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Discovering the Future of Rot Detection in Harvesters: A Design Concept

A User-centered Approach to Bridging the Gap Between Expert and Novice Operators

Master's Thesis in Industrial Design Engineering

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Cover: Visualization of the final bucking assistance human–machine interface in a harvester cockpit environment.

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Common Used Terms

Forestry Terms	
Harvester	A machine that fells trees, removes the branches, and cuts the stems into timber segments, which are placed in piles for the forwarder to collect.
Forwarder	A machine that collects the logs cut by the harvester and places them in piles by the roadside.
Clear-cutting	All trees within the area are cut down by the harvester..
Stem Cleaning	Removal of, for example, dirt and bark from a tree. This can be performed by a harvester.
Thinning	Only selected trees are cut by the harvester in order to improve, for example, growth within the forest.
Bucking	Cutting timber into optimal lengths for each timber segment, thereby maximizing its value
Classification of Timber	Timber is classified into different assortments based on attributes such as tree species, length, diameter, and quality.
Abnormal Tree Sorts	
Rot	A disease that exists in some trees that changes how the trees are handled by the harvester and their value.
Crown Forks (double- or triple crowns	A tree has two or more crowns, which affects how the tree is handled by the harvester and its value.
Root Flare/Buttress Roots	The root of the tree is uneven and bulges outward, which affects how the tree is handled by the harvester and its value.
Crookedness	An uneven tree with a bent stem, which affects how the tree is handled by the harvester and its value.

Abstract

This thesis explores the opportunities to bridge the gap between expert and novice harvester operators for detection and handling of rotten trees. The aim of this thesis is to develop a concept that eases the detection and handling of rot for harvester operators. Focus is placed on defining the gap between expert and novice operators, developing a tool to help the operators work with rot, and on how the information in this tool should be presented to the users to assist in their work.

The thesis was carried out in collaboration with Volvo Penta's User Experience team, where focus was placed on the exploration of the forestry segment. The foundation of the thesis is built upon a user-centric design process, where user studies and user needs were the main focus. This project combines methods of data collection, data analysis, concept development, and concept evaluation to generate a concept for assistance in dealing with rot during harvester operations.

From the conducted studies, it can be confirmed that the main difference between expert and novice operators is their knowledge, which is mainly gained from experience. Certain areas, such as rot detection and handling, can be especially difficult for novices due to the current lack of supporting tools. Therefore, a concept focused on rot detection and bucking assistance was created. The created concept consists of two parts, a technical solution for detecting rot and an interface for interaction with the user.

By offering assistance for bucking and rot-related assessment of rotten trees, the work process of the harvester operators will become more efficient, and the losses due to wrongfully handled rotten trees will be lowered. Considering the benefits of the created concept, it is expected to bring value to both harvester operators and Volvo Penta.

Keywords: Forestry, Harvester, Harvester Operators, Rot Detection, Bucking System, Abnormal Tree Handling, Future Concept, Product Development, User Research, User-centric Design

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Best wishes,

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Table of Contents

1. Introduction

Seventy percent of the land in Sweden is covered by forest, making it the country with the largest forest area in the European Union (Abdi & Wang, 2026). The large amount of forest in Sweden has made forestry an important part of the Swedish economy (Abdi & Wang, 2026), and therefore it is relevant from a research perspective.

There are many different roles you can have when working within forestry, one of them being a harvester operator. Harvesters work with cutting and bucking trees (United States Forest Service, n.d.), which are then sorted into different timber segments. However, if the tree is rotten, the timber will be classified differently due to its lesser quality, which causes economic losses (Hannrup et al., 2026). According to Hannrup et al. (2026), 8% of the timber in Sweden, with the right size for felling, is affected by rot, leading to economic losses between 800 million and 1.1 billion Swedish Kronor per year.

To detect and handle rot in trees can be difficult for harvester operators. Today, there is no way for harvester operators to detect rot until they have cut the tree, and even then, it can be hard to spot due to poor vision. It is not only difficult for the operators to spot, but it is also time consuming and has a high chance of making errors. Once the rot is detected, the operator needs to estimate how far into the tree the rot extends and perform optimal bucking based on their approximation of how far and where the rot has spread, which is a challenging task.

It is difficult to detect and handle rotten trees for operators with years of experience, and even more so for novices. Novices have a lower chance of detecting and bucking rotten trees correctly, due to a lack of knowledge and experience, which results in even more errors that consume time and cause economic losses.

The importance of the forestry industry in Sweden and the effect rotten trees have on it was therefore seen as relevant for further research. This is why the research area of this thesis was set to explore what solutions can help harvester operators to more easily detect and handle rotten trees, and to bridge the gap between novice and expert harvester operators.

1.1 Background

This chapter presents an overview of forestry and forestry machines, providing the necessary background to support the understanding of the problem addressed in this report.

1.1.1 Forestry

Forestry is a significant industry worldwide, employing approximately 15 million people (Schettino et al., 2021). Sweden is one of the countries in the EU with the highest surface coverage of forest (Hertog et al., 2022), almost 69% (Heder Brandt et al., 2023), and therefore has a large forestry sector (Hertog et al., 2022). In Sweden, most of the forest is owned by either private companies, 24%, or private individual owners, 48%, the rest by the state or the church (Heder Brandt et al., 2023). The three biggest forest companies own almost the entire share of forests of the private companies and buy around 40-50% of the timber produced from the private individual owners (Heder Brandt et al., 2023). Private individual owners are also offered support and help packages from large companies to maintain their lands. Approximately 10% of the Swedish export is from the forestry industry (Hertog et al., 2022), which makes it a relevant industry to explore from a business, sustainability and product development perspective.

1.1.2 Machines

To work with forest management, different tools are used to make the work possible. Two of the most used machines to work with in the forest are harvesters and forwarders. Forest harvesters are complex machines that are used to cut trees (Szewczyk et al., 2020). They are also used to cut limbs and crosscut stems. These machines have been used in Nordic countries since 1970. The machines are used for both clear-cutting and thinning of stands. The harvesters can be used in difficult terrain, and there are special harvesters made for the most challenging terrains, such as mountains and steep slopes (Szewczyk et al., 2020).

Harvesters are in general considered expensive, both to buy, maintain and run, and it can be difficult for smaller foresters to afford them (Schettino et al., 2021). The high costs of the machine and its time can lead to operators using shortcuts and exposing themselves and the forest to risks. The poor ergonomics of forest workers has, according to Schettino et al. (2021), a big impact on the numbers of injuries and accidents that occur when working with forestry.

The forwarder was developed in the 1960s to transport timber from the harvesting in places where tractors could not (Ghaffariyan, 2022). With the help of forwarders, more timber could be transported per trip. The forwarders normally work together with the harvester. There are two main kinds of forwarders: conventional forestry forwarders, and tractors with a trailer with a log grapple (Ghaffariyan, 2022). The forwarders arrive at the harvesting site empty, load the timber onto the trailer with the grapple, and then drive to the landing site and unload. Depending on factors, for example, the distance to the harvesting sites, timber volume and operator skills, the efficiency of the forwarding process can vary (Ghaffariyan, 2022).

Since the introduction of the harvester and forwarder in the forestry industry, the work has become much safer since the operators are more sheltered from the environment within the machines (Sokolov et al., 2023). However, since the machines are more complex, the cognitive loads for operators have increased, and that, in combination with the loneliness of working by yourself in the forest, can decrease the operator's capacity to work (Sokolov et al., 2023). Operating a forwarder also exposes you to risks of heavy vibration and injuries from repeating strains, since the work is repetitive and in poor working positions (Santos et al., 2020).

1.1.3 Mental Workload

Historically, manual motor felling was more common, but this form of work was less comfortable for workers due to high physical demands and lower levels of safety (Szewczyk et al., 2020). Today, approximately 60% of all harvested timber in Europe is cut using mechanized cut-to-length systems, with figures reaching up to 95% in Sweden, Norway, and Finland. However, the transition from motor-manual felling to fully mechanized harvesting techniques has led to an increase in mental workload among forestry workers (Szewczyk et al., 2020).

Mental workload has increased due to both task complexity and task simplicity. Task complexity requires continuous coordination and concentration, while task simplicity involves repetitive actions that can reduce alertness. These conditions may cause fatigue, leading to reduced concentration, slower perception, decreased motivation, and emotional disturbances. Although mechanized work has improved efficiency, it has also increased the risk of accidents due to elevated mental workload. Szewczyk et al. (2020) further highlight that mental workload increases with slope gradient, as steeper terrain significantly raises task difficulty.

1.2 Project Purpose and Objectives

The purpose and objectives of the project are presented in this section, together with the research questions that guide the study.

1.2.1 Aim

The aim of this thesis is to develop a solution that enables user-friendly interaction between operators and harvesters in the forestry sector. It should allow both novice and expert operators to easily detect rotten trees, thereby reducing their cognitive workload by reducing decision-making demands and errors. The concept should improve efficiency when it comes to decision making as well. The created solution should decrease the errors related to the detection of rotten trees, which will increase productivity and reduce costs. It should be supportive for novices, without making it more difficult for experts to use. The final concept should align with Volvo Penta's values: usability and efficiency, making it easy and convenient for operators to work in the forest.

1.2.2 Specification of the Issue Being Investigated

The aim of this thesis is defined in several research questions.

Main research question:

- What solution can help harvester operators to more easily detect and handle rotten trees?

Subordinate questions:

- What differs between the novice harvester operator and the expert regarding decision-making when operating a harvester?

- What tools can be used to help the harvester operator detect and make decisions regarding rotten trees?

- How can information regarding rotten trees be presented to the harvester operator without disturbing their work?

1.3 Limitations

This paper will not cover all aspects within the forestry industry and therefore limitations have been set, both within the scope and within the process. In this paper, the focus will be on forest maintenance, especially focusing on harvesters and detecting rotten trees. Since the project has a limited time frame, other machines and work areas will not be researched.

This project mainly will be focusing on the forestry industry in Sweden. Choosing Sweden as a focus area is because of its closeness to where the project is carried out and because of its importance to the global market. Since Sweden is one of the countries in the world with the largest forestry industry and well-developed technology, the results from this study could still be useful in other areas as well.

Another set limitation is that the focus of the project is to design for the user. This project aims to ease the operator's workload, and the design should therefore have the users and their needs as its main priority.

The design will not focus on regulations set for harvester interfaces. The project's focus is not on generating a legally approved interface, and the focus will therefore not be on following the set regulations but rather exploring the opportunities for a user-friendly interface.

Finally, the project will be limited to producing a final concept and not a finished product. The final concept should be feasible and clearly defined, but the details of, for example, how it should be produced, or technical drawings, will be left outside of the scope of this project.

1.4 Societal-, Ethical- and Ecological Aspects

In this paper, there are ethical aspects that need to be considered. The aspects are described in the following section and can be placed within three categories, societal- , ethical- and ecological aspects.

1.4.1 Societal Aspects

Looking into the societal aspects of the project, it is important to consider that different societies and parts of the world work differently, not only in forestry but also in general. In this project, the users included will be based in Sweden, which means that the Swedish work culture and the Swedish way of working with forestry will be overrepresented, and it might therefore be difficult to apply the solution to other uses across the world. This is something that needs to be considered since Volvo Penta is a global company and forestry a global industry, and the solution needs to fit all kinds of users across the world.

Another societal aspect to consider is that different parts of Sweden have different types of nature and environments. The users interviewed and observed in this project will likely be located near the Gothenburg area. Since the natural conditions vary, operators in southern Sweden may not have the same issues and thoughts as those in northern Sweden. The forests in the south are smaller than those in the north, have a different climate, and grow on different types of soil (Skogsindustrierna, 2025). In the south, trees can grow almost twice as fast as those in the north. Therefore, it must be considered whether the solution can be called general if it has not been tested in different forest environments across Sweden.

1.4.2 Ethical Aspects

There are several ethical aspects that have to be considered. Firstly, the ethical aspect of gender inequality within forestry must be considered as most forestry workers are men (Lidestav & Egan Sjölander, 2007). However, there are of course women in the field, and they should also be able to use the same equipment as men. The consideration then lies in whether to design for the target user group or to design for everyone. Inclusivity is an important part of product development today, and it also influences norms. If a product is designed primarily for men, the percentage of male workers in forestry will naturally remain high. It is therefore important to consider both aspects, with the hope that the solution will ease the work for all forestry workers.

Another aspect concerns how data from user studies will be stored and used. GDPR is a law that must be considered, meaning personal data cannot be stored for too long or for the wrong purpose. Where the data will be stored is crucial to evaluate, as some storage solutions are less secure than others. Fortunately, the group will be provided with secure, data protected computers from Volvo Penta, ensuring that the data will not be shared with external sources. The data will also be erased and anonymized at the end of the GDPR contract period.

1.4.3 Ecological Aspects

In this project, there are some ecological aspects that need to be taken into account. One of these aspects is the impact of product development on the environment, both within the forest in this case and product development in general. Developing new products can cause a strain on the environment, since it needs resources both to be produced and used. This is something that needs to be considered when designing the solution, so that it should not cause unnecessary strain on the environment in general, but also the environment in the forest.

The forest is as mentioned by Raihan (2023), sensitive to climate change, which means that when designing products for it, ecological aspects are important to consider. If the design is done poorly and the effects on the environment are negative, it will directly create a negative impact on the forest and the forestry industry, which is something that needs to be avoided and considered in this project.

Another ecological aspect that is important to consider when executing this project is the tradeoff between sustainability and profitability. To launch a product, it needs to be beneficial for the companies, both for Volvo Penta but also for the machine producers, and sometimes that comes in conflict with its sustainability, since that can, in some cases, make it more expensive. When working with product development within the forestry industry, you need to carefully consider how to make sure that the product is both sustainable and profitable for the company, which can be difficult.

1.5 Outline of the Report

1. **Introduction** – This chapter provides the background to the thesis, followed by the project's purpose, limitations, and ethical considerations.

2. **Final Result** – This chapter presents a concise summary of the final outcome of the project, with the aim of providing an overview of the developed solution.

3. **Forestry Area** – This chapter presents relevant information about the forestry domain in order to support the reader's understanding of the project context.

4. **Theory –** This chapter presents the theoretical foundations relevant to the project, focusing on academical frameworks regarding usability and cognitive ergonomics.

5. **Methodology** - This chapter describes the methods and tools applied throughout the project, covering data collection, data analysis, concept development, concept evaluation and finalizing concept.

6. **Results -** This chapter presents the results obtained from the applied methods, including findings from empirical studies, ideation and user evaluations.

7. **Final Design -** This chapter presents the final design in detail, describing the key design decisions.

8. **Discussion -** This chapter discusses the results in relation to the applied methods and theoretical framework, reflecting on the project outcomes, limitations, and other aspects.

9. **Conclusions** - The final chapter summarizes the key conclusions of the study and addresses the project objectives.

Appendices – Includes complementary documents including interview templates, a survey template, user journeys with pain points and requirements list.

2. Final Result

The final outcome of this thesis is a bucking assistance and rot detection solution that integrates a user-centered interface with complementary detection techniques. The solution is grounded in findings from the conducted user studies and was continuously evaluated with users throughout the development process. Together, these components provide harvester operators with timely and actionable support for detecting and handling rotten trees.

According to approximations of experienced operators and industry experts, the proposed solution has the potential to reduce decision-making time by five to ten seconds per rotten tree, primarily by minimizing uncertainty and reducing the need for manual inspection. Over a full working day, this time saving represents a substantial efficiency gain. In addition, the results highlight a significant gap between expert and novice operators, revealing the extent of tacit knowledge involved in harvester operation. This tacit knowledge is largely acquired through practical experience, meaning that novice operators primarily learn by doing, a process that can take several years before a high level of proficiency is achieved.

The proposed interface consists of a bucking assistance interface, a peripheral LED light mounted above the display, and a cross-sectional view of the log, see Figure 1. The interface is customizable to support individual operator preferences and needs.

Figure 1. Final design in context of a harvester cockpit. The design includes a bucking assistance interface, a LED-light for detection and a cross-section view of the cut log.

The bucking system provides continuous information about the currently gripped log, including the distance from the end of the log to the gripping position, log diameter, tree species, product name, and rot percentage, see Figure 2.

Among these parameters, the rot percentage was highlighted by the operators as particularly valuable, as it plays an important role in determining the appropriate assortment category for the log.

In addition, the interface includes a graphical log representation that visualizes the suggested cut, the product name, and the recommended log length. When rot is detected, the graphical log clearly indicates this using a distinct red color scheme, a visual marking illustrating the presence of rot, and an adjusted suggested length, see Figure 2. This visualization allows operators to quickly interpret the situation and make informed cutting decisions with minimal cognitive effort.

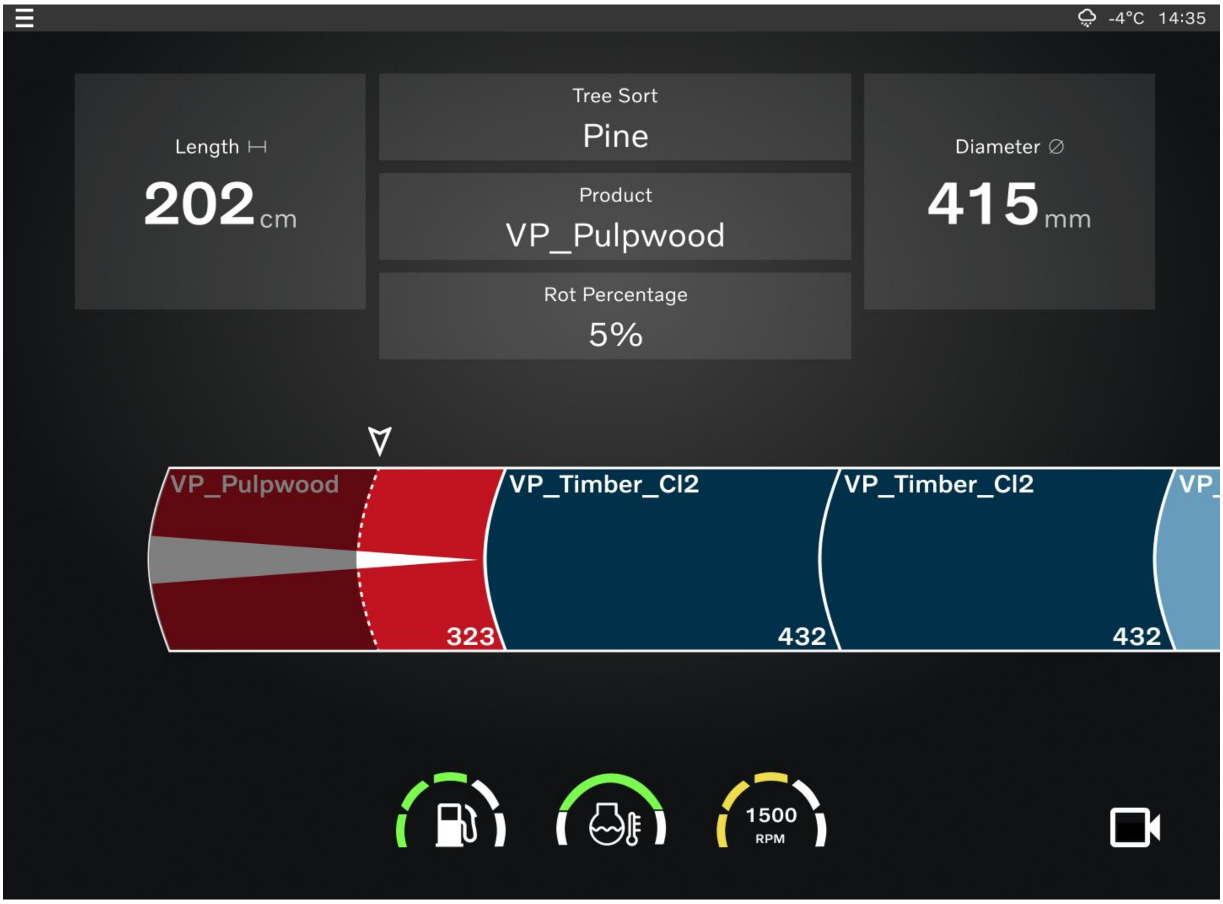


Figure 2. Bucking assistance interface where the red log indicates a rotten log.

When rot is detected, a peripheral LED light mounted on the display is activated, see Figure 3(a). When rot is not detected the light is turned off, as presented in Figure 3(b). This ensures that the operator is immediately alerted that the log is affected by rot and may need to be sorted into a different pile depending on the rot percentage. As operators typically focus their attention on the cutting head rather than the screen, this peripheral visual cue provides critical feedback without requiring the operator to shift focus away from the ongoing operation.

a) b)

Figure 3. Red LED-light providing peripheral visual feedback to the operator:

a) activated b) turned off

To enable estimation of both rot depth and rot percentage, a camera is mounted on the cutting head. The camera captures an image of the log's cross-section, which is then analyzed using image-recognition techniques. Two additional techniques can be used together with the camera to support the estimated values. These techniques include measuring saw efficiency and analyzing vibrations transmitted through the log. Since rotten wood has a different density from healthy wood, deviations from normal values may indicate the presence of rot.

Based on the detected rot diameter, the system calculates the rot percentage, while a preliminary estimation of the rot depth is derived using an algorithm. The camera also enables the operator to view the cross-section directly, thereby preserving a sense of control and transparency in the automated decision support process. The cross-section view can be displayed either on the reverse camera screen or on the main front display, depending on equipment availability and operator preference, see Figure 4. The cross-section view may be presented either in full-screen mode or in a reduced size, as illustrated in Figures 4(b) and 5.

a) b)

Figure 4. The cross-section view in the harvester:
a) on the reversing camera display b) on the main display

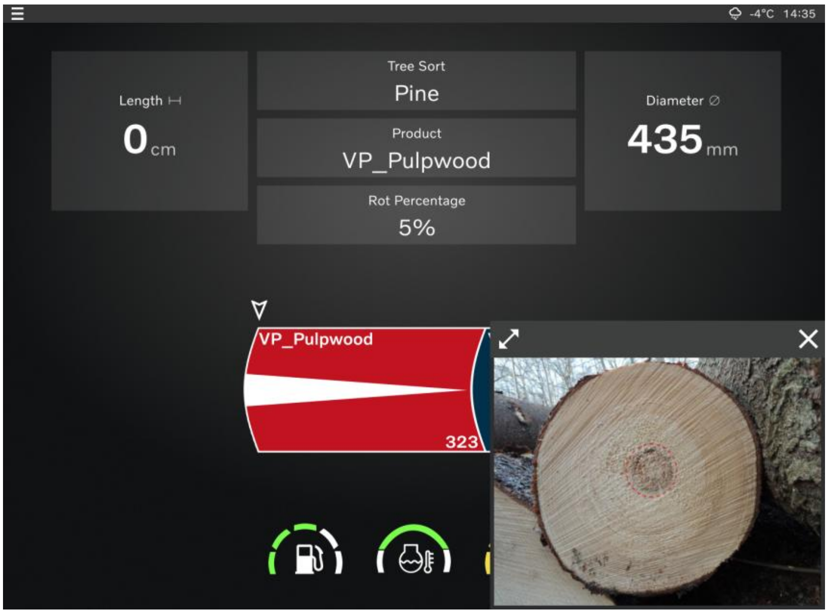


Figure 5. Small cross-section view of the log on the main display.

As operators differ in experience, working styles, and preferences, the interface is designed to be customizable. Users can adjust the color scheme of the graphical log, allowing some operators to choose more muted tones while others prefer more vivid visual feedback, see Figure 6. The layout of the interface can also be rearranged to match individual needs. In addition, operators can select which symbols and measurements are displayed in the taskbar, ensuring that only the most relevant information is presented during operation, see Figure 6.

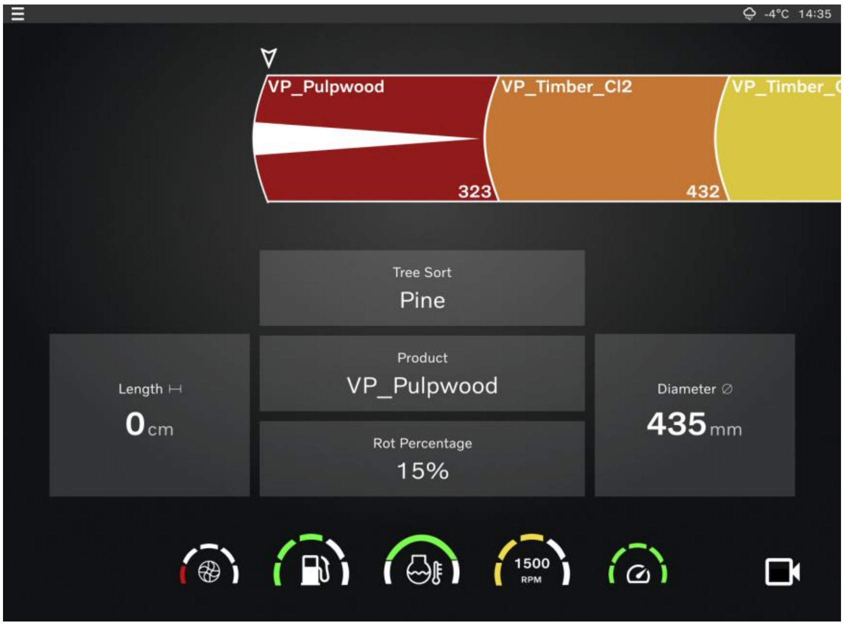


Figure 6. Customized bucking interface illustrating modified layout, log color scheme, and a change of taskbar icons.

3. Forestry Area

Forestry is a broad industry consisting of multiple areas. This chapter presents those areas that are of relevance to the topic of this study.

3.1 Harvester

A harvester, see Figure 7, is a machine that is used to cut trees in the forest (United States Forest Service, n.d.). The machine can both fell trees, help with stem cleaning and bucking it into different lengths. The machine head, see Figure 8, has two main functions: the chainsaw that cuts the trees and the feeding rolls that feed the tree through the machine head (Einola & Kivi, 2024).

(a) (b)

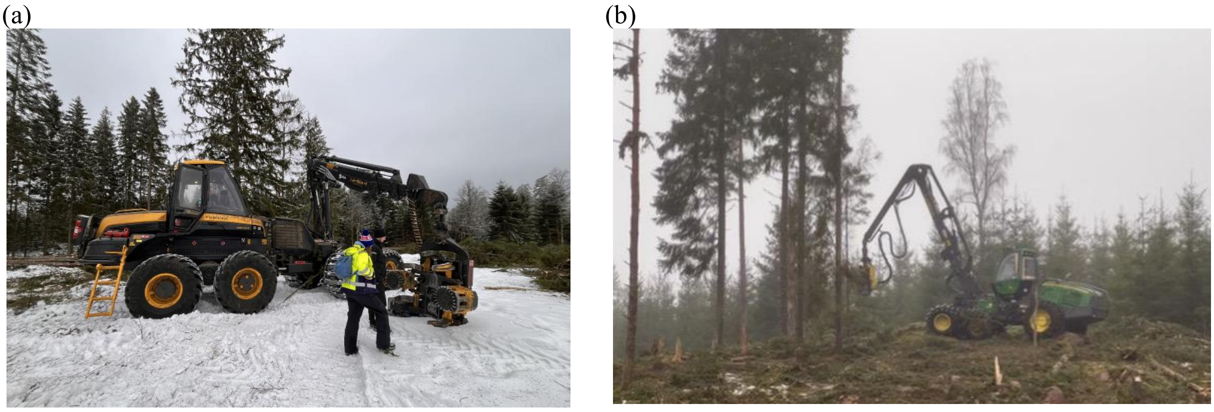


Figure 7. Examples of different harvesters used in forestry operations:

(a) Ponsse (b) John Deere

Figure 8. Cutting head of a harvester.

According to United States Forest Service (n.d.), harvesters can be either on wheels or use tracks, and there are multiple kinds of harvesters. Different harvesters can have different strengths and weaknesses regarding slope, soil conditions, tree size and tree form. Most harvesters can operate on slopes up to 40%, but the ground conditions have a big impact on how much slope is operable. Loose and wet soil conditions make the harvesters' work more difficult since the soil can withstand less ground pressure. The cutting head of the harvester is what decides what size of trees it can handle; it depends on its capacity and the machines weight (United States Forest Service, n.d.).

Harvesters have evolved a lot in recent years (JWS Forestry, 2025). The machines are now performing several tasks that used to require multiple operators. With advances in technology and automation, harvesters can now be supported by systems for route planning, optimized bucking, minimization of material waste, as well as increased precision and automation in boom control (JWS Forestry, 2025).

There are multiple brands that produce harvesters (Research and Markets, n.d.). Some of the most famous brands are John Deere, Komatsu, Ponsse, Eco Log and Rottne. The different brands of harvesters offer various features; for example, John Deere focuses more on data-driven forestry, while others, such as Komatsu, focus more on reduced fuel emissions (Research and Markets, n.d.).

3.2 Harvester Cockpit

The harvester cockpit is where the operator sits and controls the machine. The layout and construction of the cockpit impact the operators' work (Zemánek et al., 2023), especially factors such as physical ergonomics, visibility, and placement of controllers. The cockpits can be either static or rotating. If the cockpit is static, most machines offer the possibility to turn the seat around. At the top of the cockpit, lights are placed to help with visibility when working in the darkness, see Figure 9. The seat of the operator and all its components are adjustable to fit the operators' preferences and to improve the physical ergonomics.

Figure 9. Lights positioned on the roof of the harvester.

As mentioned by Zemánek et al. (2023), the crane and the machine's movements are controlled by two joysticks placed on the armrests of the operator's seat, see Figure 10. The more the operator moves the joysticks, the stronger the movement of the machine will be. Above the joysticks, on the armrests, are keyboards, see Figure 10, with buttons correlating to different machine functions. Each joystick and button on the keyboards can be changed to the operators' personal preferences (Zemánek et al., 2023).

(a) (b)

Figure 10. Examples of joysticks and keyboards in different harvesters used in forestry operations:

(a) Ponsse (b) John Deere

In the paper by Zemánek et al. (2023), they explain that the screen in front of the operators' seat, see Figure 11, is used to control the settings of the machine as well as giving the operator feedback on their work, in the form of, for example, measurements. All harvesters are equipped with bucking systems which help the operator cut the timber into optimal lengths for maximum amount of profit, see Figure 11, with the help of a sensor placed on the cutting head of the machine. The screen is often controlled by either a mouse, the keyboards or touch (Zemánek et al., 2023). The rest of the available functions, for example, air conditioning, are placed with buttons on the operators' sides or on the ceiling (Zemánek et al., 2023).

(a) (b)

Figure 11. Examples of Ponsse harvester interfaces presenting:
(a) daily feedback (b) keyboard settings

In the harvester cockpit, there are actions taken for safety measures (Zemánek et al., 2023). There is, for example, a button for emergency stop and a restriction making it impossible to drive the machine if the door is open or gets opened during the drive. The harvester has a safety belt as well as a reversing camera, which is placed on a screen often in front of or to the side of the operator (Zemánek et al., 2023), see Figure 12. The cockpit is also equipped with tools to withstand different kinds of weather, such as windshield wipers and sunscreens.

Figure 12. Reversing camera view and placement in a John Deere harvester.

Except for the main functions, there are multiple options for optional functions (Zemánek et al., 2023). Some examples of other available functions include Bluetooth connection for phones, phone holders, radio and heating boxes to store and warm the operators' lunch during their shift.

In the paper by Wallmyr (2017), they studied the line of sight of a harvester operator while performing thinning, with the help of eye tracking. The user's main point of focus when cutting was placed on the cutting head, while the screen in front of the operators was mostly used as a confirmation tool and glanced upon briefly. According to their study, 69% of the users' eye movements were directed towards the front windshield, 25% at the top of the screen, and only 0.4% towards the actual screen. However, as Wallmyr (2017) claims, the results might vary between different tasks, for example, if the operator had performed final harvesting instead of thinning. While moving the machine, the operators' gaze shifted and was directed more at the environment around the machine.

3.3 Bucking Systems

A bucking system is a tool that assists the harvester operator in determining the appropriate log lengths to cut (Dasa Control Systems, n.d.). The system operates either based on a product-value list or a preferred-length list, generating suggestions that maximize value or match the requested specifications. It also provides the operator with information regarding the log's assigned assortment (Komatsu Forest, n.d.). However, the operator always retains the ability to override the suggested cuts to maintain full control.

Bucking assistance optimizes the cutting process while simultaneously reducing the number of decisions the operator must make. Different machine brands use different software solutions. Some bucking systems display a graphical log visualizing the cuts (Dasa Control Systems, n.d.), while others present only numerical values (SP Maskiner, n.d.), and some use numerical values combined with circular indicators to signal each cut (Ponsse Oyj, n.d.).

However, the bucking system only functions effectively when the tree is in normal condition. If a tree has abnormalities that reduce the logs' value, such as rot, crookedness, or other defects, the operator must manually decide how to perform the cuts.

3.4 Work Process Harvester

The process within the forestry industry typically begins with an agreement between a forest owner or supplier and a buyer (Eriksson et al., 2022). Once the agreement has been established, the harvester operator begins the planning phase, which varies depending on whether the operation involves thinning or clear-cutting. In general, planning takes longer during thinning, as the correct trees must be selected and the available driving paths are narrower. In some machines, the operator can receive planning assistance from the system.

The operator then prepares the machine by applying personal settings and adjusting the seat and joysticks for comfortable operation, as the operator remains seated for extended periods of time. After this, harvesting begins. Depending on wind conditions, ground conditions, terrain steepness, and tree size, the positioning of the machine may vary. While harvesting a tree, the operator is typically already planning the next tree to cut.

Once a tree has been felled, the operator uses the bucking system to cut the stem into logs, which are then sorted into separate piles. However, if the tree contains rot, bucking assistance cannot be used, and the operator must manually decide the cutting lengths. After the logs have been processed and sorted by the harvester and collected by a forwarder, they are stored and transported to the next stage of the supply chain, namely industrial processing within the forest industry.

3.5 Tree Rot

Tree rot is one of several structural deficiencies that can affect both the stability and quality of trees. There are many factors that can contribute to structural risks within a tree (Pressbooks / Virginia Tech, n.d.). Weakness in the stem, crown, or roots can affect the trees' quality and cause it to fall. Examples of weaknesses that can cause failure are crown forks (double- or triple crowns), root flare/buttress roots, crookedness, and rot.

