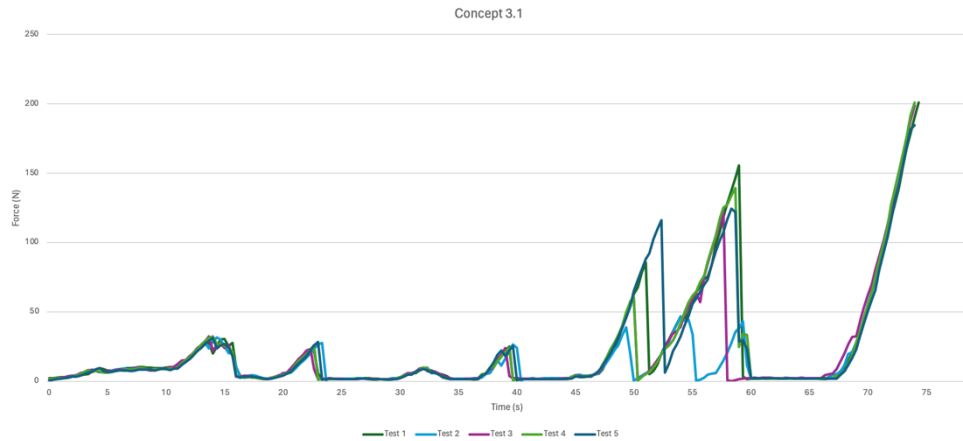
#### *6.4.3.4 Concept 3.1 (PETG)*

The 3D-printed prototype of Concept 3.1, shown in Figure 53, is attached to the same backplate as the other concepts using a 3x8 mm wooden screw. Unlike Concepts 2.1 and 2.2, this concept does not feature the reversed locking mechanism.



**Figure 53** 3D-printed prototype of Concept 3.1 (PETG)

The results of the five test runs are illustrated in Figure 54 and Figure 55. All test runs successfully reached the final obstacle (obstacle 12), as shown in both the force measurement graph (Figure 54) and the obstacle course visualization (Figure 55).



**Figure 54 Force measurements Concept 3.1 (PETG)**



**Figure 55 All test runs made it to the final obstacle (12).**

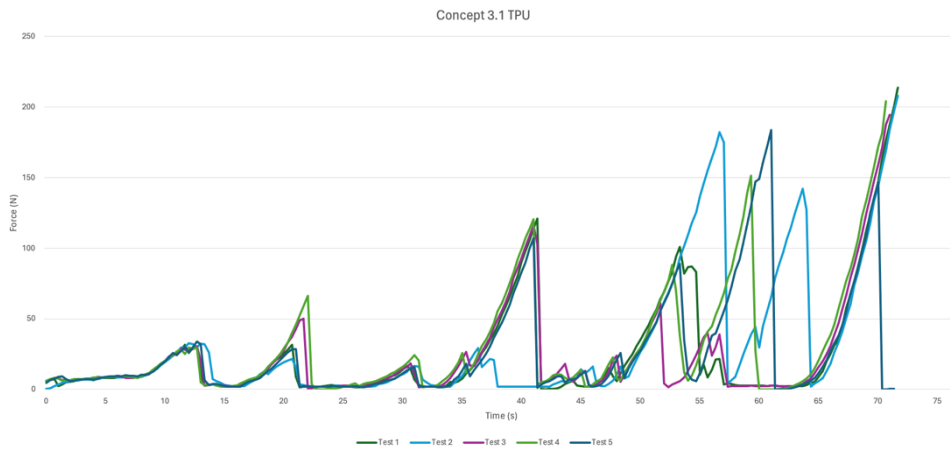
#### 6.4.3.5 Concept 3.1 (TPU)

The 3D-printed prototype of Concept 3.1, shown in Figure 56, differs from Concept 3.1 (PETG) as it is made from a softer TPU plastic. Apart from the material, all other aspects of the design and attachment remain the same.



**Figure 56 3D-printed prototype of Concept 3.1 (TPU)**

The results of the five test runs are presented in Figure 57 and Figure 58. While 4 out of 5 runs got stuck at the final obstacle (obstacle 12), test run 5 managed to make it through.



**Figure 57 Force measurements Concept 3.1 (TPU)**



**Figure 58** Test run 5 made it through the final obstacle while the rest got stuck on it.

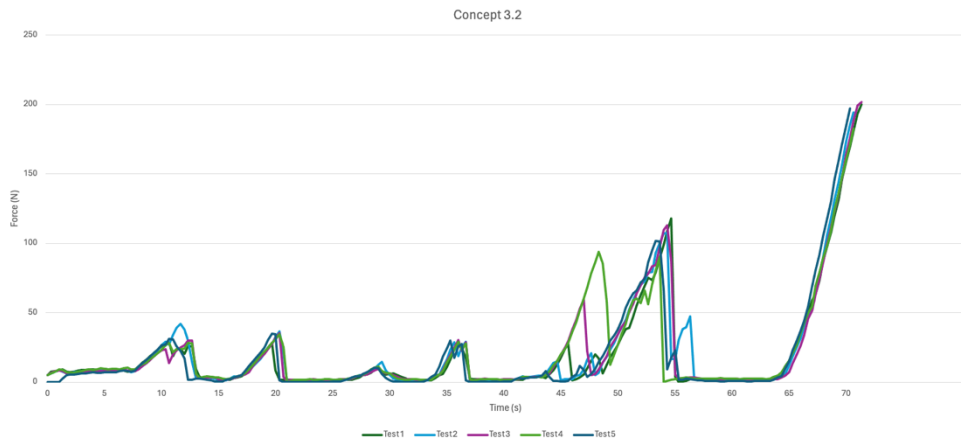
#### 6.4.3.6 *Concept 3.2*

The 3D-printed prototype of Concept 3.2, shown in Figure 59, follows the same attachment method and design principles as the other concepts, utilizing the standardized backplate and screw.



**Figure 59** 3D-printed prototype of Concept 3.2

The results of the five test runs are illustrated in Figure 60 and Figure 61. These figures show that all test runs successfully made it to the final obstacle (obstacle 12), indicating consistent performance across all attempts.



**Figure 60 Force measurements Concept 3.2**



**Figure 61 All test runs made it to the final obstacle.**

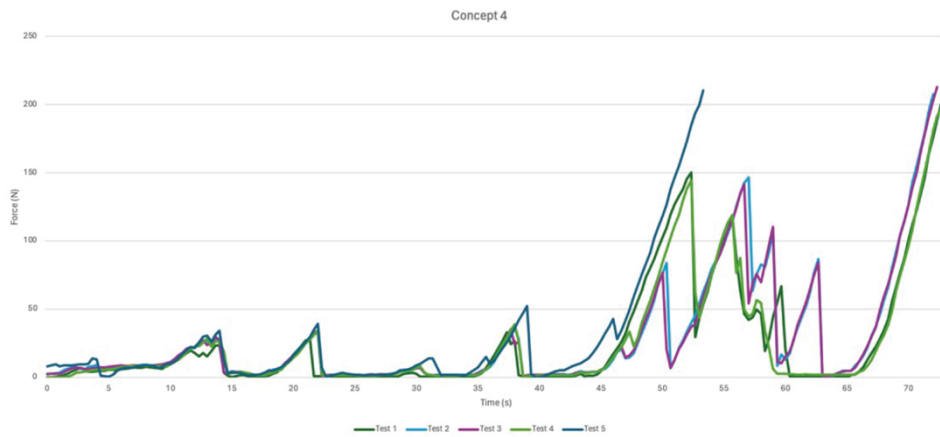
#### 6.4.3.7 Concept 4

The 3D-printed prototype of Concept 4, shown in Figure 62, follows the same standardized backplate attachment method used across all concepts.

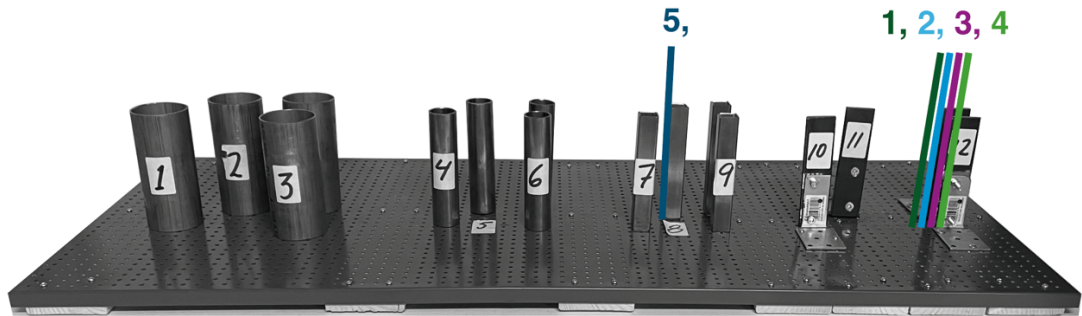


**Figure 62 3D-printed prototype of Concept 4**

The results of the five test runs are presented in Figure 63 and Figure 64. Test run 5 got stuck at obstacle 8, while the remaining runs successfully reached the final obstacle (obstacle 12).

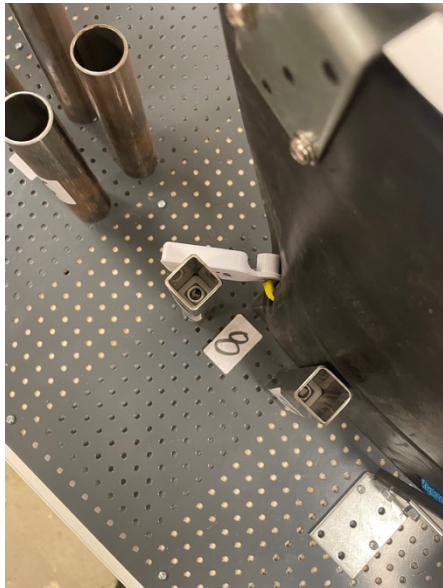


**Figure 63 Force measurements Concept 4**



**Figure 64** Test run 5 got stuck on the 8<sup>th</sup> obstacle, the rest made it to obstacle 12.

Finally, Figure 65 provides a close-up image of Concept 4 during test run 5, showing how it became stuck at obstacle 8.



**Figure 65** Concept 4 (Test run 5) stuck on obstacle 8.

# 7 Concept Evaluation

*This chapter explains the concept evaluation process.*

## 7.1 Evaluation parameters

The parameters used for the concept evaluation are derived from the list of requirements that were deemed to be dependent on the physical design, rather than other aspects. The requirements are grouped into categories such as material, mechanical, ergonomic etc.

### Material Requirements

- Facilitate injection molding

### Mechanical Requirements

- Flexibility

### Ergonomic Requirements

- Lightweight
- Minimize skin contact
- Snag-free design

### Durability/longevity requirements

- Battery life

### Safety

- Smooth edges

### 7.1.1 Methodology for parameter weighting and comparison

The risk of tags falling off was identified as the most critical aspect for evaluating the performance of the tags. This aspect is essential due to its significant impact on economic efficiency, environmental sustainability, and animal welfare. A lower risk

of falling off reduces economic losses from replacements, is beneficial for the environment, and improves animal welfare.

Therefore, to assess this aspect, the results from the obstacle course test was evaluated and used for the evaluation parameters connected to the risk of tags falling off. These are "snag-free design", "smooth edges", and "secure attachment" and were assigned a higher importance value in the evaluation matrix. While these parameters are related, they address distinct aspects of performance and were assessed in different ways using both test data and test observations.

#### *7.1.1.1 Facilitate injection molding*

The housings of the concepts are expected to be made from two injection-molded plastic parts that will be fused together to house the electronics. This manufacturing process comes with its own limitations, such as draft angles, cores, and parting lines. In this project, exact manufacturing methods have not been considered in detail. Therefore, the weighting for this parameter is relatively low compared to others (2 out of 10).

The evaluation of this parameter is based on whether the concept has any obvious features that would hinder the injection molding process. If a concept presents significant obstacles to this method, it will receive a lower score. If no such hindrances are identified, the concept receives a score of 5.