According to Hannrup et al. (2026), rotten trees have a significant impact on the Swedish forest industry. Rotten trees cause economic losses for the industry since they decrease the quality and usefulness of the timber. In Sweden, around 8% of the timber with the right dimensions for felling was affected by root, which causes losses of between 800 million and 1.1 billion SEK per year (Hannrup et al., 2026). In their paper, Hannrup et al. (2026) claim that rot in spruce trees is the major reason for timber losses.

The rot can be in the tree's trunk and in its roots and are mainly caused by fungi (Hannrup et al., 2026). The most common fungi are mainly spread to fresh cut tree stumps through particles in the air. Once the stumps are infected, the fungus can spread through their roots to other trees nearby. When the root of a tree is infected, the rot tends to spread from its base upwards through the tree. Rot in a tree, once detected, will lead to a lower classification of timber and economic loss since the quality of the tree is less. To avoid the spreading of funguses, the tree stumps are normally protected with an anti-rot agent. (Hannrup et al., 2026).

According to S. K. Jha (2020), there are different kinds of rot which are caused by different fungi. Depending on what kind of rot the tree is exposed to and where the rot is located, it will have different types of wood decays. There are three main types of rot: white-, soft - and brown rot, and some common rot locations are heart-, sap-, butt- and canker rot (S. K. Jha, 2020). In the article by Wahlman et al. (2025), they explain that root rot is a common rot location in northern Europe and Fukasawa et al. (2025) study shows that brown rot is more common than white rot in northern Europe; it is highly dependent on the climate in the area. The specifications of each kind of rot and its placement are listed in Table 1 below.

Table 1. Types of rot, placements and methods of detection.

	Definition	Wood Appearance /Symptoms	Common Tree Sorts	Source
Type of Rot				
White Rot	Decays major components of the tree (cellulose, lignin, hemicellulose) and causes full breakdown of the tree.	Soft/ spongy wood texture with a yellow or white color. Creates “zone lines” in the wood.	Most common in flowering trees and less common in conifers.	(S. K. Jha, 2020)
Soft Rot	Rot is caused by both fungi and bacteria. Decays the components of the tree at a slower rate than brown and white rot. Decays the tree most close to where the fungus grows and mostly decays the hemicellulose and lignin.	Wet, soft and crumbly wood texture.	Not in specific tree sorts, most common in wet and moist areas.	(S. K. Jha, 2020)
Brown Rot	Breaks down cellulose and hemicellulose. Does not affect the lignin and leaves it intact.	Texture becomes brittle, dry and cracks occur. Leaves have a brown color.	Most common in conifers and not as often in hardwood trees.	(S. K. Jha, 2020)
Rot Placement				
Heart Rot	Rot in the core of the tree. Often happens due to an injury to the tree, for example broken branches.	Hard to detect. First sign mushrooms on the outside. Decays the trees' structure.	Various tree species.	(S. K. Jha, 2020)
Sap Rot	Rot the sapwood (the outer parts of the tree).	Can be seen by increased deadwood, thinner canopy, and lower foliage density.	Various tree species.	(S. K. Jha, 2020)
Butt Rot	The rot is located at the bottom of the tree trunk.	Lowers the trees strength, can kill the tree after a while. Hard to detect from the outside of the tree.	Common in conifers.	(Kaitera et al., 2019)
Canker Rot	Can be detected on the branches or the trunk of the tree.	It can be seen on the bark. The bark can be falling off or sunken.	Various tree species.	(S. K. Jha, 2020)
Root Rot	In the roots of the tree. Spreads through other deceased trees' roots nearby.	Can be seen, for example, on declined growth of the tree and yellow/brown foliage. Makes the tree soft and weak.	Various tree species.	(University of Minnesota Extension, 2018)

Rot detection can be divided into two categories, according to Soge et al. (2021), invasive or noninvasive methods. Invasive methods impact the tree since you, for example, drill or remove pieces of it, while noninvasive methods use tools such as sensors to detect rot without making any impact on the tree. There are different material changes that are caused by rot that can help you detect it, for example, changes in density and changes of element composition as rotten trees can have different composures of certain elements (Soge et al., 2021).

The density changes can be detected, for example, through drilling when the resistance changes, acoustic transit tools where the time for sound waves to travel changes or with x-rays when there is a changed transmission through the material (Soge et al., 2021). A change of element composition can be detected, for example, through methods of measuring electrical resistivity and electromagnetic properties.

3.6 Forestry Education

In Sweden it is common to attend a upper secondary school with focus on forestry to become either a harvester or forwarder operator, one example of such a school is Naturbruksskolan in Svenljunga. Naturbruksskolan is an upper secondary school in Sweden that focuses on nature resources (Västra Götalandsregionen, 2026). They offer six different focus areas for students, and one of them is Forestry Machine Operator (Västra Götalandsregionen, 2026).

The school uses both simulators and real-life experience to educate their students (Västra Götalandsregionen, 2025). The education takes place during three years where the first years focus mostly on knowledge within forest management and terrain transportation. During the students second year they get more extensive knowledge within forestry and practical experience driving forwarders. The third year the students learn how to drive harvesters and get to specialize within forestry machines. During all the years the students are offered practical experience at companies to increase their knowledge and skills within the area (Västra Götalandsregionen, 2025).

When the students are done with the education they can receive multiple certificates for example a license for handling a chainsaw of type A and B, and they are also educated to start actively working within forestry, either by joining a company or starting their own (Västra Götalandsregionen, 2025).

3.7 Volvo Penta

Volvo Penta is a Swedish company that is part of Volvo Group (Volvo Penta, n.d.). The company develops power solutions with a strong focus on efficiency and sustainability for applications both on land and at sea. Volvo Penta also develops engines intended for forestry applications, designed to withstand demanding operating conditions while ensuring optimized fuel efficiency (Volvo Penta, n.d.).

Currently, Volvo Penta only delivers engines in the forestry segment but aims to also provide accessories for the cockpit. At present, Volvo Penta delivers accessories only in their marine segment, where they offer different gadgets such as cruise controls (Volvo Penta, n.d.). Their cruise controls are designed for usability and efficiency, ensuring intuitive use for the captains. These aspects will be brought into the development of features for the forestry segment.

4. Theory

To provide a foundation for this project, relevant theories were applied throughout the work. These theories primarily focus on ergonomics, product development, and usability. The theoretical framework used in this study is presented in this chapter.

4.1 Product Development Process

The product development process is a methodological foundation in this thesis and provides a structured approach to the development of the proposed solution. The product development process is iterative, meaning that the method is not linear (Wikberg Nilsson et al., 2015). Phases such as planning, research, creation, and prototyping can be carried out multiple times and in different orders. The most important aspect of this process is to consider user needs, which is well aligned with an iterative approach where newly developed ideas are continuously tested with users to gather feedback.

The method may be perceived as abstract and unclear due to its iterative nature. The scope is broadened, narrowed, broadened, and narrowed again throughout the process. The product development process has a holistic perspective, as it is more process-oriented than solution-oriented. This allows alternative solutions to be explored and prevents promising ideas from being discarded too quickly (Wikberg Nilsson et al., 2015). It also enables users to be involved in the development of each solution and to evaluate whether it can be further developed into something useful.

4.2 Cognitive Ergonomics

Processing information is one of the most important functions of being a human (Salvendy, 2012). Humans need to take in information from their surroundings, process and transform it and then act based on the processed information. To understand the processing methods of humans, how they think and how they act are crucial for designing human-machine systems (Salvendy, 2012). This is, as described by Levitin (2002), called cognitive psychology, or cognitive ergonomics, which focuses on how humans process information and how the mind works. The understanding of cognitive ergonomics is important to be able to create an effective work environment for people by reducing, for example, stress, frustration, errors, and mental overload (Berlin & Adams, 2017).

Humans' mental capacity is limited and can be affected by factors such as age, personal abilities, and current well-being (Berlin & Adams, 2017). If a person is tired, stressed, or experiencing fatigue, their mental abilities will be lowered, and tasks with high mental loads could be difficult to complete. A design can therefore either help the person and ease the mental workload if designed correctly or increase the workload and frustration if designed poorly, which shows the importance of design for human wellbeing (Berlin & Adams, 2017).

4.3 Human Information Processing Model

When designing, it is essential to consider how humans perceive, process, and respond to information. Wickens' human information processing model, see Figure 13, explains how people move through stages of sensing, perceiving, interpreting, and responding to information when performing tasks (Wickens et al., 2022). The model highlights where cognitive limitations or bottlenecks can occur, which gives important guidance when designing, to ensure that interfaces and systems align with human capabilities, reduce overload, and support clearer perception and decision-making.

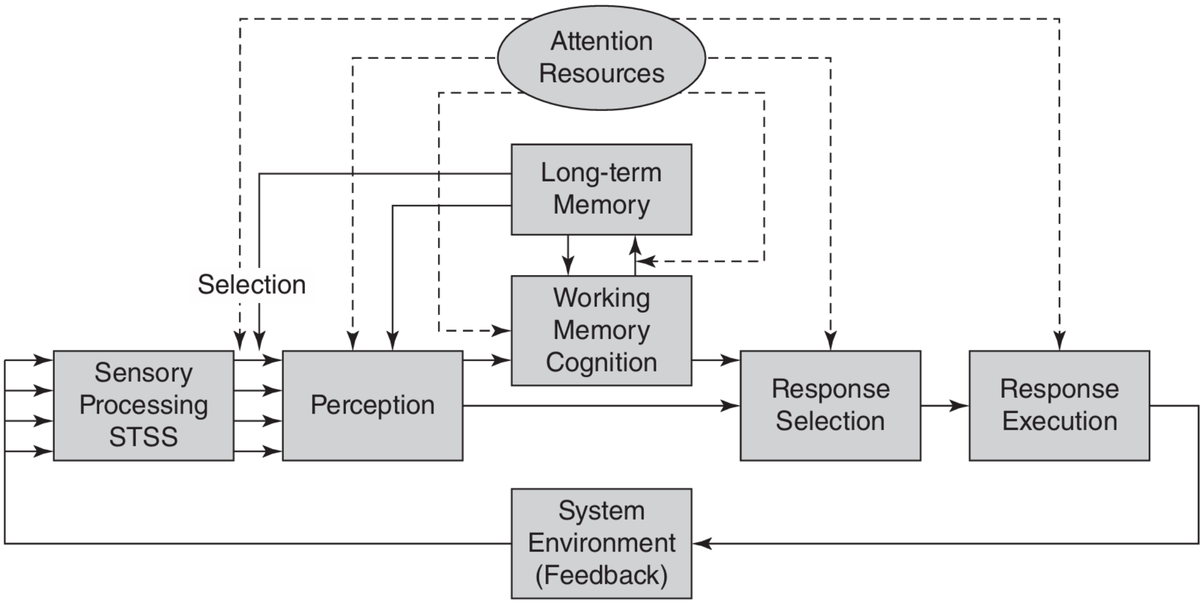


Figure 13. Wickens' human information processing model.

Note. Adapted from Engineering Psychology and Human Performance (5th ed.), by Wickens et al., 2022, Routledge.

4.4 Usability

Usability is defined as "... the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments" (ISO DIS 9241-11). Effectiveness refers to the extent to which the goal or task is achieved (Jordan, 2002). Efficiency refers to the amount of effort required to achieve the goal. Lastly, satisfaction refers to the level of comfort that users experience during the use of the product and how acceptable the product is for users to reach their goals.

Usability is not only important for consumer products, but also for products in professional and commercial contexts. Usability is important for lowering the risk of accidents. For example, a car stereo must be easy to use, otherwise, it may put lives at risk by distracting the driver's attention from the road (Jordan, 2002).

Usability is often used for interface functions, which refers to what an element of a product does to contribute to the interaction between the user and the product (Janhager, 2005). A product is successful when it is designed for the correct user target group. When working with usability, it is essential to look at details relevant to the targeted user, not the average user. Usability is not only important for safety or convenience; it has also been proven to reduce costs (Nielsen, 1994).

Usability is strongly connected to requirement engineering, which is used to set the necessary requirements for a product to suit the user well. These requirements are used to guide the designer (Sutcliffe, 2002). Requirement engineering has many definitions; however, they all share the idea that requirements involve identifying what the user wants from a computer system and how these needs are translated into design. The requirements should inform the designer about how to satisfy all stakeholders, but stay precise.

Requirements engineering must also address human errors, which includes detecting errors, understanding the consequences of errors, and helping users recover from them. Human errors can be categorized into three different levels (Sutcliffe, 2002). Firstly, the skill-based level, meaning that the problem has been solved earlier and the user applies a familiar procedure. Secondly, the rule-based level, meaning that the problem has occurred before and parts of the solution have been memorized as rules. To solve the problem, an appropriate rule is applied. Lastly, the knowledge-based level means that the user has little or no prior experience of solving the problem.

4.5 Jordan's Design Principles

There are ten design principles defined by Jordan (2002) that are used to design products to be usable and intuitive. These principles are presented in the following section.

Consistency means that similar actions should look and work alike, so users can apply what they already know and avoid mistakes.

Compatibility refers to designing systems that match users' expectations, shaped by their real-world experience, cultural norms, and other familiar interfaces.

Considerations of user resources implies that the design should minimize unnecessary physical and mental effort.

Feedback requires that the system provides clear, immediate and informative responses, so users understand what their actions led to.

Error prevention and recovery involve reducing the likelihood of mistakes and making it easy for users to recognize and fix them if they occur.

User control ensures that users feel in charge of the system and can start, stop, or reverse actions without restrictions.

Visual clarity means organizing the interface so that text, icons, and layouts are easy to read and navigate.

Prioritization ensures that the most important and frequently used functions and information are the most visible, while unnecessary elements are minimized.

Appropriate technology transfer means introducing new technology only when it clearly improves the user experience and presenting it in a way that feels natural and intuitive.

Explicitness ensures that the system clearly shows what is happening, what actions are possible, and what the consequences may be, reducing uncertainty and guesswork.

4.6 Physical Ergonomics

How well people can perform in different situations, for example, at work or when solving a task at home, is highly related to their physical health (Berlin & Adams, 2017). As soon as people start experiencing pain or discomfort, their performance is lowered. People will then start to perform either slower, with less accuracy or quality, or all of the three combined. The study regarding how different tasks affect the body from a physical perspective is called physical ergonomics, and it concerns, for example, how different tasks, loads, environmental factors, and movements affect the human body. By understanding physical ergonomics, how the body works, and what influences the workload, it is possible to create a good work environment with less injuries and strains on the body, leading to people staying healthier for longer (Berlin & Adams, 2017).

Human bodies are built to withstand different kinds of biomechanical loads; if exceeding the body limits, it can cause pain and injuries, which can be either temporary or permanent (Berlin & Adams, 2017). How the load influences the body depends on both the internal load, the work required within the body to maintain a position, the external load, outside factors, such as weights, and the time during which the load and body positions are held. It is not only physical load that can affect the body, but also the work environment (Berlin & Adams, 2017). If the temperature is too high or too low, or if the body is exposed to excessive noise or vibrations, human performance will be impaired. To consider both how the work environment and the physical load affect the human body is therefore of high importance when designing for humans, which makes physical ergonomics important to consider (Berlin & Adams, 2017).

4.7 Archetypes and Personas

When defining users and their characteristics, two commonly used methods are personas and archetypes (Yale University, n.d.). Archetypes and personas are similar; they are both used to describe a group of users; however, the difference between them is the presentation of the information (Yale University, n.d.). When using archetypes, information regarding the user behaviors and personal characteristics are presented and not biographical information, like the personas use.

Using personas, as mentioned by Pearl and Intriligator (2023), if not done correctly, can steer the entire design process in the wrong direction. When the persona is set, the designers focus on designing for that person, and if the persona does not represent the entire user group, the design might end up unsuccessful. According to Yale University (n.d.), archetypes are based on actual behavioral data from the users, compared to assumed prejudices of users like the personas use, which makes them more reliable and less affected by assumptions and prejudices.

When creating archetypes, it is common to include a nickname and a graphic to represent the user, a description about them, and an explanation of their behaviors, goals, and pain points (Yale University, n.d.). There are methods for categorizing people's way of thinking, which can explain their behaviors (Toolshero, n.d.). One of the ways to categorize users is with the eight thinking styles of Bonchek and Steele, where you combine focus and orientations to explain people's way of thinking and their behaviors. The eight categories are shown in Figure 14 and described in Table 2.

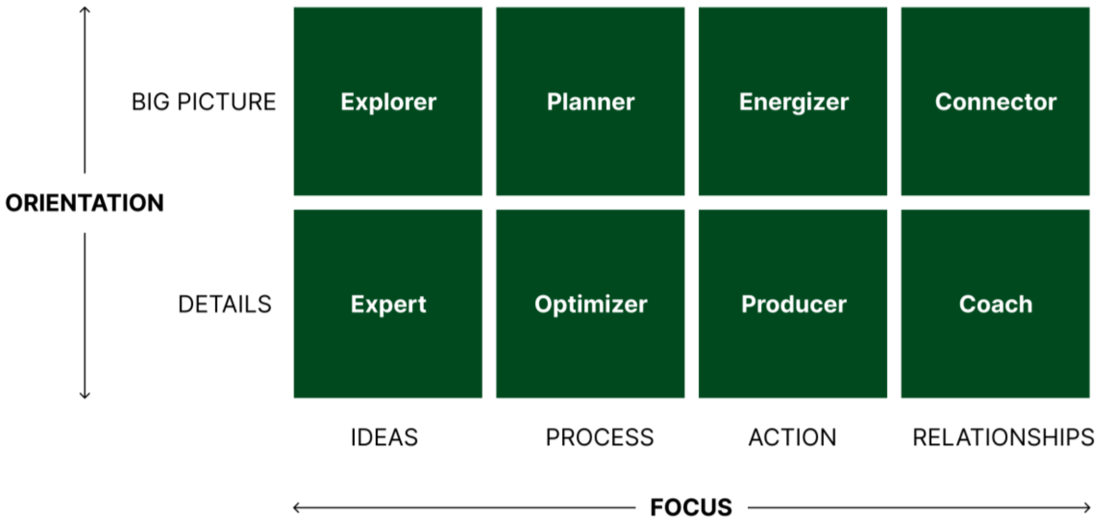


Figure 14. Overview and comparison of different behavior categories.

Table 2. Behavior categories and their descriptions.

Explorer	**Big Picture / Idea Oriented** The person creates new innovative ideas.
Planner	**Big Picture / Process Oriented** The person aims to create productive systems.
Energizer	**Big Picture / Action Oriented** The person engages people and promotes action and seamless teamwork.
Connector	**Big Picture / Relationship Oriented** The person forms strong connections and relationships within the team.
Expert	**Detail / Idea Oriented** The person is fact-based and seeks to gain new knowledge.
Optimizer	**Detail / Process Oriented** The person aims to improve performance and effectiveness.
Producer	**Detail / Action Oriented** The person is goal-driven and focused on completing tasks.
Coach	**Detail / Relationship Oriented** The person builds strong relationships with others and is a social butterfly.

5. Methodology

Many methods were used to conduct this project. These methods supported the work in data collection, data analysis, concept development, user evaluation, and generating the final design. The general procedure and the methods used will be described in this chapter.

5.1 General Procedure

The project consisted of two iterative loops followed by the finalization of the concept, aligning with the previously described product development process in Section 4.1. In Figure 15, the overall procedure is presented. The first phase, data collection, was divided into theoretical and empirical studies. The purpose of the theoretical studies was to gain insights into the forestry segment and to understand the technological maturity of the market. The empirical studies, on the other hand, aimed to gather insights about the users and their workflows.

The second phase, data analysis, focused on analyzing the collected data in a structured manner to identify relevant focus areas and problem aspects. By determining these areas, the project could be narrowed down and the scope redefined. The third phase, concept development, aimed to generate and visualize ideas that could address the identified problems within the focus area. Several methods were used to stimulate creativity, produce ideas and visualize them. The user evaluation phase aimed to gather feedback on the developed concepts in order to assess their usefulness, eliminate weaker solutions, and finalize the most promising one.

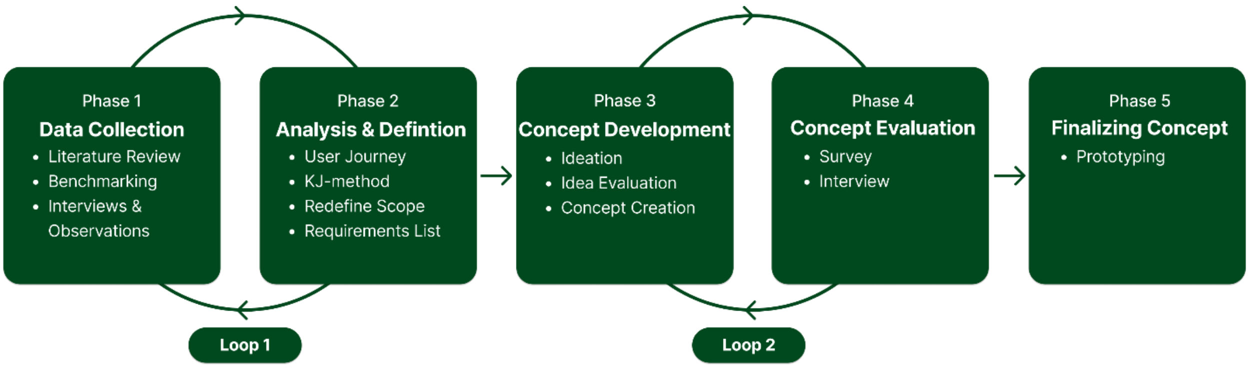


Figure 15. Figure of the process.

5.2 Data Collection

The project began with a data collection phase, the first phase, to gain insights into the selected topic. During this phase, literature reviews, benchmarking, interviews, and observations were used to collect relevant data. The methods used for data collection will be explained further in this section.

5.2.1 Literature Review

To develop an understanding of the forestry industry, a literature review was conducted to gain insight into the topic and to establish a foundation of existing knowledge (Purdue University Writing Lab, n.d.; Bligård, 2015). The conducted literature review covered topics such as forest industry, forestry processes, and forestry machinery. The literature study was essential for creating interview and observation templates, as it provided the theoretical foundation needed to formulate precise and exploratory questions.

5.2.2 Benchmarking

A benchmarking study was carried out to analyze existing forestry companies and the types of machines and technological solutions they offer. Benchmarking is a valuable method for understanding the existing market and available products (Aela School, 2022). The study provided insights into the current state of product development and the technological maturity within the industry. It also enabled an understanding of the differences between major manufacturers and the factors influencing customers' choice of brand and machine type. The benchmarking primarily focused on established brands such as John Deere, Komatsu, Ponsse, Eco Log and Rottne.

5.2.3 User Studies

User studies were conducted using two primary methods: interviews and observations, aiming to gather user insights from operators within the forestry sector. Interviews are a commonly used method for understanding how users think, reason, and act (Bligård, 2015). Interviews can be structured, semi-structured, or unstructured. Structured interviews follow a fixed set of predefined questions, semi-structured interviews combine prepared questions with flexibility for follow-up discussion, and unstructured interviews are more open-ended, allowing the conversation to develop freely. In this study, semi-structured interviews were conducted using a predefined interview guide, see Appendix A, while allowing flexibility for open discussion. The interviews provided valuable insights into forestry as a working context, as well as the operators' needs and differences in work experience.

Conducting interviews in the operators' natural work environment while they were operating the machine proved valuable, as it allowed them to speak more comfortably and refer to elements in their immediate context (Sutcliffe, 2002). Additionally, focus groups were conducted to stimulate discussions between different operators. These group dynamics encouraged more natural conversations and enabled participants to build on each other's experiences. Table 3 presents an overview of all interviews and focus groups carried out during the study.

Table 3. Overview of interviewing methods, duration, and context.

Participant	**Method**	**Duration**	**Context**	**Notes**
User 1	Semi-structured Interview	1 h	On-site	Interview reviewed using video recording.
User 2	Semi-structured Interview	1 h	On-site	Interview reviewed using video recording.
User 3	Semi-structured Interview	1.5 h	On-site	
User 4	Focus Group	0.5 h	On-site	
User 5	Focus Group	0.5 h	On-site	
User 6	Semi-structured Interview	0.5 h	Phone	
User 7	Focus Group	1.5 h	Forestry School Setting	Simulator Room
User 8	Focus Group	1.5 h	Forestry School Setting	Simulator Room
User 9	Semi-structured Interview	1.5 h	On-site	
User 10	Semi-structured Interview	1 h	On-site	

The participants included both expert and novice operators with diverse backgrounds, see Table 4. Including users with varying levels of experience enabled the study to capture a broader perspective on the topic and to identify differences between novice and expert operators. The students participating in the study had no formal professional experience.

However, they had completed practical training as part of their education, including internships. As a result, they were familiar with operating forestry machines and possessed foundational knowledge of forestry, although not to the same extent as the expert operators.

Table 4. Overview of participants' occupations, experience, and background.

Participant	**Occupation**	**Machine**	**Experience (yrs)**	**Education (yrs)**	**Age (yrs)**	**Gender**
User 1	Operator	Forwarder	20	0	45	Male
User 2	Company Owner and Operator	Harvester	30	0	50	Male
User 3	Company Owner and Operator	Forwarder	30	0	50	Male
User 4	Company Owner and Operator	Harvester	10	0	30	Male
User 5	Company Owner and Operator	Harvester	30	3	50	Male
User 6	Novice Operator	Harvester	0.5	3	20	Female
User 7	Student, Forestry	Forwarder & Harvester	0	2.5	19	Male
User 8	Teacher	Forwarder & Harvester	20	3	53	Male
User 9	Student, Forestry	Forwarder & Harvester	0	2.5	19	Male
User 10	Student, Forestry	Forwarder & Harvester	0	2.5	18	Male

Note. Students marked with "0" have no formal work experience but have completed practical training and an internship as part of their education.

During the on-site interviews, observations were carried out simultaneously while the operator was maneuvering the machine. Observation is a relevant method for capturing physical and spatial behavior and for developing an understanding of the user's situation (Sutcliffe, 2002; Bligård, 2015). The observations included how the operator was sitting, moving their body, maneuvering the machine, looking around, and handling different trees.

The observations were recorded with a 360-degree camera, which made it possible to review the videos and mark important moments. Observations helped spot the differences between what the users say and what they do. They also helped spot the tacit knowledge of the operators.

Observations of User 1 and User 2 were conducted indirectly through video recordings captured by colleagues at Volvo Penta, as the authors were not present during the observation sessions. The recordings were not obtained using a 360-degree camera, which limited the ability to fully perceive the cockpit environment. However, the observations were complemented using eye-tracking glasses, enabling analysis of where the operators directed their visual attention during operation.

5.3 Data Analysis

Once the data collection methods had been finalized, the collected data was analyzed in the second phase of the project using several analysis methods. This section describes the selected methods and explains their purpose and relevance to the study.

5.3.1 User Journey

A user journey is a visualization that provides a holistic view of the actions a user takes to achieve a specific goal (Gibbons, 2018). The visualization presents these actions along a clear timeline, making it an effective tool for identifying a workflow that aligns well with the user's mental model. Additionally, a user journey supports the identification of pain points at each stage of the workflow, enabling a structured understanding of where challenges occur. The user journey was used to gain an overview of the harvester operators' workflow, identify critical moments within it, and highlight potential areas for improvement.

5.3.2 KJ-method

A KJ-method is a method that is used to understand user data and to help with setting the hypothesis of a project, rather than confirming an existing one (Kawakita, n.d.). The start of the method includes writing down the findings from the user studies on notes and, based on their content, sorting them into categories. When the notes are in categories, the next step is to name the categories based on the common theme. The strength of the method is that it can help with organizing inputs from user studies and turning them into concrete areas, which are otherwise difficult to define (Kawakita, n.d.). The KJ-method was useful to help structure the information from the user studies, find common themes, and problem areas where improvement was needed.

The data from the data collection were added into a FigJam in Figma, which is a digital platform allowing easy workflow collaboration. The data that was added to Figma was the selected highlights from the transcriptions of the interviews and observations. After the notes had been added to Figma, they were sorted and re-sorted several times into different categories. When the final categories were made, they were named, and unnecessary information was removed. From the final categories in Figma, the focus areas of this project were selected.

5.3.3 Requirements List

As described by Bligård (2015), setting requirements are necessary to define what needs to be included in the solution for it to fulfil the demands of the operators in the system. The first step in creating a requirements list is to identify the user's needs based on user studies. Once the needs are identified, they are formulated into requirements and preferences, depending on their importance to the solution and put into an organized list. The requirements list was used as a guiding tool for the future design and what the design need to fulfill to be considered successful.

The user needs were identified in this project from the results of the KJ-method and then formulated into requirements and preferences based on six different categories. The requirements and preferences were compiled into a list and the preferences were graded based on importance to the user on a scale of 1 to 5, where 5 is the most important to fulfil, and 1 is the least important.

5.4 Concept Development

To generate ideas for potential solutions addressing the research focus, a concept development phase was conducted as the third phase of the project. This phase included ideation, idea evaluation, and concept creation, and was carried out through multiple sessions using a variety of methods.

5.4.1 Ideation

During the initial phase of concept development, an ideation phase was conducted consisting of three sessions, see Table 5. The participants for the ideation sessions were selected based on their different perspectives on the subject. Their different perspectives were used to gain a wider range of ideas and perspectives on the topic.

Table 5. Overview of the three ideation sessions conducted.

Number of Participants	Participant Background	Duration
2	Industrial Design Engineering	2 h
4	Mechanical Engineering	1.5 h
4	UX-design	1 h

To generate ideas during the sessions, methods such as braindraining, brainwriting, crazy eights, and braindrawing were used, this to increase creativity during the sessions. These methods are described in more detail later. Once multiple ideas had been generated, they were sorted into categories based on similarities and subsequently combined using idea-combination matrices, similar to morphological matrices, to increase both the number and diversity of ideas. These matrices facilitated the development of new ideas and more refined concepts.

Braindraining is a method, as described by Wikberg Nilsson et al. (2015), used to spark creativity and to unblock the flow of ideas. Braindraining was used to start all ideation sessions to help the participants with their creative thinking and to start the creative process in their brain. The participants were asked to draw a combination of two random animals to decrease critical thinking and increase the flow of creativity.

Brainwriting is, as described by Wikberg Nilsson et al. (2015), a method used to generate many elaborate ideas and let people explore their own ideas on equal terms. The method enables people's input to be considered equally, since every idea is written down, and not only voiced. There are different ways of performing brainwriting, and in this case, the participants were asked to write down their ideas on paper during the set time of three minutes, and the papers were then passed on to the next participant to build upon, develop, or refine the existing ideas. The session stopped when the papers had been passed around to all participants. Brainwriting was used to allow all participants to express their ideas without being limited by sketching abilities.

Braindrawing is a method similar to brainwriting. Braindrawing uses sketches to communicate ideas, and the different papers with ideas are passed around the participants of the session (Wikberg Nilsson et al., 2015). In this project, the participants were given two minutes to sketch one idea on a specific theme related to the focus area, and then the paper was passed on to the next participant, who had two minutes to improve it. This was repeated until the papers had been passed around to all participants. This method was used to let the participants be creative without limitations of words.

Crazy Eights is a method where the participants are given eight minutes to produce eight ideas (Jones et al., 2021). The paper is divided into eight squares, and the participants have one minute to come up with one idea for each square. When the eight minutes are up, the participants show and explain their ideas to the rest of the participants taking part in the session. This method was used during all ideation sessions to come up with many different ideas in a short period of time.

Idea-combination matrices were used to combine several ideas into many different ideas and concepts. The idea-combination matrices were inspired by morphological matrices. Morphological matrices are used to combine several features into many different ideas and are a quick way of generating a variety of ideas (Wikberg Nilsson et al., 2015). In a morphological matrix, you make a list of functions that need to be fulfilled, and then different solutions that would fulfil them by creating all possible combinations.

In the idea-combination matrices, the same principles as morphological matrices were used.. However, not all possible combinations of features were made, and multiple features from the same row could be selected. The chosen features in the matrices were then combined into different concepts. This method was used to generate ideas around four themes, and four matrices were created. The solutions from each matrix were then combined into concepts. This method was used since it allows many new combinations of ideas that might not have been considered before.

5.4.2 Idea Evaluation

Once a set of ideas had been generated, two methods were applied to reflect on and evaluate them: the six thinking hats method and a feasibility–value matrix. These methods enabled comparison between ideas and helped identify their respective strengths and weaknesses, as well as opportunities for further improvement.

Six thinking hats is a method that can be used to gain insights into ideas by discussing them from different perspectives (Wikberg Nilsson et al., 2015). In the method, six different hats with different perspectives, are either divided among the participants or used one at a time by all participants. The six hats' perspectives are facts, benefits, feelings, creativity, analysis and caution. This method was used to evaluate the ideas from the crazy eights ideation method. The participants were divided into two teams of two, where one team had the benefits hat and one team the caution hat, to gain both the positive aspects of the ideas and the negative ones.

A feasibility–value matrix was used to evaluate and compare the different ideas in relation to the collected user data and findings from the literature review. The ideas were placed inside a matrix with one of the axes representing the value for the operator and the other one with the feasibility of implementing and realizing the idea, see Figure 16. From the matrix, the most promising ideas were selected, which were the ones with both high value for the operator and high feasibility. The matrix was used to help compare the ideas and find the ones that would benefit the operators the most.

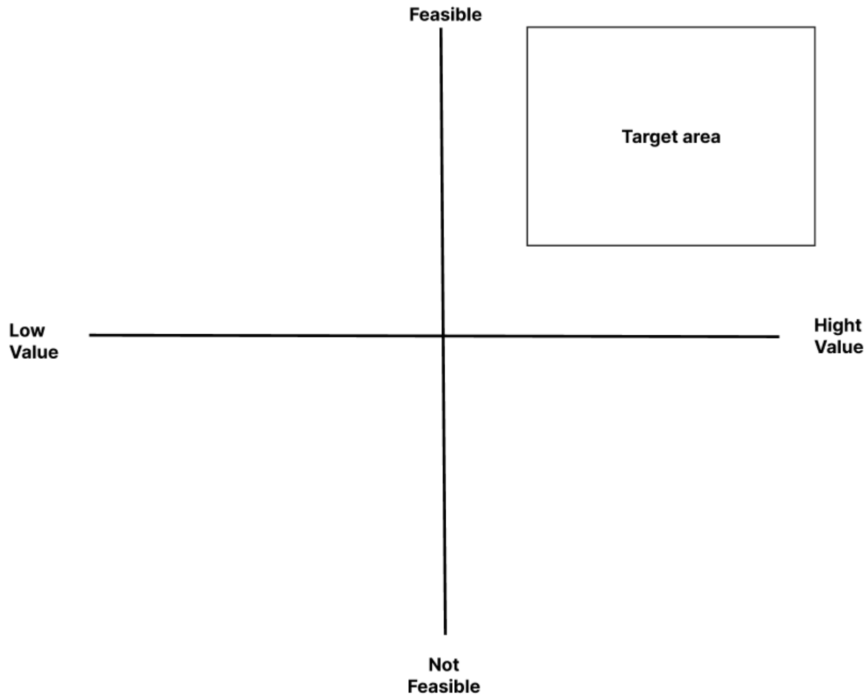


Figure 16. Feasibility–value matrix.

5.4.3 Concept Creation

Finally, the ideas were turned into concepts and visualized with the help of prototypes. When visualizing the concepts, prototyping was used. Prototyping is, according to Wikberg Nilsson et al. (2015), a method used to explore the design further and guide it towards a final design. Prototyping can be done in many ways, for example, physical, digital, or with sketches, and is often used to test the design's features and how it interacts with humans. In this project, prototyping was used to realize the concepts and make them more understandable for the users. The developed concepts were prototyped digitally, as the solution primarily takes the form of an interface, and were placed in their real context. Placing the designed interfaces in a real context was done to make them more realistic for the users and easier to understand.

5.5 User Evaluation

After the concepts had been created, concept evaluations were performed to gain insight into the strengths and weaknesses of each concept. The concept evaluations were performed in multiple steps, including interviews and surveys, which will be described further in this section.

5.5.1 Evaluation Interview

To gather qualitative feedback on the concepts, three rounds of evaluation interviews were conducted: two with novice users and one with an expert, see Table 6. The first round focused on the initial concepts, the second on the refined concepts, and the third on the final concept. The interview templates used in rounds one and two are presented in Appendix B. These evaluations were structured around five Likert-scale questions per concept, measuring respondents' levels of agreement with each statement. This approach provided quantitative input while also allowing participants to elaborate on their responses, thereby capturing qualitative insights. The final evaluation round differed by involving a digital dynamic prototype, presented to participants along with three neutral questions: "Did you understand it?", "What do you think about it?", and "Is there anything that could be improved?".

The novice participants received the interview handout in advance, as the interviews were held over telephone. The handout gave them the opportunity to read through the concepts beforehand and discuss their initial thoughts with others. This preparation resulted in rich feedback, as the participants had already reflected on the material prior to the interview.

The expert interview was conducted online, during which the concepts were presented verbally and visually as the expert rated them. Although the expert had less time for prior reflection, the interview still generated highly valuable insights.

Table 6. Overview of the participants for the user evaluation interviews.

Participant	Method	Duration	Context	Notes
First Round of Interviews				
User 6	Semi-structured Interview	0.5 h	Phone	Received a digital handout prior to the meeting.
User 7	Semi-structured Interview	0.5 h	Phone	Received a digital handout prior to the meeting.
User 8	Semi-structured Interview	1 h	Online Meeting	The concepts were presented digitally.
Second Round of Interviews				
User 6	Semi-structured Interview	0.5 h	Phone	Received a digital handout prior to the meeting.
User 7	Semi-structured Interview	0.5 h	Phone	Received a digital handout prior to the meeting.
User 8	Semi-structured Interview	0.5 h	Online Meeting	The concepts were viewed digitally.
Third Round of Interviews				
User 6	Semi-structured Interview	0.2 h	Phone	Received a digital handout prior to the meeting.
User 7	Semi-structured Interview	0.2 h	Phone	Received a digital handout prior to the meeting.
User 8	Semi-structured Interview	0.2 h	Online Meeting	The concepts were presented digitally.

5.5.2 Evaluation Survey

To gather quantitative feedback on the first created concepts, a survey was conducted, see Appendix C. The survey was distributed separately to experts and novices to gain insights from both the experts' and the novices' perspectives on the concepts. The survey asked questions regarding the different concepts, their user value, and how the concepts compared against each other.

The survey for experts was only posted on the website Skogsforum.se, which, according to Skogsforum Media AB (n.d.), is a platform for discussion and news regarding forestry. Posting the survey on Skogsforum.se was done to reach new expert operators who had not been contacted before. The survey received nine responses from expert users with varying levels of experience.

The novice survey was distributed at Naturbruksskolan in Svenljunga among their students. Distributing the survey at the school helped with gaining input from novices and their perspectives on the concepts. The novice survey received nine responses from students in different years at the upper secondary school. The surveys were used as a complement to the conducted interviews to further validate the given feedback.

5.6 Finalizing Concept

Based on the evaluation interviews and survey, user input formed the foundation for the final concept. The concept was developed in Figma using multiple frames to illustrate the interface across different situations. A digital dynamic prototype was subsequently created in Figma to further visualize the concept.

6. Results

The results gained from the different phases of the project will be presented in this chapter. The results have been divided into data collection and analysis, ideation, concept development, concept evaluation and final design.

6.1 Data Collection and Analysis

At the beginning of the project, data collection and analysis were carried out. The results from the data collection and the analysis will be presented in this section. The results are divided into the following areas: user journey, work culture, difference between experts and novices, redefined scope, and user requirements.

6.1.1 Harvester Operators

To design a solution that is beneficial for harvester operators, their workflow and work culture were analyzed in order to gain insights into how they work and what motivates them. This subsection presents the results related to harvester operators' workflow and work culture, structured into the user journey and work culture.

User Journey

Based on the real-life observations, a user journey was created to map the steps in the operator's workflow, see Figure 17. In Appendix D, pain points are presented for each step of the user journey.

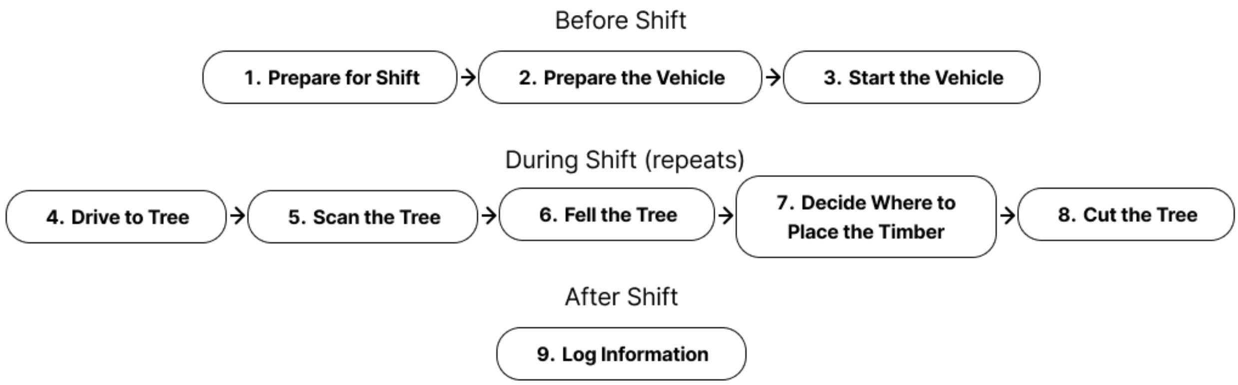


Figure 17. User Journey of harvester operator.

1. Prepare for Shift
   The operator communicates with the landowner regarding what and where to harvest, checks the weather conditions, assesses the terrain, and plans an appropriate route.

2. Prepare the Vehicle
   The operator adjusts the seat and configures the joysticks and the cutting head when operating a different machine for the day.

3. Start the Vehicle
   The operator starts the machine while simultaneously scanning the terrain, planning where to drive, and deciding which tree to cut next.

4. Drive to Tree
   The operator considers where to position the machine to ensure optimal stability during felling. This assessment is based on ground conditions, slope steepness, and the tree's weight distribution.

5. Scan the Tree
   The operator scans the tree to determine species, size, and weight distribution. The operator also looks for abnormalities such as crooked form, signs of rot, double crowns, and buttress roots.

6. Fell the Tree
   During felling, the operator monitors how the saw is cutting, controls the fall direction, and checks for internal rot.

7. Decide Where to Place the Timber
   After, or simultaneously with, felling the tree, the operator determines where the timber and branches should be placed.

8. Cut the Tree
   The operator checks the diameter, length, and suggested bucking measurements on the screen. If the tree is in normal condition, the bucking system performs the cuts. If the tree is rotten, the operator must determine the appropriate cutting lengths and ensure that all rot is removed. The different timber assortments are then placed in separate piles.

9. Log Information
   At the end of each shift, the operator logs the harvested volume or time worked, depending on the type of contract they have.

Work Culture

From the conducted interviews and observations, it became clear that there is a specific work culture within forestry that is highly valued and respected among operators. The work culture within forestry impacts the operators' behaviors, decision-making, and mindset, which makes it important to understand.

During the conducted observations, focus groups, and interviews, nearly all participating operators highlighted the importance of enjoying the forest in order to perform well as a forestry operator. They explained that being comfortable with spending extended periods alone in the forest is a key aspect of succeeding in the role. In addition, operators emphasized the need for inner motivation, both to care for the forest and to continually challenge oneself to improve professional performance. Most participants mentioned that they tend to compete with themselves on a daily basis to maintain motivation. However, they also mentioned that competition and efficiency should never compromise what is considered best for the forest.

Working within forestry is often something that is passed on within families, which became clear when talking to the operators. All operators that were interviewed and observed, expect one, had previous family connections to the occupation. Since the occupation is often passed on within the family, the operators have a lot of previous knowledge and experience even before they enter school and start driving the machines. People without this previous knowledge from their families might therefore have a hard time catching up, as one user mentioned: “Since I have zero background within forestry, I was far behind my classmates when I started school.”

Because of the family traditions of occupation, people tend to know other people working in the forestry industry. It became clear during the interviews that an operator's reputation is very important for being hired to do jobs, which also motivates them to perform well. To be able to perform well, the operator needs to work both efficiently and thoroughly, which often results in long working hours. The freedom regarding how to spend their hours and how to plan their own work is highly appreciated among the operators.

Archetypes were used to categorize the interviewed and observed operators' personalities. The operators were categories into eight categories based on the eight thinking styles of Bonchek and Steele (Toolshero, n.d.), see Figure 18, where each line represents one user. The interviewed operators could be categorized into most categories; however, nearly half were classified as optimizers. Having many operators with the treats of the optimizer, shows that the users tend to be focused on details and efficiency with a strive to improve their work process.

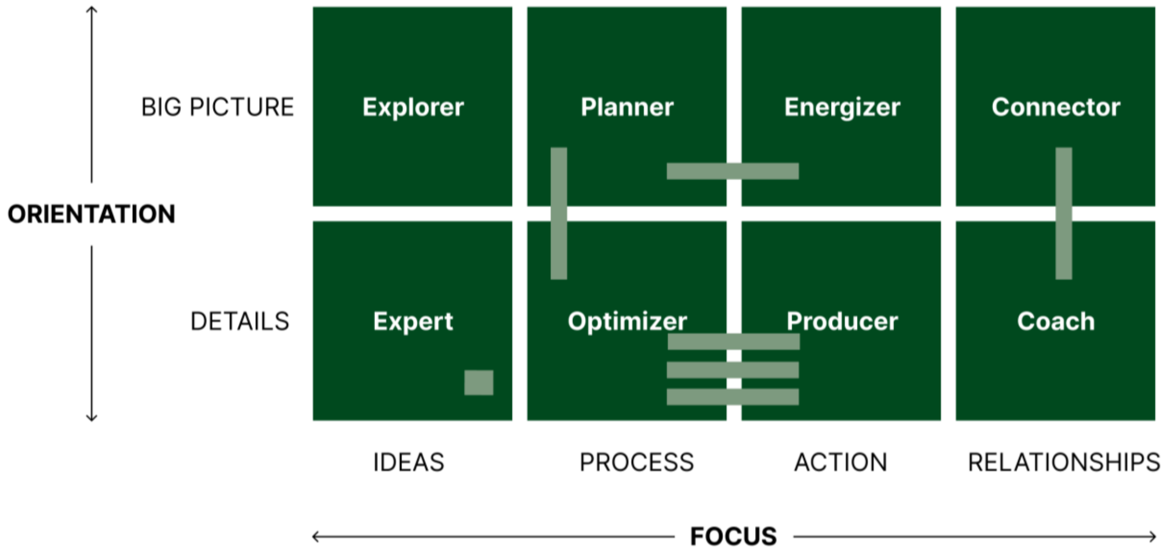


Figure 18. Illustrates the categorization of users into archetypes.

Key Findings:

During steps four to six in the user journey: drive to, scan and fell the tree, harvester operators experience a high cognitive load, as they must simultaneously scan the ground, the trees, decide where to position the machine, and determine where to place the cut logs. This illustrates that harvester operators have several complex tasks that require high cognitive effort. Consequently, the learning period is long, and operators are required to multitask effectively.

Furthermore, harvester operators are expected to work efficiently and productively, and many are motivated by competing with themselves as well as with other operators. Operators also expressed a strong appreciation for working in the forest, which they view as more than just a work environment. These insights indicate that operators strive to optimize their work not only for performance and competition, but also for the benefit of the forest. They aim to be as effective as possible while still maintaining the experience of working in a natural forest environment.

6.1.2 Differences between Experts and Novices

To design a solution which reduces the differences between experts and novices, the understanding of what differentiates them is crucial. During the user studies and the KJ-method, some key insights regarding their differences were detected, which especially can be found in the areas of knowledge, route planning, sorting logs, terrain driving, weather conditions, unforeseen situations, abnormal trees and rotten trees.

Knowledge

One of the main differences between novices and experts that was found during user studies was the knowledge gap. The expert operators did a lot of their work based on “feeling”; which proves that they have a lot of tacit knowledge that they cannot explain. They just knew that one tree, for example, was rotten based on a feeling in the joysticks or that the measurement was wrong in the machine when looking at the cut timber. As one of the expert operators mentioned during an interview, it is the trained eye that makes one good at their job.

The experts are in possession of more knowledge and can, with the help of their senses, detect things that the novice operator often misses. Some examples of this can be that they can more easily spot abnormalities in trees with the help of their sight, they hear that something is wrong with the machine based on a small noise it makes, or they feel that something is wrong with the tree based on the haptic feeling in the joysticks when cutting. Since the novice operators cannot spot these things to the same degree as the experts, it results in mistakes and that things are missed or handled wrong.

Today, the main method to gain knowledge for novices is to learn by doing. To get better, they need to drive more, which takes time and costs money for their employers. Many of the novices also learn a lot by asking questions to more experienced operators. They tend to spend a lot of time in phone calls with other harvester operators, and if they are wondering about something or need advice, they ask the more experienced driver.

Route Planning

Another aspect that emerged during the interviews as distinguishing novice operators from experts was their ability to plan routes. Route planning was highlighted by both novice and expert operators as a central part of the work. Participants from both groups described route planning as particularly challenging due to the numerous factors that must be considered, such as machine placement, ground conditions, and weather conditions.

It became clear during the interviews, but especially during the observations, that the more experienced drivers were better at planning the routes. When observing the novice operators, they had to adjust their routes multiple times due to a lack of experience and poor driving, which led to less efficiency. One common mistake that the novices made was that they placed the machine poorly in relation to where the tree they were cutting was, either where the tree would fall or with the tree out of reach for the machine, which were mistakes none of the observed experts made.

Sorting Logs

Another observed difference between experts and novices was sorting logs. When sorting the cut logs, they must be placed into different piles based on tree species, diameter, and whether the tree is classified as normal or abnormal. These decisions require cognitive effort and are particularly challenging for novice operators.

Operators also follow specific strategies when arranging logs into separate piles. The piles must be clearly distinguishable so that the forwarder operator can easily identify which assortment each pile contains. In addition, the piles need to be arranged in a way that allows logs to be collected without disturbing other piles. Another commonly observed challenge is creating well-structured piles. The logs should be aligned in a uniform direction and positioned so they cannot easily be displaced by the forwarder. Novice operators struggles with this task, as they lack the experience that expert operators have in constructing stable and well-organized piles.

Terrain Driving

It is not only route-planning skills that separate expert and novice harvester operators, but also their proficiency in terrain driving. As mentioned, most new harvester operators today are trained using simulators in combination with real-world forest driving. However, the simulators currently in use, differ significantly from real-life operation, particularly when it comes to driving in terrain. Both novice and expert operators explained during the interviews that nothing can fully compare to real-life experience when learning how to operate a harvester. According to the interviews, simulators serve as a good starting point for learning crane handling and understanding the work process, but are lacking in regards of driving in real terrain.

The lack of knowledge among novice operators regarding terrain driving is another factor that differentiates them from expert operators. In real-life conditions, there are a lot of factors that influence driving, for example, balance, the slope of the ground, tree felling directions, rocks and ancient monuments, which cannot be practiced in the simulators. There are also no real consequences in the simulators, which, as one of the novices mentioned, makes them take simulator driving less seriously.

Weather Conditions

Knowledge of how different weather conditions affect operating the harvester are another aspect that, during user studies, became clear separates novices from experts. There are multiple weather conditions, such as wind, rain, sun, snow and outside temperature, that affect operating a harvester, which are not available to practice in the simulators and needs to be taught through real life driving practice. This results in a big gap between novices' and experts' knowledge regarding handling the machine in different weather conditions.

Wind can affect the balance of the cutting head and crane, which for an inexperienced driver might be very dangerous if not handled correctly. Snow, rain and sun all affect the operators' sight and might make it hard to, for example, separate different kinds of timber for the novice driver, whereas the experienced operator has dealt with it before and therefore can handle it. During one of the observations, there was a lot of snow on the ground, which made it hard to locate the cut timber. The experienced driver had no issue locating the timber, even if it was covered in snow, whereas the novices could struggle and accidentally drive on the timber or place the logs in the wrong piles.

Unforeseen Situations

From the interviews and observations conducted in the forest, it became clear that a wide range of unforeseen situations occur on a daily basis. These situations can include anything from mechanical breakdowns to the discovery of endangered species, which could make continued work in that area illegal. Handling unforeseen situations is something that the experts are much better at compared to the novices. One of the experts stated, “Driving often goes pretty fast, but it is the mystical errors that can occur that take time, because you must figure out how to solve them.“ which shows that the “mystical errors” take time for experts to solve, which makes it even more difficult for the novices to handle.

Abnormal Trees

There are not only unforeseen situations in the machine that can happen that affect operators, but also unforeseen abnormalities in trees. Many trees are imperfect, and abnormalities such as rot, crookedness, buttress roots and double crowns are common and affect the way the operator cuts the tree. From the observations and interviews, it became clear that abnormal trees are common and that they can be hard to detect and handle.

Detecting abnormal trees was described as difficult by most experts and even more so for novices. During the observations, it could be noted that the novices did not detect all abnormal trees, which cause errors later in multiple stages of the supply chain. It is not only the detection that separates the novices from the experts, but also the handling of abnormal trees. Handling abnormal trees must be performed manually and requires a high level of skill, which is primarily developed through experience. This further distinguishes expert operators from novice operators.

Rotten Trees

One of the most common tree abnormalities described in the interviews is rot. Detecting rot, as explained by one of the experts, can be difficult since it is not visible until the tree is cut.

When harvesting healthy trees, operators typically rely on automated bucking systems that support the cutting of logs into optimal lengths, either to maximize value or to meet specified log requirements (Dasa Control Systems, n.d.). However, the system is not applicable when harvesting rotten trees, as it lacks the capability to detect rot and assess its extent within the tree.

The operator is therefore required to assess whether the tree is affected by rot, determine appropriate cutting points, and estimate the extent of the rot. This often involves a trade-off: cutting the log too long may result in unnecessary material loss, while insufficient cuts may require additional cuts if rot remains. Some experts mentioned that they can sometimes detect rot through haptic feedback in the joysticks or by observing the sawdust.

Despite such strategies, assessing rot remains a challenging task, particularly for less experienced operators. While expert operators have developed individual methods for rot detection over time, novice operators lack the experience required to establish such strategies.

As a result, handling rotten trees places considerable cognitive demands on operators and is time-consuming, particularly for novice operators, who must simultaneously assess rot and make precise cutting decisions. When uncertainty arises, operators frequently seek guidance from more experienced colleagues or turn to online communities, such as Skogsforum.se, to obtain advice and share knowledge (Skogsforum, n.d.).

Key Findings:

There is a knowledge gap between expert and novice operators, as much of the required knowledge is tacit, meaning that many skills are best learned through hands-on experience. This highlights the significant differences in competence and explains the reduced efficiency observed among novice operators due to their limited knowledge and experience.

Route planning and terrain driving are particularly challenging for novices, as every forest differs in structure and conditions, and weather varies over time. The complexity of real forest and weather conditions is rarely captured by simulator environments, in which novices are partly trained. There are many uncontrollable factors that novice operators must learn to manage, and these can only be fully understood through real-world experience. The lack of such experience strongly contributes to the knowledge gap between novices and experts.

Abnormal trees occur frequently, with rot being one of the most difficult defects to detect, especially for novice operators. This indicates that a tool designed to support rot detection could improve operational efficiency and has the potential to reduce the knowledge gap between expert and novice operators.

6.1.3 Redefined Scope

From the collected and analyzed data, it became clear that there were some areas that were more difficult for the harvester operators to navigate, and where the differences in skills between experts and novices were substantial. One of these areas was the detection and handling of abnormal trees, where there were very few, to no tools to help the operator deal with the abnormalities. The difficulty of detecting and handling abnormal trees in combination with the knowledge gap between experts and novices resulted in a refinement of the scope. When further literature research in combination with the user studies confirmed rot as one of the most common and hardest abnormalities to detect, the project's scope shifted. The focus of the project was now placed on detection and handling of rot for harvesters within forestry, with emphasis on reducing the gap between novice and expert harvester operators.

6.1.4 Requirements List

Based on the user studies, a list of user requirements was developed. These requirements reflect the user needs identified through the studies. The requirements are formulated to be quantifiable, and most of them can be evaluated through user testing.

In addition to the requirements, the list includes a number of user preferences. These preferences capture user-expressed wishes but are not considered essential for ensuring usability. Each preference was rated on a five-point scale (from one to five) based on its perceived relevance to the users. To illustrate, preference 1.3, “The solution should be possible to integrate into simulators,” received a rating of 2 out of 5, see Table 7. This rating reflects that simulator integration could be beneficial, as students partially conduct their training in such environments. However, current simulator training primarily focuses on machine handling and operational techniques, rather than rot detection. As rot detection is not presently practiced in simulators, the preference was considered relevant to a limited extent but not of high priority.

The requirements and preferences are organized into six categories: Learning, Performance, Personalization & Features, Cognitive Ergonomics, Physical Ergonomics, and Machine Compatibility.

Table 7 presents one representative requirement or preference from each category to illustrate the structure and formulation of the requirement set. The complete list of requirements and preferences is provided in Appendix E.

Table 7. Shortened requirements list illustrating the structure of the requirements list.

Criteria's	**Requirement or Preference**	**Grading 1-5**	**Description**
1. Learning (Ease of use, Onboarding, Acceptance, Workflow fit)			
1.3 It should be possible to integrate the solution into simulators.	P	2	The solution can be used and learned in the simulators before the novice starts working in the forest.
2. Performance (Operational results, Efficiency, Precision)			
2.1 The solution should reduce detection errors of rot with 75%.	R		The solution should help with detecting rot, reducing the errors that might occur.
3. Personalization & Features (Customization, User control, Balance between automatic, manual work)			
3.1 Users shall be able to activate, deactivate, or modify automated features manually within 5 seconds from the control interface during usability testing.	R		The user can make manual decisions and actions on automatic features.
4. Cognitive Ergonomics (Attention, Mental load, Usability while multitasking)			
4.1 The solution should not hinder visibility through the window.	R		The solution should be placed or used in such a way that it does not obstruct the view.
5. Physical Ergonomics (Comfort, Safety, Inclusiveness)			
5.1 At least 90 % of test users shall report equal or better physical comfort compared to today's working process.	R		The solution should not worsen the physical ergonomics of the user.
6. Machine Compatibility (Machine integration, Maintenance, Cross- brand compatibility)			
6.1 The solution should follow the design layout of today's harvester machines.	R		The solution should be compatible and consistent with existing machines and their features.

6.2 Ideation

After the data had been collected and analyzed, ideation started. From the data with the focus on rot detection, four main ideas arose: camera detection, saw efficiency measurement, vibrations, and x-ray. In this section, these ideas and input from other ideas will be shortly presented with initial sketches.

6.2.1 Camera Detection

A rotten tree can be identified on the cross-sectional area when the tree is felled. To inspect the cross-section, the operator must rotate the stem toward the cabin if the tree is not felled straight in front of the machine. To make this step more efficient, one proposed idea is to add a camera to the cutting head that provides a clear view of the cross-sectional surface. Using AI or image-recognition techniques, the system could automatically detect signs of rot. In Figure 19, a initial draft sketch of the camera concept is presented.

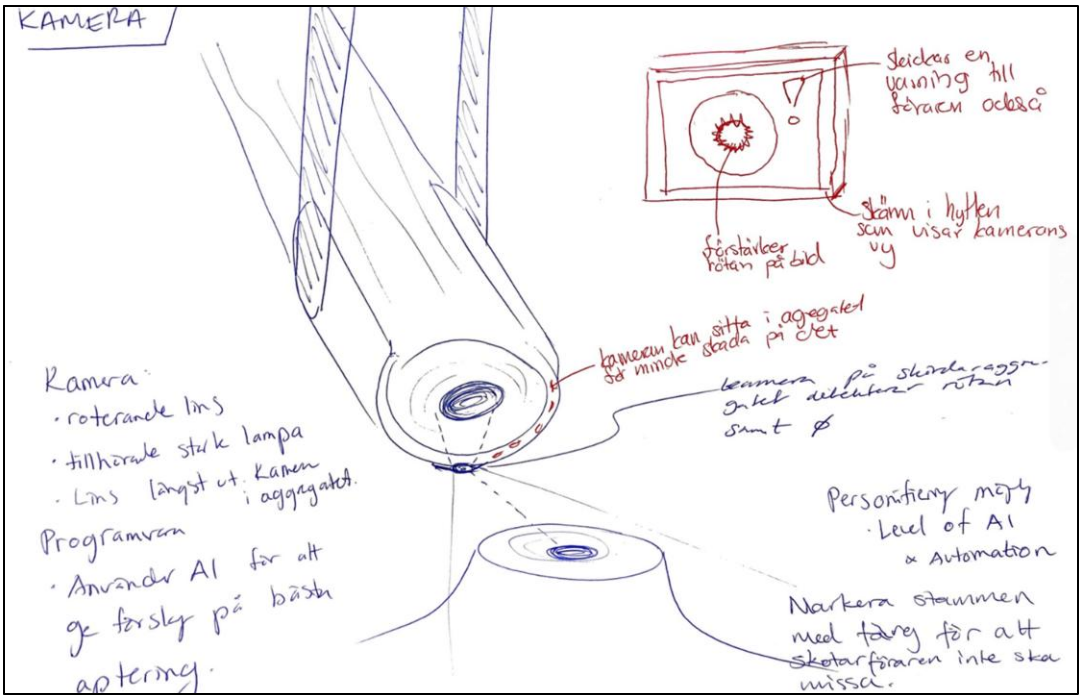


Figure 19. Initial draft sketch of camera idea.

6.2.2 Saw Efficiency Measurement

Rot has a different density than healthy timber. Therefore, the second idea is to measure the saw's efficiency to detect irregularities and thereby identify rot. With this solution, the cutting head does not require any new features beyond a measurement tool that can track the saw's performance. In Figure 20, an initial draft sketch of the saw idea is presented.

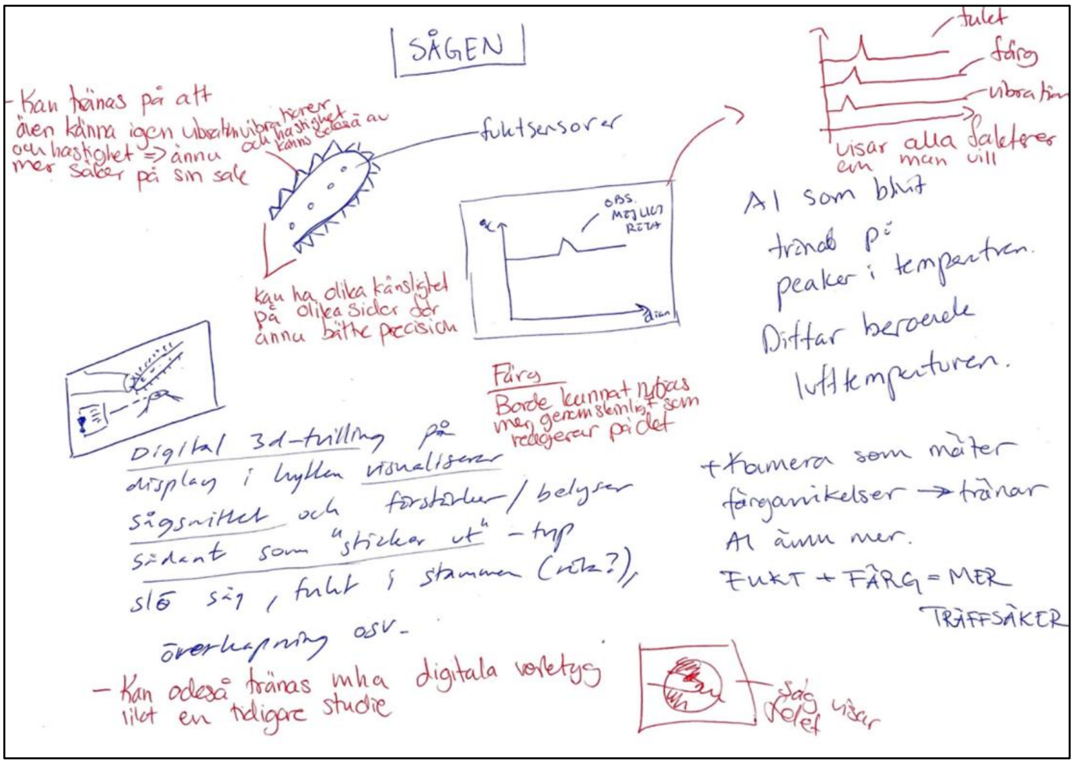


Figure 20. Initial draft sketch of saw efficiency idea.

6.2.3 Vibrations

The difference in density was used not only to generate ideas around the saw, but also to explore the usefulness of vibrations. The difference in density between a healthy and a rotten tree means that vibrations will travel differently through a rotten tree compared to a healthy one. Using vibrations of different types as both a detection and a measuring tool was therefore one of the proposed ideas. There were a variety of ideas that used vibrations for measuring and detecting rot, one example, see Figure 21, was that vibrations were sent through the tree with the help of sensors that detect if there is rot and where that rot is located.

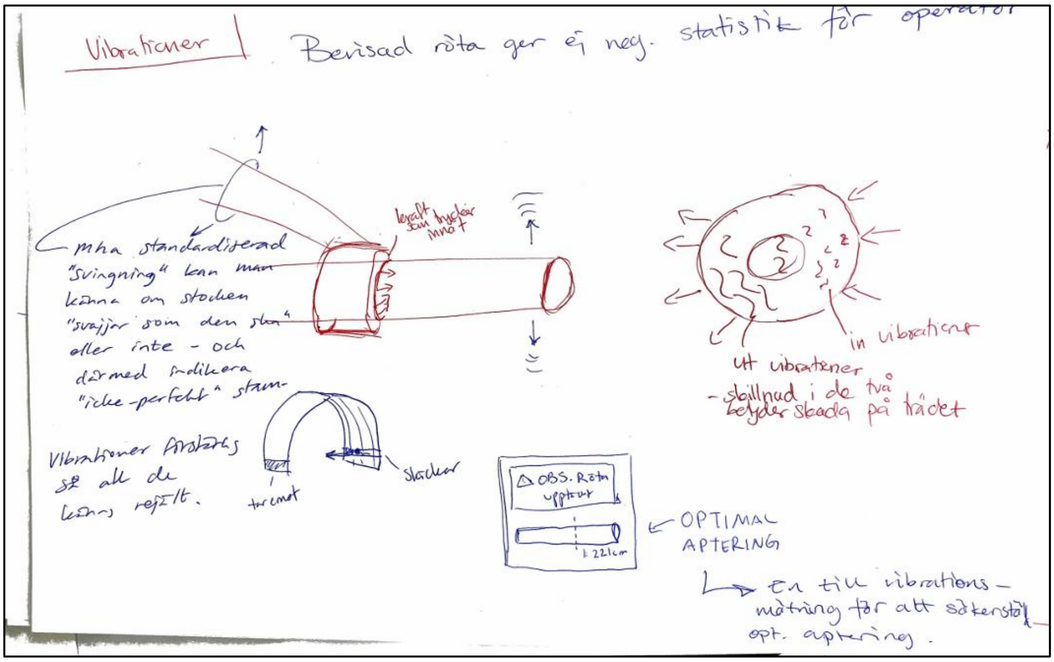


Figure 21. Initial draft sketch on vibrations idea.

6.2.4 X-rays

Another area that was explored during ideation was the possibility of using X-rays as a tool to detect rot. Due to the difference in density and elemental composition, X-ray scans could be used to detect where the rot is and how it is formed in either one or multiple trees. Most ideas circulated around scanning either one or multiple trees live while driving or beforehand. Figure 22 shows a live scan idea where the trees are scanned while the machine is driving and then modeled on the screen in the cockpit.