#### *7.1.1.2 Flexibility*

In concept testing, it was observed that a softer tag was able to navigate more challenging obstacles compared to a rigid tag with the same design. This direct correlation between tag flexibility and the risk of falling off gives this parameter a higher weight (8 out of 10) in the evaluation matrix.

Since all prototypes, except one, are made from the same plastic material, as well as their test results, their ability to flex has been assessed qualitatively based on design features that enable or restrict flexibility.

#### *7.1.1.3 Lightweight*

The lightness of the tag is an important requirement for the welfare of the animals, even though it is not believed to significantly increase the risk of getting stuck falling off directly. The reasoning is that a heavier tag causes more wear on the hole in the ear, increasing the risk of the hole enlarging over time. This can lead to more play in the connection, potentially resulting in a weaker attachment.

To simplify the evaluation process, the volume of the concept together with the density of nylon was used to estimate weight, rather than considering individual components such as the battery. While using the battery as a specific metric could have provided additional insights, this approach was chosen to reduce complexity in the assessment.

As a result, the weight of the concept is given a weighting of 5 out of 10. While it is an important factor, it is not as critical as other parameters in terms of preventing the tag from getting stuck or falling off.

#### *7.1.1.4 Minimize skin contact*

Minimizing the surface area of the tag in contact with the ear is important for the comfort and welfare of the animals. A smaller contact area allows for better airflow around the ear, reducing the risk of heat buildup and irritation. This design consideration helps ensure the tag is less likely to cause discomfort or skin issues over extended periods.

To evaluate this parameter, the contact surface area is calculated and compared between the concepts. Tags with a smaller surface area are favored, as they are less intrusive and promote better ventilation. This parameter is given a weighting of 5 out of 10, acknowledging its importance for animal welfare without being as critical as parameters directly tied to preventing the tag from falling off.

#### *7.1.1.5 Snag-free*

This parameter is directly connected to the risk of tags falling off, making it a clear 10 out of 10 in weighting. Designs that minimize snagging on obstacles, such as fences or headlocks, are essential for ensuring secure attachment. A snag-free design not only reduces the risk of detachment but also prevents injuries caused by sudden pulls. This makes it one of the most critical factors for both retention and animal welfare.

#### *7.1.1.6 Battery life*

The different concepts feature varying types of batteries, including both rechargeable and non-rechargeable options. For evaluation, the battery capacity (Wh) serves as the primary metric. While rechargeable batteries have the potential for significantly longer lifespans, they are not rewarded for this due to the increased complexity and the current limitations of recharging technologies, which are not yet proven to be practical in this context.

This parameter is given a weighting of 8 out of 10, as a tag with a dead battery effectively has the same impact as a lost tag, rendering it non-functional. While a dead battery does not have the same environmental impact as a lost tag that ends up in nature, it still represents unnecessary strain on materials and manufacturing resources. A longer battery life is therefore important for minimizing waste and maintaining functionality.

#### *7.1.1.7 Smooth edges*

Smooth edges are important to avoid harming the animal's ear and to prevent injuries when animals come into contact with each other. This parameter focuses on

sharp corners or edges that could cause irritation or damage. It is given a weighting of 3 out of 10, as it is less critical compared to other factors.

Some prototypes for the concepts have sharper edges due to 3D printing limitations, especially where the parts meet the build plate. These edges would not be present in the final injection-molded versions. Because of this, it is hard to make strong conclusions about this parameter's importance and performance based on the prototypes alone.

### 7.1.2 Evaluation matrix

Table 7.1-1 shows the evaluation matrix, complete with weights, total scores, and the final rankings. An in-depth explanation of the scores in the evaluation matrix can be found in Appendix E.

**Table 7.1-1 Evaluation matrix**

<i>Parameter</i>	<i>Weight</i>	<i>Weight Normalized</i>	<i>Concept</i>							
			<i>1</i>	<i>2.1</i>	<i>2.2</i>	<i>3.1</i>	<i>3.1 F</i>	<i>3.2</i>	<i>4</i>	
Material										
Facilitate injection molding	2	0,2	4	4	4	5	5	4	5	
Mechanical										
Flexibility	8	0,8	1	1	1	4	4	2	4	
Ergonomic										
Lightweight	5	0,5	5	4	3	2	2	2	1	
Minimize skin contact	5	0,5	3	5	4	2	2	3	1	
Snag-free	10	1,0	2	1	3	4	5	4	3	
Longevity										
Battery life	8	0,8	1	4	5	4	4	4	2	
Safety										
Smooth edges	4	0,4	5	5	3	3	3	4	2	
<b><i>Total Score (Weighted):</i></b>			<b>10,4</b>	<b>12,3</b>	<b>13,3</b>	<b>14,6</b>	<b>15,6</b>	<b>13,7</b>	<b>10,6</b>	
<b><i>Ranking:</i></b>			<b>7</b>	<b>5</b>	<b>4</b>	<b>2</b>	<b>1</b>	<b>3</b>	<b>6</b>	

### 7.1.3 Testing design aspects and their interdependencies

In the concept testing of Concept 3.1, the same design was tested using two materials, PETG (Polyethylene Terephthalate Glycol) and TPU (Thermoplastic Polyurethane). The softer TPU version showed that it could pass the final obstacle, which is designed to be very difficult. This highlighted that even with a well-designed concept and good component layout, other factors also play an important role.

To better understand these factors, a factorial test was designed. This method involves testing several parameters at both high and low levels to explore their effects systematically. By selecting three parameters, a total of eight combinations ( $2^3$ ) were tested. This was chosen to keep the number of tests manageable, as adding a fourth parameter would have required testing 16 combinations ( $2^4$ ). Factorial testing is an efficient way to identify significant factors and interactions according to Montgomery, (Montgomery, 2019)

One of the key aspects investigated was flexibility, which is strongly influenced by the choice of material. Since flexibility and friction are difficult to separate, all test samples were lubricated with grease to minimize the impact of friction. This ensured the tests could focus more accurately on flexibility and the other selected parameters. Another parameter tested was the thickness of the tag, with both 10 mm (representing the thinnest practical design) and 16 mm (representing one of the thickest feasible designs). Finally, the geometry of the tag was tested, focusing on its length. To maintain the same surface area, the width of the tag was adjusted inversely to its length, making shorter tags wider and longer tags narrower.

To reduce the impact of the cylinder that is there to protect the backplate, the length was reduced from 10 mm to 3 mm, as the goal is to see the effect of differences in the main part of the tag.

### 7.1.4 Factorial test

#### 7.1.4.1 Parameters:

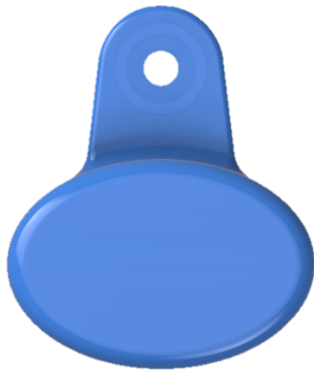
##### 7.1.4.1.1 Geometry (Short & Wide vs. Long & Narrow)

The shape of the main cylindrical part of Concept 3.1 was modified for this parameter. Instead of being circular, the shape was replaced with an ellipse. The ellipse was designed to have the same area as the circle in Concept 3.1, ensuring

that the overall surface area remained constant. The ellipse was then oriented in two different ways:

1. **Sideways** - This resulted in a shorter but wider tag.
2. **Lengthwise** - This made for a longer but narrower tag.

The difference is illustrated in Figure 66 and Figure 67 below.



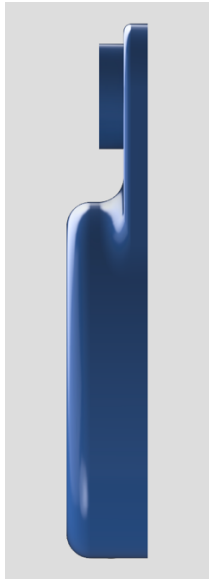
**Figure 66 Short & Wide**



**Figure 67 Long & Narrow**

#### 7.1.4.1.2 Thickness (Thin vs. Thick)

The thickness of the ellipse was the second parameter. The thinner version was designed with the thinnest batteries available on the market in mind. Given the battery technology of 2024, it is unlikely that a smart tag could be thinner than 10 mm. Therefore, the thin version was chosen to be 10 mm thick, which is 3,5 mm thinner than the original Concept 3.1, shown in Figure 68. Similarly, the thicker version was designed to be 3,5 mm thicker than Concept 3.1 (16 mm), see Figure 69.



**Figure 68 Thin**



**Figure 69 Thick**

#### 7.1.4.1.3 Flexibility (Flexible vs. Stiff)

The third parameter is the flexibility of the tag, evaluated using two materials:

1. **Stiff (PETG)** - PETG was chosen for its rigidity, durability, and excellent 3D printability. Its strength and dimensional stability make it ideal for testing stiff configurations. PETG is also cost-effective, allowing for the production of multiple test samples without significant expense.
2. **Flexible (TPU 95A Shore)** - TPU with a Shore hardness of 95A was used to represent a flexible configuration. TPU's elasticity allows the tag to deform and navigate tight gaps more easily. Its 3D printability and affordability make it a practical choice for consistent and reliable testing.

These materials were selected not only for their mechanical properties but also for their ease of manufacturing and cost efficiency, ensuring high-quality and comparable test samples.

#### 7.1.4.2 Factorial test order

Table 7.1-2 shows the different variants and test combinations done in the factorial test.

**Table 7.1-2 Factorial tests order**

<i>Variant nr:</i>	<i>Length and width (Area the same)</i>	<i>Thickness (thin/thick)</i>	<i>Flexibility (soft/stiff)</i>
1	52 x 44 mm (Short & Wide)	10 mm (Thin)	TPU (Soft)
2	60 x 30 mm (Long & Narrow)	10 mm (Thin)	TPU (Soft)
3	52 x 44 mm (Short & Wide)	17 mm (Thick)	TPU (Soft)
4	60 x 30 mm (Long & Narrow)	17 mm (Thick)	TPU (Soft)
5	52 x 44 mm (Short & Wide)	10 mm (Thin)	PETG (Stiff)
6	60 x 30 mm (Long & Narrow)	10 mm (Thin)	PETG (Stiff)
7	52 x 44 mm (Short & Wide)	17 mm (Thick)	PETG (Stiff)
8	60 x 30 mm (Long & Narrow)	17 mm (Thick)	PETG (Stiff)

#### 7.1.4.3 Factorial test setup

The same setup was used as for the concept test was used even the exact same screw and length of backplate was used for fixing the tag in the setup. The main difference was that for this test, to reduce the influence of friction, both tags and obstacles were lubricated with universal grease. This was not done to say that the effect of friction is not significant, but it was a necessary step to isolate the flexibility parameter. All variants were tested and recorded 5 times each.

#### 7.1.4.4 Factorial test result

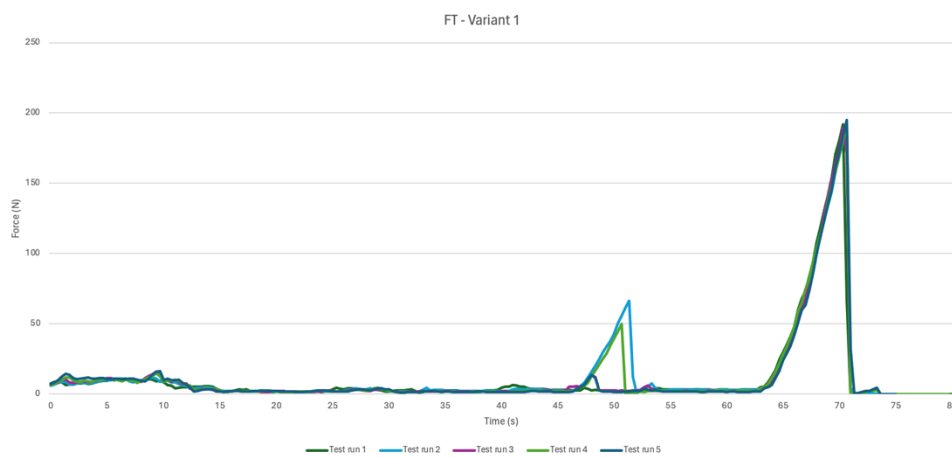
##### 7.1.4.4.1 Variant 1 (Short Thin Soft)

The first variant, pictured in Figure 70, is the short, thin, and soft variant.