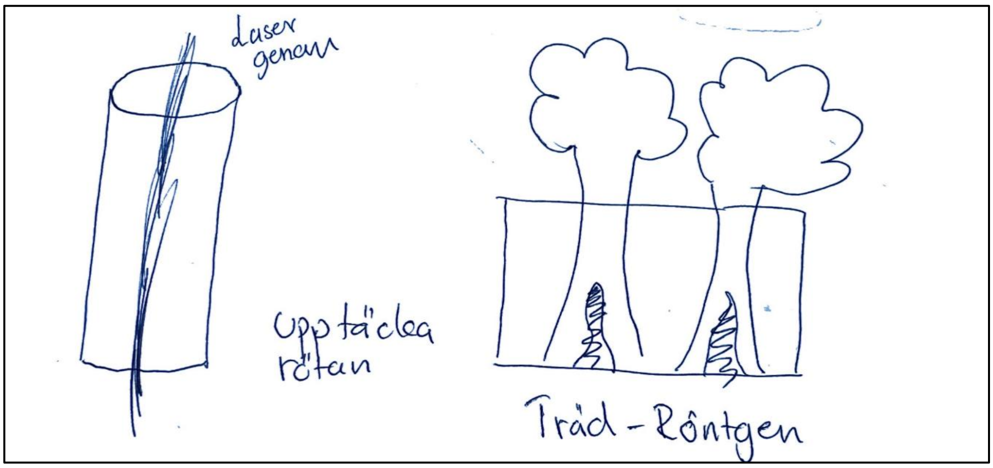


Figure 22. Initial sketch of X-ray idea.

6.2.5 Insights into Other Areas

Except for the previously mentioned areas of camera detection, saw efficiency, vibrations, and X-rays, other areas of ideas were discussed as well. These areas were either too small to be their own category or not chosen based on low user value or low feasibility. However, these areas still had relevant ideas and aspects to consider for future ideation, and therefore the key input was collected and used further. Some examples of insights that were gained from these areas were the importance of peripheral information so as not to distract the working operator, the collection and combination of many factors to detect rot, and the importance of the users being able to personalize the features based on preference.

6.3 Concept Development – Initial Concepts

From the ideation concepts were developed. The results from the idea-combination matrices, feasibility-value matrices and the initial concepts will be presented in this section.

6.3.1 Idea-combination Matrix

An idea-combination matrix was created for each of the idea areas: camera, saw, vibrations, and X-ray. From each matrix, four paths were selected, where different idea components were combined from the categories: *detect, placement camera, visualization data, information about rot, and extra features*. In some categories, more than one idea was chosen. This resulted in 16 new idea combinations. In Figure 23, the idea combinations for the camera idea are presented and, Figure 24, illustrates the new concepts.

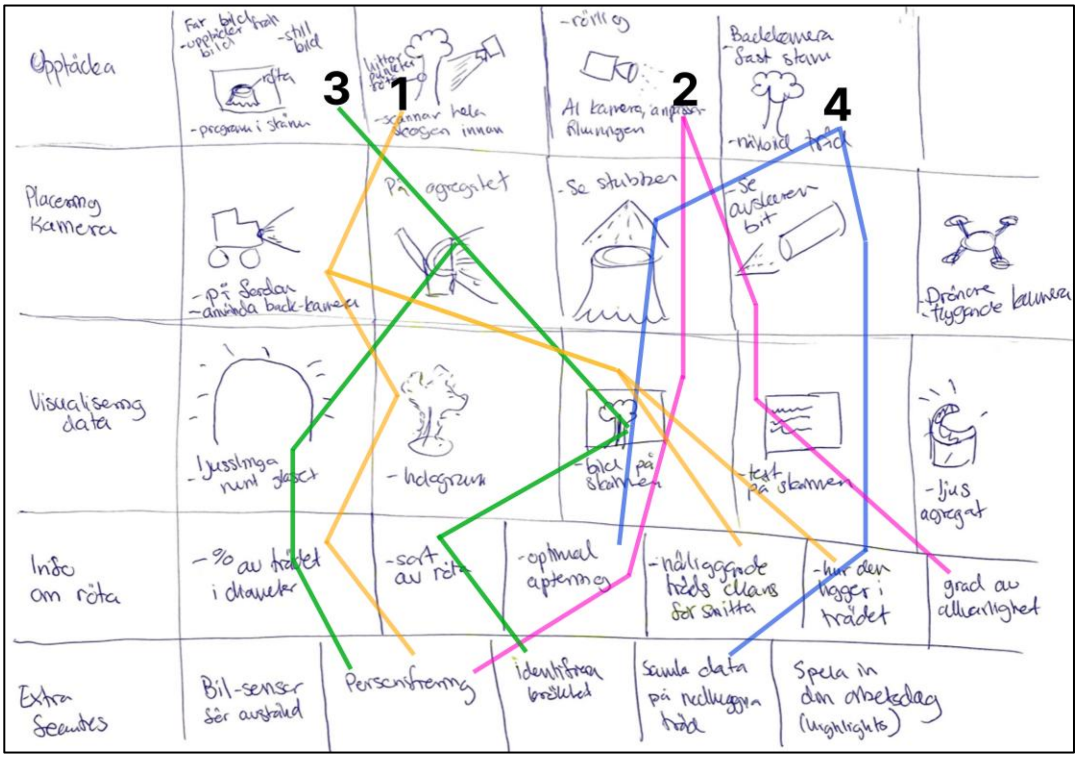


Figure 23. Idea-combination matrix illustrating the selected ideas from each category.

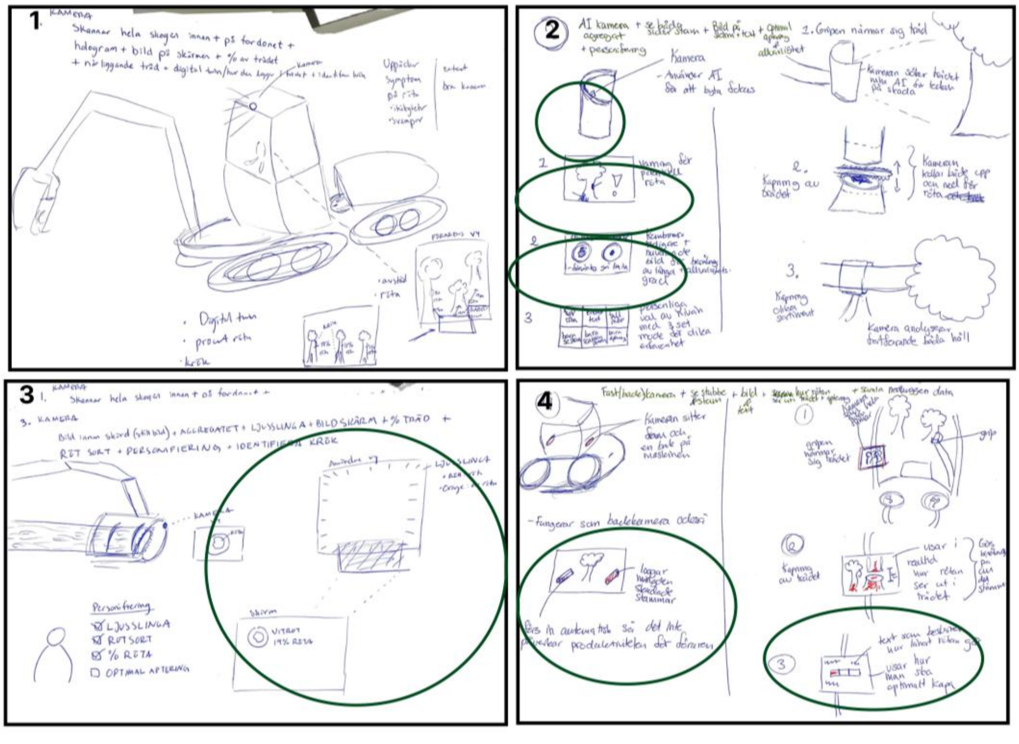


Figure 24. Overview of the camera concepts derived from the idea-combination matrix.

From these 16 combinations, idea elements that appeared multiple times or introduced new concepts were marked with a circle, see Figure 24. When analyzing the marked elements, it became clear that the ideas could be grouped into three categories: requested information, information presentation, and detection techniques.

Detection techniques represent the initial ideas for identifying rot, such as using a camera, measuring saw efficiency, monitoring vibrations, or applying X-ray technology. Examples of requested information include presenting data such as a graph, a percentage, or the type of rot. Information presentation methods, on the other hand, include modalities such as lights, haptic feedback, or audio signals.

6.3.2 Idea Evaluation

The most promising features from the idea-combination matrices were then transferred to a feasibility–value matrix, where they were compared against collected user data and findings from the literature review. The purpose was to assess both the potential value they could provide to users and their technical feasibility.

The top performing detection ideas were a still camera, measuring saw efficiency, measuring vibrations in the saw, and using the measuring wheel for data collection, see Figure 25.

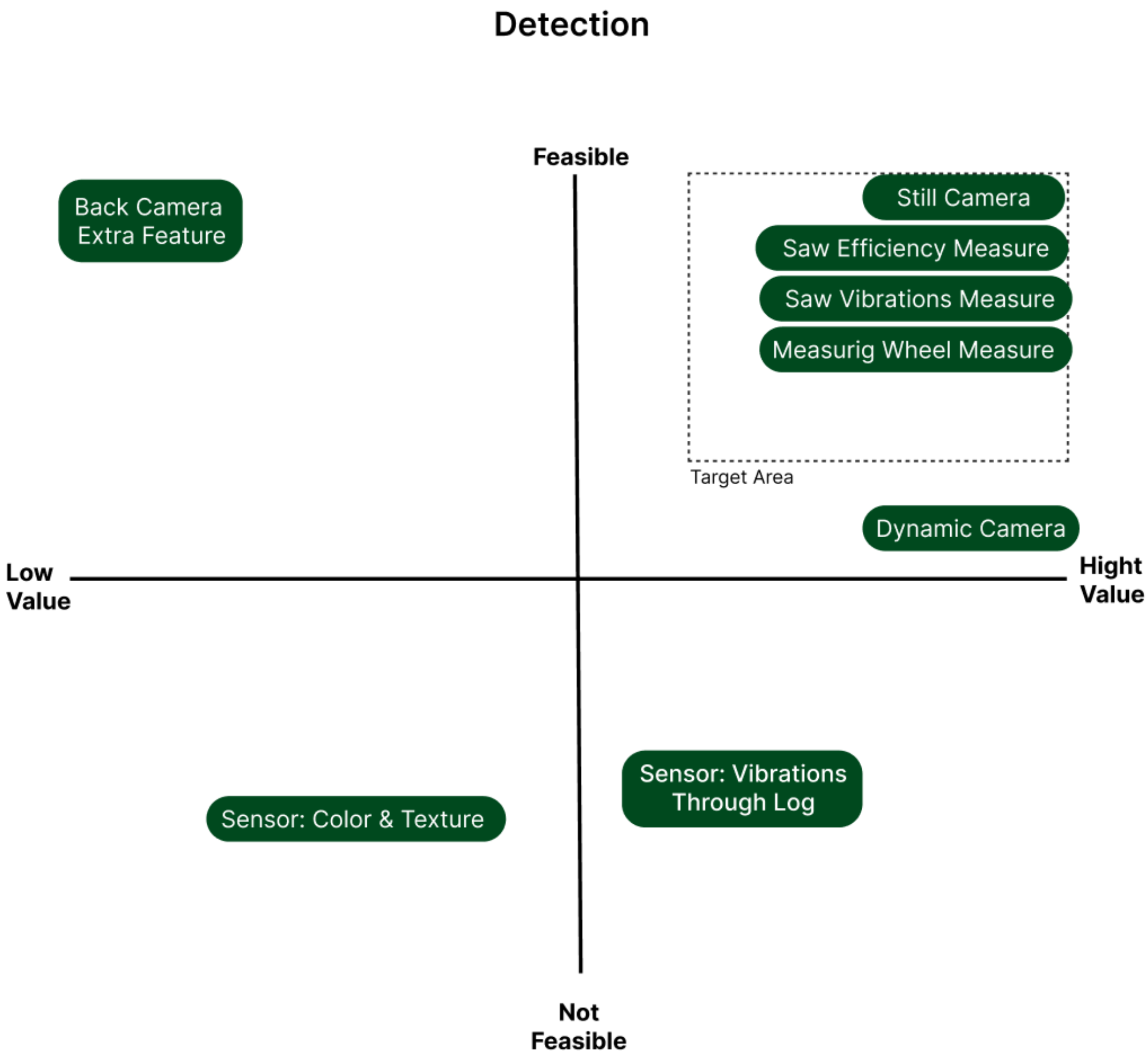


Figure 25. Feasible-value matrix for detection ideas.

For the requested information and its presentation, the most feasible and value-adding ideas were personalization, haptic feedback in the joysticks, light frame on window, cross-section views, bucking system for rot and percentage rot, see Figure 26.

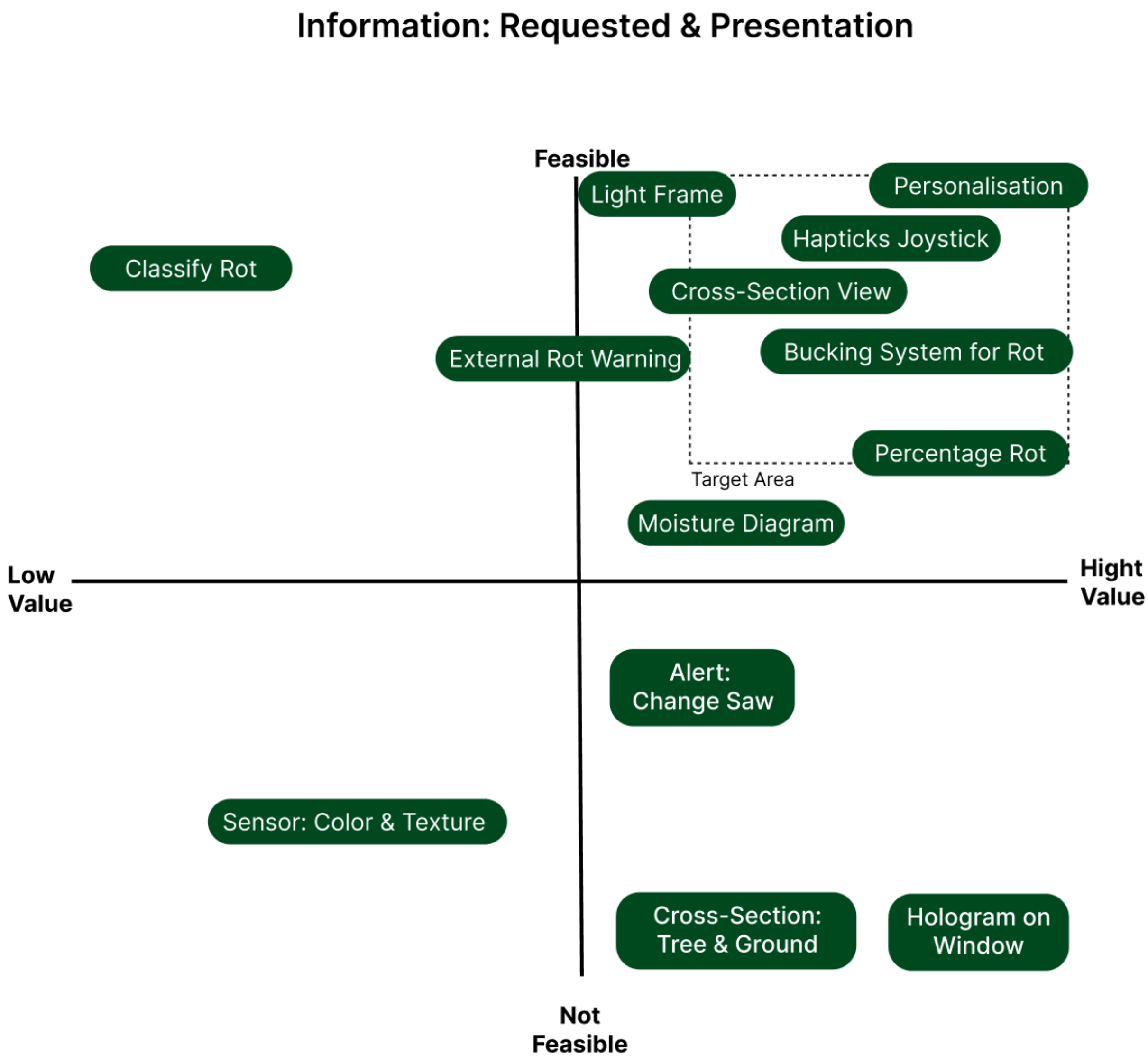


Figure 26. Feasibility-value matrix for information ideas.

6.3.3 Initial Concepts

The ideation in combination with the concept creation from the idea combination matrices led to the development of the first concepts that would be presented to the users. The concepts were divided into either detection concepts, focusing on the technical aspects of how to detect rot, or information concepts, focusing on what information should be presented to the user and how. In addition to the concepts the users were presented with information options, to give them the opportunity to explain what information is most important, which will also be described below.

Detection Concepts

Three detection concepts were developed and visualized. The concepts were detection by a camera on the cutting head, by measuring saw efficiency, and by measuring vibrations from the measuring and feeding wheels. These will be further described below.

Detection with Camera

The first concept, a camera on the cutting head, see Figure 27, detects rot with the help of a small camera placed on the cutting head of the harvester. The camera can either use AI to help with the rot detection by image recognition or simply show the operator a live image or video of the cross-section of the log. By showing the operator the cross-section of the log or an AI visualization of it, they do not have to twist the log to see if there is rot, and they can thereby save time and be more accurate in their work. The camera images could, with the help of an algorithm, calculate how far and where the rot is in the tree, helping the harvester operator even further with where to cut and how far to cut.

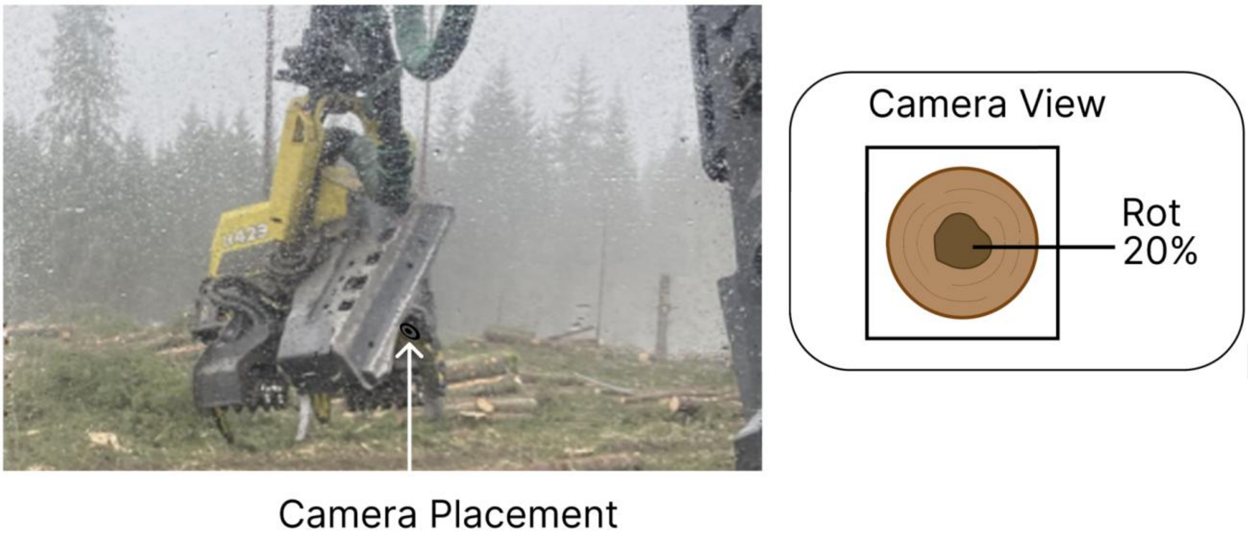


Figure 27. Detection concept: camera on the cutting head. Shows the camera placement and the cross-section view from it.

Detection with Saw Efficiency

The second concept, efficiency measurements on the saw, see Figure 28, helps with rot detection through measuring shifts in the saw's efficiency. Since the density changes within the wood when a tree becomes rotten, the saw will cut differently in a rotten tree compared to a healthy one. By equipping the saw with sensors capable of detecting changes in cutting efficiency, rot could be identified. With the help of the changes in efficiency of the saw, optimal bucking for the rotten tree can be calculated and used as a helpful tool for harvester operators.

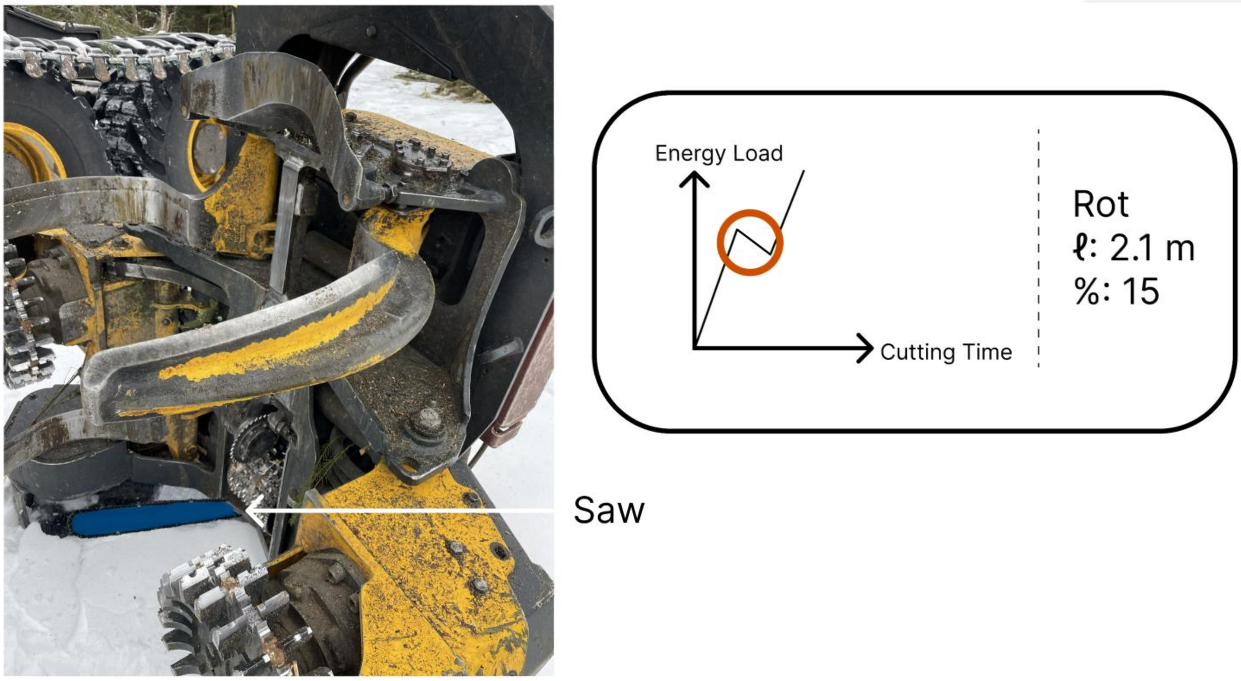


Figure 28. Detection concept: efficiency measurements on the saw. Shows an example of how a change in efficiency in the saw can be presented.

Detection with Vibrations

The third and final concept of the detection concepts is vibration analysis on the cutting head, see Figure 29. Since rotten timber has a different density, the vibrations will travel differently in rotten wood compared to healthy wood. By measuring the changes in vibrations with the help of either the feeding rollers or the measuring wheel, rot could be detected and measured. With the help of an algorithm, the rot placement can be detected, which can help the harvester operators when bucking rotten trees.

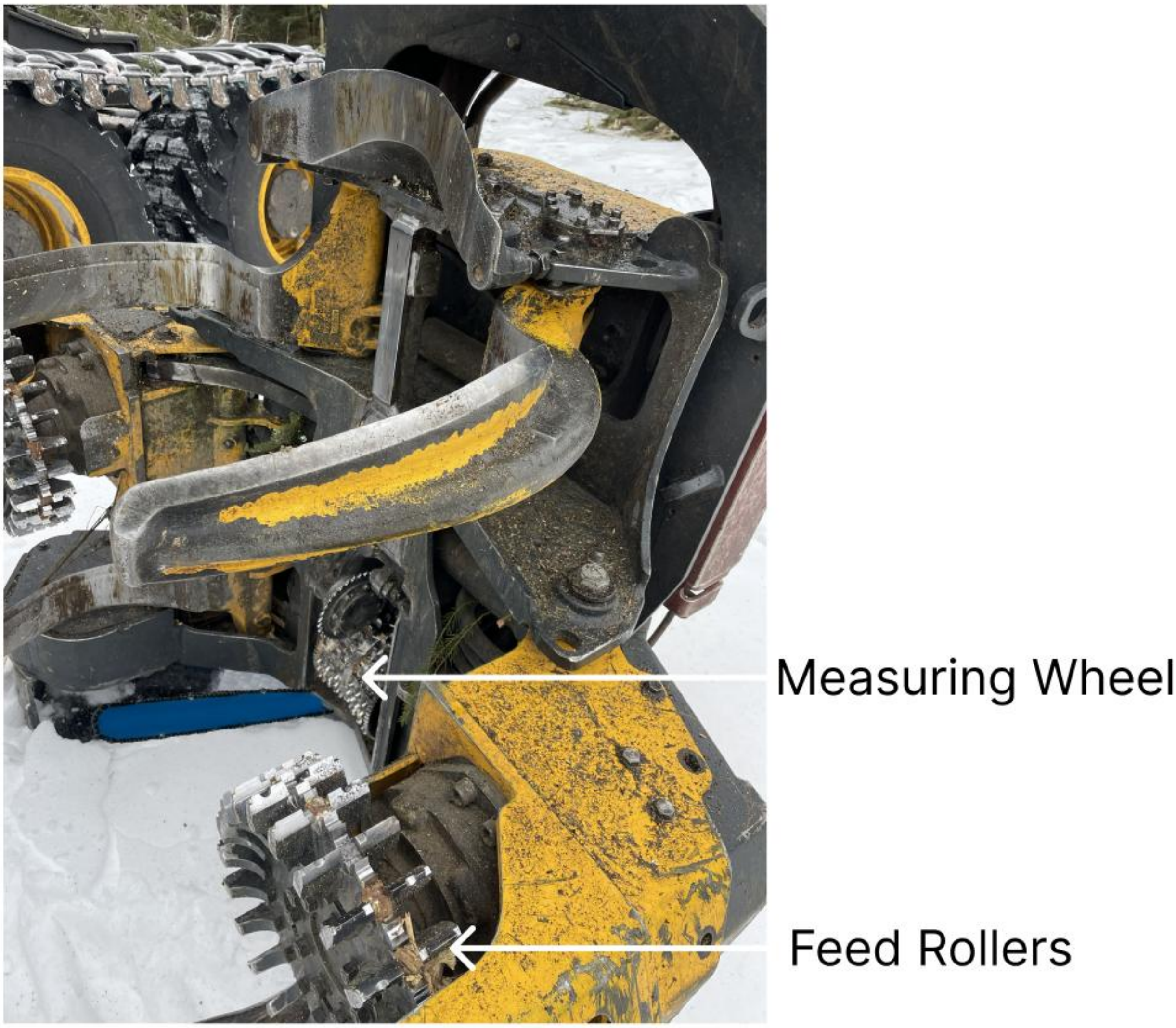


Figure 29. Detection concept: vibration analyzation on measuring wheel or feed rollers. Shows where vibrations can be analyzed.

Information Concepts

The users were asked which information they would like to receive and in what form. The requested information is presented first, followed by four information concepts: bucking assistance, cross-section view, light feedback, and haptic feedback.

Requested Information

The users were asked what information they considered the most important and how they would want that information presented. The options the users were presented with were percentages of rot, type of rot, numerical data, graphs, sorting, and suggested bucking, see Figure 30. The options were selected based on previous user studies where the detection and placement of rot was considered important for the user.

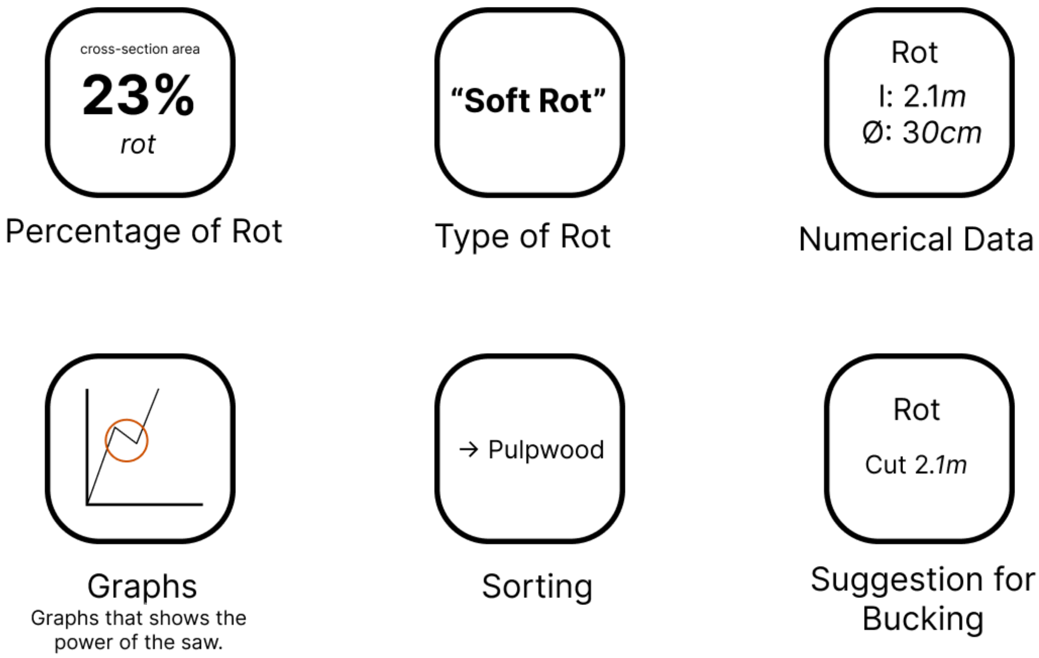


Figure 30. Information options presented to users during the user evaluation.

Bucking Assistance Concepts

The first concept for visualizing information was created to help the operator with bucking assistance for rotten trees, see Figure 31. In harvesters today, the operator is only provided with bucking suggestions for healthy trees, and not for rotten ones. By providing users with bucking assistance for rotten trees, both the mental workload and the user's errors would decrease. The difference between the four suggested options is mainly the placement of the information provided and what information is provided. The first two parts of the concept are based on the existing screen view when bucking healthy trees, however, now it covers rotten trees as well. The second two parts of the concept use a 3D-model to visualize the tree to the operator and show where the rot is located. During the user studies, the operators explained the difficulty of deciding where to cut if a tree had rot, since it was hard to know how far into the tree the rot went. The bucking suggestions for rotten trees could therefore help and support the operator in their bucking decisions.

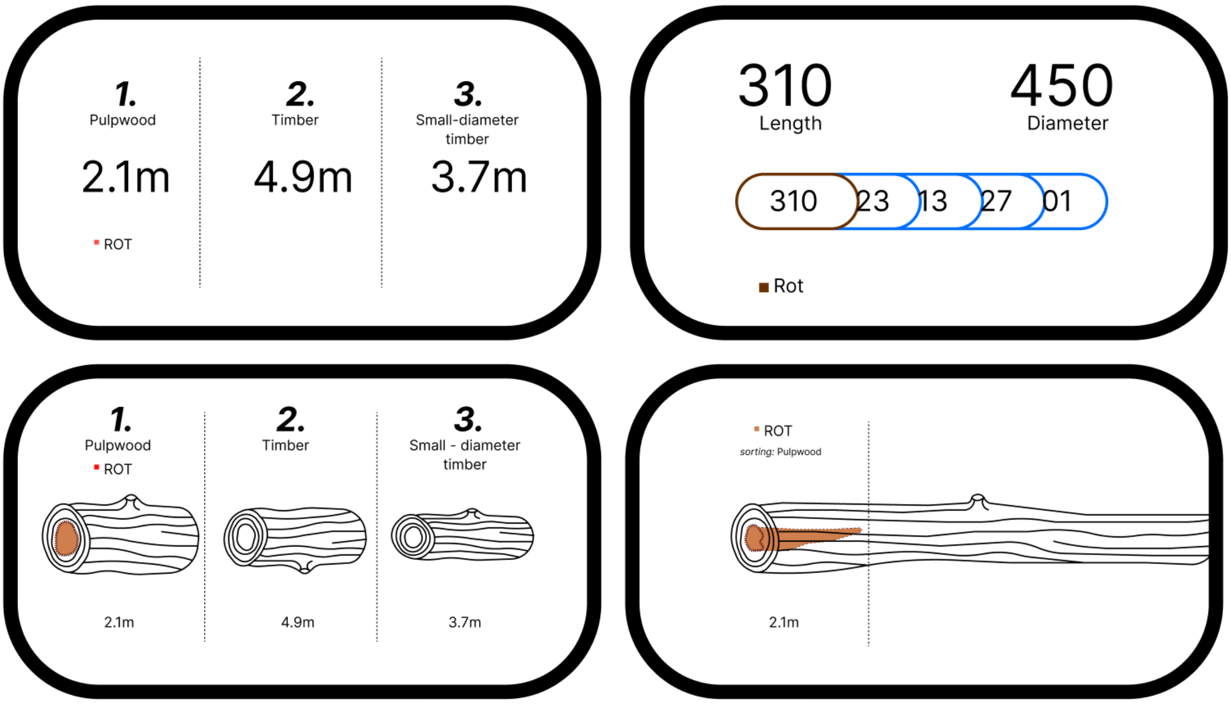


Figure 31. Visualizations of bucking suggestions concepts.

Cross-section View Concepts

The second concept focused on visualizing different cross-sections, see Figure 32. With the help of a cross-section of either the full tree or the cut parts, the harvester operator would get a clear view of the inside of the tree and can then more easily detect and handle the rot. There were three options for visualization of the cross-section, two where it only showed parts of the tree and one where the full tree was modeled. The difference between the two visualizations of parts of the tree is that one is a model of the tree and the other is a real image or video of the tree. From the user research, it became clear that it was difficult to spot rot, and with the help of visualizations of the tree's cross-section, the operator will be able to both detect and handle rot more easily. The importance for the operator to feel in control also became clear during the user studies, and the concept with the real image was therefore made to enhance the operator's feeling of being in control.

Figure 32. Visualization of cross-section concepts. (Partly AI generated)

Light Concepts

The third of the information concepts focused on light feedback when detecting rot, see Figure 33. The light was placed in different parts of the cockpit, either around the windshield, on the screen or as a lamp, and lit up red when rot was detected inside the tree. The main function of the lights was to alert the operator to the rot and to increase their attention towards the tree. The concept was created to minimize the time it takes to spot rot and to make it clearer for the operator when there is rot in a tree. From the literature research and the observations, it became clear that the operator focuses mainly on the cutting head while working and uses the screen more peripherally for confirmation, which was the reason why peripheral light was used in this concept.

Figure 33. Visualization with lights concepts. (AI generated)

Haptic Feedback

The fourth concept focused on using haptic feedback to help the harvester operator detect rot, see Figure 34. The haptic feedback could either be provided through vibrations in the joystick when rot is detected or with a change of stiffness in them. The background to the haptic feedback concepts came from the observations in which the experienced operators were more observant of smaller changes in the haptic feedback from the joystick. By enhancing feedback in the joystick, the novices would experience the same thing as the experts without having the same working experience.

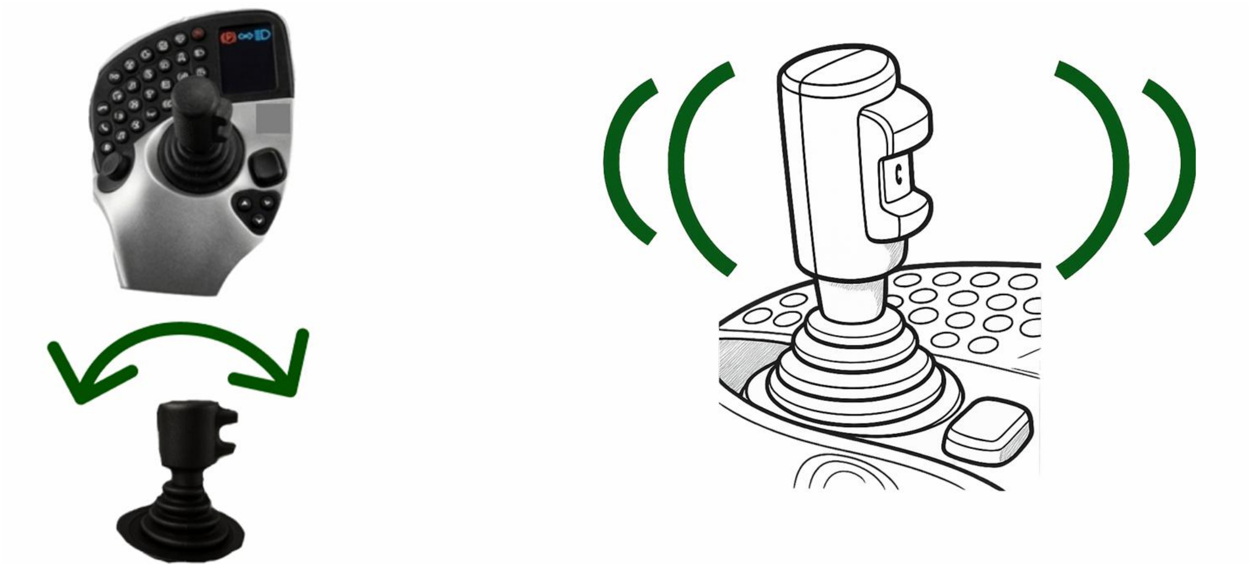


Figure 34. Haptic feedback concepts. (Partly AI generated)

6.4 Concept Evaluation – Initial Concepts

The initial concepts were evaluated by users, and the outcomes of the first evaluation round are presented in this section. The insights gained formed the basis for the continued development of the concepts.

6.4.1 Requested Information

During the evaluations with the users, they were asked which information regarding rot they preferred and how they wanted it displayed. From the evaluation interviews, the operators favored rot percentage, bucking suggestions, and sorting of the timber. They explained that the percentage of rot is important information since it is what decides which kind of timber the log is classified as. To get suggestions for bucking when there is rot in the timber was also highly valued, but as one of the users mentioned, all three types of information are connected. If the operator knows the rot percentage, they will know how to buck the log and therefore also which segment of timber it will be placed into.

The results from the evaluation survey regarding requested information, see Figure 35, show that they prioritize percentage of rot and suggestions for bucking, like the users in the evaluation interviews. The aspect rated lowest by both user groups was the type of rot, as it was described as having limited relevance to their work. Consequently, percentage of rot, sorting, and bucking suggestions were prioritized for further development, as they were expected to provide the greatest support for operators in detecting and handling rot. The numerical data were considered important for the users as well, however, this was considered to be included in the other kinds of information.

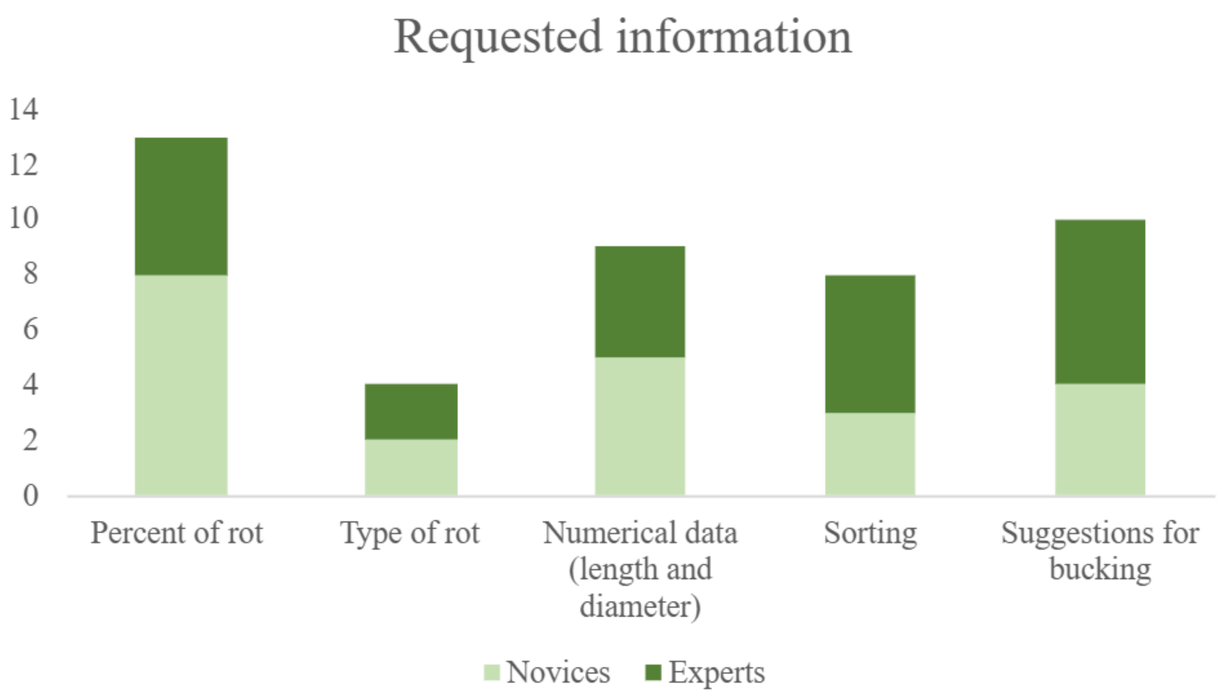


Figure 35. Results from the evaluation survey regarding the requested information from the users.

6.4.2 Bucking Assistance Concepts

During the evaluation with users, it became clear that bucking suggestions for rot were the most important feature to the users. From the evaluation interviews, see Table 8, three out of the four bucking concepts scored the highest out of all concepts. As one of the users said, “This would be a highly valuable tool to use. It would be really helpful and easy to include in today's ways of working”. Users explained that their preference for a concept depended on the type of machine they were operating, with a tendency to favor concepts that most closely resembled the existing interface of their machine. The concept with the 3D model was the least favorite, since the users pointed out that it took up too much space. As one user said, “I do not understand why you need a 3D model; it takes up too much space”.

Table 8. Presenting the results of concept evaluation interviews with users. The users graded each concept from one to five in each category, and the average score for each concept is presented below. The highest scoring concepts are highlighted in blue and underlined. Green color is considered approved, yellow almost approved and red not approved.

Concept	Helpful	Time efficient	Intuitive	Integration	Trustful	Total score
Joystick - Stiffness	1.67	2.67	1.67	2.67	2.33	2.2
Joystick - Vibrations	2.83	2.83	3.33	4	2.67	3.13
Light -Frame	2.67	3.67	4.67	4.67	3	3.74
Light - Line	3.67	4.67	5	5	3	4.27
Light - Lamp	3.5	4.33	4.5	4.67	2.33	3.87
Visualization - Cut tree model	4.83	3.33	4.33	5	3.33	4.16
Visualization - Cut tree real	4.83	3.33	4.33	4.33	3.33	4.03
Visualization - Full tree	3.5	3.5	3.83	3.83	2.83	3.5
Bucking - Text & Numbers	4.33	4.33	5	5	3.67	4.47
Bucking - Existing layout	4	4.33	5	5	3.67	4.4
Bucking - 3D cut	2.67	3.33	4.33	4.33	3.67	3.67
Bucking - 3D visible rot	4.5	4.67	5	5	3.67	4.57

Green ≥4 4> Yellow >3 3 ≥ Red

The information from the evaluation survey confirmed what was said during the evaluation interviews. When the users were asked if they would appreciate support for bucking rotten trees, almost all users said they would, see Figure 36. The users from the survey preferred the existing layout and the more minimalistic concepts with text and numbers the best, see Figure 37, confirming the other user's perspective on saving space on the screen. Therefore, offering a tool for bucking suggestions for rotten trees would be considered helpful for the users, however, it needs to be reliable, fit into their ways of working, and not compromise other information on the display.

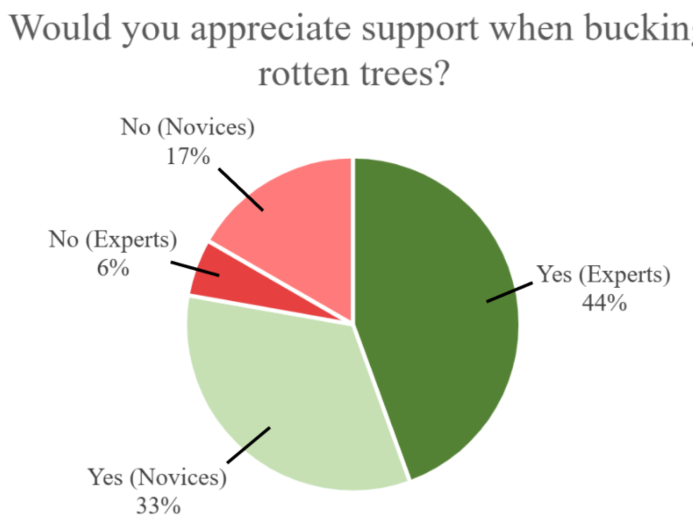


Figure 36. Results from the evaluation survey regarding bucking support for rotten trees.

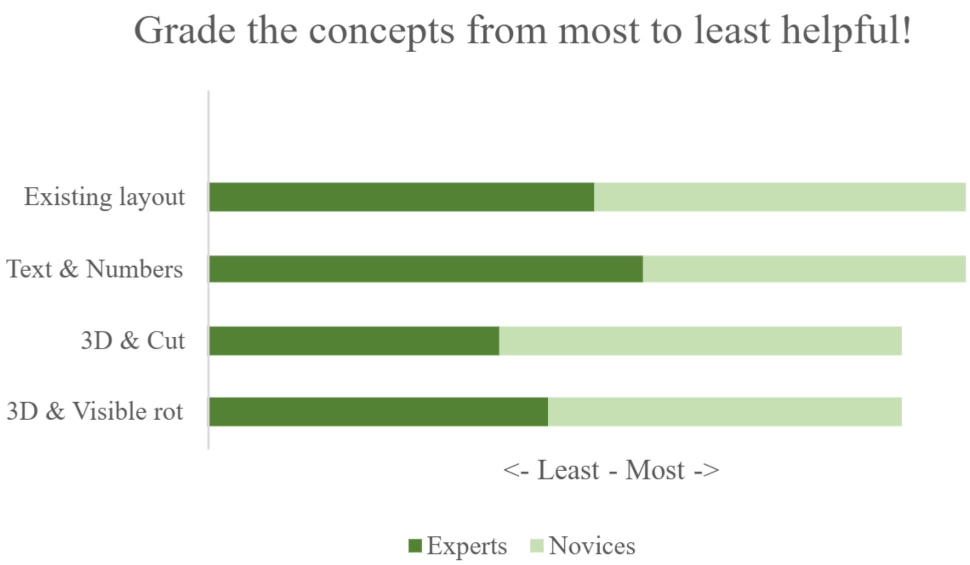


Figure 37. Results from the evaluation survey regarding which bucking suggestion concept the users preferred.

6.4.3 Cross-section View Concepts

From the evaluations with users, the concepts using cross-section views of the timber to inform the operator about rot performed well, second-highest of all concept areas. From the evaluation interviews, see Table 8, both the model of the cut tree and the image of the real cut tree were approved. The full modeled tree concept was almost approved but did not score as high as the other two concepts. The survey confirmed the information received in the evaluation interviews, and most users would like to use cross-section views for rot detection, see Figure 38. Among the survey respondents, the cut-tree model concept was rated highest, followed by the cut-tree real image concept, while the full model concept was rated lowest, see Figure 39.

The evaluations with users showed that using cross-section views would be helpful for detection and handling of rot. However, it cannot compromise other features, and if it is used, the presented footage needs to be of high quality and the rot easy to spot.

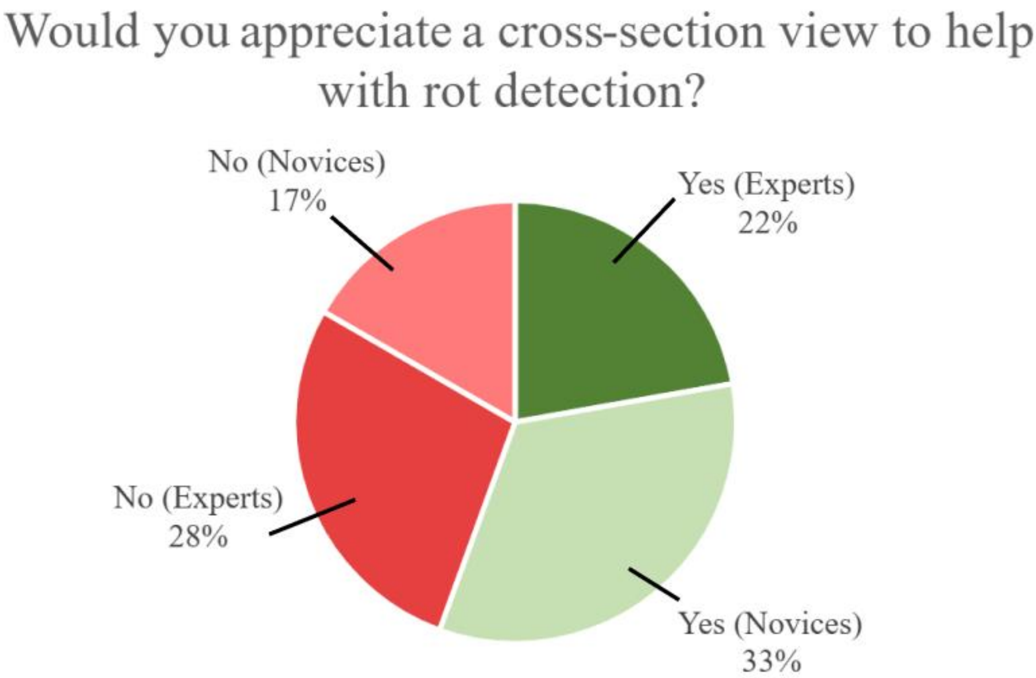


Figure 38. Results from the evaluation survey regarding cross-section view for indication of rot.

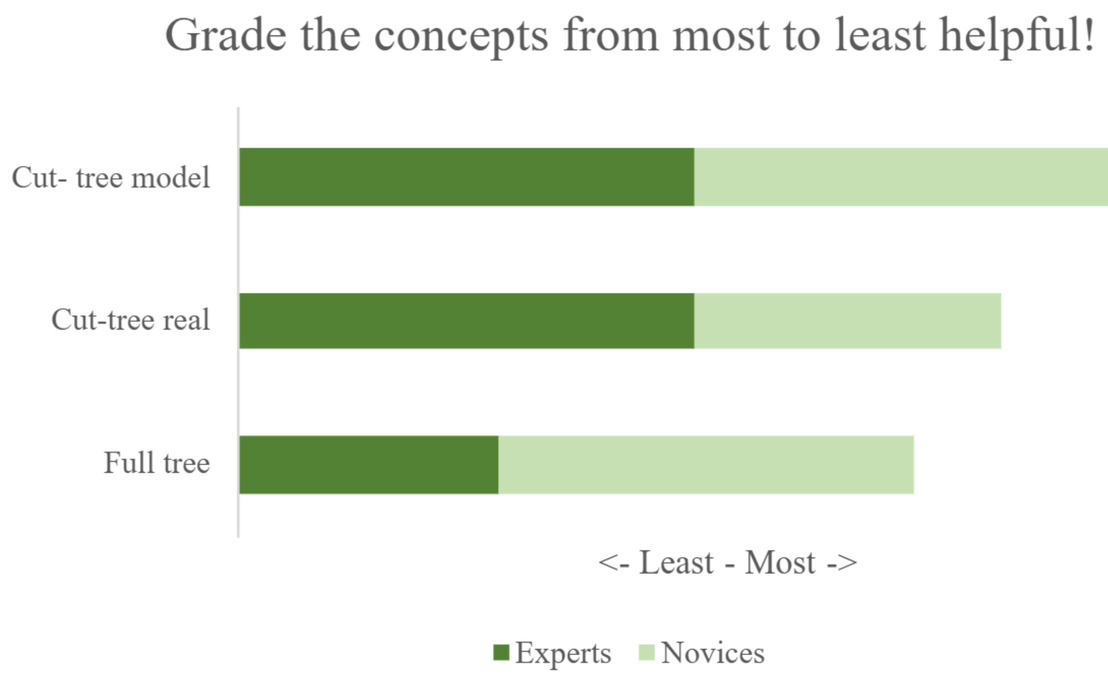


Figure 39. Results from the evaluation survey regarding which cross-section concept the users preferred.

6.4.4 Light Concepts

The three concepts using light to help the operators detect rot scored quite high in the user evaluation interviews, see Table 8. One concept, the light on the screen, was approved and the two other concepts, the light frame and the lamp, were almost approved. From the survey, it could be concluded that most users would appreciate light as a tool for rot detection, see Figure 40. The survey confirmed what was detected during the evaluation interviews, that the light on the screen was the users' preferred solution and the lamp their second favorite, see Figure 41. From the evaluations it became clear that using light could be a useful tool for rot detection, however, as the users mentioned, it needs to be presented in an appropriate way. The light should not be mistaken for other warning symbols in the harvester, and it should not hide or make it more difficult to spot other important information.

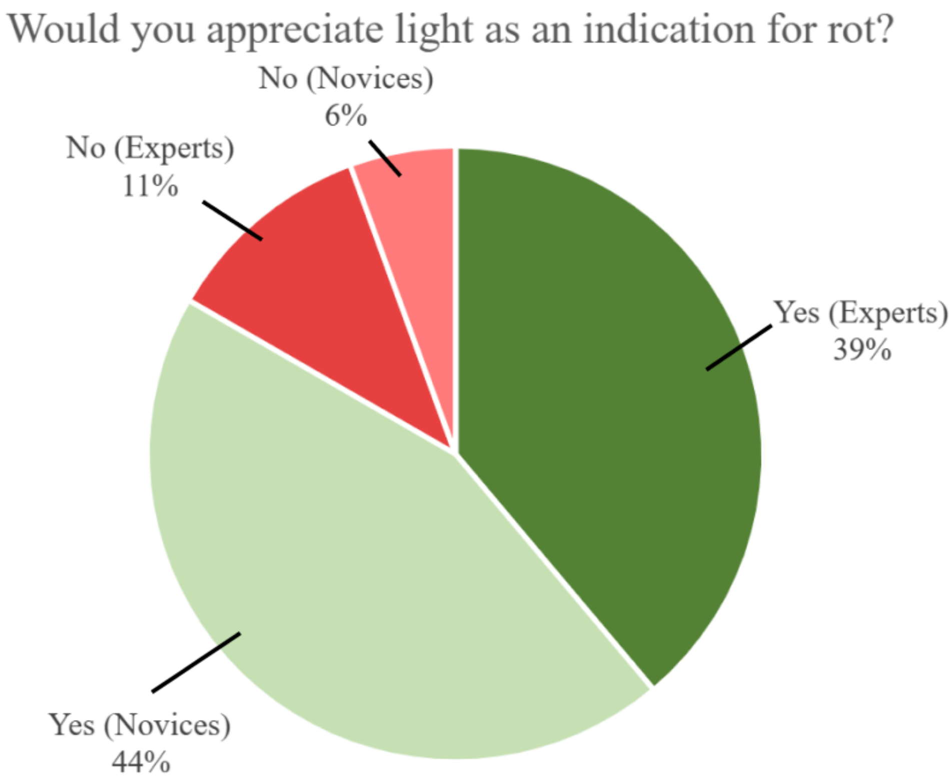


Figure 40. Results from the evaluation survey regarding light as an indication for rot.

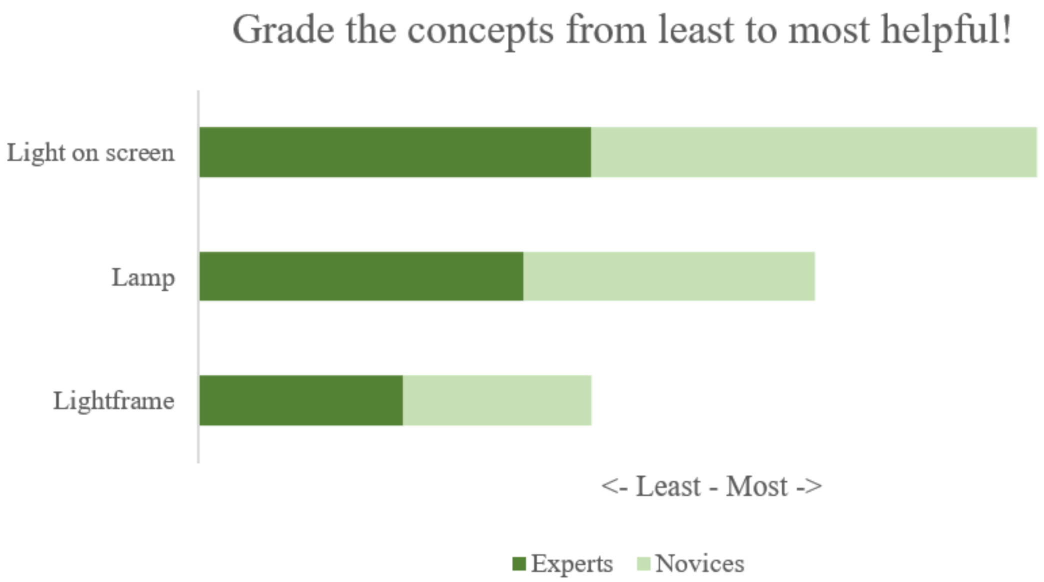


Figure 41. Results from the evaluation survey regarding the preferred light concept.

6.4.5 Haptic Feedback

From the evaluation with the users, the haptic feedback concepts performed worst, see Table 8. As described by one of the users in the interview, “The machine is already vibrating a lot, adding more vibrations might be worse for the body and they can easily be missed”. The users pointed out that there already are a lot of vibrations in the machine and that adding more vibrations might both be harmful to their bodies, but also to their work, since a more stiff or vibrating joystick could make operators think something is out of order. Even if the users saw more potential in adding vibrations in the joystick compared to altering the stiffness, see Figure 42 and Figure 43, 50% of the users would not appreciate haptic feedback for rot detection. Haptic feedback was therefore removed from the potential solutions, since it most likely would not be a helpful tool for harvester operators to detect rot.

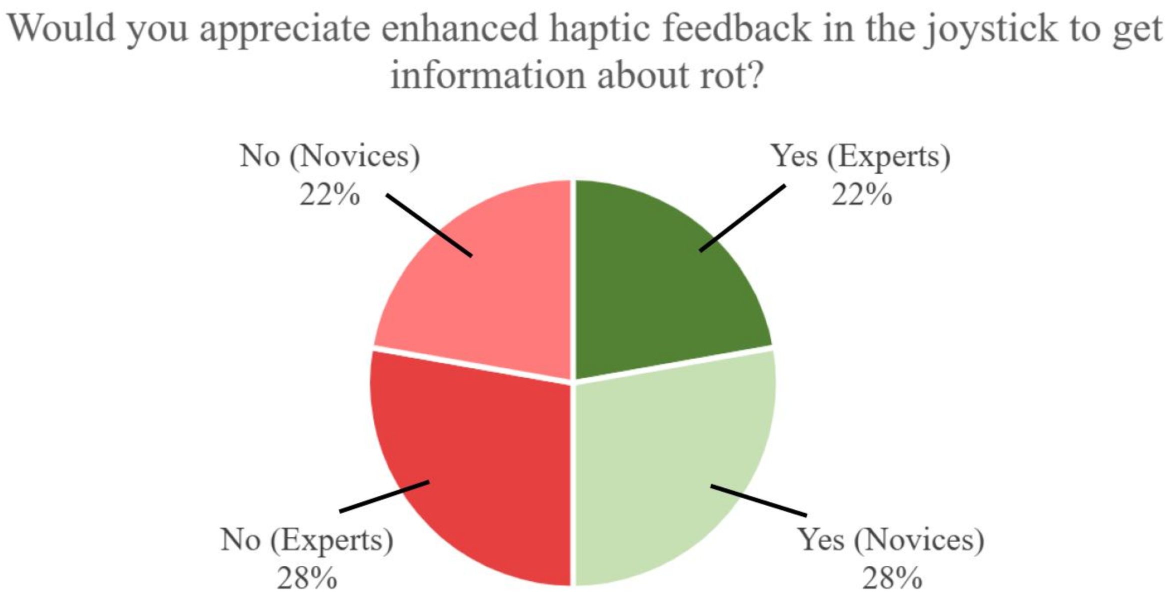


Figure 42. Results from the evaluation survey regarding haptic feedback in the joysticks as an indication for rot.

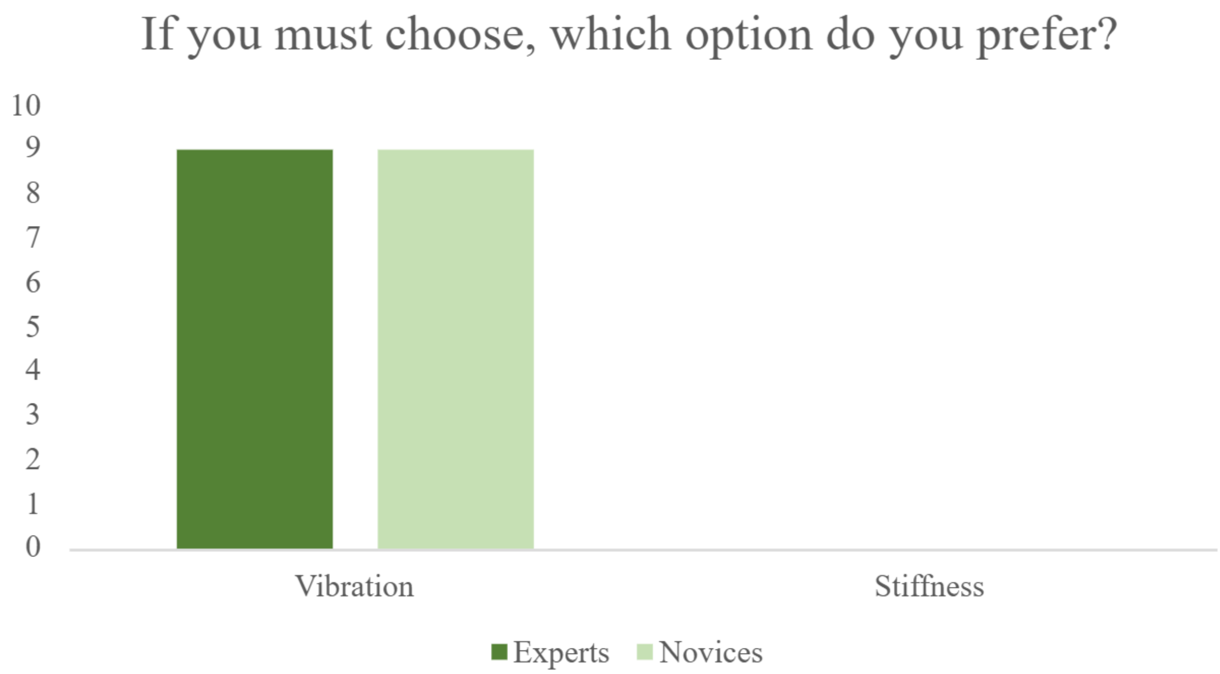


Figure 43. Results from the evaluation survey regarding what kind of haptic feedback for rot detection the harvester operators prefer.

6.5 Concept Development – Refined Concepts

Based on the user evaluations, the concepts were refined. This section presents the refined concepts. The haptic feedback concept was eliminated, therefore, the concepts presented focus on bucking assistance, cross-section view, and light feedback.

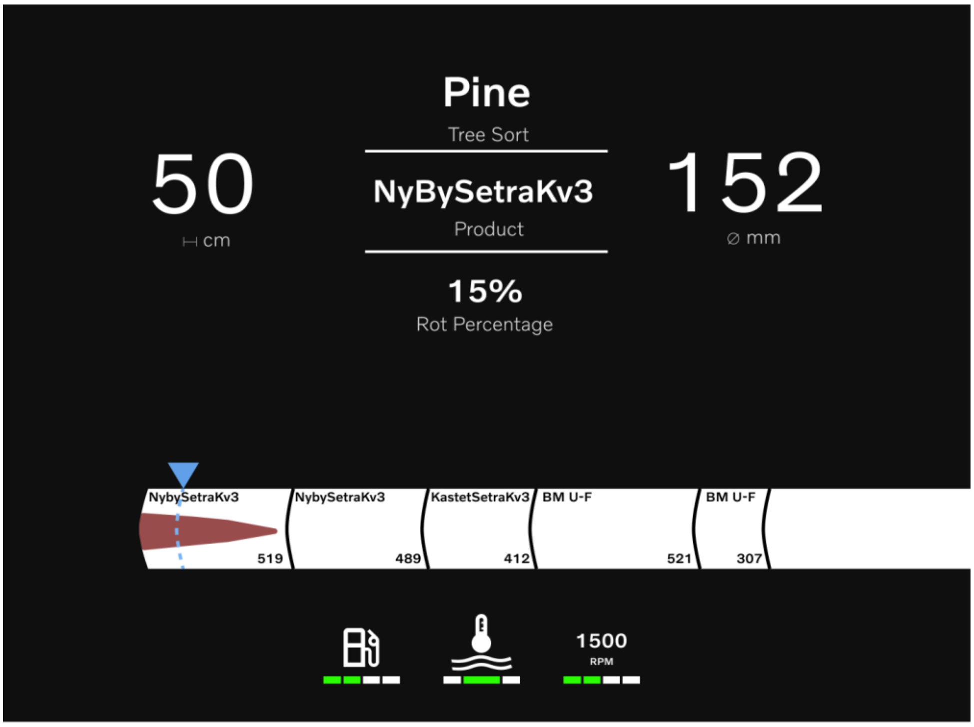
6.5.1 Bucking Assistance Concepts

The user evaluations helped identify the importance of a tool to help with bucking of rotten trees, and therefore the bucking concepts were refined and developed based on the users' input. Three new concepts were developed, see Figure 44, Figure 45 and Figure 46. In the concepts, the tree sort, rot percentage, and the product can be viewed. The product is the segment the timber will be placed in depending on, for example, length and width. The product name varies between different companies and is created based on a short form of, for example, company name and size of timber. The three new concepts are made to resemble existing interfaces with the added tool for bucking of rotten trees.

Figure 44 shows two concepts for visualization of the rot, where (a) displays the cuts of the full tree, while (b) shows some, but not all, of the future cuts. Another way of displaying the rot when bucking is shown in Figure 45, where the part with rot is highlighted in red. Another concept is shown in Figure 46, where a more realistic model of the tree is used, and the difference between the two versions is the visible rot and placements of labels.