**Figure 70 3D-model Variant 1**

The results of the five test runs are presented in Figure 71. All runs successfully made it through the final obstacle (obstacle 12).



**Figure 71 Force measurements Variant 1**

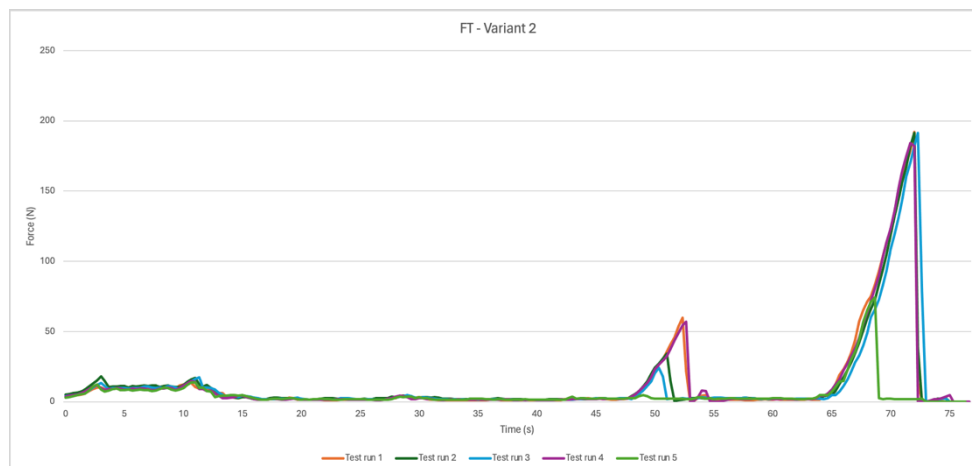
#### 7.1.4.4.2 Variant 2 (Long Thin Soft)

The second variant, pictured in Figure 72, is the long, thin, and soft variant.



**Figure 72 3D-model Variant 2**

The results of the five test runs are presented in Figure 73. All runs successfully made it through the final obstacle (obstacle 12).



**Figure 73 Force measurements Variant 2**

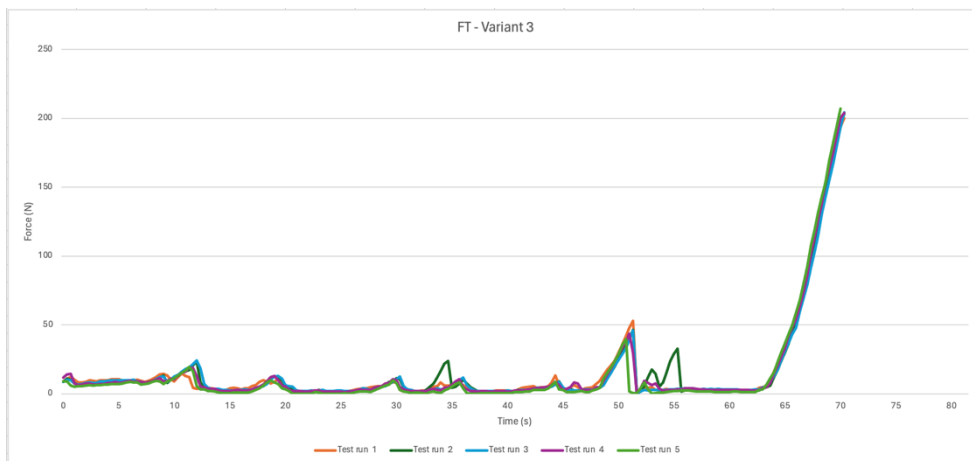
#### 7.1.4.4.3 Variant 3 (Short Thick Soft)

The third variant, pictured in Figure 74, is the short, thick, and soft variant.



**Figure 74 3D-model Variant 3**

The results of the five test runs are presented in Figure 75. All runs got stuck on the final obstacle (obstacle 12).



**Figure 75 Force measurements Variant 3**

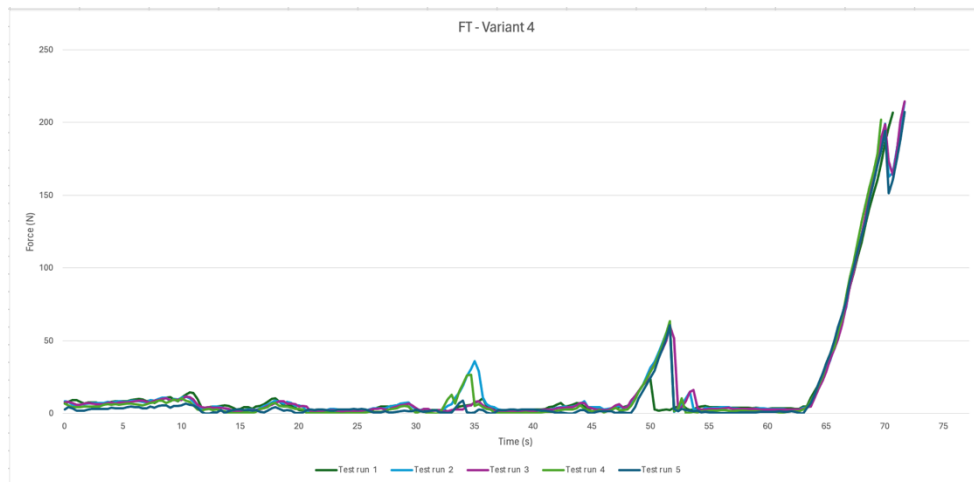
#### 7.1.4.4.4 Variant 4 (Long Thick Soft)

The fourth variant, pictured in Figure 76, is the long, thick, and soft variant.



**Figure 76 3D-model Variant 4**

The results of the five test runs are presented in Figure 77. All runs got stuck on the final obstacle (obstacle 12).



**Figure 77 Force measurements Variant 4**

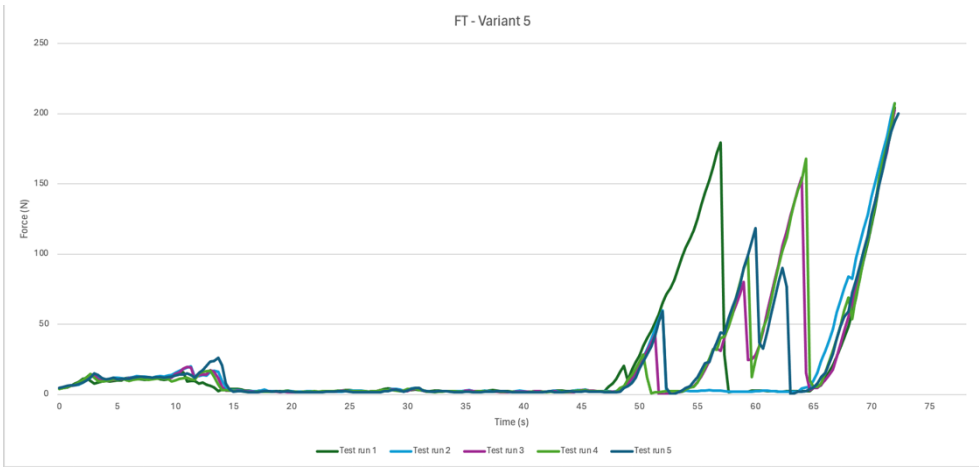
#### 7.1.4.4.5 Variant 5 (Short Thin Stiff)

The fifth variant, pictured in Figure 78, is the short, thin, and stiff variant.



**Figure 78 3D-model Variant 5**

The results of the five test runs are presented in Figure 79. All runs got stuck on the final obstacle (obstacle 12).



**Figure 79 Force measurements Variant 5**

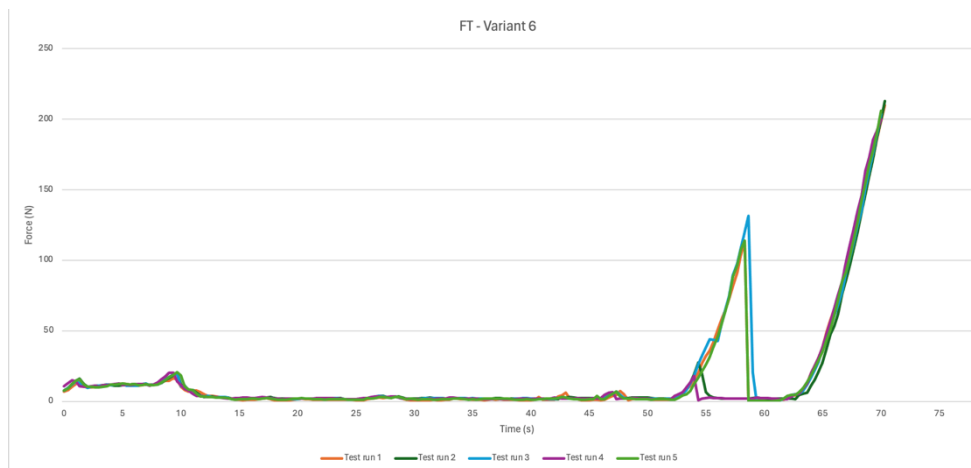
7.1.4.4.6 Variant 6 (Long Thin Stiff)

The sixth variant, pictured in Figure 80, is the long, thin, and stiff variant.



**Figure 80 3D-model Variant 6**

The results of the five test runs are presented in Figure 81. All runs got stuck on the final obstacle (obstacle 12).



**Figure 81 Force measurements Variant 2**

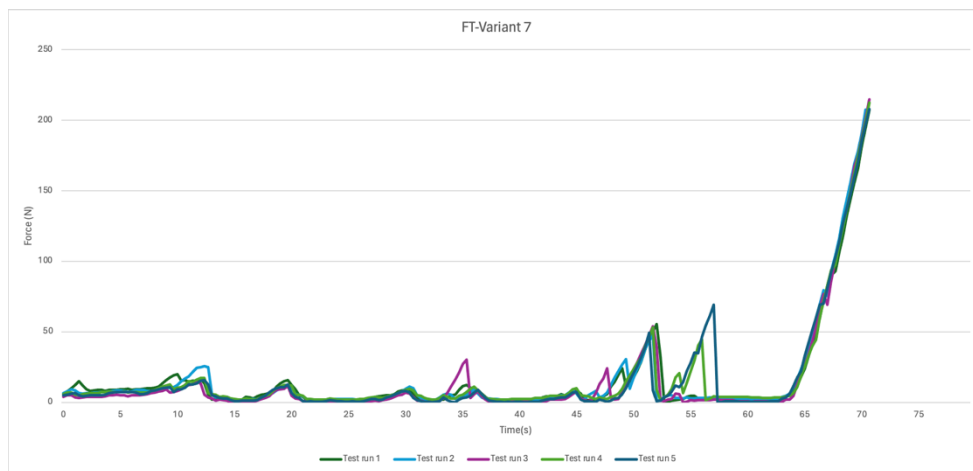
#### 7.1.4.4.7 Variant 7 (Short Thick Stiff)

The seventh variant, pictured in Figure 82, is the short, thick, and stiff variant.



**Figure 82 3D-model Variant 7**

The results of the five test runs are presented in Figure 83h. All runs got stuck on the final obstacle (obstacle 12).