From the user evaluations, it was mentioned that the bucking tool for rotten trees needs to be easy to integrate with their current ways of working. To make the bucking tool easy to integrate, the developed concepts were made more similar to current existing bucking tools, but with an added function for bucking and detecting rot. The placement of the tree that is being cut and the markings for the rot were placed at the bottom of the screen to not overshadow other important information and functions. Versions that use different amounts of space on the screen were made to make sure that it did not take up unnecessary space on the display, since the users mentioned the importance of prioritizing information and its size on the displays.

a)



b)

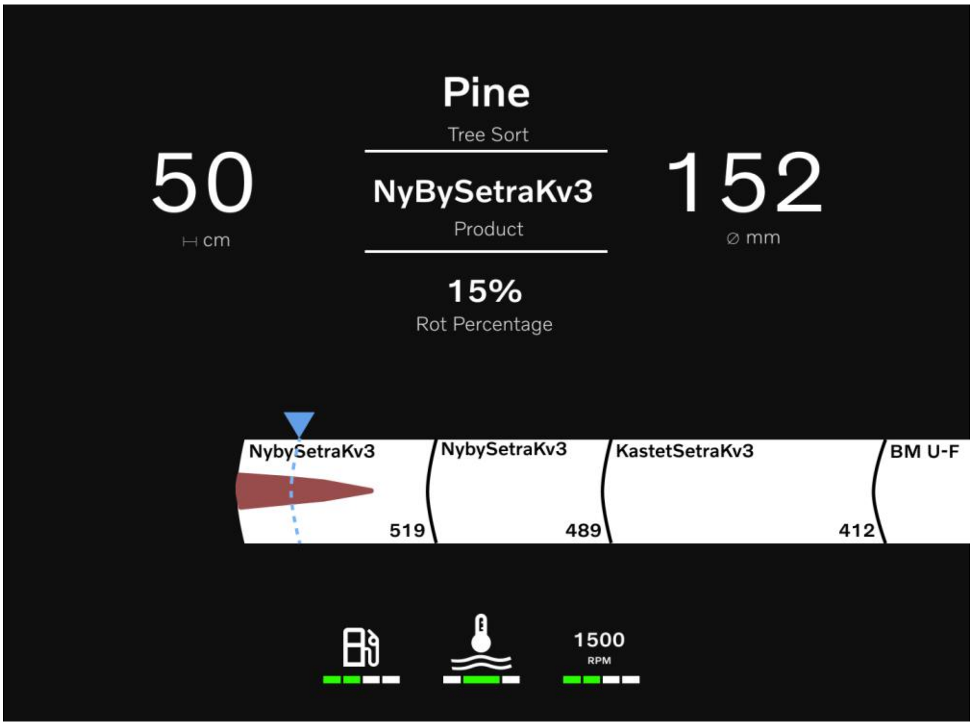


Figure 44. Presents two different ways the rot can be displayed when bucking, with markings for where the rot is in the tree: a) all future cuts b) some future cuts

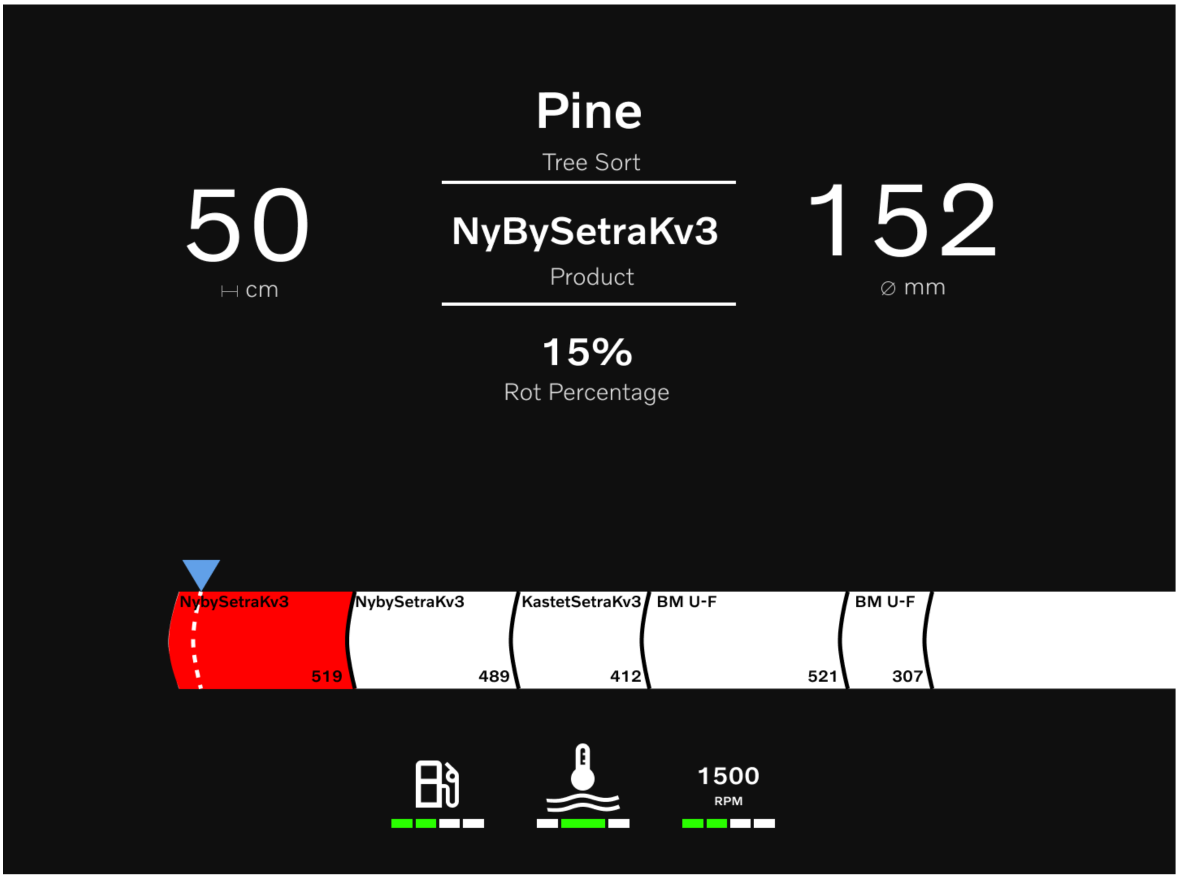
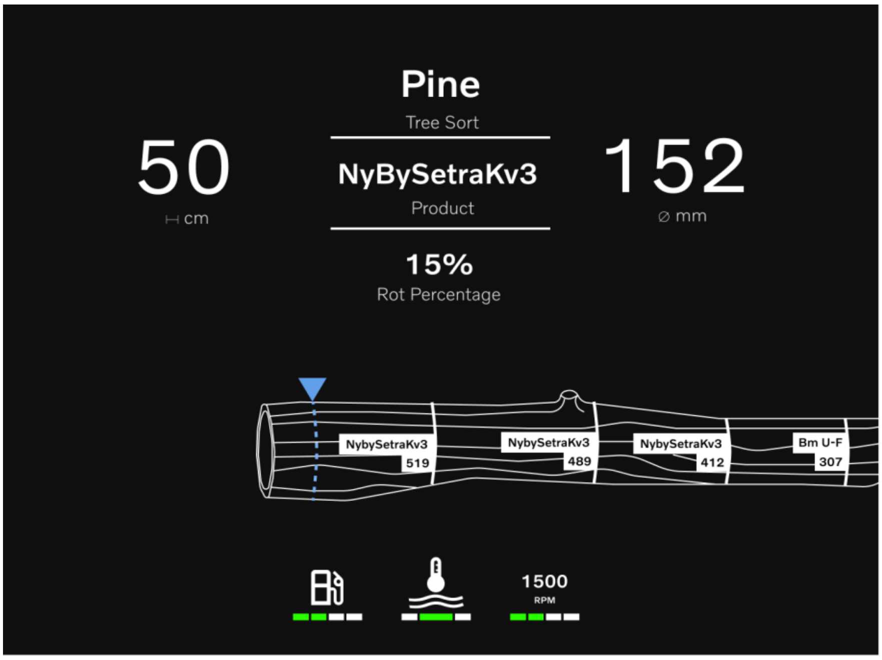


Figure 45. Presents a concept where the tree rot is marked with red.

a)



b)

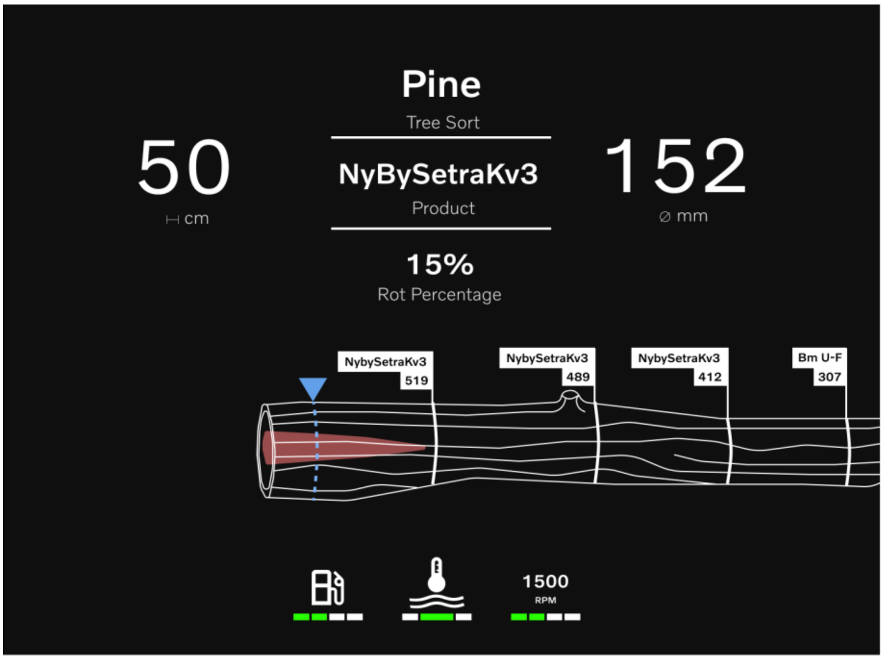


Figure 46. Presents two different ways the rot can be displayed with 3D logs: a) without visual rot b) with visual rot

6.5.2 Cross-section View Concepts

From the user evaluation, the findings indicated that the users appreciated cross-section views to help with handling and detecting rot, the visualization concepts with cross-sections were therefore developed further. Two different placements of the interface were made, on the reverse camera, see Figure 47, and on the main display, see Figure 48(b). Four different interfaces were also made to show different ways to visualize the rot on the displayed cross-section view, see Figure 49.

When the first concepts were evaluated, it became clear that when using a cross-section view the footage of the timber needs to be of high quality and easy to see. To achieve better visibility, the two different placements of the cross-section view were made. One concern from the users was that the view might block other important information and features, which motivated the new placements of the view. The new cross-section view was therefore either placed on an entirely different screen or gave the user the possibility to control the placement and size of the view on the main display. The different ways of showing rot on the cross-section view were created with the users' need to easily spot rot in mind. By highlighting the rot in different ways, the operator can perceive it in their peripheral vision, allowing them to remain informed about rot while maintaining focus on their task.

Figure 47. Placements of the refined cross-section concept, where it is placed on the reversing camera display.

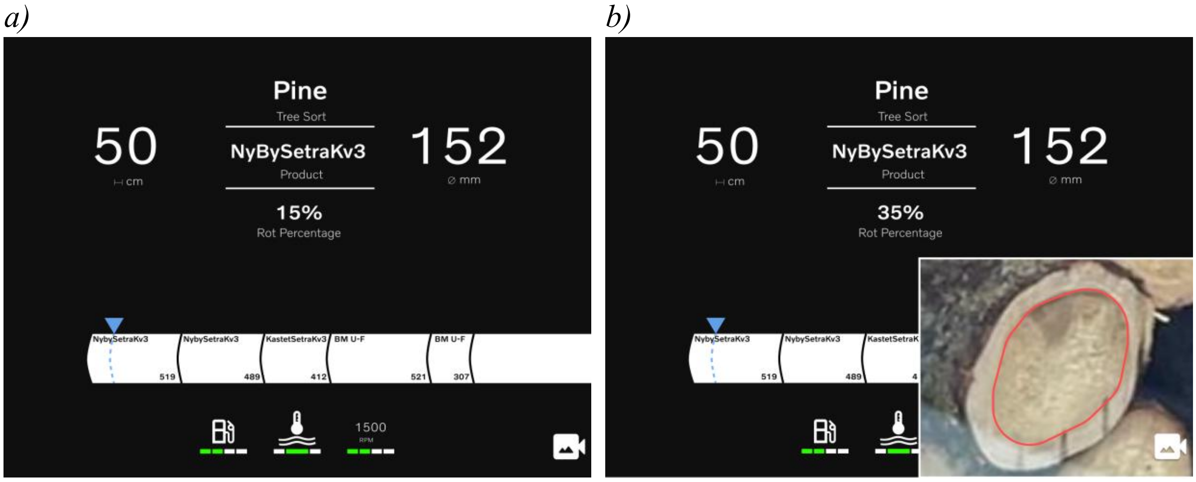


Figure 48. Refined cross-section concepts placed on the main display:

a) screen before opening cross-section view b) screen with small cross-section view

Figure 49. Four different ways of marking rot in the cross-section view.

6.5.3 Light Concepts

Since the users were positive towards using light to help with rot detection, new light concepts were created, see Figure 50 and Figure 51. The first concept, Figure 50, has a new placement of the previous lamp, which is now on top of the front display, and it lights up when rot is detected. The second concept, see Figure 51, is similar to the previous concept with a light stripe on the screen that shows up when rot is detected, but it now explores more possible placements for it.

The main insights from the user evaluations were that the light should not be mistaken for a warning light, which resulted in the new placement of the lamp for rot detection, see Figure 50, and in the placement of the strip on the screen, see Figure 51. The new placement of the lamp was motivated by previous literature studies which showed that the operators tend to focus their eyesight, if not through the windshield, on top of the front display. Multiple placements of the strip on the screen were made to reflect on where it should be placed to minimize the risk of it overshadowing other important information or features.

Figure 50. Refined light concepts where a glowing lamp is placed on top of the main display.

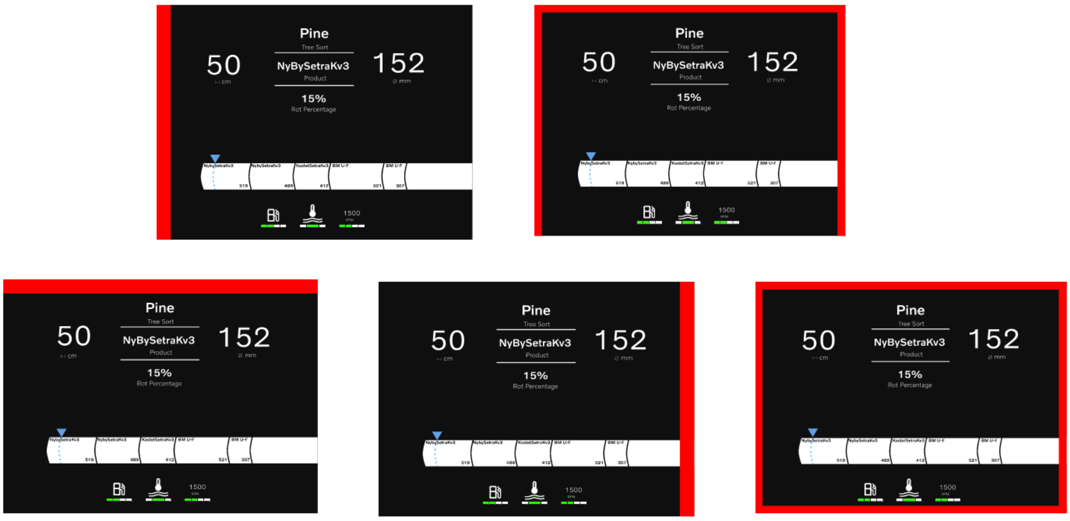


Figure 51. Refined light concepts where a light stripe is placed on the screen to indicate rot. The figure presents different placements of the stripe.

6.6 Concept Evaluation – Refined Concepts

This section presents the results from a second round of user evaluation conducted through interviews, where user input formed the foundation for the final design.

6.6.1 Bucking Assistance Concepts

The users expressed overall satisfaction with receiving bucking suggestions for rotten trees. The interviewed expert emphasized that such support would result in significant time savings. All three interviewees appreciated the concepts where the depth of the rot was displayed and where the rotten section was marked in red. One participant preferred the red marking, as it clearly indicated the necessary information. The two other participants preferred the rot visualization, as it gave them greater control over the cutting decision by allowing them to decide how much to cut beyond the suggested point.

The expert also highlighted that the accuracy of the bucking suggestion is critical for building trust in the system. An error margin of three to five centimeters was considered acceptable; however, larger deviations would reduce trust.

Two users preferred to see only a limited number of future cuts, whereas one expressed a desire to see all future cuts, if possible. Displaying only some future cuts enabled participants to focus more clearly on the current product and its length, and they did not find it relevant to visualize future cuts. Some users suggested that the interface could focus more on the current cutting position to improve clarity.

None of the users preferred the concept featuring a more realistic tree representation. However, one user noted that a realistic model could be of interest if additional information, such as crookedness or branch distribution, were included.

6.6.2 Cross-section View Concepts

The users agreed that the cross-section view should preferably be displayed on the reversing camera screen. This placement allowed all bucking-related information to be viewed simultaneously while examining the cross-section view. In contrast, the concept where the cross section could be displayed as a pop-up was perceived as potentially hiding relevant information. However, some users noted that having the option to display the cross-section as a pop-up could be useful, as the bucking suggestion already provides essential information about the cut length. The ability to view the cross-section and see how the system had marked the rotten areas was described as providing a sense of control and enabling the users to "double-check" the decision.

Regarding the visualization of rot in the cross-sectional view, all users preferred the rotten areas to be indicated using an outlined stroke rather than a filled area. This approach allowed the entire cross section to remain visible, which was perceived as providing greater control. One user preferred the rot percentage to be displayed in the center of the cross-section, whereas the other two preferred this information to be shown on the bucking suggestion screen, as displaying it within the cross section could obstruct visibility. Overall, the users appreciated the ability to view the cross-section, particularly in situations where visibility from the cockpit was limited.

6.6.3 Light Concepts

From the evaluation with the users regarding the refined concepts, it was found that using light to visualize rot would be appreciated. The main usage of lights would be rot detection, it should notify the user to pay more attention to the current log since it contains rot. One of the users said, "It would be highly valuable to get a light notification when rot appears, since it would save us a lot of time". However, the users preferred a combination of the light concepts and other concepts, since they saw a higher value in the combination of concepts instead of only using light. The users also mentioned using auditory feedback as a complement to the light, notifying the operator further about the detected rot, and allowing them to keep their sight on the work.

The users deemed both the presented options, either a red stripe on the screen or a lamp on top of the display, useful. The only light configurations that users expressed negative responses toward were those in which the light stripe was placed along the sides of the display, as it was perceived to be difficult to notice. Users instead preferred configurations where the stripe was positioned at the top of the screen or surrounded the display, as these placements were considered more noticeable.

Nevertheless, the users addressed a few concerns about the visualization with light concepts, one of them being its visibility. Depending on the outdoor conditions such as, sunlight or darkness, the light could be hard to detect or become too bright. To use lights for rot detection, the light therefore needs to be adjustable to the users' liking and the outdoor conditions. The lights also need to be visible from the operators' peripheral sight, since they need to stay focused on the work task. One user mentioned a concern of misinterpretation of the red light, since it could be confused with other warning signals of the machine, and the light therefore needs to be easy to distinguish from other functions.

7. Final Design

The project resulted in a final design that demonstrates how bucking assistance can be extended to support both healthy and rotten trees, with a strong emphasis on usability and decision support. The design is grounded in findings from the conducted user studies, which identified limitations in current bucking systems and highlighted opportunities to reduce operator workload and increase confidence when handling rotten trees. The final design concept, including its interface, is presented in the following sections and illustrated in the context of a harvester cockpit in Figure 52.

Figure 52. Final design in context of a harvester cockpit. It includes the features of a bucking assistance interface, a LED light for detection of rot and a cross-section view.

The final design provides bucking assistance that works for both healthy and rotten trees, representing a novel approach compared to existing solutions on the market. The solution integrates underlying rot detection techniques with a user-centered bucking assistance interface, including a LED light for feedback and a cross-sectional view of the log. In addition, the interface can be customized by the operator based on individual needs. The design can be used both for rotten and normal trees, and the interface for normal trees can be seen in Figure 53.

Figure 53. The final design interface when bucking a normal tree. The logs are blue and no rot is visible on the screen.

The design aims to support both novice and experienced operators by making the handling of rotten trees as efficient as healthy trees. By reducing complexity and uncertainty during bucking, the solution has the potential to save time for the operator, which may in turn reduce operational costs and machine ground pressure, thereby contributing to more sustainable forestry operations.

This potential was supported by the final evaluation round, in which all three users expressed a highly positive perception of the concept and stated that it would be useful for them. One expert commented: “Wow, I’d say that’s enormously useful. It’s almost an ideal scenario, if that were really the case.”

This chapter presents the bucking assistance system in detail, covering the following components: rot detection techniques, the bucking assistance interface, the cross-section view feature, the LED light feedback, and interface personalization.

7.1 Rot-detection Technique

The final design comprises both rot detection techniques and information presentation through an operator interface. The detection approach includes a camera mounted on the cutting head, measurements of saw efficiency, and vibration analysis through the log, see Section 6.3.3 . Among these, the camera on the cutting head is mandatory in the final design, as it enables assistance through a cross-sectional view of the log. The camera utilizes image recognition and algorithmic processing to detect rot and estimate its depth. In combination with the cutting-head camera, one or both of the techniques, saw efficiency measurement and vibration analysis, can be applied to increase the reliability of rot detection.

7.2 Bucking Assistance Interface

The main contribution of the final design is that the bucking system supports both healthy and rotten trees. The red part of the log represents rot, while the blue part represents healthy wood, as shown in Figure 54. This functionality reduces the operator's workload by eliminating several manual tasks, including assessing the presence of rot, estimating its depth, and determining appropriate cutting points, in accordance with Jordan's consideration of user resources. Through the bucking assistance, the operator is provided with a predicted rot depth and a recommended cutting length, enabling cuts that minimize material loss from cutting too long as well as avoiding unnecessary additional cuts. This assistance is estimated by experts to save approximately five to ten seconds per rotten tree, which accumulates to a substantial time saving over an entire work shift.

The bucking assistance is designed to closely resemble conventional bucking systems in order to maintain operator familiarity and comfort, consistent with Jordan's design principles of compatibility and appropriate technology transfer. On the left side of the interface, the distance from the end of the log to where the cutting head is gripped is displayed, see Figure 55. The current diameter of the log, as gripped by the cutting head, is presented to the right. As length and diameter are the most frequently consulted information by users, these elements are given greater visual emphasis, consistent with Jordan's prioritization design principle. In the center of the interface, information regarding tree species, product name, and rot percentage is shown, see Figure 55. The display of rot percentage is not included in current bucking systems, however, it was highly requested by the operators, as it supports decision-making regarding product classification and assortment selection.

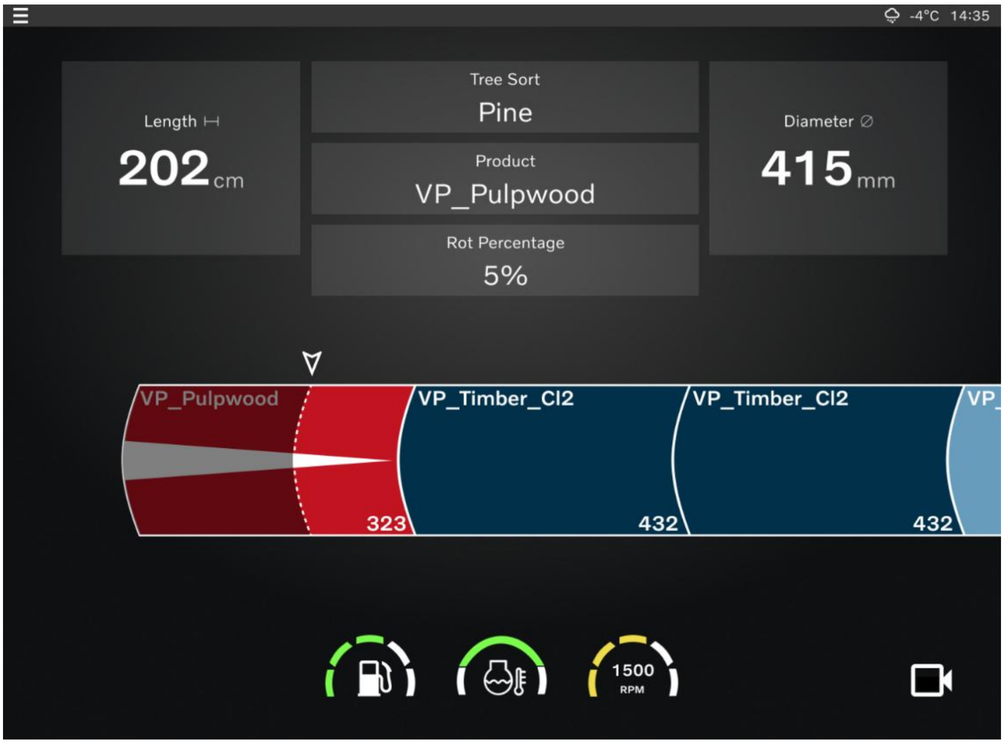


Figure 54. Bucking system interface where rot is detected in the log.

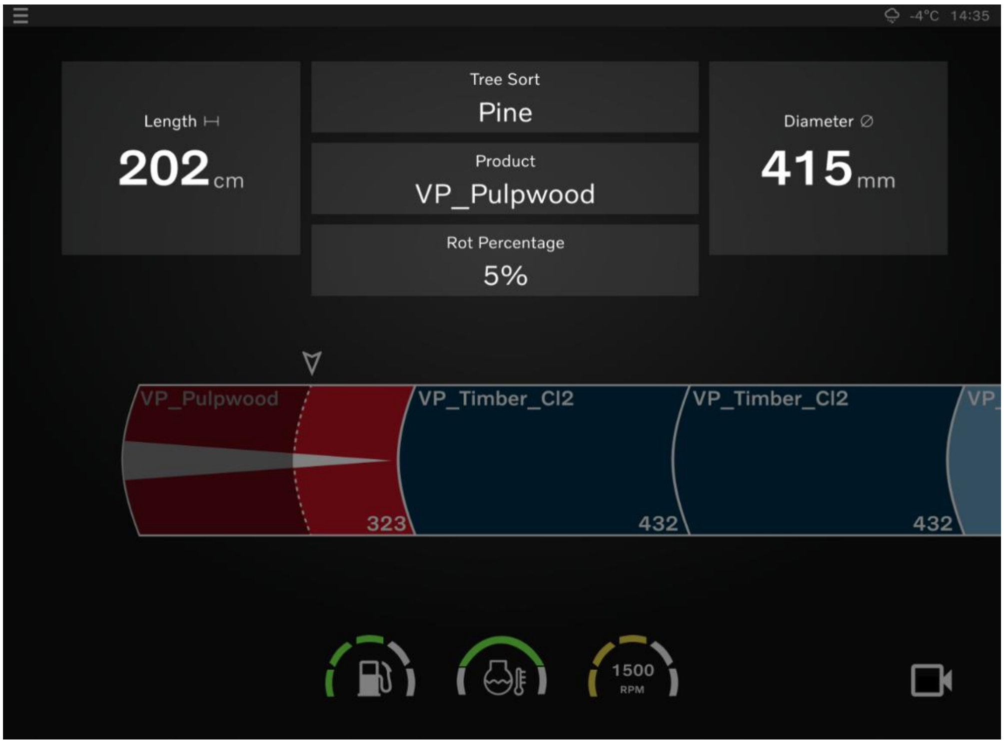


Figure 55. Bucking system interface information. The presented information is length, diameter, tree sort, product and rot percentage.

For each log, the system provides a suggested cut, marked by a white stripe, see Figure 56. Text above in the log indicates the product name, while the suggested cutting length is displayed beneath it. Rotten logs are clearly indicated using a red color, accompanied by a visual marker representing the estimated depth of the rot. Red was chosen due to its strong association with warnings and its high visual noticeability.

Figure 56. Graphical log representation in the bucking system showing suggested cuts.

The visualized rot does not represent the exact shape of the rot within the tree, as current technology does not allow for complete form reconstruction. Nevertheless, operators expressed a preference for seeing the estimated rot depth even with limited shape accuracy, as this provided a sense of control and allowed them to choose whether to cut closer to or further from the suggested cut. The system includes a safety margin beyond the predicted rot depth to account for uncertainty. Future technological developments may enable full visualization of the rot shape.

When the operator initiates a cut at the suggested position, the interface provides visual feedback by displaying an arrow progressing through the log, see Figure 57. Continuous feedback is provided throughout the cutting process, and a clear completion indicator is displayed once the cut is fully executed, represented as 100% completion, consistent with Jordan's feedback design principle, see Figure 57.

a) b)

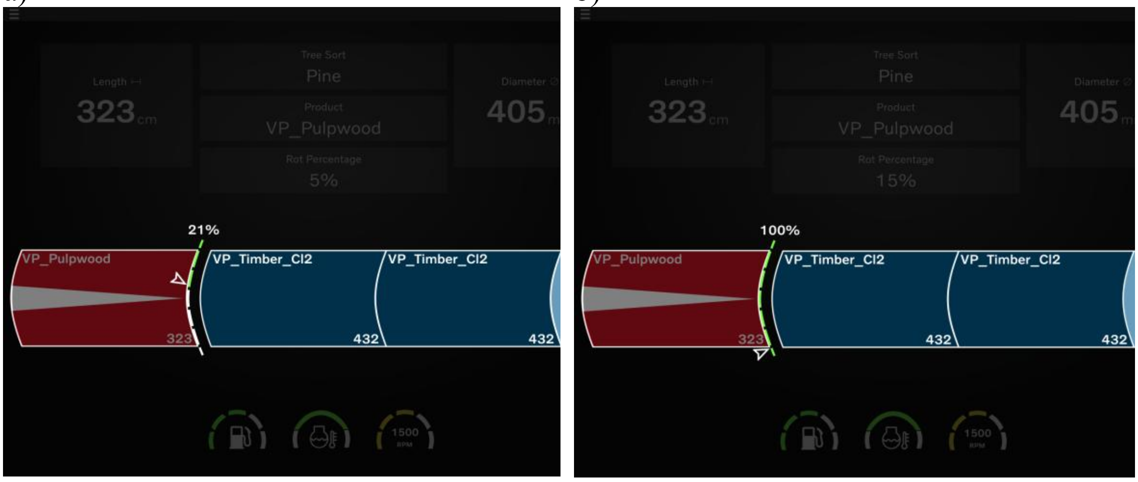


Figure 57. Cutting progress displayed in the bucking interface:
a) displays 21%   b) displays 100%

7.3 Cross-section View

For the final design, a cross-section view, see Figure 58, was chosen to be included based on user evaluations. The cross-section view will show the cross-section of the tree that is being cut to help the user identify and classify the rot. To help the user spot the rot, a red dotted marking will be placed on the spotted rot by the machine. The red dotted marking was chosen since the users liked that it helped them with noticing the rot by highlighting it, and that it did not cover the view. The users liked that they, with the help of the cross-section view, could make their own decisions regarding the rotten tree based on a better overview of it, which aligns well with Jordan's user control design principle. By providing footage of the tree's cross-section, the operator also saves time in their work, since they do not have to turn the tree to be able to look at the cross-section for rot detection.

Figure 58. Full screen cross-section view on the main display. The red circle marks the rotten part of the log.

The cross-section view can be displayed either on the main display in front of the operator, see Figure 59(a), or on the reversing camera, if the machine has one, see Figure 59(b). The option to display the cross-section view on the reversing camera was selected, as it was well received by the operators. They appreciated being able to retain access to all information on the main display while simultaneously viewing the cross-section, enabling them to monitor both perspectives at the same time. The reversing camera is not used when cutting the trees, which allows it to switch between the cross-section and the reversing view when needed. Using the existing reversing camera is therefore both user friendly and sustainable since it does not require any new screens. When the machine does not have a reversing camera, the user is still able to use the cross-section view by tapping the camera icon on the main display, see Figure 60.

a) b)

Figure 59. Full screen cross-section view: a) on main display b) on reversing camera display

Figure 60. Camera icon located in the bottom right corner of the screen, providing access to the cross-section view.

When accessing the cross-section footage on the main display, the user is presented with two options. They can either have the cross-section view smaller on a part of their display, see Figure 61, or change it into full-screen mode, see Figure 58. Allowing the user to choose the size and placement of the view makes the design adjustable to the users' different needs, which also was something that was requested by them, since every operator has different preferences.

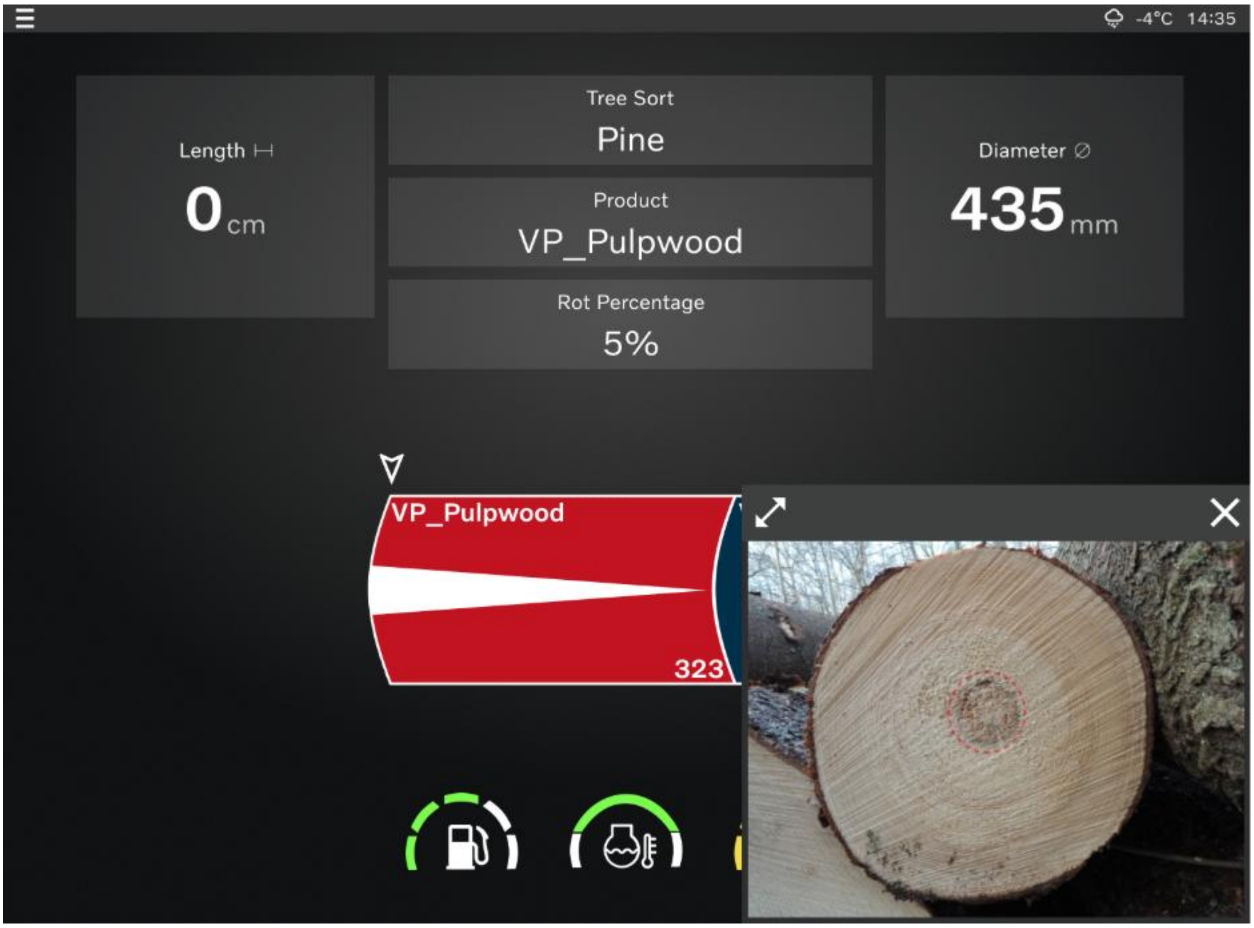


Figure 61. Small cross-section view that appears when pressing the camera icon on the main display.

7.4 LED Light

To complement the bucking and the cross-section view, a LED light was added to the top of the main screen, see Figure 62. The LED light complements the other features since its main purpose is to catch the attention of the operator, to inform them that there is rot in the tree that they are cutting and that they can use either the cross-section view, the bucking assistance, or both to help with the bucking and sorting. The LED light glows red when rot is detected in the tree, and the brightness of the light can be adjusted through the machine's main display.

Figure 62. LED light to detect rot that is placed on top of the main display in the harvester.

Users valued the possibility to adjust brightness, as harvesters are operated in varying weather and lighting conditions. Therefore, the brightness level needs to be adaptable, for example when operating in darkness compared to sunny conditions. The placement of the LED light, on top of the main display, was chosen since it allows the operator to see it peripherally, and still stay focused on the work in front of them. Placing the LED light above the screen, rather than on the screen itself, was intended to ensure that the on-screen information was not obstructed or compromised. Red was selected as the LED light color, as it is commonly associated with warnings or danger, making it more likely to attract the user's attention and prompt a timely response.

7.5 Personalization

Since all harvester operators are different and have different preferences for how they work, customization and personalization of the interfaces were therefore highly requested. One of the personalization features that was added was the adjustable taskbar, see Figure 63. The user can, with the help of the settings menu, see Figure 64, customize their own taskbar, and add or remove information from it. By allowing the user to design their own taskbar, they can continue with their way of working seamlessly and become more efficient at what they do.

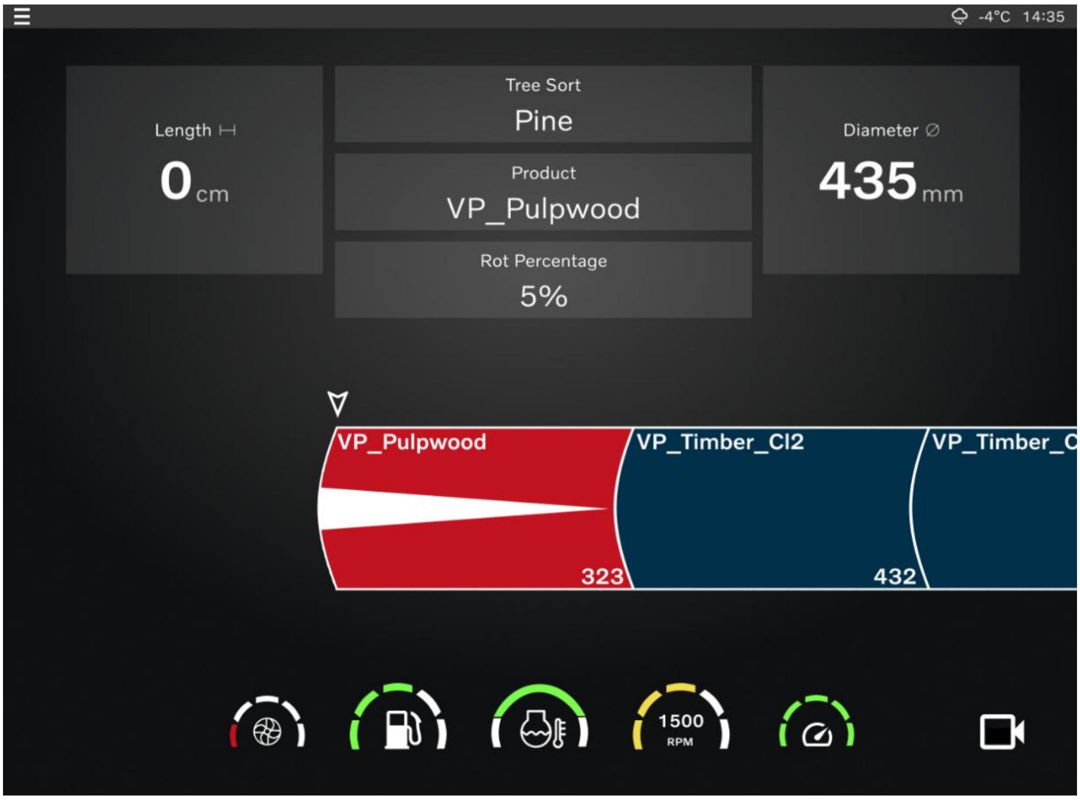


Figure 63. Personalized taskbar, at the bottom of the screen, with more presented information.

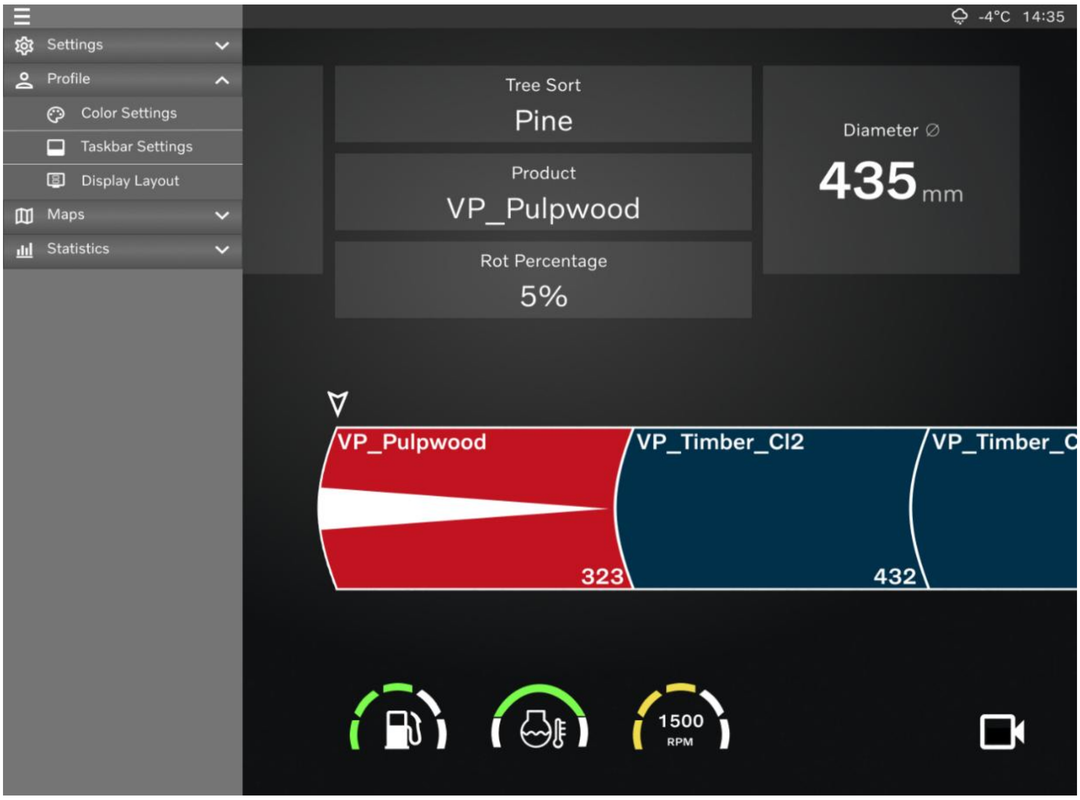


Figure 64. The settings menus, placed on the left of the screen, for personalized features.

Another personalization feature that was added was the customization of the coloring of the displayed log, see Figure 65. The user can use the settings menu to change the color of the log and the different timber segments that it represents to their own liking. Providing a choice for the coloring of the log and the different segments of timber will make sure that the presented information will be clearer to the user, since they have selected their own coloring system. The user can choose to have different colors for different segments, different kinds of tree sorts, or combine the two. To be able to select your own coloring scheme also benefits the user from a physical ergonomics perspective, since it allows them to adjust it to their eyesight.

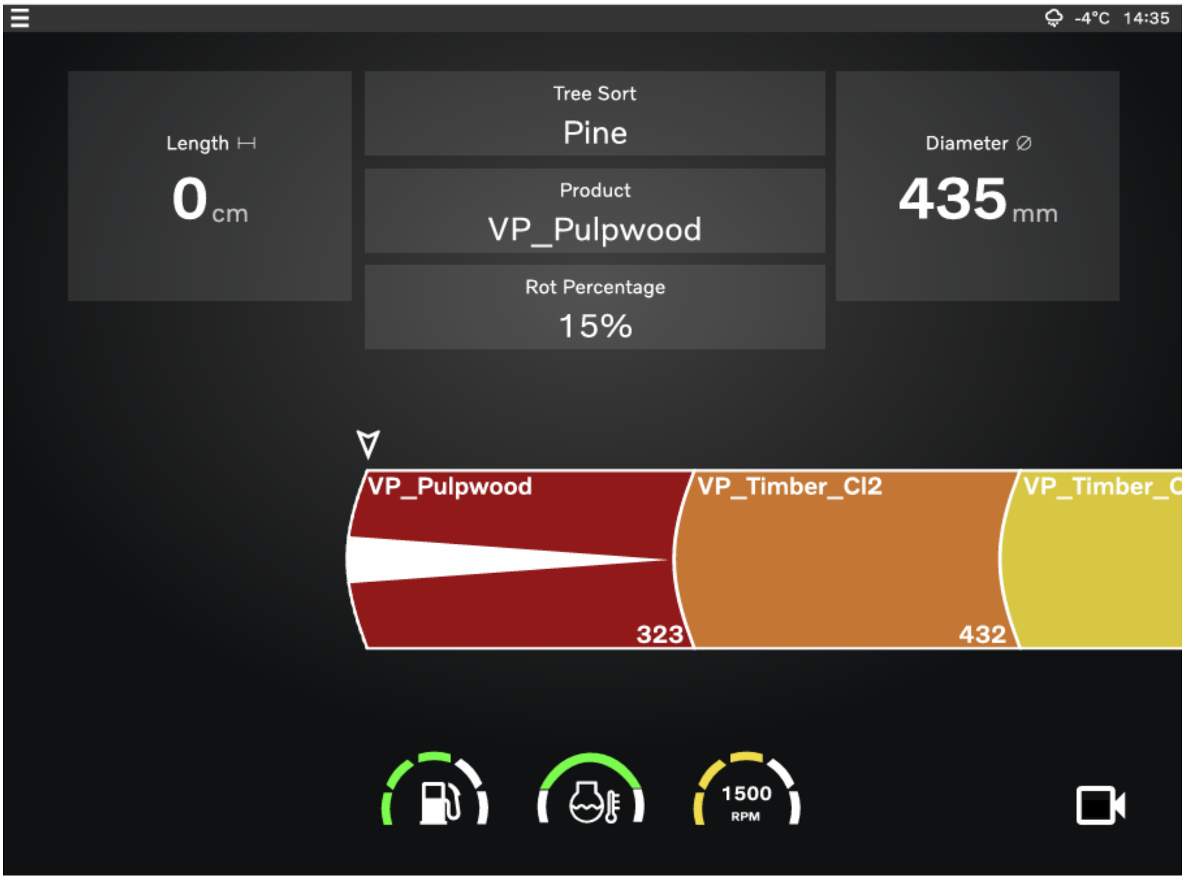


Figure 65. A log with a personalized color scheme, where each color represents a different segment of timber.

The user can also adjust the layout of the designed interface to their liking, see Figure 66. By using the settings menu, see Figure 64, the user can move around the features of the interface to fit their preferences. A personalized layout will ease the workload of the user since it helps them locate information faster and therefore also make their work more efficient.

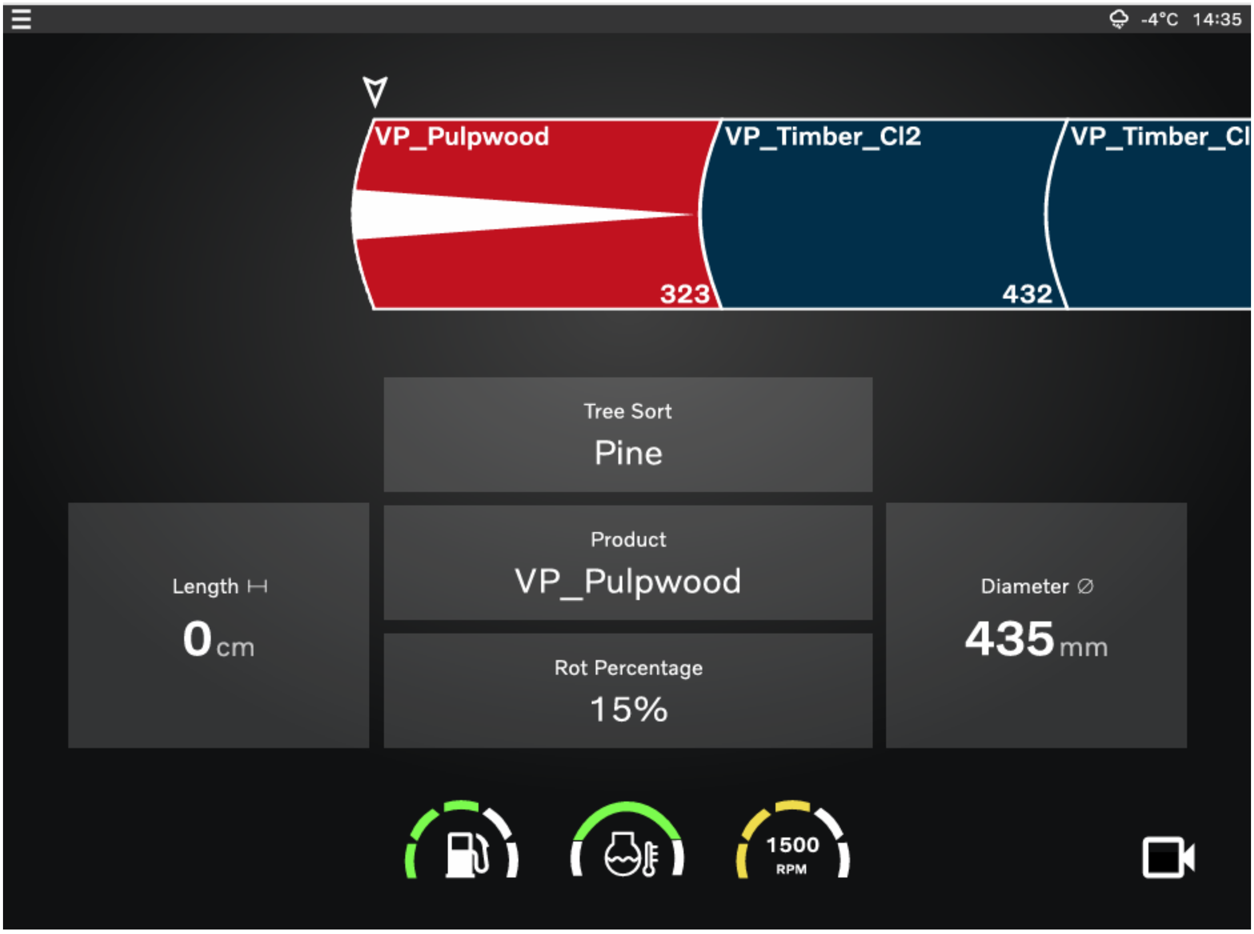


Figure 66. One example of a personalized layout.

8. Discussion

This chapter will cover the discussion of the thesis work. The discussion will reflect upon the quality of the project based on objective and purpose, work processes, final design, and future development of the final design.

8.1 Objective and Purpose

Considering the results of this study, the objective and purpose of this thesis can be considered fulfilled. A design concept that helps the harvester operators detect, and handle rot has been developed, which answers the main question of the thesis, "*What solution can help harvester operators to more easily detect and handle rotten trees*?". By using techniques for detection, see Section 6.3.3, and informing the operator about the detected rot with light, cross-sections, and then providing them with a bucking assistance tool, the result can be considered successful and the objectives and purpose met.

Looking into the subordinate questions, starting with "*What differs between the novice harvester operator and the expert regarding decision making when operating a harvester*?, this question can also be considered answered successfully. The result, see Section 6.1.2, shows that from the user studies, certain traits, such as tacit knowledge and handling of abnormal trees and rotten trees are areas where the decision-making differs between a novice and an expert when operating a harvester.

Addressing the second question, "*What tools can be used to help the harvester operator detect and make decisions regarding rotten trees?*", the tool in question is the final design concept, presented in Chapter 7. The tools that can be used to help the harvester operator detect and make decisions regarding rotten trees with the help of a combined detection and information system, which notifies the operator about rot and gives them bucking and sorting suggestions through an interface. Therefore, this question can be considered successfully answered as well.

The final question that was raised was "*How can information regarding rotten trees be presented to the harvester operator without disturbing their work?*", the answer to which can be found in the designed interface, explained in Chapter 7. By integrating a bucking assistance tool into a design which resembles existing interfaces and allowing the users to customize their interface, the information regarding rotten trees will be presented to the operator without disturbing their work.

8.2 Work Process

In this section, the work process of this thesis, the process, the methods, the user studies, and the company collaboration will be discussed.

8.2.1 Process

The chosen process for this project followed a structure of a product development process, where the project used iterations of the different phases and consultations with the users throughout the entire project. Using different phases for data collection, analysis and definition, concept development, concept evaluation, and finalizing the project was important to gain a structure for the thesis work. By setting up a clear structure, the project was guided in the right direction from the start, and iterations were allowed to take place without stress, which resulted in an extensive and thorough project. The user-centric focus of the process was highly valuable since it increased the value of the final concept. Designing with the users instead of for them made sure that the project focused on a relevant topic, added valuable insights throughout the process, as well as ensured that the produced concept was accepted by the users in the end.

8.2.2 Methods

There were several methods included in the process of this project, which in different ways have affected the results of the study. Overall, the chosen methods can be seen as suitable, since they allowed, helped, and guided exploration, ideation, and creation, which led to the final design. However, the importance of the different methods varied and in hindsight, alterations could have been made to evolve the result even further.

The literature research, benchmarking, starting interviews and observations, included in the data collection phase, were very important for gaining basic knowledge about forestry and harvesters. The first visits to the forest and the research papers about forestry allowed a solid foundation to build upon, and therefore these methods can be seen as very successful. However, since the research and study visits were made early in the project, the focus was more general, which it had to be. But once the scope was refined, the project could have benefited from more visits specifically focused on the refined scope of rot detection and handling of rotten trees to get even more detailed insight into the topic.

During the analysis and definition phase, methods such as a user journey, KJ-method, and requirements lists were used. Using a variety of methods to find the users' pain points and main improvement areas was very useful. The KJ-analysis together with the user journey helped successfully sort the insights from the user studies into categories which led to the refinement of the scope and later also the requirements list. The requirements list, however, could have been done differently. Since the project's aim was not to develop a finished product, the set requirements were hard to test and were not tested, and the project could in hindsight have benefited from complementary guidelines instead.

The ideation, idea evaluation, and concept creation during the concept development phase can be seen as successful since it resulted in many unique ideas that then could be turned into different concepts. Having participants in the ideation and idea evaluation from different fields of expertise was one of the factors why it can be considered successful. The diverse background of the participants resulted in a broader range of ideas and critical thinking from different perspectives during the evaluation. One improvement that could have been made to the concept development phase is the inclusion of harvester operators when ideating. Including the harvester operators would have added another perspective to the ideas that could have refined them even more. However, since the operators often work in remote areas, it would be very time-consuming and difficult to find participants, which is why it was not done.

The results gained from the evaluation interviews and surveys, in the concept evaluation phase, clarified the users' perspective on the different concepts. The evaluation phase highlighted the strengths and weaknesses of the concepts and allowed for further development, which is why the methods used in this phase can be considered successful. To strengthen this phase further, another loop of evaluation could have been conducted on the final concept to adjust it even more to the users' needs. However, considering the time available for this project, the methods used within this phase could be considered sufficient.

The final part of the project, finalizing concept, included the design of a prototype of the concept in Figma with different frames. The designed prototype allows for a good overview and clear representation of the final design concept, which strengthens the results of the study. However, further strength to the result could be added by making a functional prototype and conducting user testing in a real context. By testing a functional prototype in a real context, more insight could be given from the users, and the concept could be refined even further. But the designed prototype can still provide a solid design foundation for a future product and interface, which strengthens the methods and results of this study.

8.2.3 User Studies

There were multiple user studies carried out through the project, both to gain insights into the forestry area but also to evaluate and generate ideas and concepts. How the user studies were structured and which users who participated have highly influenced this project since it is a project that is based on user centric design.

Participants

During the user studies a total of ten users participated in the observations and interviews, where six of them are considered experts and four novices. The users were selected based on convenience sampling, since it can be difficult to find expert and novice harvester operators. Selecting users based on accessibility can highly influence the result since they might not represent the entire user group. The users might also then have similar opinions since they were reached through connections of other harvester operators, which then could steer the final design in a direction related to their beliefs.

However, in addition to the carried-out interviews and observations, two surveys were sent out, which reached 18 independent operators. The answers from the surveys, most of the time, confirmed the insights from the interviews, which makes the result from the other user studies more reliable, even if the participants were selected based on accessibility. On the other hand, surveys cannot be considered as informative and reliable as in-person interviews and observations, which is why the opinions from the in-person user studies were valued higher throughout the project. The surveys were also only carried out in connection to the user evaluation, which means that they cannot confirm or deny the results from earlier interviews or observations.

To conclude, there could be a bias that affects the result of the study due to the selection of users for participation. However, ten users can be considered a large number of experts and novices within the field of harvester operators and that, in combination with the 18 respondents in the surveys, should be enough to guarantee reliability and credibility within the results from the user studies.

Methods of User Studies

When the user studies were carried out, they were conducted in different ways. Semi-structured interviews and observations were conducted with pre-determined questions and explanations. The structure of the user studies, the explanations of the concepts, and the questions that were asked could have affected the result, since they can be interpreted in different ways depending on how they are formulated and perceived by the users.

Using semi-structured interviews and observations allowed for openness among the users and helped with deepening the studies, since a lot of follow-up questions were asked. Nevertheless, since the interview or observation took different turns, depending on which follow-up questions were asked and how they were asked, some areas could have been overlooked or user opinions influenced. The influence of the questions asked, and the interviewers could have impacted the project's results.

During the evaluation of the concepts, there could also be a bias based on the questions asked and how well the different concepts were explained. The presentation and explanation of the different concepts were supposed to be on the same level of fidelity and detail, however, some concepts were more realistic and feasible than others, which made them easier to explain to the users. The concepts that were more realistic and feasible might then have been favored by the users since they were easier to grasp, which could affect the result of the project.

Another factor that could have affected the result, especially from the user evaluation, is the lack of a real functioning prototype. Due to the limited time of this project, no functioning prototypes were built and tested with the users, only a dynamic prototype and images with different views of the concepts. Using only images limits the users' ability to give feedback since they cannot interact with the concept, which might result in less accurate user feedback and a less user-friendly final design. Nevertheless, since most of the concepts were interfaces based on existing functions in the harvester, they could be considered easy to understand for the users. Since the concepts were recognizable and easy to understand, the image-based user evaluation can be considered sufficient and the result viable.

The influence of the set structure, fidelity of prototypes, explanations, and questions in the user studies is difficult to determine beforehand and could affect the results. Nevertheless, precautions were taken by executing multiple user studies with different users and different interviewers, to prevent bias and influence. Therefore, the result can be seen as viable even if parts could have been influenced by the execution of the user studies.

8.2.4 Collaboration with Industry

This master's thesis was conducted in collaboration with Volvo Penta. This collaboration influenced the project, as the company naturally aimed to derive value from the work. The project scope was broad at the outset, which allowed the project group a high degree of freedom in choosing areas of focus, something that proved beneficial. The collaboration with Volvo Penta also enabled additional opportunities, such as access to transportation, participation in field visits to Lantbruksskolan together with Volvo Penta staff, and support from experienced UX designers and human machine interface engineers. The company provided a high level of freedom and supported the research activities required for the project. In conclusion, the collaboration with Volvo Penta ultimately contributed more to the quality and possibilities of the master's thesis than it constrained or limited it.

8.3 Final Design

The final design has both strengths and limitations, which are discussed in this section.

Strengths

One of the main strengths of the final design is that the bucking assistance extends beyond a traditional interface. In addition to visual information, the solution incorporates a peripheral LED light that provides feedback without requiring the operator to shift visual attention away from the cutting head and the log. This allows the operator to remain focused on the cutting task while still receiving alerts when rot is detected in the log, providing a notification that informs the operator to consider alternative sorting decisions, based on the rot percentage.

Furthermore, the solution provides the operator with access to a cross-sectional view of the log through a camera mounted on the cutting head. This feature enhances transparency and user control by allowing the operator to see the same information as the system uses for decision support. As a result, the operator maintains authority over the cutting decision rather than passively relying on automated suggestions, which aligns with Jordan's design principle of user control.

The final design also aligns with Jordan's principles of compatibility and appropriate technology transfer, as it closely resembles existing bucking systems in both structure and interaction. Because bucking systems are already well established in forestry operations, the proposed solution builds on familiar practices rather than introducing a fundamental change. This level of compatibility reduces the learning effort and allows the system to be integrated into existing work practices without increasing task complexity. Instead, the added decision support has the potential to make bucking operations more efficient and less cognitively demanding. During the final evaluation round, all users demonstrated an immediate understanding of the concept when presented visually, indicating a high level of compatibility

Another strength of the solution is its support for individual differences among operators. As operators have varying preferences, the interface offers customization options, including adjustable information placement, color themes, and toolbar configuration. This flexibility increases the likelihood that the system can support a broad range of operator needs and preferences, thereby benefiting both novice and experienced users.

Finally, the proposed design is technically feasible, as it builds on technologies that are already available today, such as camera, image recognition, algorithm-based data processing, analysis of saw efficiency measurements, vibration analysis within the log, graphical interfaces, and LED lights. Rather than relying on fundamentally new technology, the primary challenge lies in integrating these components into existing cutting heads and machine systems in a coherent and reliable manner.

Limitations

The final design also has several limitations. One limitation is that the solution primarily relies on a single modality: visual feedback. From a cognitive ergonomics perspective, using multiple feedback modalities could help make the information clearer for the operator. For example, auditory feedback could complement visual information and support the operator. The potential benefits and risks of introducing multiple modalities require further investigation.

The concept relies on one or more rot detection techniques. While using multiple techniques may improve reliability, it is unclear whether all proposed methods are necessary or if a camera-based approach alone would be sufficient. This balance between system complexity and detection reliability should be further investigated.

Finally, the interface was not designed with full consideration of existing regulatory requirements and standards governing harvester interfaces. In a real-world context, such requirements influence which information must be presented and how it should be structured.

8.4 Future Development of the Final Design

If the final design is further developed, several aspects need to be considered. These aspects outline opportunities for improvement as well as necessary next steps and are discussed in the following subsections.

Real-context Testing

The final design has not yet been evaluated in its intended real-world operational context of a harvester cockpit in a forest environment. Conducting real-context testing is a crucial next step to assess how the solution performs during actual operation. Such testing would make it possible to evaluate whether operators appreciate the interface layout, color schemes, graphical log representation, LED feedback, and cross-section view under realistic conditions.

During the final interview round, one user expressed a need for larger representations of length and diameter, which could be further evaluated through real-context testing. In addition, real-context testing would provide insights into how the solution fits into daily work practices and supports operators during real harvesting task

Technological Aspects

As discussed earlier, the final design builds on existing technologies, including a camera, algorithm-based data processing, graphical interfaces, and LED lights. In addition, measurements of saw efficiency and vibrations within the log are proposed as detection techniques.

Further development should investigate how these technologies can be effectively combined and whether all detection techniques are required simultaneously or if some are redundant. Factors such as camera placement for an optimal viewing angle, sensor positioning for measuring saw efficiency, and the mounting of vibration sensors on the cutting head would need to be carefully evaluated and refined. Finding a balance between system durability and technical complexity remains an important area for further investigation.

Audio Feedback

The current design primarily relies on visual feedback. However, during user evaluations, some participants repeatedly expressed a desire for audio feedback in addition to visual cues. For example, when the LED light indicates rot by turning red, a corresponding sound could be used to notify the operator. This could enhance the solution by providing feedback through an additional channel, particularly in environments where visual cues may be harder to perceive, such as in bright sunlight.

Further investigation would be required to determine when audio feedback should be activated, its duration, the type of sound used, and whether such feedback should be customizable to suit individual operator preferences.

Personalization

The final design currently allows a limited degree of customization, such as adjusting log color themes, information layout, and the toolbar configuration. With further development, additional customization options could be introduced, including adjustable text sizes, background color themes, audio feedback settings, LED light color, and other interface parameters. As operators have different preferences and working styles, increased personalization could improve acceptance and usability across a wider range of users. During the final evaluation round, two users expressed a desire to control whether the cross-sectional view would appear automatically on the main screen or be accessed by clicking on the screen, in cases where the harvester did not have a reversing camera in which the cross-sectional view would automatically be displayed. The users explained that while some operators might prefer the view to be shown automatically, others might not want it to be displayed at all, highlighting the need for flexible customization options.

9. Conclusions

The aim of this project was to develop a user-friendly solution that eases the integration between operators and harvesters, in collaboration with Volvo Penta. The solution aims to support operators in the detection and handling of rotten trees and to bridge the gap between novice and expert operators. The developed solution should include tools to help with rot-related assessments and be possible to integrate into current ways of working with harvesters.

During the thesis, five phases were carried out, with a strong focus on user-centered design and user studies. From the empirical studies, it became clear that there is a significant difference in efficiency and effectiveness between experts and novices, especially within the handling and detection of rotten trees. Working as a harvester operator requires a high amount of focus and decision-making, which results in a high mental load placed on the user. Therefore, when designing for harvester operators, the design should ease the mental workload and be compatible with their current ways of working.

With the insights from the user studies, a design concept was created that includes rot detection and advice on the handling of the rot, with, for example through bucking assistance. By combining detection techniques with a user-friendly interface, this project indicates that the mental workload and the gap between novice and expert harvester operators can be reduced. The designed concept can also be viewed as a starting point for future development and exploration of the forestry segment at Volvo Penta. Future work could include developing a functional prototype and in-context evaluation.

This project has not only provided a design concept, but also an example of how a user-centric design approach can guide the project towards a more user-friendly design, by including the users in all parts of the project. Designing with and for the user has a clear impact, which can be concluded from this thesis.

The conclusion drawn can therefore be summarized in the following bullet points:

- From the empirical studies, it can be concluded that the difference between novices and expert harvester operators regarding knowledge is large, especially within detection and handling of rotten trees.
- A bucking assistance tool with an LED-light and a cross-section view can be a useful tool to improve efficiency and reduce mental workload for harvester operators. The tool would be appreciated by the users.
- Using a user-centric design process is important for generating a design with high relevance and user acceptance.

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Appendix A - Interview Templates

Two examples of interview templates, one for experts, and one for novices.

Interview template example expert:

Interview Template – Expert User

About you:

Name: Age: Date:

Education (years): Experience (years): OK to contact for follow-up questions:

About the work:

- Describe your work process.
- Weather conditions – how do they affect you? Windshield wipers? Frost on the window?
- How important is precise visibility? Squinting? (weather, dirty window, glasses)
- What do you find most difficult or challenging in your job?
- What is the most enjoyable part of your job?
- How do you know you've had a good day?
- What does the gender distribution look like?

Productivity:

- When do you feel most stressed during a shift?
- Does the job require a lot of multitasking (e.g., driving + planning + reading the screen)?
- Are there moments where it's easy to make mistakes?
- How does time pressure or production demands affect your way of working?

About the machine:

- What machine do you operate and what do you think about it?
- Have you tried different forest machines? Which has been your favorite and why?
- Built-in speakers:
- How often do you need to fix your machine? What usually breaks?

- Do you usually leave the machines outside or bring them home?
- How do you transport the machines?

Communication:

- How much do you collaborate with others (harvester/forwarder/planner)?
- How does communication work today?
- Are there situations where misunderstandings occur?
- Does the machine's system affect how well the collaboration works?

Safety:

- If something goes wrong, what do you do?
- What are the most common safety risks?
- Have you ever been in or close to a dangerous situation? What happened?
- Is there anything in the machine’s design that makes the work safer/less safe?
- How do you perceive warnings and alarms in the machine, clear or disruptive?
- Do you trust the machine’s safety systems? Why/why not?

UX questions:

- Is there an expert function/shortcut you use frequently?
- Is there any function that annoys you?
- Where would you place the backup camera if you could choose? (could it be placed on the side, higher up?)
- How easy is it to understand the machine’s menus and system?
- Are there functions you never use? Why?
- How often is the software updated, and how does the process work?
- Do you trust automatic functions (e.g., bucking, crane control)?
- Has technology made the job easier or more complex over time?
- How would you prefer information to be presented? Visually, sound, or contextual?
- If we removed your screen, how would it affect your work?

Ergonomics:

- Do vibrations affect how you read the screen and controls?
- Can you adjust the seat?

- Is there any muscle or part of the body that aches after one or more workdays?

Expert's perspective on beginners:

- How long did it take until you felt confident in the work?
- What is the biggest difference between when you were new and now?
- What do you think of newly graduated operators? What skills do they have and which are missing?
- If you were to hire a newly graduated operator, what qualities would you look for?
- Is there anything in the machines that could be better adapted for novices?
- How did you learn the job best? Education, practice, colleagues?
- What was the hardest thing to learn in the beginning?
- Is there something you wish someone had told you when you were new?
- How do new operators learn today compared to when you started?
- Which functions are important for all operators, regardless of experience?
- Which functions are used mostly by experts? And which are most important for beginnes?
- Which problems affect novices the most, and which affect experts?

Improvements:

- Is there anything you would like to improve in the cockpit?
- Any improvements you want for the machine overall?
- Anything you want to improve in your working conditions?

Future:

- How do you think the job will change in the next 5–10 years?
- What do you think will become automated?
- What will still require human experience?
- What would make the job more attractive for younger operators?
- If you had a magic wand, what would you change?

Other:

- What would you think about using games in your work? For example, a leaderboard to compare with others?
- If you could keep five functions, which would they be and why?

- If you had to remove five functions, which ones and why?