**Figure 83 Force measurements Variant 7**

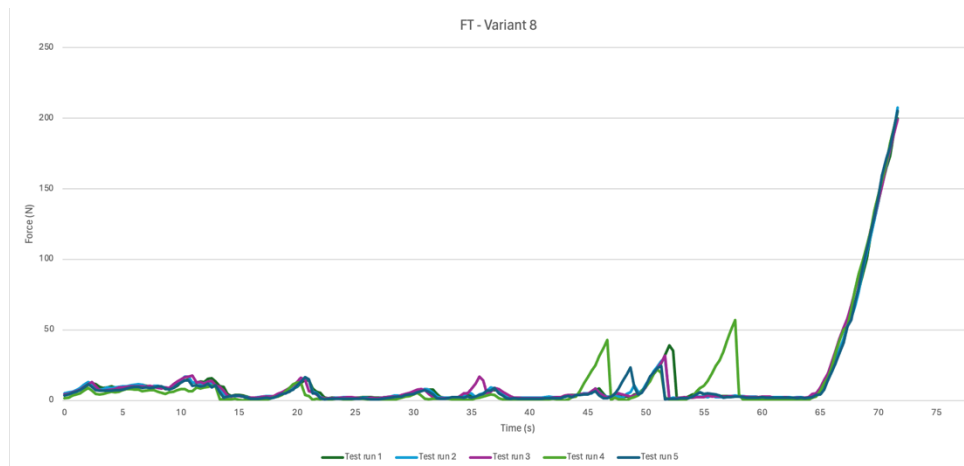
#### 7.1.4.4.8 Variant 8 (Long Thick Stiff)

The eights variant, pictured in Figure 84, is the long, thick, and stiff variant.



**Figure 84 3D-model Variant 8**

The results of the five test runs are presented in Figure 85. All runs got stuck on the final obstacle (obstacle 12).



**Figure 85 Force measurements Variant 8**

#### 7.1.4.5 Result analysis

Based on the graphs in the results above, it is shown that both the thin and flexible variants make it through all the obstacles while the rest gets stuck on the final obstacle “12”. This presents a challenge in comparing the results in a statistical way, as the graph stops earlier for the variants that gets stuck and are therefore benefitted when using the area below the graph as a basis for comparison. For this reason, to add nuance to the results, both the raw data as well as using a penalty for every tag that gets stuck. The penalty works by keeping the max value of the force meter for the 3 seconds that is left of the course.

One of the advantages of a factorial test is that each level (high/low) for a given parameter is evenly represented across all combinations of the other parameters. This enables a clear and isolated comparison of the effects of each parameter, independent of the others. The differences between high and low levels for each parameter can be analyzed to determine which parameter has the greatest impact on the results.

To make the result graphs less cluttered and easier to compare, all test runs for each variant were combined into a mean curve. This curve was then used to compare the effects of different parameters.

#### 7.1.4.6 Length comparison

To make the length comparison, seen in Figure 86, all short variants were collected in the top graph while the long variants were collected in the lower one. Also marked in the figure was the cut-off point.

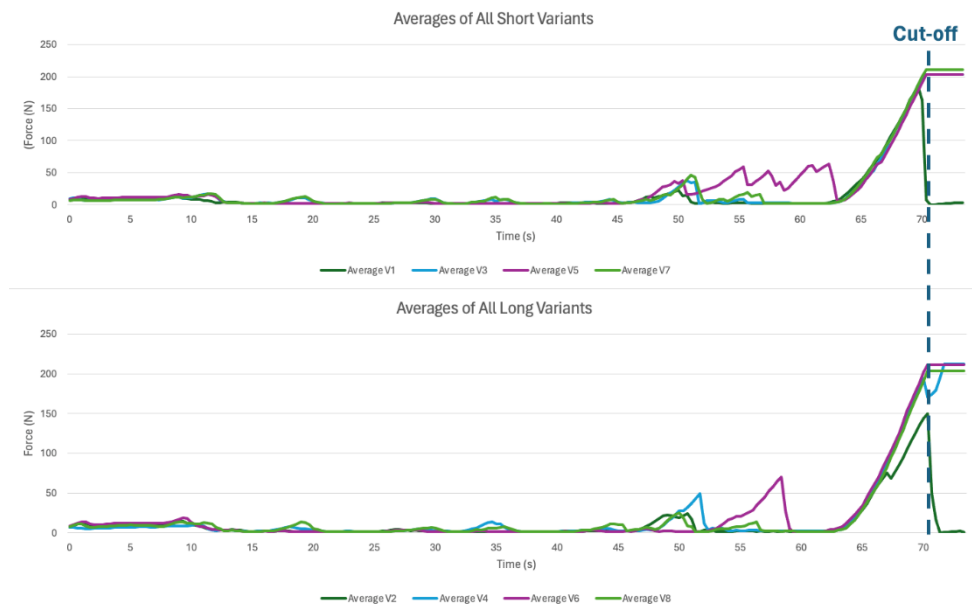


Figure 86 Length comparison

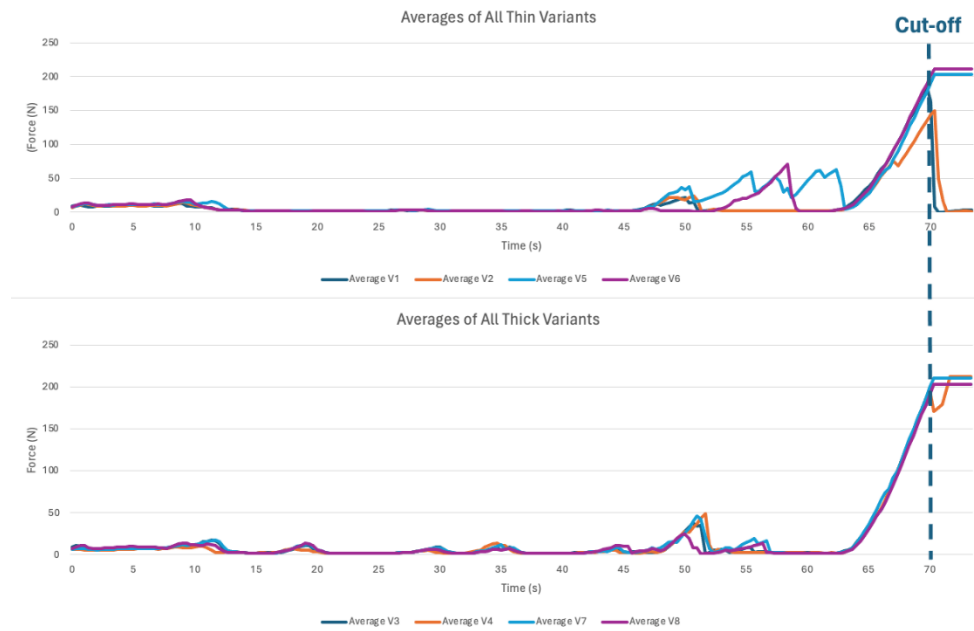
To quantify the results and enable comparisons between the variants, the most fair and reliable approach is to use the area under each respective graph. This method accounts for both the magnitude and duration of the forces throughout the entire course. By also including a force penalty for the variants that get stuck, where the maximum force is maintained for the last three seconds, the results reflect the overall performance of each variant even if they fail to complete the entire course. This approach provides a nuanced comparison of the sensitivity of the tags to getting stuck. Table 7.1-3 the results, showing both the total Ns comparison and the percentile difference between the short and long variants.

**Table 7.1-3 Area calculation – Short/Long**

<i>Variant</i>	<i>Area Bellow Graph With force penalty</i>	<i>Area Bellow Graph Without force penalty (Cut-off at final peak)</i>
Short	7859,99 Ns	5260,00 Ns
Long	7246,90 Ns	4605,50 Ns
<b><i>Difference</i></b>	8%	14%

#### 7.1.4.7 Thickness comparison

In this section, the results of the thickness comparison are presented. Figure 87 displays the average force curves for all thin variants (top graph) and all thick variants (bottom graph). The cut-off point, indicated in the graphs, marks the final obstacle where some variants stop progressing.



**Figure 87 Thickness comparison**

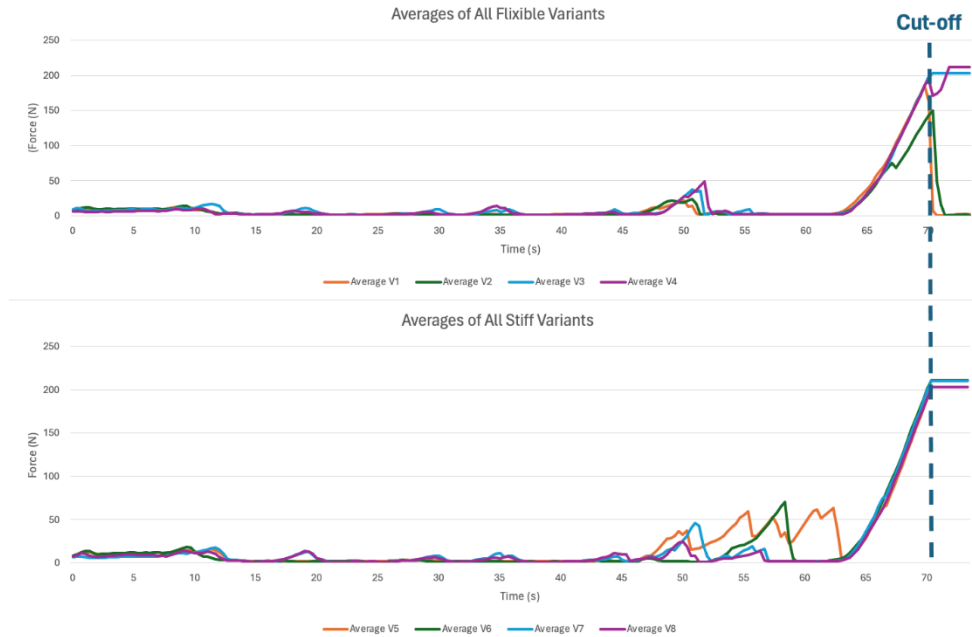
Table 7.1-4 provides the calculated areas under the curves for both variants, with and without the application of a force penalty.

**Table 7.1-4 Area calculation - Thin/Thick**

<i>Variant</i>	<i>Area Bellow Graph With force penalty</i>	<i>Area Bellow Graph Without force penalty (Cut-off at final peak)</i>
Thin	6300,54 Ns	5074,38 Ns
Thick	8013,49 Ns	5125,86 Ns
<b>Difference</b>	<b>-21%</b>	<b>-1%</b>

### 7.1.4.8 Flexibility comparison

The average force curves for soft and stiff variants are displayed in Figure 88, with the cut-off point indicating the final obstacle where some variants stop progressing.



**Figure 88 Flexibility comparison**

Table 7.1-5 shows the areas under the curves and percentage differences for soft and stiff variants, with and without a force penalty.

**Table 7.1-5 Area calculation - Soft/Stiff**

<i>Variant</i>	<i>Area Bellow Graph With force penalty</i>	<i>Area Bellow Graph Without force penalty (Cut-off at final peak)</i>
Soft	5748,65 Ns	4323,62 Ns
Stiff	8722,95 Ns	5433,82 Ns
<b>Difference</b>	<b>-34%</b>	<b>-20%</b>

#### 7.1.4.9 Comparison analysis

The comparisons reveal that, when the penalty is applied, the greatest difference is observed for flexibility, with a 34% impulse reduction for the flexible variants. This is followed by a 21% reduction for the thin variants and an 8% increase for the shorter variants.

Using the cut-off instead of the penalty, the results show a 20% impulse reduction for the flexible variants, a 1% reduction for the thin variants, and a 14% increase for the shorter variants. These results highlight several key points.

Firstly, flexibility has the most significant impact on reducing impulse, regardless of the method used. Secondly, thickness primarily affects the ability to pass the final obstacle, as its impact is minimal (1%) when using the cut-off. Lastly, the longer and narrower tag consistently performs better in both approaches. Since it is unlikely that the length alone contributes to better performance, the results suggest that the narrower shape plays a crucial role. This observation is supported by test observations, where the tag's tendency to turn makes its narrowness an advantage in navigating obstacles.

#### 7.1.4.10 ANOVA-analysis

To dive further into the results, an ANOVA-analysis was performed on the measurements. For this analysis, the force penalty is used, as it is a mathematical analysis and the element of tags getting stuck would otherwise not be considered.