Interview template example novice:

Interview Template – Novice User

About you:

Name: Age: Date:

Education (years): Experience (years): OK to contact for follow-up questions:

About you:

- Why did you choose to study this?
- How did it feel the first time you entered the forest?
- What did the process look like when you first started working in the forest?
- What do you find the hardest/most challenging in your work?
- What is the most enjoyable part of your job?
- How do you know you've had a good day?
- What does the gender distribution look like?

About the education:

- What does the training look like? Curriculum? Timeline?
- Did you get any practical experience from the forest?
- How many new vs old tools do you use?
- How much simulator vs how much actual machines?
- Did you feel ready when you entered the forest?
- What are your expectations for the job?

UX - questions:

- Is there any function you use frequently?
- Is there any function you wish existed?
- Is there anything in the machines that could be better adapted for novices?
- Are there functions you never use and why?
- Do you trust automatic functions (e.g. bucking, crane control)?
- How do you prefer information to be presented? Visually, audio, or contextual?

- If we removed your screen, how would that affect your work?

Productivity:

- When do you feel most stressed during a work shift?
- Does the job require a lot of simultaneous thinking (e.g. driving + planning + reading the screen)?
- Are there moments where mistakes are easy to make?
- How does time pressure or production demands affect your way of working?

About the machine:

- What machine do you operate and what do you think about it?
- Have you tested different types of forest machines, and which has been your favorite and why?
- How often do you need to fix your machine? What usually breaks? How do you know what to do?

Communication:

- How much do you collaborate with others (harvester/forwarder/planner)?
- How does communication work today?
- Are there situations where misunderstandings occur?
- Does the machine's system affect how well collaboration works?

Safety:

- If something goes wrong, what do you do?
- What are the most common safety risks?
- Have you experienced or been close to a dangerous situation? What happened?
- Is there anything in the machine’s design that makes the work safer/less safe?
- How do you experience warnings and alarms in the machine? Are they clear or distracting?
- Do you trust the machine’s safety systems? Why/why not?

Improvements:

- Is there anything you would like to improve in the cockpit?
- Are there any improvements you would like to make to the machine overall?
- Is there anything you want to improve in your working conditions?

Future:

- How do you think the job will change in the next 5–10 years?
- What do you think will be automated away?
- What will still require human experience?
- What would make the job more attractive to younger operators?
- If you had a magic wand, what would you change?

Other:

- What would you think about using games in your work? For example, a leaderboard to compare with each other?
- If you could keep 5 functions, which would they be and why?
- If you had to lose five functions, which ones and why?

Appendix B - Evaluation Interview Template

Evaluation interview template 1 – The first round of evaluations

HUR VILL DU FÅ INFORMATION OM RÖTA?

Joystick- tröghet

Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

Joystick - vibrationer

Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

Ljusram

Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

Ljuslinje

Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

Lampa

Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

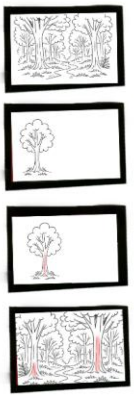
Genomskärning - kapat träd modell

Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

Genomskärning - kapat träd verklig bild

Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

Genomskärning - helt träd



Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

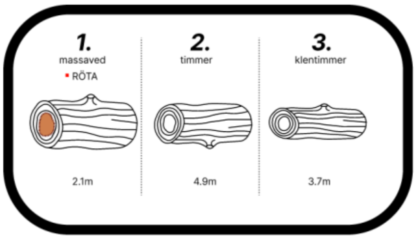
Apterings förslag - text & siffror

Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

Apteringsförslag - Highlighta befintlig layout

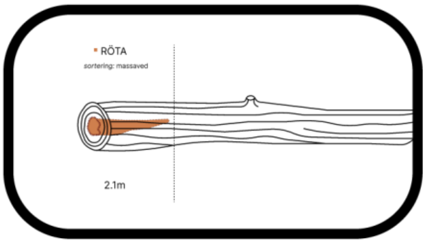
Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

Apterings förslag - 3D & Uppskuret



Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

Apterings förslag - 3D & synlig röta

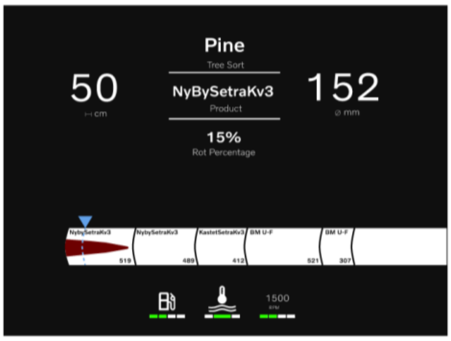


Hjälpsamt	○	○	○	○	○	Ohjälpsamt
Tidseffektivt	○	○	○	○	○	Icke tidseffektivt
Intuitivt	○	○	○	○	○	Komplicerat
Lätt att integrera	○	○	○	○	○	Svårt att integrera
Tillförlitligt	○	○	○	○	○	Opålitligt

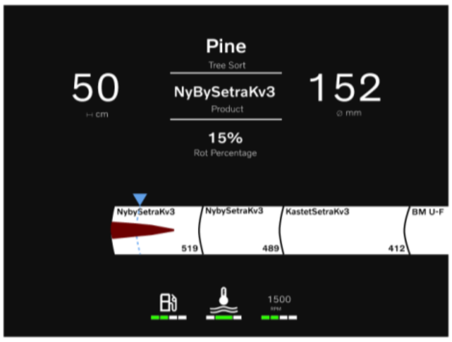
Evaluation interview template 2 – The second round of evaluations

Visualization of Log:

Stock med röta i

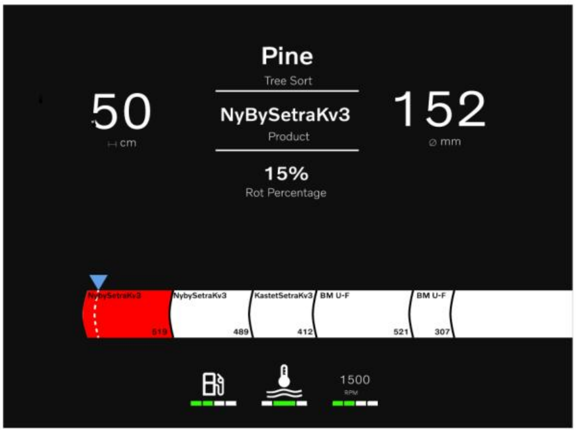


hela stocken synlig

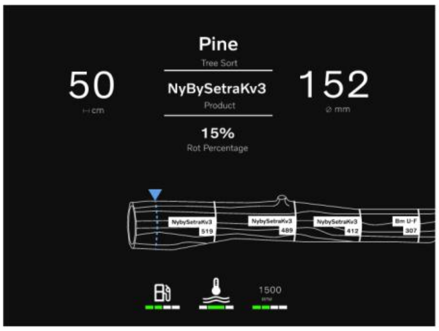


förstorad stock, hela stocken ej synlig

Röt-del blir röd



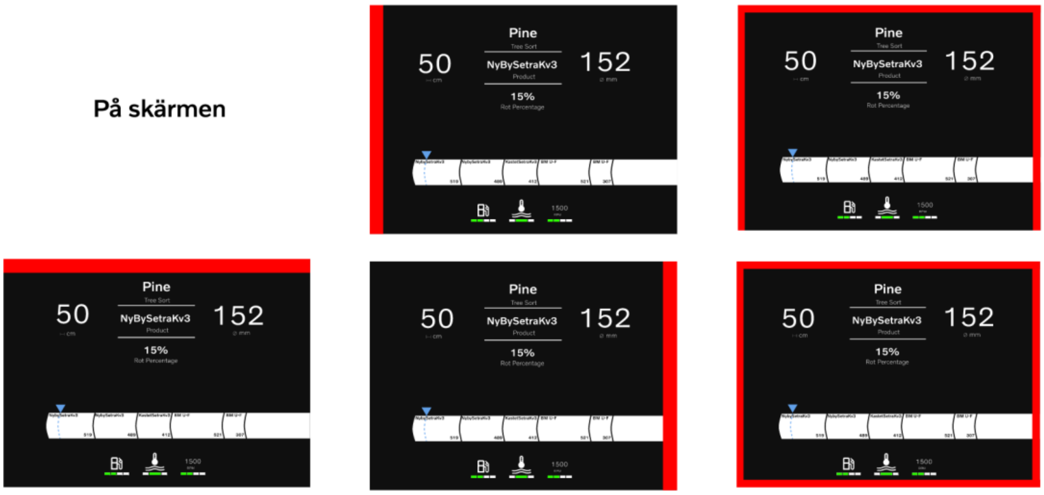
3D vy av trädet



Light Concepts:

Ovanpå skärmen

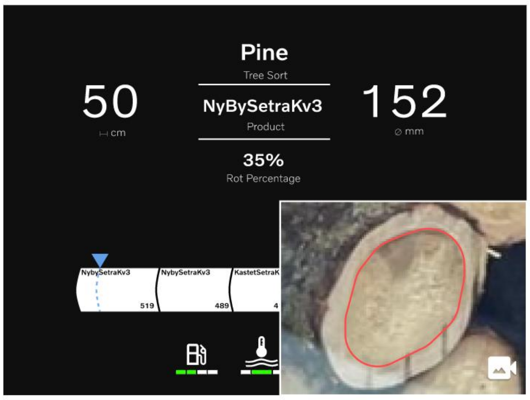
På skärmen



Cross-section View of Log:

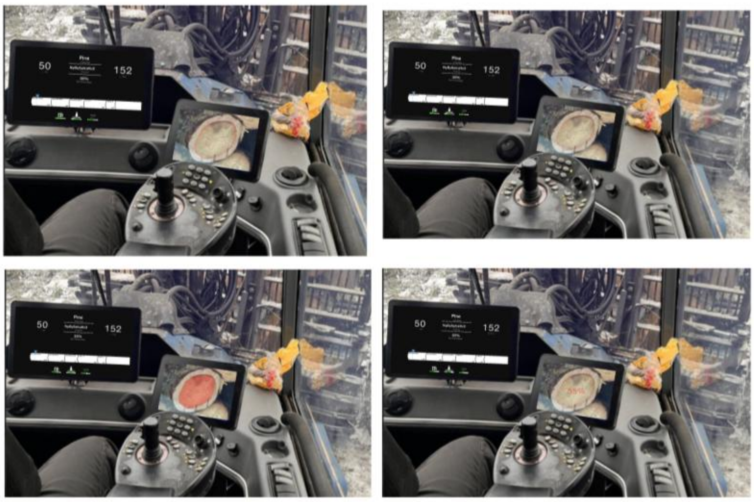
Egen skärm eller liten del av skärm?

kameravy på separat skärm

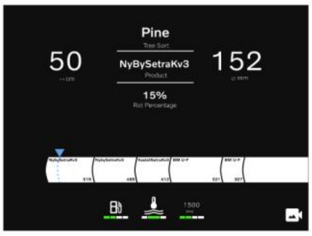


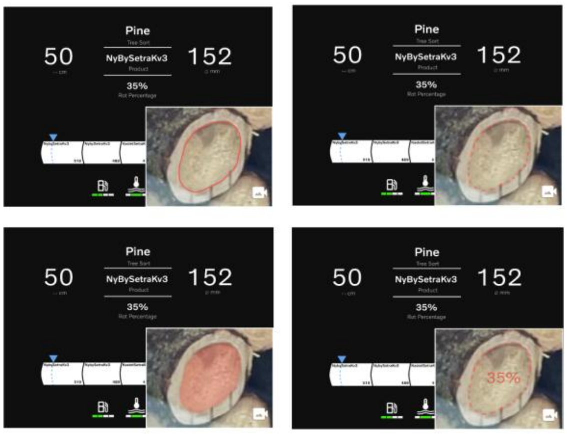
kameravy, kan klickas upp på skärmen

Visualisering av röta

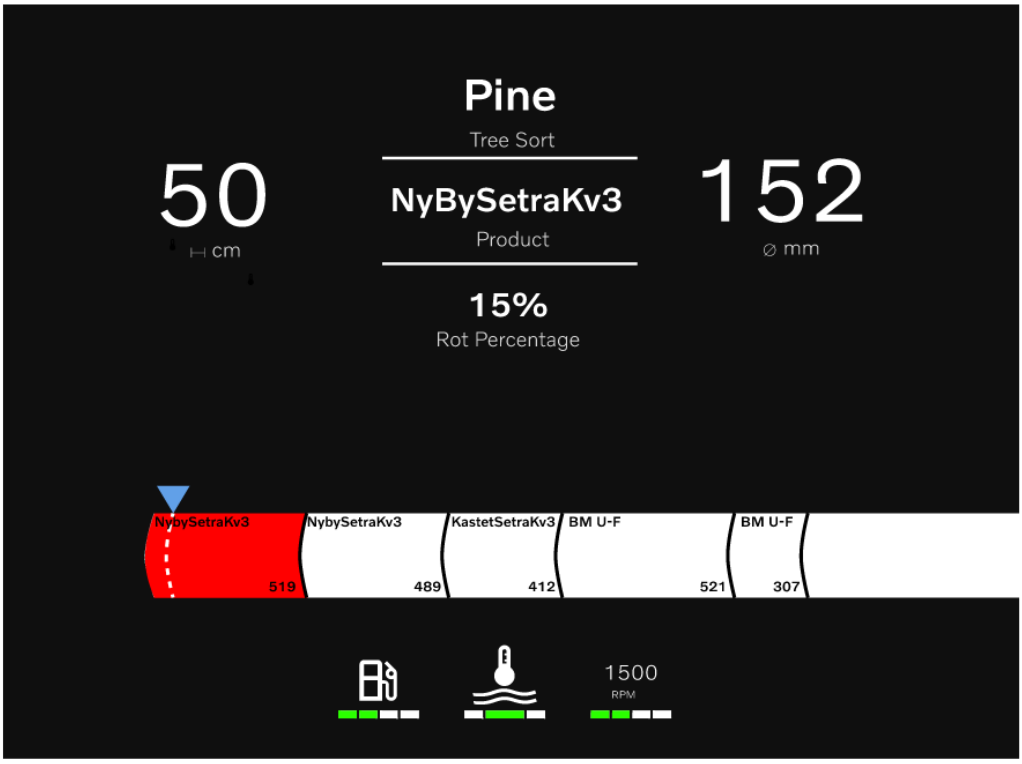


Visualisering av röta





Information Placement:



Appendix C – Evaluation Survey

The evaluation survey that was sent to the experts. The novice survey was the same except for the questions regarding previous experience.

Hjälp oss förenkla rötdetektionen i skördare!

Stort tack för att ni tar er tiden att fylla i detta formulär som tar max 10 min att fylla i. Vi är två Chalmersstudenter som skriver vårt exjobb på Teknisk design, där vi ska komma fram med ett koncept som förenklar detektionen av röta för skördarförare. Vi vill att lösningen ska vara lika lättanvändbar av nya i yrket som experter. Er input är så värdefull! Tack!

* Required

Fakta om röta

Vilken fakta är viktig att ha om röta? Saknas alternativ eller har du några kommentarer - skriv i kommentarsrutan! Du får gärna motivera dina svar om du har tid!

1

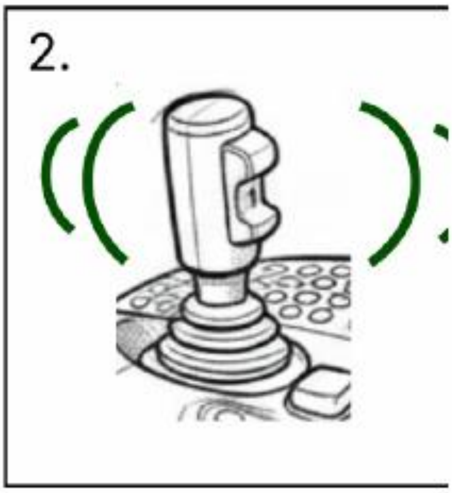
Vilken eller typer vilka data tycker du är viktiga att ha gällande röta i ett träd? (Välj ett eller flera alternativ) *

- ☐ Längd och diameter av rötan
- ☐ Sortiment av timmer baserat på röta
- ☐ Procent av röta
- ☐ Apteringsförslag
- ☐ Sort av röta
- ☐ Other

2

Kommentar:

Nedan presenteras två förslag som använder förstärkt känsel för att ge indikation om röta.
Alternativ 1: Vibrationer i joysticken
Alternativ 2: Ökad tröghet i joysticken



3

Hade du uppskattat förstärkt känsel i joysticken för information av röta? *

- ○ Ja
- ○ Nej

4

Om du var tvungen att välja, vilket förslag gillar du bäst? *

- ○ Alternativ 1: Vibrationer i joysticken
- ○ Alternativ 2: Ökad tröghet i joysticken

5

Kommentar:

Information genom ljus

Nedan presenteras tre förslag som använder ljus för att ge indikation om röta.
Alternativ 1: Ljusram runt vindrutan
Alternativ 2: Ljuslinje på skärmen
Alternativ 3: Lampa på fönsterbrädet

6

Hade du uppskattat ljus som indikation för röta? *

- ◯ Ja
- ◯ Nej

7

Ranka förslagen från mest givande till minst givande? (1=mest, 3=minst) *

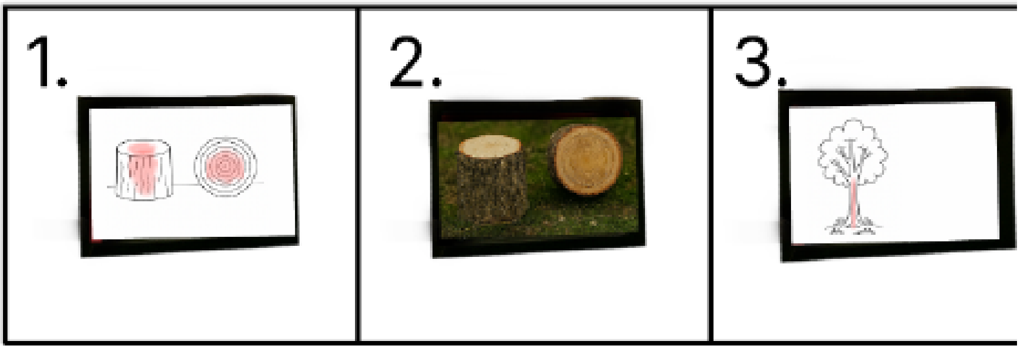
- Alternativ 1: Ljusram runt vindrutan
- Alternativ 2: Ljuslinje på skärmen
- Alternativ 3: Lampa på fönsterbrädet

8

Kommentar:

Information om genomskärning

Nedan presenteras två förslag som använder genomskärning för att ge indikation om röta.
Alternativ 1: Den kapade stubben och timret, visas i 3D modell
Alternativ 2: Den kapade stubben och timret, visas med verklig bild
Alternativ 3: Hela trädet visas i 3D modell



9

Hade du uppskattat genomskärningsvyer på skärmen för information om röta? *

- ○ Ja
- ○ Nej

10

Om du var tvungen att välja, vilket förslag gillar du bäst? *

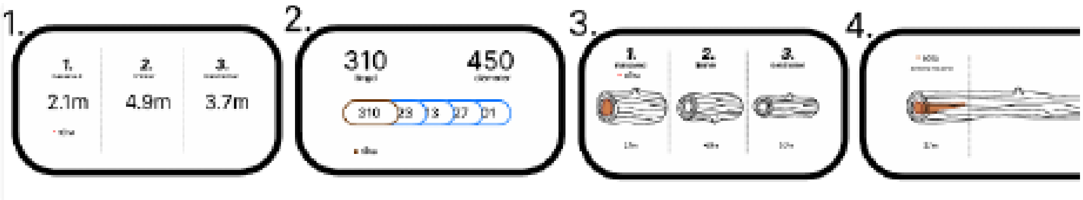
- Alternativ 1: Kapat träd, 3D modell
- Alternativ 2: Kapat träd, verklig bild
- Alternativ 3: Helt träd, 3D modell

11

Kommentar:

Aptering av träd med röta

Nedan presenteras fyra förslag för aptering av träd med röda.
Alternativ 1: Text & siffror
Alternativ 2: Visualisering befintlig aptering
Alternativ 3: 3D uppskurna stockar
Alternativ 4: 3D stock där rötan är synlig



12

Hade du uppskattat få apteringsstöd för träd med röta? *

- ◯ Ja
- ◯ Nej

13

Ranka förslagen från mest givande till minst givande? (1=mest, 4=minst) *

- Alternativ 1: Text & siffror
- Alternativ 2: Visualisering befintlig aptering
- Alternativ 3: 3D uppskurna stockar
- Alternativ 4: 3D stock där rötan är synlig

14

Kommentar:

Jämförelse av förslag

Nedan får du gärna ranka de olika förslagen baserat på hur väl de stämmer in på påståendet!

15

Jag tycker förslaget är användbart: *

	Håller med starkt	Håller med	Neutral	Håller inte med	Håller verkligen inte med
Känsel i joystick	○	○	○	○	○
Information med ljus	○	○	○	○	○
Information med genomskärning	○	○	○	○	○
Apteringsstöd	○	○	○	○	○

16

Kommentar:

Appendix D – User Journey with Pain Points

User Journey	1. Prepare for Shift	2. Prepare the Vehicle	3. Start the Vehicle	4. Drive to Tree	5. Scan the Tree	6. Fell the Tree	7. Decide where to Place the Timber	8. Cut the Tree	9. Log Information
Line of Action									
Measures	Check • Check the ground • Talk to colleagues • Check the weather Task execution • Look at the set map or placed markers • Talk to colleagues on the phone • Check the weather on the phone	Adjust the seat • Adjust the seat • Set the joystick settings • Adjust the settings for the controls • Adjust the settings for the cutting head • Download the forest map Task execution • Adjust the seat by manually entering all your personal settings • Set the machine settings either by selecting a profile (when available) or entering them manually • Download the map to the machine's screen	Planning • Plan the next tree to cut • Plan the positioning of the machine • Plan how to drive safely on the ground Task execution • Look around at the surrounding trees to decide which one to take next • Observe the trees, stones, ground conditions, and potential fall direction to determine where to place the machine and how much force will be needed • Check the map and terrain to assess soil conditions and choose a driving path that causes as little damage as possible	Planning • Plan the next tree to cut • Plan the positioning of the machine • Plan how to drive safely on the ground Task execution • Look around the surrounding trees to decide which one to take next • Observe the trees, stones, ground conditions, and potential fall direction to determine where to place the machine and how much force will be needed • Check the map and terrain to assess soil conditions and choose a driving path that causes the least possible damage	Detection • Look for crookedness • Look for double crowns • Look for buttress roots • Look for branches • Look for height • Look for thickness • Look for rot • Assess how the tree will fall • Decide how to cut it: direction and speed • Check the tree species Task execution • Visually scan the tree and assess its characteristics using experience and judgment • Consider wind, branch distribution, and tree placement to determine the fall direction • The screen assists with cutting guidance when the tree is "normal" and fits expected parameters	Inspection • Check the saw • Handle the fall • Check for rot Task execution • Check whether the saw is cutting correctly by observing its speed and cutting depth • Select the correct tree species using the joysticks • Scan for rot visually, for example by examining the freshly cut surface or the color of the sawdust	Planning • Decide where to place the tree • Decide where to place the branches for future paths Task execution • Assess the terrain and ground limitations using both your visual view and the screen • Decide where you want to drive later and plan the placements accordingly	What the operator checks • Check the diameter • Check the saw • Check the tree for rot • Decide on log bucking • Decide on log lengths • Decide where to place the logs: assortment and direction Task execution • Observe whether the saw is cutting correctly by monitoring its speed and cutting depth • Check the screen for diameter and length measurements • Plan, using experience, how the logs should be sorted, their direction, and their assortment • If the tree is normal, the machine automatically determines the cutting lengths; if not, the operator must decide manually • Scan for rot visually, for example by examining the freshly cut surface or the color of the sawdust	Enter and receive data • Enter information about volume • Enter information about tree species • Enter information about length • Check statistics from the day Task execution • Use the screen to enter today's work • Check how well the recorded data matches the set volume • Review the statistics on the screen
Pain Points	• Wrongly placed or missing markers Wrongly placed or missing markers can make it difficult for the operator to know what should be included in their work. This can lead to errors, such as cutting down the wrong trees, or create stress and a high cognitive load when the operator must determine where the ground limitations are on their own. • No weather indications in the machine There are no features in the machine that show current or upcoming weather conditions. The operator must rely on weather apps on their phone. Weather conditions can greatly influence the work, for example the wind direction when felling trees or the ground conditions when it rains.	• Time-consuming to enter settings Entering all required settings takes a long time and is difficult for the user to remember. This costs time and money and causes frustration, especially since operators often need to redo the process every day. • Poor ergonomics due to incorrect settings Because the settings take time to adjust, and because each operator has their own preferences, there is a risk of poor physical ergonomics if the settings are forgotten or set incorrectly. This may lead to physical strain and discomfort. • Higher risk of errors if the settings are incorrect Incorrect settings, for example crane speed, can make the operator unsure of how the crane will move. This can lead to mistakes, since different harvesting methods require different levels of precision and speed, and therefore different machine settings. • No reception when downloading the map The user may experience stress and frustration if they are unable to download the map due to poor reception, which can lead to delays in their work.	• Incorrect planning may cause route obstructions There are many decisions that need to be made regarding where to begin driving and how to progress. One wrong decision early in the process can create obstacles and lead to errors later on. Some machines offer support tools for this, while others do not. • High cognitive load due to many simultaneous decisions The operator must take many factors into account when planning. For a new user, this can cause significant stress and lead to fatigue due to the high cognitive load.	• Need for split focus The operator must think several trees ahead of the one they are currently working on. This reduces focus on the immediate task and increases cognitive load, which can lead to fatigue and decreased performance. • Risk of the tree falling on the machine If the machine is incorrectly positioned, the tree being cut may fall onto it, posing a significant safety risk for the operator. • Reduced machine force if positioned poorly The machine's effectiveness depends on its positioning. If it is unbalanced, its strength is reduced and the risk of tipping over increases. • Risk of getting stuck in the terrain Ground conditions can vary greatly. If the operator fails to account for this, the machine may get stuck, causing frustration and time loss. • Risk of hitting surroundings Driving in difficult terrain combined with poor rear-camera visibility reduces situational awareness. This can lead to collisions with surrounding objects, causing damage to the machine, the environment, and potentially the operator. • Risk of tipping over due to poor placement If the terrain is steep and the machine does not compensate properly, or is placed incorrectly, it may become unbalanced and tip over. This can seriously injure the operator, damage the machine, and harm the forest. Recovery from such an incident also takes considerable time.	• Missing abnormal trees Even experienced operators may find it difficult to detect abnormalities in trees. Missing these can lead to errors in quality, sorting, logistics, and length measurement. This results in time and cost losses and requires significant cognitive effort and attention from the operator. • Tree falling in the wrong direction If the operator does not assess the branch placement and weight distribution, the tree may fall unpredictably. This can cause damage to the operator, the machine, and the surrounding forest. • Incorrectly measured and cut trees If a tree is not "standard," the operator must decide the cutting lengths manually. This may result in non-optimal log lengths, leading to loss of value and material. It also increases decision-making demands and cognitive load, making errors more likely. • Many decisions within a short period of time A large number of simultaneous decisions must be made during cutting. This can cause the operator to overlook details or make mistakes. The high cognitive load can lead to fatigue and reduced productivity, ultimately affecting profit.	• Loss in efficiency If the machine settings are incorrect, the saw will take longer to cut through the tree. This results in reduced efficiency and therefore loss of profit. The operator may also experience stress due to the slower workflow. • Loss of resources If the wrong tree species is selected, the machine will handle the tree incorrectly. This can result in unusable timber and create logistical errors. These issues lead to economic losses and may increase workload or delays for the forwarders as well. • Tree falling in the wrong direction If the fall direction is not assessed correctly, the tree may hit the machine. This can unbalance it or cause damage to both the machine and the operator. Such incidents can lead to serious physical injuries as well as psychological strain. • Missing abnormalities in the tree If irregularities in the tree are overlooked, it may be cut and sorted incorrectly. This leads to loss of valuable timber and creates logistical challenges for the forwarder.	• Obstruction of routes If the trees are placed incorrectly, it may become difficult for both the forwarder and the harvester to drive through the area. The operator must plan log placement in advance to make future work easier. The branches also need to be placed strategically to build the path the operator intends to use later. If the branch placement is unsuccessful, the operator may need to choose a different route, causing inefficiency. • Poor sorting of timber If the log stacks are poorly sorted or placed, it becomes difficult for the forwarder to distinguish between different tree assortments. This creates errors for the forwarder and complicates the later stages of the processing chain. • Many cognitive decisions The operator must make numerous decisions during this step, which can lead to tiredness and fatigue. Errors made here significantly affect the forwarder, which may result in long-term stress and increased pressure on both roles.	• Ensuring correct measurements & sorting The measuring tool on the crane can be inaccurate and needs to be checked manually once a day to ensure correct measurements. If measurements are wrong, the timber will be sorted incorrectly, resulting in logistics errors and loss of value. If the tree is normal, the crane's measuring and bucking logic operates automatically. If the tree is abnormal, the operator must manually determine how the logs should be cut. This requires significant cognitive effort, especially for novice operators. The operator must also detect abnormalities during cutting, otherwise the logs may end up the wrong length or in the wrong assortment, causing loss of timber value and increased sorting challenges for the forwarder. • Poor sorting of timber If log stacks are poorly sorted or placed incorrectly, it becomes difficult for the forwarder to distinguish between different assortments. This leads to errors during forwarding and affects later stages of the processing chain.	• Information errors If the operator has selected the wrong tree sort or failed to detect abnormal trees, the recorded daily volume will be incorrect. This leads to production errors and affects planning for both the production chain and the landowner. • Short-term statistics The statistics shown only cover the productivity for the current day and do not provide long-term insights. Most operators are competitive and want to improve, but they do not receive the appropriate feedback necessary to understand their performance or how to enhance it over time.

Appendix E – Requirements List

Criteria's	Requirement or Preference	Grading 1-5	Description
1. Learning (Ease of use, Onboarding, Acceptance, Workflow fit)			
1.1 The solution should achieve at least 90 % accuracy during final usability test of both experts and novices.	R		The solutions should reduce the rot detection errors for both novices and experts.
1.2 The solution should be understood and usable within one working day.	R		The learning time should be short. The solution should be intuitive and quick to learn for all users.
1.3 It should be possible to integrate the solution into simulators.	P	2	The solution can be used and learned in the simulators before the novice start working in the forest.
1.4 The solution should improve the work procedure by reducing the time required for cutting and sorting rotten trees by at least 30 %.	R		The solution should minimize the time for cutting and sorting rot trees, as can take long time.
1.5 The solution should accelerate novice learning in cutting and sorting rot trees, resulting in an 50 % improvement in learning efficiency.	R		The solution should speed up the process of novice training, making them more useful quicker for the companies.
1.6 The solution shall achieve a user satisfaction rating of at least 80% in the final user evaluation.	R		The solution should be used by the user, and therefore it needs satisfaction.
2. Performance (Operational results, Efficiency, Precision)			
2.1 The solution should reduce detection errors of rot with 75%.	R		The solution should help with detecting rot, reducing the errors that might occur.
2.2 The solution should decrease the loss of volume with 30 %.	R		The solution should help the user cut the rotten tree into optimal lengths, reducing volume loss of timber.
2.3 The solution should effective the work by 25 % for both novices and experts.	R		The solution should reduce time for detecting, cutting and sorting rot trees.
2.4 The solution should signal when rot is detected.	R		The solution should help the user detect the rot and provide them with information that helps with decision making.
2.5 The solution should reduce the time for checking each log for rot with 50%.	R		The solution should provide a more efficient way of detecting rot needing less steps.
2.6 The solution should help the operator to track harvested rot trees.	P	1	The solution should give the user data regarding amount of harvested rotten trees to not compromise their productivity results.

3. Personalization & Features (Customization, User control, Balance between automatic, manual work)			
3.1 Users shall be able to activate, deactivate, or modify automated features manually within 5 seconds from the control interface during usability testing.	R		The user can make manual decisions and actions on automatic features.
3.2 The operator can choose the level of automation in the solution.	P	2	The user can personalize the level of automatic functions.
3.3 The solution should allow personalized settings and layout.	R		The user should be able to select how they want to use it and customize it to their needs.
3.4 The process to change the personalized settings should take less than 30 seconds.	R		The settings should be easily accessible and easy to set and use. It should not take unnecessary time.
3.5 The solution can be integrated with other system features in the harvester.	R		The solution should work well with the other features of the harvester.
4. Cognitive Ergonomics (Attention, Mental load, Usability while multitasking)			
4.1 The solution should not hinder visibility through the window.	R		The solution should be placed or used in such a way that it does not obstruct the view.
4.2 At least 95 % of test users shall report a low level of distraction, corresponding to a rating of 1 or 2 on a 5-point Likert scale, during usability testing	R		The solution should not take to much focus from the user so that they get distracted.
4.3 Users shall be able to complete at least 90 % of all primary tasks correctly while engaging in a phone conversation.	P	3	The solution should be compatible with conversations with others, since this is a common way of working for the operator.
4.4 The solution shall communicate alerts using at least two distinct sensory modalities (e.g. visual and auditory).	R		The solution should not relay only on one modality to communicate information.
5. Physical Ergonomics (Comfort, Safety, Inclusiveness)			
5.1 At least 90 % of test users shall report equal or better physical comfort compared to today's working process.	R		The solution should not worsen the physical ergonomics of the user.
5.2 User evaluations shall indicate a perceived added-value score of no less than 80% for the working process enabled by the solution.	P	3	The solution should bring value to the user and make them feel comfortable.
5.3 The solution should not compromise the safety of the operator or the machine.	R		The solution should not make the work more dangerous.

6. Machine Compatibility (Machine integration, Maintenance, Cross- brand compatibility)			
6.1 The solution should follow the design layout of today's harvester machines.	R		The solution should be compatible and consistent with existing machines and their features.
6.2 The solution should be able to be repaired easily.	P	3	The solution should be easy to repair.
6.3 The solution should be compatible with existing pre-used machines.	P	2	The solution could be implemented in existing older machines, as an add on feature.
6.4 The solution should facilitate collaboration between the harvester and forwarder by achieving a 75 % improvement in rot-related sorting accuracy for the harvester.	P	4	The solution should ease the workflow and reducing the errors.
6.5 The solution should be compatible with 3 brands of machines.	P	2	The solution should be able to be placed and used in different kinds of harvester.

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