##### 7.1.4.10.1 ANOVA Method

To investigate the effects of the three factors Geometry (relationship between length and width), Thickness, and Flexibility on the dependent variable Impulse, a three-way ANOVA was performed. The analysis included main effects and all possible two-way interaction terms. The ANOVA model used was specified as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 \times X_2 + \beta_{13} X_1 \times X_3 + \beta_{23} X_2 \times X_3 + \epsilon$$

Where:

- Y: The dependent variable “Impulse”
- $\beta_0$ : The intercept term, representing the mean response when all predictors are at their baseline levels.
- $\beta_1, \beta_2, \beta_3$ : Coefficients representing the main effects of Geometry ( $X_1$ ), Thickness ( $X_2$ ), and Flexibility ( $X_3$ ).
- $\beta_{12}, \beta_{13}, \beta_{23}$ : Coefficients representing the interaction effects between factors.
- $\epsilon$ : The error term, accounting for variability not explained by the model.

The analysis was conducted using the Python stats-models library.

#### 7.1.4.10.2 ANOVA results

The ANOVA results are summarized in Table 7.1-6 below:

**Table 7.1-6 ANOVA summary**

<i>Factors</i>	<i>Sum of Squares (SS)</i>	<i>df</i>	<i>F-value</i>	<i>p-value</i>
Geometry	103395	1	4,87	0,035
Thickness	1760434	2	41,49	< 0,001
Flexibility	2402723	1	113,26	< 0,001
Geometry × Thickness	96808	2	2,28	0,119
Geometry × Flexibility	60055	1	2,83	0,102
Thickness × Flexibility	2868557	2	67,61	< 0,001
Residual	678863	32		

#### 7.1.4.10.3 ANOVA result interpretation

Main Effects:

- Thickness ( $F = 41,49$ ,  $p < 0,001$ ) and Flexibility ( $F = 113,26$ ,  $p < 0,001$ ) show strong, statistically significant effects on Impulse (Ns)
- Geometry ( $F = 4,87$ ,  $p = 0,035$ ) also has a statistically significant but smaller effect.

Interaction Effects:

- Thickness × Flexibility ( $F = 67,61$ ,  $p < 0,001$ ) is highly significant, indicating that the combined effect of these factors significantly influences the dependent variable.
- Geometry × Thickness and Geometry × Flexibility is not significant ( $p > 0,05$ ), suggesting no notable combined effect of Geometry with the other factors.

#### 7.1.4.10.4 ANVOA result discussion

The significant Thickness × Flexibility interaction suggests that these two factors influence the dependent variable ("Area under graph") in a non-additive way. For example, certain combinations of Thickness and Flexibility might either amplify or diminish the observed results.

Practical implications of these results include prioritizing the optimization of Thickness and Flexibility together rather than independently and that the geometry appears to have a weaker effect and no significant interactions with other factors, indicating a lower priority for optimization in this case.

# 8 Final Result

*Presenting the proposal of a new tag, along with overall goal fulfillment.*

## 8.1 Final Design - Concept 3.1 Flex (TPU)

In the final design phase Concept 3.1 Flex was chosen after a thorough evaluation using a weighted scoring system, depicted in Figure 89 and Figure 90. This system considered multiple parameters, each assigned a weight based on its importance to the overall performance and usability of the ear tag. Concept 3.1 Flex achieved the highest total weighted score (15.6), outperforming the other concepts and proving to be the most balanced and well-suited design for the intended application.

One of the key reasons for selecting Concept 3.1 Flex was its strong performance in critical parameters like flexibility and snag-free design. These parameters had the highest weights in the evaluation due to their importance in suggesting that the tag can adapt to farm conditions without detaching. Concept 3.1 Flex scored the maximum points in both areas, demonstrating its ability to bend under stress and avoid getting stuck, which reduces the likelihood of detachment.

The concept also scored highly in manufacturability, with a top score in facilitating injection molding. This suggests that the design can be produced efficiently and without unnecessary complexity, which is a requirement for successfully scaling up production. While its scores for lightweight design and minimizing skin contact were not the highest, these factors had lower weights in the evaluation, making them less critical to the final selection. Importantly, Concept 3.1 Flex also performed well in battery life and smooth edges, ensuring longevity and safety.

The evaluation matrix highlights how Concept 3.1 Flex strikes the best balance among all design parameters. With its strong performance in the most heavily weighted criteria, it is the optimal choice for addressing the challenges of real-world farm environments while remaining practical and cost-effective to produce.



**Figure 89 Concept 3.1 Flex prototype**



**Figure 90 Concept 3.1 Flex - CAD-model**

### **8.1.1 Conclusion**

Concept 3.1 Flex successfully met the evaluation criteria, demonstrating reduced detachment risk and robust performance in the simulated farm environment. Its design achieved the outlined objectives for flexibility, durability, and ergonomic suitability, making it a strong candidate for further development and refinement in future projects.

### 8.1.2 Technical drawing of final concept

The final concept drawings included below in Figure 91.

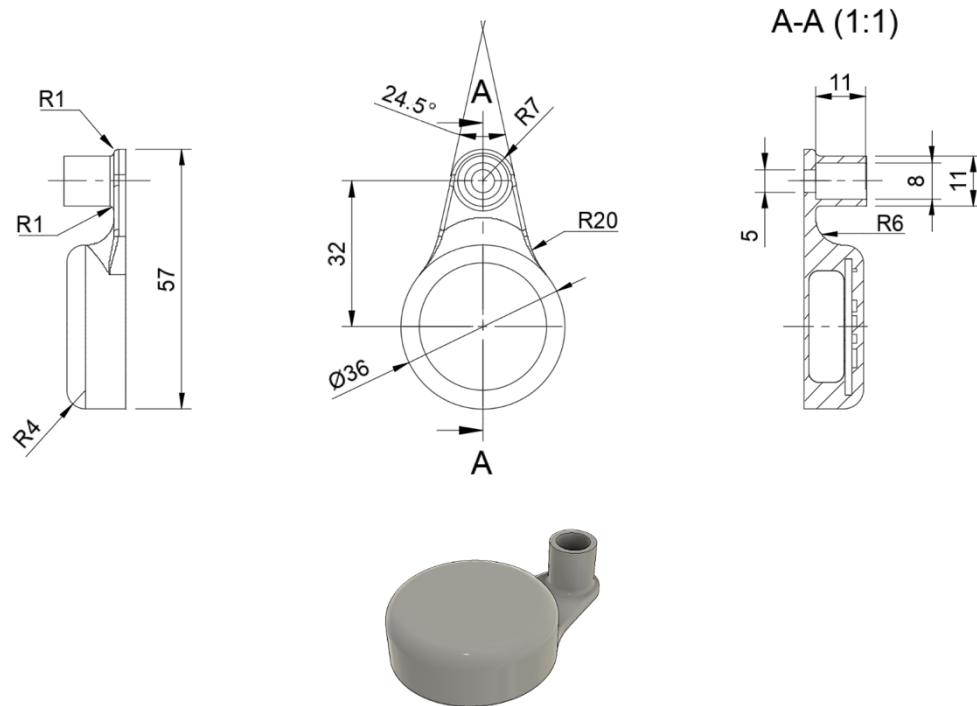


Figure 91 Technical Drawing, Constructed for FDM 3D-printing.

# 9 Discussion

*Discussion about the project, of the final concept and of evaluation of the methods.*

## 9.1 Result discussion

The primary goal of this project was to create a smart ear tag that reduces the risk of falling off, as this affects important areas like economics, sustainability, animal welfare, and milk production. Another key goal was to understand how design factors like size, thickness, and flexibility affect each other. Since designing a product often requires making compromises, knowing which factors to focus on will be very helpful for future development. Finally, the project also aimed to address environmental concerns, including sustainability and the long-term impact of the design.

The results show that the project made good progress in achieving these goals. The final concept has a compact and ergonomic design that reduces the chances of getting stuck or falling off in tough farm environments. This was confirmed through testing using the obstacle course, which was designed to simulate real-world conditions. The testing method was accurate and repeatable, showing that the design works well in practice.

Flexibility and thickness were found to be the most important factors for how well the tag performs. The ANOVA analysis showed that flexibility had the biggest effect on reducing the forces the tag experiences, followed by thickness. Flexible tags performed better because they could handle physical stress without breaking. The combination of flexibility and thickness also showed a strong impact, meaning both factors need to be carefully balanced. The tag's shape (geometry) had less of an impact, making it less important to optimize in this case. These findings make it clear which design features should be prioritized in the future.

The project also looked at sustainability and environmental impact. The materials used and ideas to improve recyclability and battery life were considered during the design process. Although not all environmental problems were solved, the project showed that features like longer-lasting batteries and a lower risk of falling off are important for reducing waste and minimizing environmental harm. These are important steps toward making smart ear tags more sustainable.

In summary, the project met most of its goals. The improved tag design successfully addresses key challenges like detachment risk and usability, and the testing method ensures the tag's performance can be evaluated reliably. The focus on environmental concerns adds extra value to the work and provides a strong base for future improvements in smart ear tags and their role in sustainable and efficient farming.

## 9.2 Project discussion

The project aimed to balance areas of focus by prioritizing efforts where they would have the most significant impact. Simplifications were necessary in certain aspects to allow a deeper exploration of physical design, particularly in minimizing the fall-off rate. For example, while the development of the circuit board is critical for a smart tag's functionality, focusing on the physical design became a prerequisite for the entire project. Data collection served as the foundation for identifying the most impactful areas, ensuring that the effort was targeted effectively.

## 9.3 Test method discussion

The test method obstacle course proved to be both repeatable and effective at highlighting performance differences between the concepts. Its simplicity allowed for reliable comparisons under consistent conditions. However, the method also had limitations that makes room for future development.

One of the most notable limitations with the method is the need for adaptation of the course to suit the test equipment. The sampling rate of the force gauge with only 3 samples per second was insufficient to replicate the speed and force with which cows pull when feeling trapped. To address this, the test speed was significantly reduced, from a test run time of about 4 seconds to 1 min. Additionally, the force gauge's maximum capacity of 200 N, while sufficient to produce decisive results, is lower than the forces that tag locks typically withstand. A higher maximum force capability would yield even clearer comparisons, especially for tags or concepts that is more prone to get stuck.

Another area for improvement involves the material of the obstacles. The actual headlocks that were observed were often galvanized, meaning a rougher surface than the untreated steel used in the test setup. But also, in some other observed cases, also stainless steel was used, which is even smoother, introducing additional variability.

Finally, the method of attaching prototypes also deviated from real-world conditions. The use of a cut off backplate and screw created a stiffer attachment than a standard tag on the market. That attachment allows some play within the lock. However, it is important to emphasize that all concepts were tested under identical conditions, ensuring a fair comparison.

## 9.4 Evaluation discussion

The evaluation process focused on weighting parameters based on their relevance to the project's primary goal, reducing the risk of tags fall-off. While all the requirements listed in the project are important for the overall development of a smart tag, not all were included in the evaluation matrix. Requirements related to areas outside the project's focus, such as material selection or regulatory compliance, were excluded because either they did not differentiate the evaluated concepts, or the information needed to differentiate the concepts wasn't known. If these had been included, their weight would have been negligible (essentially 0) due to lack of difference between concepts.

This weighting approach reflects the project's strategic focus on areas with the greatest impact. By prioritizing physical design and attachment performance, the evaluation aligned with the overarching goal of improving tag retention and reducing detachment risk.

## 9.5 Ulrich & Eppinger product development process

To structure this project, parts of Ulrich and Eppinger's product development framework were applied (Ulrich & Eppinger, 2015). While not every step from planning to ramping up production was used, the most relevant parts were selected.

Their emphasis on reliable and repeatable testing to compare designs played a big part in putting so much effort into the testing. And even though the method had limitations, such as equipment constraints and simplified test conditions, it still worked well to show the differences between concepts and provided a good foundation for future developments, while also showing the importance of testing.

For instance, FDM 3D-printing was used for prototyping as it was the most accessible and efficient option. While this choice enabled rapid development, it limited the ability to create and test more detailed designs to evaluate both performance and manufacturability. This trade-off made sense as manufacturing concerns are better suited for a future detailed design phase.

Some requirements, like material selection and regulatory standards, were left out to keep the focus on the project's main goal. While this helped prioritize the most important areas, it meant stepping away from their more complete and holistic approach to product development.

Despite these challenges, the project still captured the key ideas of their process by focusing on the most impactful areas. Moving forward, the detailed design phase will help address these gaps and bring the project closer to their full development framework.

## 9.6 Future developments

Several areas for future development emerged from the project, particularly in testing and design refinement.

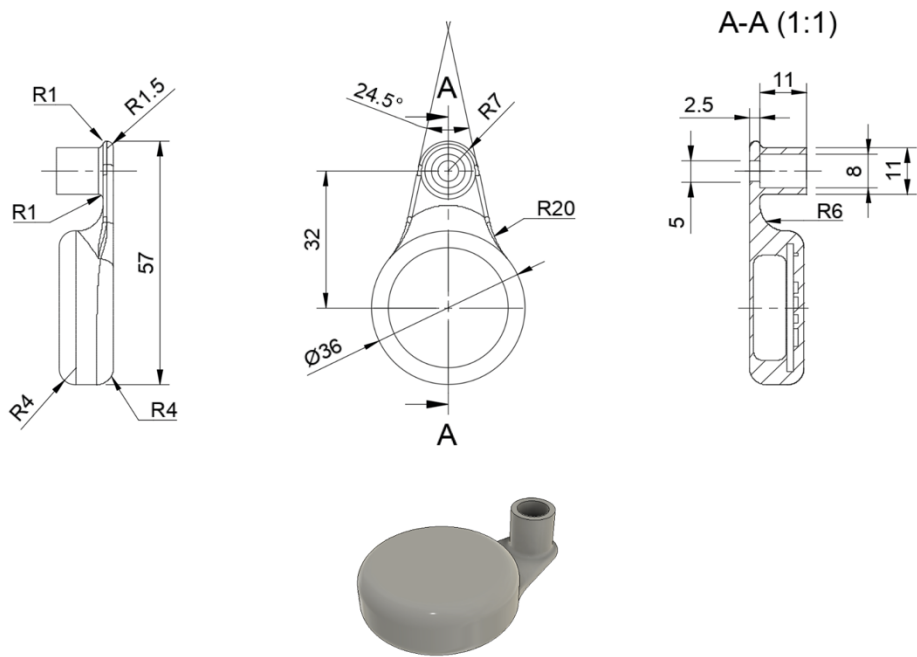
### 9.6.1 Test method improvements

The sampling rate needs to be increased to better capture the rapid forces exerted when cows pull under stress, as the current rate of 3 samples per second proved insufficient. Testing equipment capable of handling higher maximum forces would further improve the method, as the current 200 N limit falls short of the forces that tag locks typically endure. Additionally, refining the obstacle material to better match real-world headlocks, such as using galvanized or stainless steel with appropriate surface roughness, would enhance the test's realism and reliability.

### 9.6.2 Design refinement – detail design

Moving forward, going beyond the constraints of FDM 3D-printing will enable a more detailed and refined design. For example, rounding the backside of the tag would improve ergonomics for the animals by reducing irritation and discomfort. Additionally, this phase offers the opportunity to transition to more advanced materials. By selecting materials with similar flexibility to TPU but with improved durability, UV resistance, and chemical resistance, the tag's performance in harsh farm environments could be significantly enhanced.

Transitioning to a detail design phase, as described by Ulrich and Eppinger (Ulrich & Eppinger, 2015), would provide the framework for refining the final concept for manufacturability. This includes addressing injection molding requirements and optimizing the design for large-scale production. Combining these material advancements with optimized production standards would further elevate the tag's functionality and real-world applicability.



**Figure 90 Technical Drawing, with a rounded backside for increased ergonomics.**

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# Appendix A Time plan

## A.1 Project Plan

	September			October				November				December				January		
Project week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Calendar week	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3
Literature research																		
Preparations																		
Planning																		
Concept development																		
System level design																		
Detail design																		
Testing and refinement																		
Writing report																		
Prepare presentation																		
Presentation																		
Report hand-in																		
Check in with Axel (LTH supervisor)																		

Figure 92 Project plan

## A.2 Outcome

	September			October				November				December				January		
Project week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Calendar week	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3
Literature research																		
Preparations																		
Planning																		
Concept development																		
System level design																		
Detail design																		
Testing and refinement																		
Writing report																		
Prepare presentation																		
Presentation																		
Report hand-in																		
Check in with Axel (LTH supervisor)																		

Figure 93 Project outcome

Looking at the comparison between the planned (blue) and actual (green) timelines, a few differences stand out. One major change was that the detailed design phase wasn't completed or even begun as intended. Concept generation, testing, and evaluation took longer than expected, and became a much larger part of the project. This left little room for detailed design, the extra effort in these earlier phases resulted in better outcomes than anticipated and led to a stronger, more validated concept.

Another difference was the goal to finish well ahead of the deadline. Unsurprisingly, that didn't work out. Challenges and unexpected adjustments used up most of the extra time. While it would have been nice to have extra time for final touches, the project still achieved its main objectives, and the additional time spent on testing and refinement was well worth it.

# Appendix B Semi-Structured Interview Guide – Ear Tag Equipment for Cows

## **Ear Tag Equipment**

Do you use ear tags on your cows? (Yes/No)

## **Types of Ear Tags**

What types of ear tags do you use? For example: Animal Label, Iso-transponder, Smart tag, or other types? Could you specify how many or which brands/models you use?

## **Best Aspects of the Equipment**

What do you think is the best feature of the ear tag equipment you use? (Probe for details: durability, ease of use, visibility, functionality, etc.)

## **Worst Aspects of the Equipment**

What do you think is the worst feature or problem with the ear tag equipment? (Probe for issues: malfunctioning, discomfort, ease of loss, etc.)

## **Choice of Ear Tags Over Collars**

Why have you chosen ear tags over collars for your cows? (Probe for reasons: cost, practicality, comfort, tradition, etc.)

## **Problems with Lost Tags**

Have you experienced any problems with lost ear tags? (Yes/No) (If yes, ask for more details about how often this happens and in what circumstances)

## **Differences Between Lost Tags (Different Types)**

How do the issues with lost tags differ between the different types of ear tags you use? For example: Animal Label, Iso-transponder, Smart tag, etc. Are some more likely to get lost than others?

## **Advantages of Smart tags**

What are the advantages of using Smart tags in the ears of your cows? (Probe for features like data tracking, ease of use, reliability, etc.)

**Disadvantages of Smart tags**

What are the disadvantages of using Smart tags in the ears of your cows? (Probe for issues like technical failures, durability, animal discomfort, etc.)

**Impact of Lost Tags**

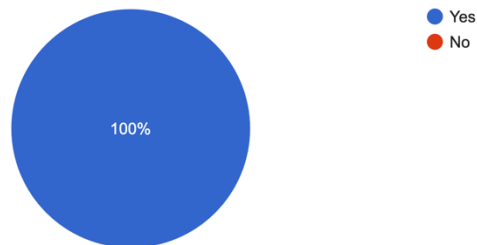
What would you say is the biggest issue for you when ear tags get lost? (Probe for consequences: time lost, cost, animal identification issues, etc.)

# Appendix C Ear tag insight Survey

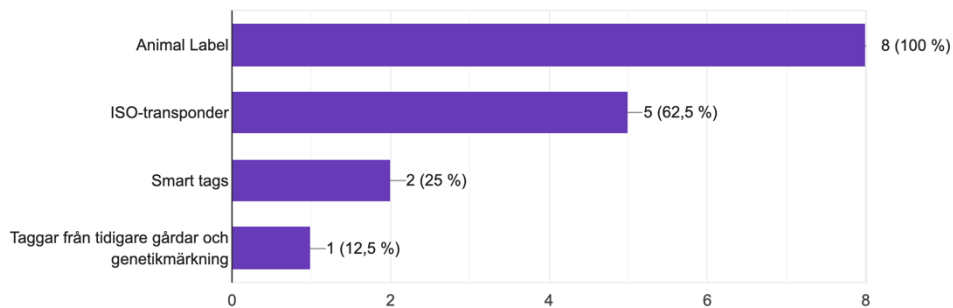
*Questions with corresponding diagrams for the collected answers.*

## General information

Do you use ear tags on your cows?  
8 svar

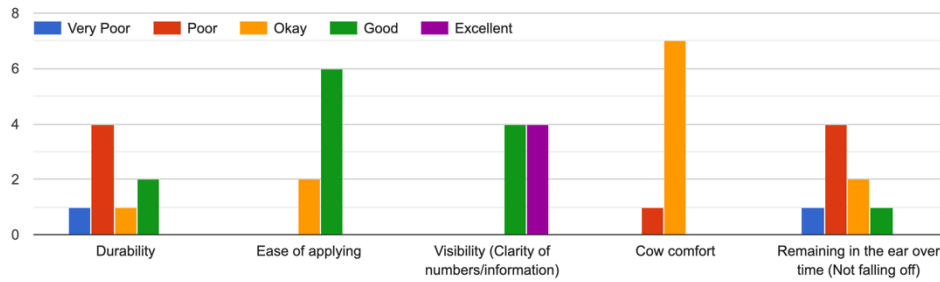


If yes, what types of ear tags do you use? (Select all that apply)  
8 svar



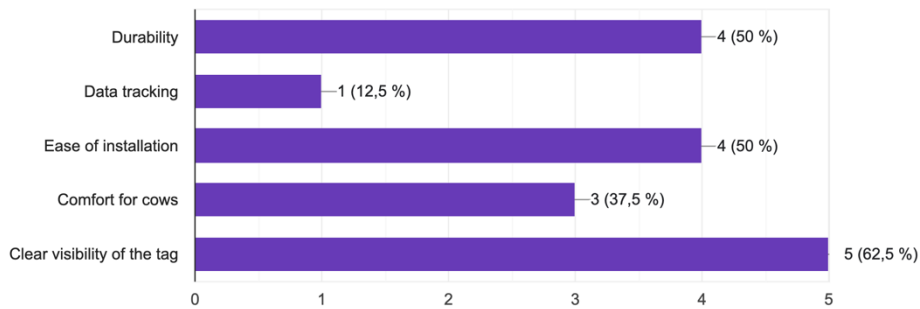
## Equipment evaluation

How would you rate the following aspects of the ear tags you use? (1 = Very Poor, 5 = Excellent) Please rate based on your overall experience with ear tags



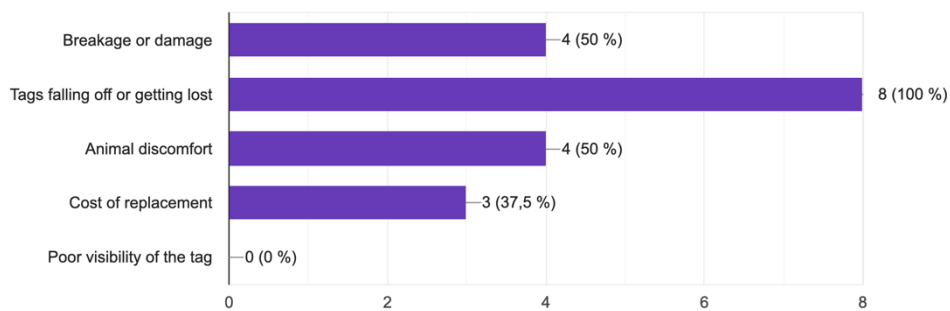
What do you consider to be the best feature of the ear tags you use? (Select maximum of 3 that apply)

8 svar



What do you consider to be the worst issue with the ear tags you use? (Select maximum of 3 that apply)

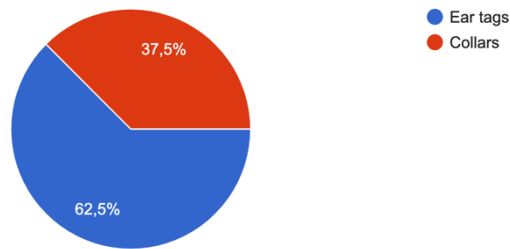
8 svar



## Ear tags vs. Collars

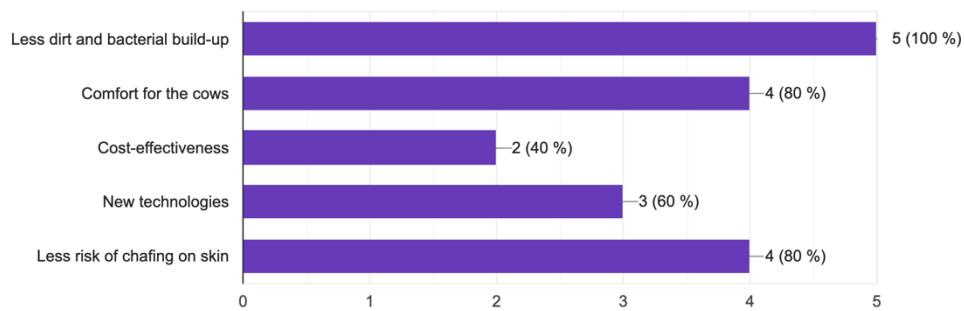
When given the option, have you gone for ear tags or collars?

8 svar



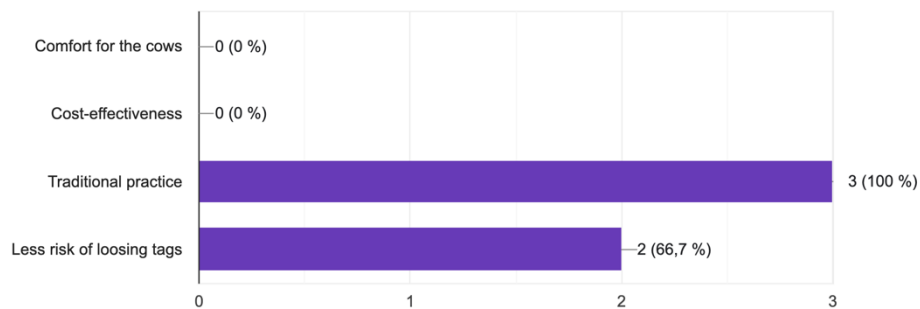
If choosing ear tags, why did you choose ear tags over collars for your cows?

5 svar



If choosing collars, why did you choose collars over ear tags for your cows?

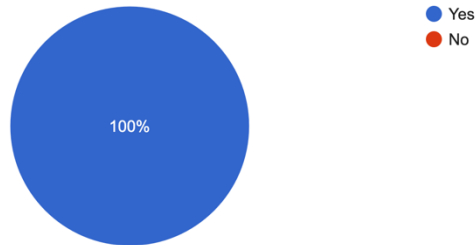
3 svar



## Lost tags and tag replacements

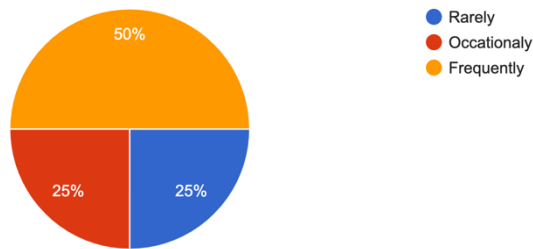
Have you experienced issues with ear tags falling off and getting lost?

8 svar



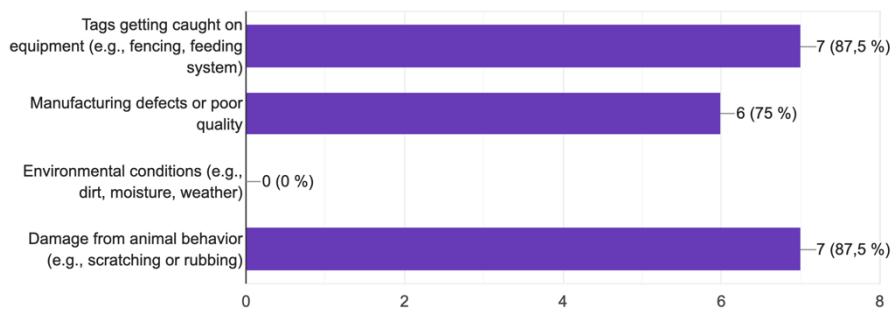
How often do you experience lost or fallen-off ear tags?

8 svar

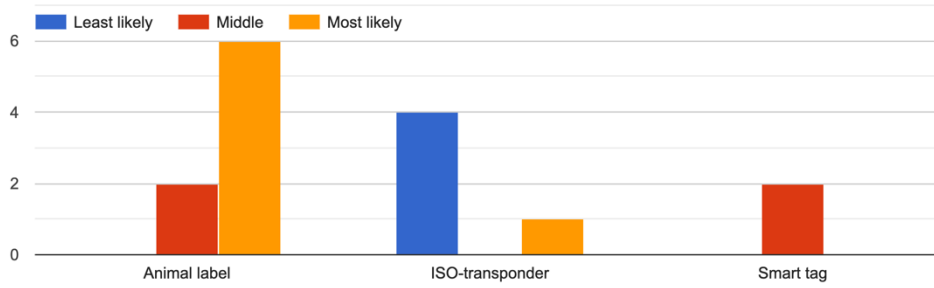


What do you think is the most common cause for tags falling off or getting lost? (Select the up to 3 of the most likely)

8 svar

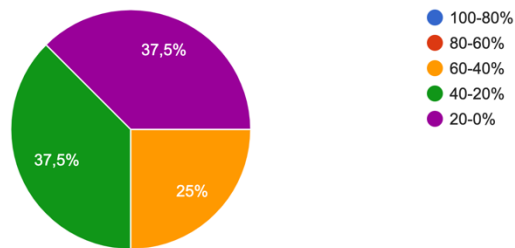


How do the issues with lost tags differ between types of ear tags? Answer for the tags you have



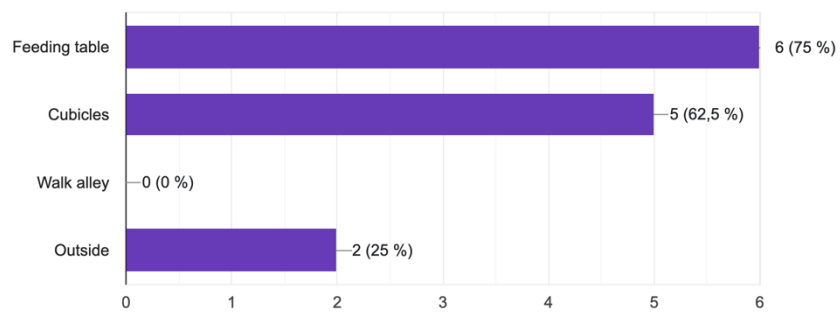
How many of the total amount of lost tags are found?

8 svar



Where are the tags mainly found? (Select the two where most are found)

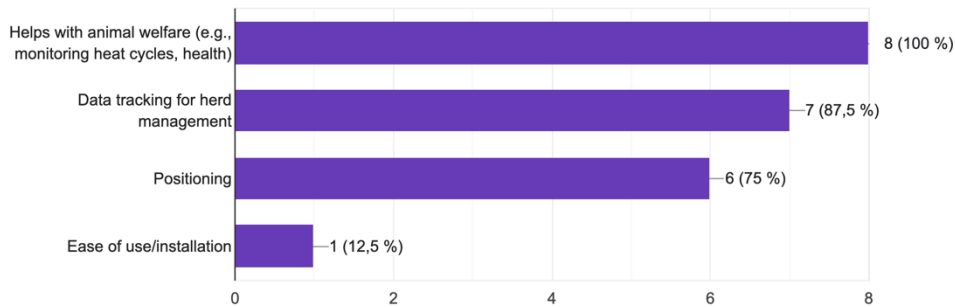
8 svar



## Smart tags

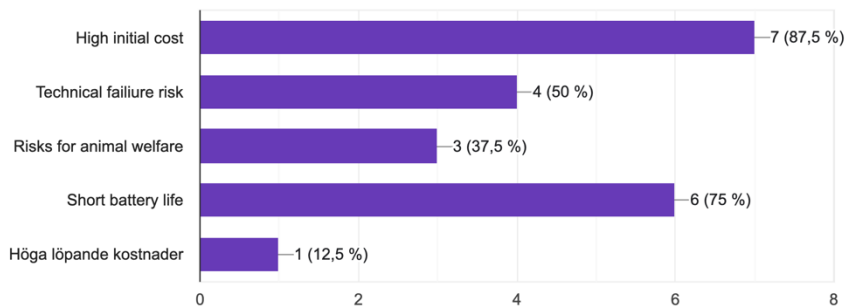
**What advantages do you see in using Smart tags? (Select all that apply)**

8 svar



**What disadvantages do you see in using Smart tags? (Select all that apply)**

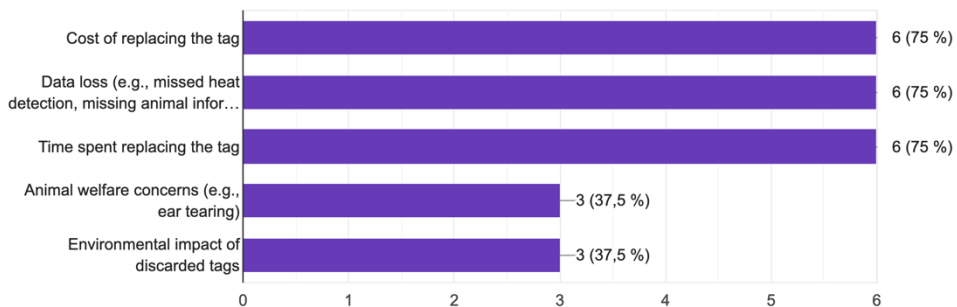
8 svar



**Concerns and impact of lost tags**

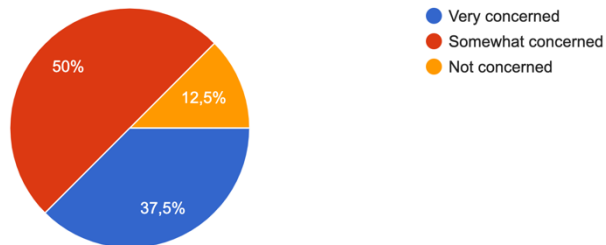
**What is the biggest issue for you when ear tags fall off? (Select up to 3 of the most fitting)**

8 svar



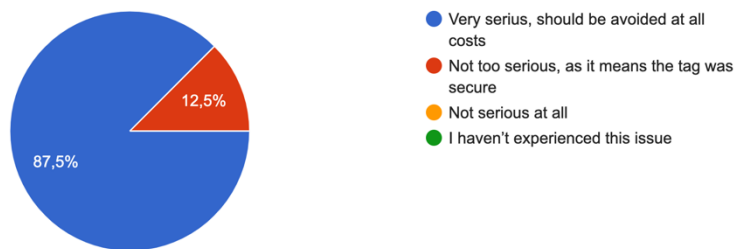
How concerned are you about the environmental impact of fallen-off ear tags?

8 svar



How serious is it if a tag causes ear tearing or injury to the cow?

8 svar



# Appendix D Test setup development - “Obstacle course”

*The lengthy process of developing the test setup*

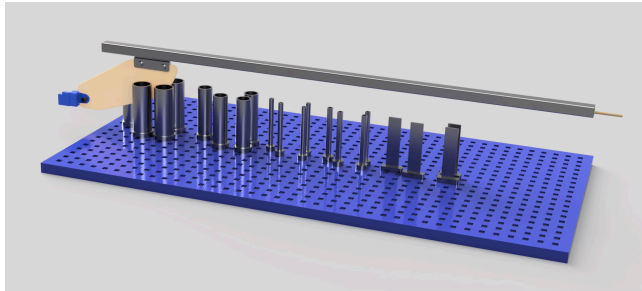
## D.1 Background

Through farm visits and observations, headlocks were identified as the main reason ear tags get stuck or fall off. These headlocks often have narrow openings that snag ear tags as animals move through them. To test how well different ear tag designs handle these challenges, an obstacle course was developed. The setup uses a rubber plate, similar in thickness to an animal’s ear, which is pulled through obstacles. These obstacles reflect the dimensions and shapes observed on farms, including pipes, square tubing, and flat steel.

The goal of the obstacle course is to simulate real farm conditions in a controlled way. This allows for repeated, accurate testing without risking animal health, making it possible to compare the durability and functionality of various designs for long-term farm use.

## D.2 Concept

After reviewing available materials in hardware stores, several options were selected, including two pipe diameters, square tubing, and flat steel. A modular tool board was chosen as the base to allow flexibility and precise calibration of the test setup. The course starts with two pipes arranged in a zig-zag pattern, followed by a gate-like obstacle, ensuring the ear tags are tested from multiple angles.

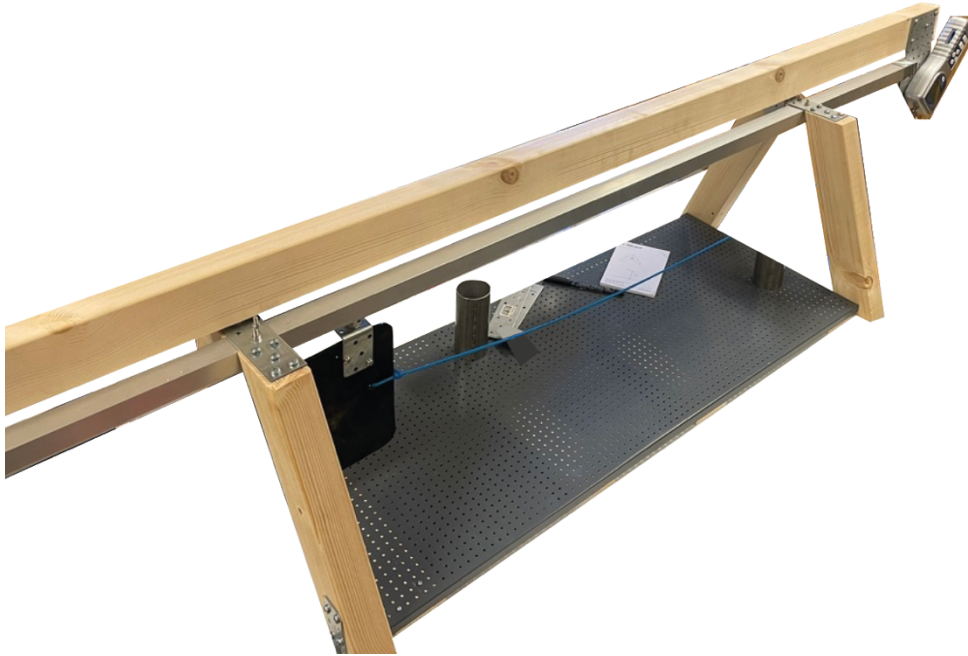


**First render of the plans for the test setup**

### D.3 Physical test setup

The base of the setup is made from a Biltema tool board (960 x 400 mm, grey, 2024), reinforced with 22x70 mm wooden boards for stability. The A-frame structure, built from 45x70 mm lumber, supports both the mechanical “ear” track and the force gauge mount. A sliding door system was repurposed to serve as the track for the test mechanism.





### D.3.1 Obstacle Material Selection

- 4 pcs:  $\varnothing 50$  mm pipes (120 mm length)
- 4 pcs:  $\varnothing 25$  mm pipes (120 mm length)
- 4 pcs: 20x20 mm square tubing (120 mm length)
- 4 pcs: 3x30 mm flat steel (120 mm length)

All pipes were fitted with 3D-printed inlays containing square nuts and were attached using threaded M6 rods. The flat steel was mounted using construction brackets for secure positioning.



The  $\varnothing 50\text{mm}$  obstacles before being installed

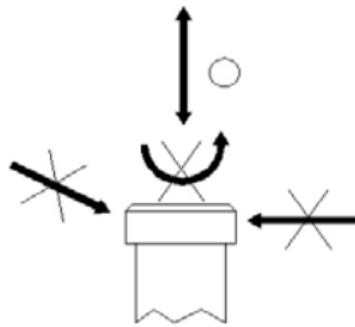
## D.4 Measuring device

### D.4.1 Force gauge

The force gauge used for this test is a RSpro 111-3690. The max force it can handle is 200N and it has a sampling rate of just 1 Hz out of the box, but with a custom-made RS232 connector and a python script it was possible to get the sampling rate to 3 Hz. The low sampling rate meant that the test would have to run very slowly to get good accuracy. For this reason, a heavily geared down 80W motor was used together with a 50 mm thick pulley. This combination of a motor that makes one full rotation in 11 seconds and a 50 mm roller with 157 mm circumference means a pulling speed of 14,3 mm/s. The course length of  $\sim 900$  mm gives above 180 samples per run.



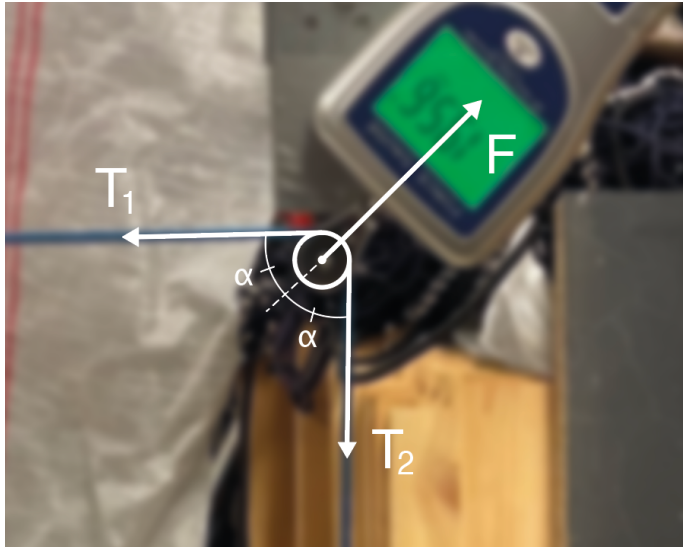
RSpro 111-3690



**The allowed forces that could be measured by the tool.**

The force gauge could only measure forces along a single line and was unable to handle sideways forces. To solve this, a pulley was attached to redirect the force at a 45° angle, ensuring accurate measurements while maintaining a consistent load path. The force calculation:

$$\begin{aligned}
 2\alpha &= 90^\circ \\
 T &= T_1 = T_2 \\
 F &= T_1 \cos(45) + T_2 \sin(45) = 2T \cos(45) = \sqrt{2}T
 \end{aligned}$$



**How the force gauge was mounted with a free body diagram of the forces.**



**Electric motor and force gauge setup**

# Appendix E Explanations for scores

## E.1 Facilitate injection molding

This parameter evaluates whether the design hinders the injection molding process. Concepts with simpler designs that posed no manufacturing obstacles, such as Concept 3.1 and Concept 4, received the highest scores. Concepts 2.1 and 2.2 required combining the tag with a backplate, adding complexity, which resulted in slightly lower scores.

**Table E-1 Facilitate injection molding**

<i>Concept</i>	<i>Hindrance for manufacturing</i>	<i>Score</i>
Concept 1	Small - Combining tag with lock	5
Concept 2.1	Small – Combining tag with backplate	4
Concept 2.2	Small – Combining tag with backplate	4
Concept 3.1	None	5
Concept 3.1 Flex	None	5
Concept 3.2	Small - Combining tag with lock	4
Concept 4	None	5

## E.2 Flexibility

Flexibility was assessed qualitatively based on the ability of the tag to bend and adapt to obstacles. Concepts 3.1, 3.1 Flex, and Concept 4, which demonstrated significant flexibility, received the highest scores. Concept 3.2 showed some flexibility, which allowed it to score slightly higher than Concepts 1, 2.1, and 2.2, all of which were rigid and received the lowest scores.

**Table E-2 Flexibility**

<i>Concept</i>	<i>Potential for flexibility</i>	<i>Score</i>
Concept 1	None	1
Concept 2.1	None	1
Concept 2.2	None	1
Concept 3.1	A good amount	4
Concept 3.1 Flex	A good amount	4
Concept 3.2	Small amount	2
Concept 4	A good amount	4

### E.3 Lightweight

The weight of each concept was calculated using CAD models to determine the volume, combined with the density of nylon. Lighter tags received higher scores. Concept 1, with the lowest weight, scored the highest, while Concept 4, the heaviest, scored the lowest.

**Table E-3 Lightweight**

<i>Concept</i>	<i>Weight calculated from volume</i>	<i>Score</i>
Concept 1	12,65g	5
Concept 2.1	14,31g	4
Concept 2.2	19,43g	3
Concept 3.1	20,15g	2
Concept 3.1 Flex	20,15g	2
Concept 3.2	19,93g	2
Concept 4	24,51g	1

## E.4 Minimize skin contact

The contact area between the tag and the ear was calculated using CAD models. Smaller areas were favored, resulting in Concept 2.1 receiving the highest score. Concepts with larger areas, such as Concepts 3.1, 3.1 Flex, and Concept 4, received the lowest scores.

**Table 9.6-4 Minimize skin contact**

<i>Concept</i>	<i>Area against ear</i>	<i>Score</i>
Concept 1	1070 mm <sup>2</sup>	3
Concept 2.1	331 mm <sup>2</sup>	5
Concept 2.2	710 mm <sup>2</sup>	4
Concept 3.1	1133 mm <sup>2</sup>	2
Concept 3.1 Flex	1133 mm <sup>2</sup>	2
Concept 3.2	983 mm <sup>2</sup>	3
Concept 4	1812 mm <sup>2</sup>	1

## E.5 Snag-free design

This parameter was scored based on how many obstacles each concept successfully cleared in the obstacle course. Concepts 3.1 Flex and 3.1, which cleared the most obstacles, scored the highest. Concepts 2.1 and 1 cleared fewer obstacles and received lower scores.

**Table 9.6-5 Snag-free design**

<i>Concept</i>	<i>Total obstacles cleared</i>	<i>Score</i>
Concept 1	46	2
Concept 2.1	18	1
Concept 2.2	53	3
Concept 3.1	55	4
Concept 3.1 Flex	56	5
Concept 3.2	55	4
Concept 4	51	3

## E.6 Battery life

The electric capacity of each concept's battery was evaluated in watt-hours (Wh). Concepts with higher capacities, such as Concept 2.2, received the highest scores. Concepts with lower capacities, like Concept 1, scored the lowest.

**Table 9.6-6 Battery life**

<i>Concept</i>	<i>Electric capacity</i>	<i>Score</i>
Concept 1	0,77 Wh	1
Concept 2.1	3,00 Wh	4
Concept 2.2	3,38 Wh	5
Concept 3.1	3,00 Wh	4
Concept 3.1 Flex	3,00 Wh	4
Concept 3.2	3,00 Wh	4
Concept 4	1,85 Wh	2

## E.7 Smooth edges

Edge quality was assessed visually, with sharpness and finish being key factors. Concepts with the smoothest edges, including Concepts 1 and 2.1, received the highest scores. Concepts with sharper or less refined edges, such as Concept 4, scored the lowest.

**Table 9.6-7 Smooth edges**

<i>Concept</i>	<i>Assessment of smooth edges</i>	<i>Score</i>
Concept 1	Excellent	5
Concept 2.1	Excellent	5
Concept 2.2	Excellent	5
Concept 3.1	Good	3
Concept 3.1 Flex	Good	3
Concept 3.2	Very good	4
Concept 4	Okay	2